IBM XL Fortran for Linux, V15.1.6

Optimization and Programming Guide for Little Endian Distributions

Version 15.1.6
Optimization and Programming Guide for Little Endian Distributions

Version 15.16
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About this document

This document is part of the IBM® XL Fortran for Linux, V15.1.6 information suite. It provides both reference information and practical tips for using the optimization and tuning capabilities of XL Fortran to maximize application performance, as well as expanding on programming concepts such as I/O and interlanguage calls.

Who should read this document

This document is for anyone who wants to exploit the capabilities of XL Fortran for optimizing and tuning Fortran programs. Readers should be familiar with their Linux operating system and have extensive Fortran programming experience with complex applications. However, users new to XL Fortran can still use this information to help them understand how the compiler’s features can be used for effective program optimization.

How to use this document

This guide focuses on specific programming and compilation techniques that can maximize XL Fortran application performance. It covers optimization and tuning strategies, recommended programming practices, and compilation procedures, debugging, and information about using XL Fortran advanced language features. This guide also contains cross-references to relevant topics of other reference guides in the XL Fortran information suite.

Topics not described in this information are available as follows:

- Installation, system requirements, last-minute updates: see the XL Fortran Installation Guide and product README file.
- Migration considerations and guide: see the XL Fortran Migration Guide.
- Overview of XL Fortran features: see the Getting Started with XL Fortran book.
- Syntax, semantics, and implementation of the XL Fortran programming language: see the XL Fortran Language Reference book.
- Compiler setup, compiling and running programs, compiler options, diagnostics: see the XL Fortran Compiler Reference book.
- CUDA Fortran support to exploit NVIDIA GPU on OpenPOWER systems: see the Getting Started with CUDA Fortran programming using XL Fortran.
- Operating system commands related to the use of the compiler: consult the man page help and information of your Linux distribution.

How this document is organized

This guide includes the following topics:

- Chapter 1, “Optimizing your applications,” on page 1 provides an overview of the optimization process.
- Chapter 2, “Tuning XL compiler applications,” on page 35 discusses the compiler options available for optimizing and tuning code.
- Chapter 3, “Advanced optimization concepts,” on page 43, Chapter 4, “Managing code size,” on page 47, and Chapter 5, ”Debugging optimized code,” on page 53 discuss advanced techniques, such as optimizing loops and inlining code, and debug considerations for optimized code.
• The following sections contain information about how to write optimization
friendly and portable XL Fortran code that is interoperable with other languages. Also included is a description of XL Fortran support for OpenMP and SMP with
guidelines for writing parallel code.
  – Chapter 6, “Compiler-friendly programming techniques,” on page 57
  – Chapter 8, “High performance libraries,” on page 67
  – Chapter 9, “Parallel programming with XL Fortran,” on page 85
  – Chapter 11, “Interlanguage calls,” on page 307
• Chapter 10, “Offloading computations to the NVIDIA GPUs,” on page 301
  provides an overview of the methods to exploit the NVIDIA GPUs by using XL
  Fortran.
• The following sections contain information about XL Fortran and its
implementation that can be useful for new and experienced users alike:
  – Chapter 12, “Implementation details of XL Fortran Input/Output (I/O),” on
page 329
  – Chapter 13, “Implementation details of XL Fortran floating-point processing,”
on page 345
  – Chapter 14, “Vector element order toggling,” on page 361
• Chapter 15, “Sample Fortran programs,” on page 365 provides coding examples
for XL Fortran.

Conventions

Typographical conventions

The following table shows the typographical conventions used in the IBM XL
Fortran for Linux, V15.1.6 information.

<table>
<thead>
<tr>
<th>Typeface</th>
<th>Indicates</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>lowercase bold</td>
<td>Invocation commands, executable names, and compiler options.</td>
<td>The compiler provides basic invocation commands, xlf, along with several other compiler invocation commands to support various Fortran language levels and compilation environments. The default file name for the executable program is a.out.</td>
</tr>
<tr>
<td>italics</td>
<td>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 size parameter if you return more than the size requested.</td>
<td></td>
</tr>
<tr>
<td>underlining</td>
<td>The default setting of a parameter of a compiler option or directive.</td>
<td>nomaf</td>
</tr>
<tr>
<td>monospace</td>
<td>Examples of program code, reference to program code, file names, path names, command strings, or user-defined names. To compile and optimize myprogram.f, enter: xlf myprogram.f -03.</td>
<td></td>
</tr>
</tbody>
</table>
Table 1. Typographical conventions (continued)

<table>
<thead>
<tr>
<th>Typeface</th>
<th>Indicates</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPPERCASE bold</td>
<td>Fortran programming keywords, statements, directives, and intrinsic procedures. Uppercase letters may also be used to indicate the minimum number of characters required to invoke a compiler option/suboption.</td>
<td>The ASSERT directive applies only to the DO loop immediately following the directive, and not to any nested DO loops.</td>
</tr>
</tbody>
</table>

Qualifying elements (icons and bracket separators)

In descriptions of language elements or programming models, this information uses icons and marked bracket separators to delineate segments of text as follows:

Table 2. Qualifying elements

<table>
<thead>
<tr>
<th>Icon</th>
<th>Bracket separator text</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2008</td>
<td>Fortran 2008 begins / Fortran 2008 ends</td>
<td>The text describes an IBM XL Fortran implementation of the Fortran 2008 standard</td>
</tr>
<tr>
<td>F2008</td>
<td>Fortran 2008 ends</td>
<td>The text describes an IBM XL Fortran implementation of the Fortran 2008 standard and it applies to all later standards</td>
</tr>
<tr>
<td>F2003</td>
<td>Fortran 2003 begins / Fortran 2003 ends</td>
<td>The text describes an IBM XL Fortran implementation of the Fortran 2003 standard and it applies to all later standards</td>
</tr>
<tr>
<td>TS 29113</td>
<td>TS 29113 begins / TS 29113 ends</td>
<td>The text describes an IBM XL Fortran implementation of Technical Specification 29113, referred to as TS 29113</td>
</tr>
<tr>
<td>IBM</td>
<td>IBM extension begins / IBM extension ends</td>
<td>The text describes a feature that is an IBM XL Fortran extension to the standard language specifications.</td>
</tr>
<tr>
<td>CUDA Fortran</td>
<td>CUDA Fortran begins / CUDA Fortran ends</td>
<td>The text describes CUDA Fortran, the CUDA Fortran support provided by IBM XL Fortran, or both.</td>
</tr>
<tr>
<td>GPU</td>
<td>GPU begins / GPU ends</td>
<td>The text describes the information that is relevant to offloading computations to the NVIDIA GPUs.</td>
</tr>
</tbody>
</table>

Note:
1. If the information is marked with a Fortran language standard icon or bracket separators, it applies to this specific Fortran language standard and all later ones. Otherwise, it applies to all Fortran language standards.

Syntax diagrams

Throughout this information, diagrams illustrate XL Fortran syntax. This section helps 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.
  IBM XL Fortran extensions are marked by a number in the syntax diagram with an explanatory note immediately following the diagram.
  Program units, procedures, constructs, interface blocks and derived-type definitions consist of several individual statements. For such items, a box encloses the syntax representation, and individual syntax diagrams show the required order for the equivalent Fortran statements.
  • Required items are shown on the horizontal line (the main path):

  ►►keyword—required_argument—►◄

  • Optional items are shown below the main path:

  ►►keyword [optional_argument]—►◄

  Note: Optional items (not in syntax diagrams) are enclosed by square brackets ([ and ]). For example, [UNIT=u]

  • 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.

  ►►keyword—required_argument1
  —required_argument2—►◄

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

  ►►keyword
  [optional_argument1
  —optional_argument2]—►◄

  • 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:

  ►►keyword—repeatable_argument—►◄

  • 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 a variable or user-specified name ends in _list, you can provide a list of these terms separated by commas.
• 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 is an example of a syntax diagram with an interpretation:

Notes:
1 IBM extension

Interpret the diagram as follows:
• Enter the keyword EXAMPLE.
• EXAMPLE is an IBM extension.
• Enter a value for char_constant.
• Enter a value for a or b, but not for both.
• Optionally, enter a value for c or d.
• Enter at least one value for e. If you enter more than one value, you must put a comma between each.
• Enter the value of at least one name for name_list. If you enter more than one value, you must put a comma between each. (The _list syntax is equivalent to the previous syntax for e.)

How to read syntax statements

Syntax statements are read from left to right:
• Individual required arguments are shown with no special notation.
• When you must make a choice between a set of alternatives, they are enclosed by { and } symbols.
• Optional arguments are enclosed by [ and ] symbols.
• When you can select from a group of choices, they are separated by | characters.
• Arguments that you can repeat are followed by ellipses (...).

Example of a syntax statement
EXAMPLE char_constant |a|b|c|d|e[,]... name_list{name_list}...

The following list explains the syntax statement:
• Enter the keyword EXAMPLE.
• Enter a value for char_constant.
• Enter a value for a or b, but not for both.
• Optionally, enter a value for c or d.
• Enter at least one value for e. If you enter more than one value, you must put a comma between each.
• Optionally, enter the value of at least one name for name_list. If you enter more than one value, you must put a comma between each name.

Note: The same example is used in both the syntax-statement and syntax-diagram representations.

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 default installation; these need little or no modification.

Notes on the terminology used

Some of the terminology in this information is shortened as follows:
• The term free source form format often appears as free source form.
• The term fixed source form format often appears as fixed source form.
• The term XL Fortran often appears as XLF.

Related information

The following sections provide related information for XL Fortran:

Available help information

IBM XL Fortran information

XL Fortran provides product information in the following formats:
• Quick Start Guide
  The Quick Start Guide (quickstart.pdf) is intended to get you started with IBM XL Fortran for Linux, V15.1.6. It is located by default in the XL Fortran directory and in the \quickstart directory of the installation DVD.
• 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 Fortran directory, and in the root directory and subdirectories of the installation DVD.
• 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 Fortran for Linux, V15.1.6 Installation Guide.
• Online product documentation

- **PDF documents**


The following files comprise the full set of XL Fortran product information.

**Note:** To ensure that you can access cross-reference links to other XL Fortran PDF documents, download and unzip the .zip file that contains all the product documentation files, or you can download each document into the same directory on your local machine.

**Table 3. XL Fortran PDF files**

<table>
<thead>
<tr>
<th>Document title</th>
<th>PDF file name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>What’s New for IBM XL Fortran for Linux, V15.1.6, GC27-8037-00</td>
<td>whats_new.pdf</td>
<td>Provides an executive overview of new functions in the IBM XL Fortran for Linux, V15.1.6 compiler, with new functions categorized according to user benefits.</td>
</tr>
<tr>
<td>Getting Started with IBM XL Fortran for Linux, V15.1.6, SC27-6620-05</td>
<td>getstart.pdf</td>
<td>Contains an introduction to XL Fortran, with information about setting up and configuring your environment, compiling and linking programs, and troubleshooting compilation errors.</td>
</tr>
<tr>
<td>IBM XL Fortran for Linux, V15.1.6 Installation Guide, GC27-6580-05</td>
<td>install.pdf</td>
<td>Contains information for installing XL Fortran and configuring your environment for basic compilation and program execution.</td>
</tr>
<tr>
<td>IBM XL Fortran for Linux, V15.1.6 Migration Guide, GC27-8038-00</td>
<td>migrate.pdf</td>
<td>Contains migration considerations for using XL Fortran to compile programs that were previously compiled on different platforms, by previous releases of XL Fortran, or by other compilers.</td>
</tr>
<tr>
<td>IBM XL Fortran for Linux, V15.1.6 Compiler Reference, SC27-6610-05</td>
<td>compiler.pdf</td>
<td>Contains information about the various compiler options and environment variables.</td>
</tr>
<tr>
<td>IBM XL Fortran for Linux, V15.1.6 Language Reference, SC27-6590-05</td>
<td>langref.pdf</td>
<td>Contains information about the Fortran programming language as supported by IBM, including language extensions for portability and conformance to nonproprietary standards, compiler directives and intrinsic procedures.</td>
</tr>
<tr>
<td>IBM XL Fortran for Linux, V15.1.6 Optimization and Programming Guide, SC27-6600-05</td>
<td>proguide.pdf</td>
<td>Contains information on advanced programming topics, such as application porting, interlanguage calls, floating-point operations, input/output, application optimization and parallelization, and the XL Fortran high-performance libraries.</td>
</tr>
</tbody>
</table>
Table 3. XL Fortran PDF files (continued)

<table>
<thead>
<tr>
<th>Document title</th>
<th>PDF file name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Getting Started with CUDA Fortran programming using IBM XL Fortran for Linux, V15.1.6, GI13-3562-02</td>
<td>getstart_cudaf.pdf</td>
<td>Contains detailed information about the CUDA Fortran support that is provided in XL Fortran, including the compiler flow for CUDA Fortran programs, compilation commands, useful compiler options and macros, supported CUDA Fortran features, and limitations.</td>
</tr>
</tbody>
</table>

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](http://www.adobe.com).


For more information about the compiler, see the XL compiler on Power® community at [http://ibm.biz/xl-power-compilers](http://ibm.biz/xl-power-compilers).

**Other IBM information**


**Standards and specifications**

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

- Federal (USA) Information Processing Standards Publication Fortran, FIPS PUB 69-1.
- Information technology - Programming languages - Fortran, ISO/IEC 1539-1:1991. (This information uses its informal name, Fortran 90.)
- Information technology - Programming languages - Fortran - Part 1: Base language, ISO/IEC 1539-1:1997. (This information uses its informal name, Fortran 95.)
- Information technology - Programming languages - Fortran - Part 1: Base language, ISO/IEC 1539-1:2004. (This information uses its informal name, Fortran 2003.)
- Information technology - Programming languages - Fortran - Part 1: Base language, ISO/IEC 1539-1:2010. (This information uses its informal name, Fortran 2008. We currently provide partial support to this standard.)
- Information technology - Further interoperability of Fortran with C, ISO/IEC TS 29113:2012. (This information uses its informal name, Technical specification 29113, referred to as TS 29113. We currently provide partial support to this specification.)
- Military Standard Fortran DOD Supplement to ANSI X3.9-1978, MIL-STD-1753 (United States of America, Department of Defense standard). Note that XL Fortran supports only those extensions documented in this standard that have also been subsequently incorporated into the Fortran 90 standard.
• OpenMP Application Program Interface Version 3.1 (full support), OpenMP Application Program Interface Version 4.0 (partial support), and OpenMP Application Program Interface Version 4.5 (partial support), available at http://www.openmp.org.

Other IBM information


Technical support

Additional technical support is available from the XL Fortran Support page at https://www.ibm.com/support/home/product/U128148Q26691I65/XL_Fortran_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 an email to compinfo@cn.ibm.com.

For the latest information about XL Fortran, visit the product information site at https://www.ibm.com/us-en/marketplace/xl-fortran-linux-compiler-power

How to send your comments

Your feedback is important in helping us to provide accurate and high-quality information. If you have any comments about this information or any other XL Fortran information, send your comments to compinfo@cn.ibm.com.

Be sure to include the name of the manual, the part number of the manual, the version of XL Fortran, and, if applicable, the specific location of the text you are commenting on (for example, a page number or table number).
Chapter 1. Optimizing your applications

The XL compilers enable development of high performance 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 bring the following benefits:

- Reduce the number of instructions that 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 2 for an overview of the common sequence of steps that you can use to increase the performance of your application.

Tuning

Tuning is a user-driven process where you experiment with changes, for example to source code or compiler options, to make the compiler better optimize your program. 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 make the following improvements:

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

When 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 [High-order transformation (HOT)] step can help you reduce loop execution time.
4. The [Interprocedural analysis (IPA)] step can optimize your entire application at once.
5. The [Profile-directed feedback (PDF)] 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.
7. The [Getting more performance] section offers other strategies and tuning alternatives to compiler-driven optimization.

The section [Compiler-friendly programming techniques] contains tips for writing more easily optimized source 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 you try more aggressive optimizations. This topic discusses two optimizations levels, listed with complementary options in [Table 4]. The table also includes a column for compiler options that can have a performance benefit at that optimization level for some applications.

<table>
<thead>
<tr>
<th>Optimization level</th>
<th>Additional options implied by default</th>
<th>Complementary options</th>
<th>Other options with possible benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>-00</td>
<td>None</td>
<td>-qarch</td>
<td>None</td>
</tr>
<tr>
<td>-02</td>
<td>-qmaxmem=8192</td>
<td>-qarch</td>
<td>-qmaxmem=-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-qtune</td>
<td>-qhot=level=0</td>
</tr>
</tbody>
</table>

Table 4. Basic optimizations
**Optimizing at level 0**

**Benefits at level 0**
- Provides minimal performance improvement with minimal impact on machine resources
- Exposes some source code problems that can be helpful 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 it 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 `-qfloat=nofold` option 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.

Additionally, specifying `-qarch` at this level targets your application for a particular machine and can significantly improve performance by ensuring that 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 about tuning, consult [Tuning for Your Target Architecture](#).

See `-O` in the XL Fortran Compiler Reference for information about the `-O` level syntax.

Related information in the XL Fortran Compiler Reference

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**Optimizing at level 2**

**Benefits at level 2**
- Eliminates redundant code
- Performs basic loop optimization
- Structures code to take advantage of `-qarch` and `-qtune` settings

After you successfully compile, execute, and debug 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` attain 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`.

**Starting to tune at level 2**

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 available hardware facilities. If you choose a family of
hardware targets, the -qtune option can direct the compiler to emit code that is consistent with the architecture choice and that can execute optimally on the chosen tuning hardware target. With this option, you can compile for a general set of targets and have the code run best on a particular target.

For details on the -qarch and -qtune options, see Chapter 2, “Tuning XL compiler applications,” on page 35.

The -O2 option can perform a number of additional optimizations as follows:
- 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
- Global 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: 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.

The section on Chapter 5, “Debugging optimized code,” on page 53 discusses other debugging strategies in detail.

See “-O” in the XL Fortran Compiler Reference for information on the -O level syntax.

### 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 2 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 that your application undergoes are largely under your control. The discussion of each optimization level in Table 5 on page 5 includes information on the performance benefits and the possible trade-offs and information on how you can help guide the optimizer to find the best solutions for your application.
Table 5. Advanced optimizations

<table>
<thead>
<tr>
<th>Optimization Level</th>
<th>Additional options implied</th>
<th>Complementary options</th>
<th>Options with possible benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>-03 -O3 -Ofast</td>
<td>-qnostrict</td>
<td>-qarch</td>
<td>-qpdf</td>
</tr>
<tr>
<td></td>
<td>-qmaxmem=-1</td>
<td>-qtune</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-qhot</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-04</td>
<td>All of -03</td>
<td>-qarch</td>
<td>-qpdf</td>
</tr>
<tr>
<td></td>
<td>-qipa</td>
<td>-qtune</td>
<td>-qsmp=auto</td>
</tr>
<tr>
<td></td>
<td>-qarch=auto</td>
<td>-qcache</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-qtune=auto</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-qcache=auto</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-05</td>
<td>All of -04</td>
<td>-qarch</td>
<td>-qpdf</td>
</tr>
<tr>
<td></td>
<td>-qipa=level=2</td>
<td>-qtune</td>
<td>-qsmp=auto</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-qcache</td>
<td></td>
</tr>
</tbody>
</table>

When you compile programs with any of the following sets of options:
- -qhot -qnostrict
- -Ofast
- -03
- -04
- -05

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 `vatan2`, `vsatan2`, `vdint`, `vdint`, `vcosisin`, `vscosisin`, `vqdrt`, `vsqdrt`, `vrqdrt`, `vrsqdrt`, `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 "Aliasing" on page 43 analysis
- Better loop scheduling
- High-order loop analysis and transformations (`-qhot`)
- Inlining of small procedures within a compilation unit by default
- Eliminating implicit compile-time memory usage limits

Specifying `-03` initiates more intense low-level transformations that remove many of the limitations present at `-02`. For instance, the optimizer no longer checks for memory limits, by setting the default to `-qmaxmem=-1`. Additionally, optimizations encompass larger program regions and attempt more in-depth analysis. Although not all applications contain opportunities for the optimizer to provide a measurable increase in performance, most applications can benefit from this type of analysis. Specifying `-03` also implies `-qhot`, which performs the default set of high-order transformations.
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, because -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=ieeefp 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 Fortran Compiler Reference).

Without -qstrict, the difference in computation for any one source-level operation is very small in comparison to "Basic optimization" on page 2. 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.

For information about the -O level syntax, see "-O" in the XL Fortran Compiler Reference.

An intermediate step: adding -qhot suboptions at level 3

At -O3, the optimization implies -qhot to increase performance. To further increase your performance benefit from -qhot, increase the optimization aggressiveness by increasing the optimization level of -qhot.

The following -qhot suboption can also provide additional performance benefits, depending on the characteristics of your application:

- **-qhot=arraypad** to enable array padding

For more information about -qhot, see "High-order transformation (HOT)" on page 9.

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 time and link time.

Beyond -qipa, -O4 enables other optimization options:

- **-qhot**
  Enables more aggressive HOT transformations to optimize loop constructs and array language.
- **-qhot=vector**
  Optimizes array data to run mathematical operations in parallel where applicable.
- **-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 the execution environment of your application, you must specify a different -qarch suboption after the -O4 option. This overrides -qtune=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.

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.

See "-O" in the XL Fortran Compiler Reference for information about the -O level syntax.

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 -03 level optimizations.

The “Interprocedural analysis (IPA)” on page 11 section contains more information about IPA including details on IPA suboptions.

### Optimizing at level 5

#### Benefits at level 5

- Makes most aggressive optimizations available
- Makes full use of loop optimizations and “Interprocedural analysis (IPA)” on page 11

As the highest optimization level, -05 includes all -04 optimizations and deepens whole program analysis by increasing the -qipa level to 2. Compiling with -05 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 -05 option.

#### Potential trade-offs at level 5

Compiling at -05 requires more compilation time and machine resources than any other optimization levels, particularly if you include -05 on the IPA link step. Compile at -05 as the final phase in your optimization process after successfully compiling and executing your application at -04.

See “-O” in the XL Fortran Compiler Reference for information on the -0 level syntax.

### Specialized optimization techniques

While some optimization techniques are active at advanced optimization levels, certain types of applications can receive a performance benefit even when you apply only basic optimizations.

**Table 6. Specialized optimization techniques**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT</td>
<td>Minimizes loop execution time which is beneficial to most applications that contain large loops, or many small loops. HOT also improves memory access patterns in your application.</td>
</tr>
<tr>
<td>IPA</td>
<td>Performs whole program analysis, providing the optimization suite with a complete view of your entire application. This applies performance enhancements with more focus and robustness.</td>
</tr>
<tr>
<td>PDF</td>
<td>Targets the code paths your application executes most frequently for optimization.</td>
</tr>
</tbody>
</table>
Table 6. Specialized optimization techniques (continued)

<table>
<thead>
<tr>
<th>Technique</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector technology</td>
<td>Vector technology is a PowerPC technology for accelerating the performance-driven, high-bandwidth communications and computing applications. You can use the vector technology to get dramatic performance improvement for your applications.</td>
</tr>
<tr>
<td>Compiler reports</td>
<td>You can use the <code>-qlistfmt</code> option to generate a compiler report in XML 1.0 format that indicates some of the details of how your program was optimized. You can use this information to understand your application code and to tune your code for better performance.</td>
</tr>
</tbody>
</table>

**High-order transformation (HOT)**

As part of the XL compiler optimization suite, the HOT transformations focus specifically on loops which typically account for the majority of the execution time for most applications. HOT transformations perform in-depth loop analysis to minimize their execution time.

Loop optimization analysis includes:
- Interchange
- Fusion
- Unrolling loop nests
- Reducing the use of temporary arrays

The goals of these optimizations include:
- Reducing memory access costs through effective cache use and translation look-aside buffers (TLBs). Increasing memory locality reduces cache and TLB misses.
- Overlapping computation and memory access through effective utilization of the hardware data prefetching capabilities.
- Improving processor resource utilization by reordering and balancing the use of instructions with complementary resource requirements. Loop computation balance typically involves creating an equitable relationship between load/store operations and floating-point computations.

Compiling with `-O3` and higher triggers HOT transformations by default. You can also see performance benefits by specifying `-qhot` with `-O2`, or adding more `-qhot` optimizations than the default `level=1` at `-O3`.

You can see particular `-qhot` benefits if your application contains Fortran 90-style array language constructs, as HOT transformations include elimination of intermediate temporary variables and statement fusion.

You can also use directives to assist in loop analysis. Assertive directives such as `INDEPENDENT` or `CNCALL` allow you to describe important loop characteristics or behaviors that HOT transformations can exploit. Prescriptive directives such as `UNROLL` or `PREFETCH` allow you to direct the HOT transformations on a loop-by-loop basis. You can also specify the `-qreport` compiler option to generate
information about loop transformations. The report can assist you in deciding where best to include directives to improve the performance of your application. For example, you can use this section of the listing to identify non-stride-one references that may prevent loop vectorization.

You can use the `-qreport` option in conjunction with `-qhot` or any optimization option that implies `-qhot` to produce a pseudo-Fortran report showing how the loops were transformed. The LOOP TRANSFORMATION SECTION of the listing file also contains information about data prefetch insertion locations.

When used with `-qsmp` and `-qhot=level=2` instructs the compiler to perform the transformations of `-qhot=level=1` plus some additional transformation on nested loops. The resulting loop analysis and transformations can lead to more cache reuse and loop parallelization. If you use `-qhot=level=2` and `-qsmp` together with `-qreport` or `-qlistfmt`, you can see this information on aggressive loop analysis performed on loop nests in the LOOP TRANSFORMATION SECTION of the listing file or compiler report.

When you use `-qprefetch=assistthread` to generate prefetching assist threads, a message Assist thread for data prefetching was generated also appears in the LOOP TRANSFORMATION SECTION of the listing file. For details, see `-qprefetch` in the XL Fortran Compiler Reference.

With the `-qassert=refalign` suboption, the compiler might generate more efficient code. This assertion is particularly useful when you target a Single Instruction Multiple Data (SIMD) architecture with `-qhot=level=0` or `-qhot=level=1` with the `-qsimd=auto` option.

In addition to general loop transformation, `-qhot` supports suboptions that you can specify to enable additional transformations detailed in this section.

**HOT short vectorization**

When you are targeting a PowerPC processor that supports Vector Multimedia Extension (VMX) or Vector Scalar Extension (VSX), you can specify `-qsimd=auto` to enable the compiler to transform code into VMX or VSX instructions. These machine instructions can execute up to sixteen operations in parallel. This transformation mostly applies to the loops that iterate over contiguous array data and perform calculations on each element. You can use the NOSIMD directive to prevent the transformation of a particular loop.

**HOT long vectorization**

When you specify any of the following:

- `-O3` and higher
- `-qhot` with `-qnostrict`

you enable `-qhot=vector` by default. Specifying `-qnostrict` with optimizations other than `-O4` and `-O5` ensures that the compiler looks for long vectorization opportunities. This can optimize loops in source code for operations on array data by ensuring that operations run in parallel where applicable. The compiler uses standard machine registers for these transformations and does not restrict vector data size; supporting both single- and double-precision floating-point vectorization. Often, HOT vectorization involves transformations of loop calculations into calls to specialized mathematical routines supplied with the compiler such as the Mathematical Acceleration Subsystem (MASS) libraries. These mathematical routines use algorithms that calculate results more efficiently than executing the original loop code.
For more information about optimization levels like `-O4` and the other compiler options they imply, see “Advanced optimization” on page 4.

**HOT array size adjustment**

An array dimension that is a power of two can lead to a decrease in cache utilization. The `-qhot=arraypad` suboption allows the compiler to increase the dimensions of arrays where doing so could improve the efficiency of array-processing loops. Using this suboption can reduce cache misses and page faults that slow your array processing programs. The HOT transformations will not necessarily pad all arrays, and can pad different arrays by different amounts in order to gain performance. You can specify a padding factor to apply to all arrays. This value is typically a multiple of the largest array element size.

Use `-qhot=arraypad` with discretion as array padding uses more memory and the performance trade-off does not benefit all applications. Also, these HOT transformations do not include checks for array data overlay, as with Fortran EQUIVALENCE, or array shaping operations.

**HOT fast scalar math routines**

The XLOPT library contains faster versions of certain math functions that are normally provided by the operating system or in the default runtime. With `-qhot=fastmath`, the compiler replaces calls to the math functions with their faster counterparts in XLOPT library. This option requires `-qstrict=nolib` in effect.

**Interprocedural analysis (IPA)**

Interprocedural Analysis (IPA) can analyze and optimize your application as a whole, rather than on a file-by-file basis.

Run during the link step of an application build, the entire application, including linked libraries, is available for interprocedural analysis. This whole program analysis opens your application to a powerful set of transformations available only when more than one file or compilation unit is accessible. IPA optimizations are also effective on mixed language applications.
The following are some of the link-time transformations that IPA can use to restructure and optimize your application:

- Inlining between compilation units.
- Complex data flow analyses across subprogram calls to eliminate parameters or propagate constants directly into called subprograms.
- Improving parameter usage analysis, or replacing external subprogram calls to system libraries with more efficient inline code.
- Restructuring data structures to maximize access locality.
- Cloning subprograms where calls pass constant parameters to allow optimizing expressions using those parameters.

In order to maximize IPA link-time optimization, you must use IPA at both the compile and link step. Objects you do not compile with IPA can only provide minimal information to the optimizer, and receive minimal benefit. However when IPA is active on the compile step, the resulting object file contains program information that IPA can read during the link step. The program information is invisible to the system linker, and you can still use the object file and link without invoking IPA. The IPA optimizations use hidden information to reconstruct the original compilation and can completely analyze the subprograms the object contains in the context of their actual usage in your application.

During the link step, IPA restructures your application, partitioning it into distinct logical code units. After IPA optimizations are complete, IPA applies the same low-level compilation-unit transformations as the -O2 and -O3 base optimizations levels. Following those transformations, the compiler creates one or more object files and linking occurs with the necessary libraries through the system linker.

It is important that you specify a set of compilation options as consistent as possible when compiling and linking your application. This includes all compiler options, not just -qipa suboptions. When possible, specify identical options on all compilations and repeat the same options on the IPA link step. Incompatible or
conflicting options that you specify to create object files, or link-time options in conflict with compile-time options can reduce the effectiveness of IPA optimizations.

Notes:

- XL C/C++ and XL Fortran provide backwards compatibility with IPA object files that are created by earlier compiler versions. If IPA object files that are compiled with newer versions of compilers are linked by an earlier version, errors occur during the link step. For example, if IPA object file a.o is compiled by XL C/C++ for Linux, V13.1.3 and is to be linked with IPA object file b.o that is compiled by XL Fortran for Linux, V15.1.0, then you must use a compiler whose version is XL C/C++ for Linux, V13.1.3 or later.
- XL C/C++ and XL Fortran versions released at the same time produce matching IPA level information and can be linked together. For example, the IPA level for XL C/C++ for Linux, V13.1.3 matches with the IPA for XL Fortran for Linux, V15.1.3. The following table lists some matching XL C/C++ and XL Fortran releases:

<table>
<thead>
<tr>
<th>Compiler version</th>
<th>General availability (Release date)</th>
</tr>
</thead>
<tbody>
<tr>
<td>XL C/C++ for Linux, V13.1.3</td>
<td>11-Dec-2015</td>
</tr>
<tr>
<td>XL Fortran for Linux, V15.1.3</td>
<td>06-Jun-2014</td>
</tr>
<tr>
<td>XL C/C++ for Linux, V13.1.0</td>
<td>18-May-2012</td>
</tr>
<tr>
<td>XL Fortran for Linux, V15.1.0</td>
<td>18-May-2012</td>
</tr>
</tbody>
</table>

For more information about the release dates of compiler products, see the Support Lifecycle website at [http://www.ibm.com/software/support/lifecycle/index_x.html](http://www.ibm.com/software/support/lifecycle/index_x.html).

If your compiler version has two release dates on the Support Lifecycle web site, determine the date based on your product ID.

**Using IPA on the compile step only**

IPA can still perform transformations if you do not specify IPA on the link step. Using IPA on the compile step initiates optimizations that can improve performance for an individual object file even if you do not link the object file using IPA. The primary focus of IPA is link-step optimization, but using IPA only on the compile-step can still be beneficial to your application without incurring the costs of link-time IPA.
IPA Levels and other IPA suboptions

You can control many IPA optimization functions using the -qipa option and suboptions. The most important part of the IPA optimization process is the level at which IPA optimization occurs. Default compilation does not invoke IPA. If you specify -qipa without a level, or specify -O4, IPA optimizations are at level one. If you specify -O5, IPA optimizations are at level two.

Table 8. The levels of IPA

<table>
<thead>
<tr>
<th>IPA Level</th>
<th>Behaviors</th>
</tr>
</thead>
</table>
| qipa=level=0 | • Automatically recognizes standard library functions  
• Localizes statically bound variables and procedures  
• Organizes and partitions your code according to call affinity, expanding the scope of the -O2 and -O3 low-level compilation unit optimizer  
• Lowers compilation time in comparison to higher levels, though limits analysis |
| qipa=level=1 | • Level 0 optimizations  
• Performs procedure inlining across compilation units  
• Organizes and partitions static data according to reference affinity |
IPA includes many suboptions that can help you guide IPA to perform optimizations important to the particular characteristics of your application. Among the most relevant to providing information on your application are:

- **lowfreq**, with which you can specify a list of procedures that are likely to be called infrequently during the course of a typical program run. Performance can increase because optimization transformations will not focus on these procedures.
- **partition**, with which you can specify the size of the regions within the program to analyze. Larger partitions contain more procedures, which result in better interprocedural analysis but require more storage to optimize.
- **threads**, with which you can specify the number of parallel threads available to IPA optimizations. This can provide an increase in compilation-time performance on multi-processor systems.

### Using IPA across the XL compiler family

The XL compiler family shares optimization technology. Object files you create using IPA on the compile step with the XL C, C++, and Fortran compilers can undergo IPA analysis during the link step. Where program analysis shows that objects were built with compatible options, such as `-qnostrict`, IPA can perform transformations such as inlining C functions into Fortran code, or propagating C++ constant data into C function calls.

### 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 the PDF process as one of the last steps of optimization before you put 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 from PDF process.

The following diagram illustrates the PDF process.

---

**Table 8. The levels of IPA (continued)**

<table>
<thead>
<tr>
<th>IPA Level</th>
<th>Behaviors</th>
</tr>
</thead>
<tbody>
<tr>
<td>qipa=level=2</td>
<td>• Level 0 and level 1 optimizations</td>
</tr>
<tr>
<td></td>
<td>• Performs whole program alias analysis which removes ambiguity between</td>
</tr>
<tr>
<td></td>
<td>pointer references and calls, while refining call side effect information</td>
</tr>
<tr>
<td></td>
<td>• Propagates interprocedural constants</td>
</tr>
<tr>
<td></td>
<td>• Eliminates dead code</td>
</tr>
<tr>
<td></td>
<td>• Performs pointer analysis</td>
</tr>
<tr>
<td></td>
<td>• Performs procedure cloning</td>
</tr>
<tr>
<td></td>
<td>• Optimizes intraprocedural operations, using specifically:</td>
</tr>
<tr>
<td></td>
<td>– Value numbering</td>
</tr>
<tr>
<td></td>
<td>– Code propagation and simplification</td>
</tr>
<tr>
<td></td>
<td>– Code motion, into conditions and out of loops</td>
</tr>
<tr>
<td></td>
<td>– Redundancy elimination techniques</td>
</tr>
<tr>
<td></td>
<td>• Performs data reorganization</td>
</tr>
</tbody>
</table>
To use the PDF process to optimize your application, follow these steps:

1. "Compiling with -qpdf1."
2. "Training with typical data sets” on page 17
3. “Recompiling or linking with -qpdf2” on page 20

Related information in the XL Fortran Compiler Reference

-qpdf1, -qpdf2
-O, -qoptimize
-qipa

Compiling with -qpdf1

Compile some or all of the source files in a program with the -qpdf1 option. This step is called the PDF1 step.

Usage

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 you compile multiple programs with -qpdf1, you must ensure that the PDF file that is to be generated in the PDF2 step has a different name for each program because each PDF file can contain data for only one application. Otherwise, if the PDF file names of multiple programs are the same, you can run the first application in the PDF training step and write profile information into the PDF file successfully. However, if you try to run the second application, an error is issued to indicate that there is an existing incompatible PDF file and the program exits with a nonzero return code.

PDF optimization must be done at least at the -O2 optimization level and is recommended at -O4 and higher.

When you compile your program with -qpdf1, the -qipa=level=0 option is enabled by default. 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.

A PDF map file is generated at this step. You can use the `showpdf` command to display part of the profiling information in text or XML format. If you do not need to view the profiling information, specify the `-qnomoshowpdf` option at this step so that the PDF map file is not generated.

**Example**

You can compile the following source files with `-qpdf1` at `-O3`.

```
xlf -qpdf1 -O3 file1.f file2.f file3.f
```

**Related information in the XL Fortran Compiler Reference**

- `-qpdf1`, `-qpdf2`
- `-O`, `-qoptimize`
- `showpdf`
- `-qshowpdf`

**Training with typical data sets**

Run the resulting application with typical data sets. This step is called the PDF training step.

You can train the resulting application multiple times with different typical data sets. The profiling information is accumulated into PDF files to provide a count of how often branches are taken and blocks of code are run, based on the input data used.

You can get PDF files in the following ways:

- Generate PDF files upon normal termination. For more information, see “Generating PDF files upon normal termination” on page 18.
- Dump snapshot PDF profiling information to files during execution. For more information, see “Dumping snapshot PDF profiling information during execution” on page 18.

**Usage**

You should use typical data sets for the PDF training step. Otherwise, the analysis of infrequently executed code paths might be distorted.

The PDF file is placed in the current working directory or the directory specified by the PDFDIR environment variable. To override the default file path or name, use the `-qpdf1=pdfname` or `-qpdf1=defname` option. If the PDFDIR environment variable is set but the specified directory does not exist, the compiler issues a warning message. 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 the PDF process finishes.
If you have several PDF files, use the `mergepdf` command to combine these PDF files into one PDF file.

If you recompile your program with `-qpdf1`, the compiler removes the existing PDF file or files whose names and locations are the same as the file or files that are to be created in the training step before the compiler generates a new application.

Notes:
- You cannot mix PDF and PDF map files that are generated for different programs. Further, you cannot mix PDF and PDF map files that are generated from multiple compilation processes with different `-qpdf1` settings for the same program.
- You must use the same version and PTF level of the compiler to generate the PDF file and the PDF map file.
- 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.

Related information in the XL Fortran Compiler Reference

- `-qpdf1, -qpdf2`
- `-O, -qoptimize`
- `mergepdf`
- `PDF environment variables`

Generating PDF files upon normal termination:

When you run an application that was generated in the PDF1 step and end the application using normal methods, a standard PDF file is generated.

This PDF file is named `.<output_name>_pdf` by default, where `<output_name>` is the name of the output file that was generated in the PDF1 step.

Normal termination methods include reaching the end of the execution for the main function.

Related information

- Profile-directed feedback
- `-qpdf1, -qpdf2`
- Training with typical data sets
- Dumping snapshot PDF profiling information during execution

Dumping snapshot PDF profiling information during execution:

Before you begin

Compile some or all of the source files in a program with the `-qpdf1` option.
About this task

In addition to getting PDF profiling information that is written to one or more PDF files upon normal termination, you can dump PDF profiling information to one or more PDF snapshot files during execution. This is especially useful when the application is to be terminated abnormally, for example, when you end a process by using SIGKILL or a system call exit(), _Exit(), or abort().

Procedure

1. Define environment variable PDF_SIGNAL_TO_DUMP as a signal value that is an integer in the range of SIGRTMIN and SIGRTMAX inclusive. This value is read during program initialization.
2. Run the application that was generated in the PDF1 step.
3. Send the user-defined signal value as a trigger to dump PDF profiling information to PDF snapshot files. You can send the user-defined signal value multiple times for each process, and the corresponding PDF snapshot file is overwritten each time. The running application processes continue running until normal termination.

Results

A PDF snapshot file is created for each process with suffix _snapshot.<pid>, and it is named .<output_name>_pdf_snapshot.<pid> by default, where <output_name> is the name of the output file that is generated in the PDF1 step and <pid> is the ID of the process.

If the application creates more than one process, equivalent number of PDF data files are generated when each process receives the signal.

If multiple PDF snapshot files are generated, you must merge the PDF snapshot files for multiple processes by using the mergepdf command before linking or recompiling the program with -qpdf2.

If the application ends normally by executing exit handlers, a standard PDF file named .<output_name>_pdf is also generated.

Example

In this example, program myprogram has a parent process and a child process. You can dump snapshot PDF profiling information to files during execution and use the merged PDF file to fine-tune the optimizations as follows:
1. Compile myprogram.f with -qpdf1 and name the executable file as myprogram.
   xlf -O2 -qpdf1 -o myprogram myprogram.f
2. Define environment variable PDF_SIGNAL_TO_DUMP as 52, which is in the range of SIGRTMIN and SIGRTMAX inclusive.
   export PDF_SIGNAL_TO_DUMP=52
3. Run the compiled application.
   ./myprogram < sample.data &

   The following process ID is displayed:
   [138705]   ./myprogram &
4. Send the user-defined signal 52 to dump PDF profiling information by using the kill command.
Note: The `kill` command does not terminate the processes when the signal value is recognized.

```
kill -s 52 138705
```

Because the application creates a parent process and a child process, both processes receive the signal value. The following messages are displayed for both processes:

```
PDFRunTime: Caught user signal "52", dumping PDF data ... Done.
PDFRunTime: Caught user signal "52", dumping PDF data ... Done.
```

Two PDF snapshot files that are suffixed with process ID, `.myprogram_pdf_snapshot.138705` and `.myprogram_pdf_snapshot.138706`, are created, where 138706 is a child process of 138705.

5. Merge PDF data for the two processes as `.myprogram_pdf`

```
mergepdf .myprogram_pdf_snAPSHOT.* -o .myprogram_pdf
```

6. Recompile `.myprogram.f` by using the same compiler options as step 1, but change `-qpdf1` to `-qpdf2`. `.myprogram_pdf` is used to fine-tune the optimizations.

```
xlf -O2 -qpdf2 -o myprogram.myprogram.f
```

Related information in the XL Fortran Compiler Reference

- `-qpdf1`, `-qpdf2`
- `mergepdf`

Recompiling or linking with `-qpdf2`

Recompile or link your program by using the same compiler options as before, but change `-qpdf1` to `-qpdf2`. This step is called the PDF2 step.

If you want to optimize the entire application, you can do the PDF2 step at executable level in the link step and create executable files for your programs. For details, see “Executable level profile-directed feedback” on page 21.

In addition to optimizing entire application, you can do the PDF2 step at object level in the compile time and create object files for your programs. This can be an advantage for applications where patches or updates are distributed as object files or libraries rather than as executables. In this case, you cannot enable interprocedural analysis (IPA) optimizations. For details, see “Object level profile-directed feedback” on page 22.

Usage

The accumulated profiling information is used to fine-tune the optimizations. The resulting program contains no profiling overhead and runs at full speed. You must ensure the PDF file that is fed into the PDF2 step is the one that is generated in the PDF training step. For example, when the `-qpdf1=pdfname=file_path` option is used during the PDF1 step, you must use the same `-qpdf2=pdfname=file_path` option during the PDF2 step for the compiler to recognize the correct PDF file.

This rule also applies to the `-qpdf1[1|2]=exename` and `-qpdf1[1|2]=defname` options.

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. If you have not changed your program between the **-qpdf1** and **-qpdf2** phases, the number is 100, which means that all the profiling information can be used to optimize the program. If the number is 0, it means that the profiling information is completely outdated, and the compiler cannot take advantage of any information. When the number is less than 100, you can choose to recompile your program with the **-qpdf1** option and regenerate the profiling information.

If the compiler cannot read any PDF files in this step, the compiler issues error message 1586-401 but continues the compilation. If you want the compiler to stop the compilation, specify **-qhaltonmsg=1586-401**.

If you want to erase the PDF information, use the `cleanpdf` command.

**Related information in the XL Fortran Compiler Reference**

- Profile-directed feedback
- **-qpdf1**, **-qpdf2**
- **-O**, **-qoptimize**
- **-qreport**
- `cleanpdf`

**Executable level profile-directed feedback:**

**About this task**

When you compile your program with **-qpdf2**, the **-qipa=level=0** option is enabled by default, so IPA and PDF optimization is done in the link step.

It is recommended that you use the **-qpdf2** option to link the object files that are created during the PDF1 step without recompiling your program. Using this approach, you can save considerable compilation time and achieve the same optimization result as if you had recompiled your program during the PDF2 step.

When option **-04**, **-05**, or any level of option **-qipa** is in effect, and you specify the **-qpdf1** or **-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.

**Examples**

1. Set the PDFDIR environment variable
   ```bash
   export PDFDIR=$HOME/project_dir
   ```
2. Compile most of the files with **-qpdf1**
   ```bash
   xlf -qpdf1 -03 -c file1.f file2.f file3.f
   ```
3. Compile the file that does not need optimization without **-qpdf1**
   ```bash
   xlf -c file4.f
   ```
4. Link the PDF object files (file1.o, file2.o, and file3.o) with the non-PDF object file (file4.o)
   ```bash
   xlf -qpdf1 -03 file1.o file2.o file3.o file4.o
   ```
5. Run the resulting application several times with different input data
   
   ```
   ./a.out < polar_orbit.data
   ./a.out < elliptical_orbit.data
   ./a.out < geosynchronous_orbit.data
   ```

6. Link all the object files into the final application with `-qpdf2`.
   
   ```
   xlf -qpdf2 -O3 file1.o file2.o file3.o file4.o
   ```

   Instead of step 6 in this example, you can recompile your program with `-qpdf2`.
   
   ```
   xlf -qpdf2 -O3 file1.f file2.f file3.f file4.f
   ```

Both recompiling and linking your program with `-qpdf2` can use the accumulated profiling information to fine-tune the optimizations.

**Related information**

- Profile-directed feedback
- `-qpdf1, -qpdf2`
- Recompiling or linking with `-qpdf2`
- Object level profile-directed feedback
- `-O, -qoptimize`
- `-qipa`

**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 approach 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 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 executable level PDF process but with a small change to the PDF2 step. For object level PDF, compile your program by using the `-qpdf1` option, run the resulting application with representative data, compile the program again with the `-qpdf2` option. You need to specify `-qnoipa` with `-qpdf2`, which means you cannot use interprocedural analysis (IPA) optimizations and object level PDF at the same time.

If you specify `-qpdf2 -qnoipa`, object level PDF optimization is done in the compile step. You must take either one of the following actions to ensure that the compiler can recognize the correct PDF file:

- In the PDF1 step, specify `-qpdf1=defname` to revert the PDF file name to .pdf. Thus, the compiler looks for .pdf in the PDF2 step.
- In the PDF2 step, specify `-qpdf2=pdfname=file_path`, where `file_path` is the path and name of the generated PDF file.

The following steps outline this process:

1. Compile your program by using the `-qpdf1` option. For example:
   
   ```
   xlf -c -O3 -qpdf1 file1.f file2.f file3.f
   ```
In this example, the optimization level -O3 is used, which is a moderate level of optimization.

2. Link the object files to get an instrumented executable:
   xlf -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 by 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.
   xlf -c -O3 -qpdf2 -qnoipa file1.f file2.f file3.f

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 object files can be linked by using the system loader ld or by omitting the -c option in the PDF2 step.

Related information

- Profile-directed feedback
- -qpdf1, -qpdf2
- Recompiling or linking with -qpdf2
- Executable level profile-directed feedback
- -O, -qoptimize
- -qipa

Vector technology

Vector technology is a PowerPC technology for accelerating the performance-driven, high-bandwidth communications and computing applications. You can use the vector technology to get dramatic performance improvement for your applications.

There are two ways of using the vector technology: hand coding and automatic vectorization. Automatic vectorization often brings the best performance when you write the code in the right way, but appropriate hand coding can provide additional performance improvement.

The following example shows the difference between a simple array element addition and a vectorized version of the same loop.

Array element addition without using the vector technology:

subroutine myadd(n)
   integer :: i, n
   real(4), dimension(n) :: a, b, c
   do i=1, n
      a(i) = b(i) + c(i)
   enddo
end subroutine

Modified array element addition utilizing the vector technology:
subroutine myadd_vector(n)
  integer :: j, n
  ! vector_size is a constant; for real(4) it must be 16/4 = 4
  ! n must be a multiple of vector_size
  vector(real(4)), dimension(n/vector_size) :: v_a, v_b, v_c

  do j=1, n/vector_size
    v_a(j) = vec_add(v_b(j), v_c(j))
  enddo
end subroutine

In the vectorized version of the code, the data type is replaced by the vector data type. The loop range is reduced from n to n/vector_size. With the vector technology, the operation, $v_a(j) = \text{vec add}(v_b(j), v_c(j))$, is executed in a single machine instruction for each vector. Without the vector technology, the same operation requires multiple instructions costing several processor clock cycles. Therefore, the vector technology can improve the performance of an application.

This section provides general information about vector technology with the following three subsections:

- "Vector technology information"
- "Explicitly calling vector libraries for vectorization" on page 25
- "Auto-vectorization limitations" on page 26

Vector technology information

This section provides links to all of the information about the vector technology and categorize them into the following types:

- Using vector technology with hand coding
- Using vector technology with auto-vectorization

Using vector technology with hand coding

The following table lists the information about using the vector technology with hand coding and provides the links to the detailed information in different documents.

<table>
<thead>
<tr>
<th>Information you need</th>
<th>Sections you can read</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic data types</td>
<td>Vector (IBM extension) in XL Fortran Language Reference</td>
</tr>
<tr>
<td>Vector type declaration statement</td>
<td>VECTOR (IBM extension) in XL Fortran Language Reference</td>
</tr>
<tr>
<td>Vector intrinsic procedures</td>
<td>Vector intrinsic procedures (IBM extension) in XL Fortran Language Reference</td>
</tr>
<tr>
<td>Using the vector libraries</td>
<td>Using the vector libraries</td>
</tr>
</tbody>
</table>

Using vector technology with auto-vectorization

The following table lists the information about compiler options for auto-vectorization and provides the links to the detailed information in different documents.
Table 10. Information about compiler options for auto-vectorization

<table>
<thead>
<tr>
<th>To do...</th>
<th>Read...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enable automatic generation of vector instructions for processors that support them.</td>
<td>-qsimd in XL Fortran Compiler Reference</td>
</tr>
<tr>
<td>Perform high-order transformations (HOT) during optimization.</td>
<td>-qhot in XL Fortran Compiler Reference</td>
</tr>
<tr>
<td>Produce listing files and understand how sections of code have been optimized.</td>
<td>-qlistfmt in XL Fortran Compiler Reference, -qreport in</td>
</tr>
<tr>
<td>Ensure that optimizations done by default, do not alter certain program semantics related to strict IEEE floating-point conformance.</td>
<td>-qstrict in XL Fortran Compiler Reference</td>
</tr>
<tr>
<td>Tuning for your target architecture using -qarch and -qtune.</td>
<td>Tuning for your target architecture, Using -qtune</td>
</tr>
</tbody>
</table>

The following table lists the directive and compiler option that you can use to prohibit auto-vectorization and provides the links to the detailed information in different documents.

Table 11. Directive and compiler option for auto-vectorization

<table>
<thead>
<tr>
<th>To do...</th>
<th>Read...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prohibit the compiler from auto-vectorizing the loop immediately following the directive.</td>
<td>NOVECTOR in XL Fortran Language Reference</td>
</tr>
<tr>
<td>Disable auto-vectorization.</td>
<td>-qsimd in XL Fortran Compiler Reference</td>
</tr>
</tbody>
</table>

Some optimization processes are related to auto-vectorization, you can use compiler options to control these optimizations. The following table lists these optimization processes and provides the links to the detailed information in different documents.

Table 12. Optimizations related to auto-vectorization

<table>
<thead>
<tr>
<th>To learn about...</th>
<th>Read...</th>
</tr>
</thead>
<tbody>
<tr>
<td>The High-order transformation (HOT)</td>
<td>High-order transformation (HOT), An intermediate step: adding -qhot suboptions at level 3</td>
</tr>
<tr>
<td>The Interprocedural analysis (IPA)</td>
<td>The IPA process</td>
</tr>
</tbody>
</table>

Explicitly calling vector libraries for vectorization

To use the vector technology in your applications, you can either rewrite the algorithm manually or rely on the automatic vectorization of the compiler. Although automatic vectorization can provide the highest performing solution, proper hand coding can also bring good performance.
The following example shows how to explicitly call the vector libraries to make use of the vector functionality provided by the target hardware.

```fortran
function dotp(x,y,n) result(s)
  real*8 x(*),y(*),s
  vector(real(8)) sv,xv,yv
  integer i,n

  sv = vec_splats(0.0D0)
  do i=1,n,2
    xv = vec_xld2(0,x(i))
    yv = vec_xld2(0,y(i))
    sv = vec_madd(xv,yv,sv)
  enddo
  s = vec_extract(sv,0)+vec_extract(sv,1)
  if (mod(n,2).eq.1) then
    s = s + x(n)*y(n)
  endif
end function

program dot
  real*8 x(100),y(100),s
  integer i
  do i=1,100
    x(i)=0.5*i
    y(i)=2.0
  enddo
  s = dotp(x,y,100)
  print *,s
end
```

The program performs the dot product for two arrays of REAL. At each iteration, two elements from the arrays are loaded into two REAL vector variables. The program then uses a multiply add operation to calculate the product of the two vectors and add the product with the previous sum. At the end of the loop the two elements of the vector that hold the partial sums are added to form the complete sum value. If the size of the input vectors do not evenly fit in the vector variables, a single scalar product is performed to complete the dot product computation.

**Auto-vectorization limitations**

When you use the auto-vectorization, you might find that some transformations cannot be performed. If you compile with `-qhot` and `-qlistfmt=xml=transforms` or `-qlistfmt=xml=all`, you can get a compiler report that lists the reasons why some transformations were not performed. For detailed information about the possible reasons, see [Using compiler reports to diagnose optimization opportunities](#).

This section uses two code examples to illustrate why auto-vectorization cannot be performed under certain situations.

**Example 1:**

```fortran
program try
  real*8 x(100)
  integer i
  x(1)=9
  do i=2,100
    x(i)=x(i-1)
  enddo
end
```
The \( x(i) = x(i-1) \) statement violates the restriction that "a loop cannot be automatically parallelized if one of its variables carries a dependency". \( x(i) \) and \( x(i-1) \) depend on each other in this sample, which makes the loop non-vectorizable.

Example 2:

```fortran
program try
  real*8 x(100)
  integer i
  do i=1,100,5
    x(i)=i + 8;
    x(i+1)=i + 9;
    x(i+2)=i + 12;
    x(i+3)=i + 15;
  enddo
end
```

The following statements violate the restriction that auto-vectorization cannot be performed if the loop contains a non stride one store.

```
x(i)=i + 8;
  x(i+1)=i + 9;
  x(i+2)=i + 12;
  x(i+3)=i + 15;
```

In each iteration of the loop, four elements in the array \( x \) are accessed and one element is skipped. This continues until the end of the loop, which makes the loop non-vectorizable.

**Using compiler reports to diagnose optimization opportunities**

You can use the `-qlistfmt` option to generate a compiler report in XML or HTML format. It provides information about how your program is optimized. You can also use the `genhtml` utility to convert an existing XML report to HTML format. This information helps you understand your application codes and tune codes 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, for example, `-qlistfmt=xml=all:stylesheet=x1style.xsl`, the report contains a link to a stylesheets that renders the XML readable. By reading the report, you can detect opportunities to further optimize your code. You can also create tools to parse this information.

By default, the name of the report is \( a.xml \) for XML format, and \( a.html \) for HTML format. You can use the `-qlistfmt=xml=filename` or `-qlistfmt=html=filename` option to override the default name.

**Inline reports**

If you compile with `-qinline` and one of `-qlistfmt=xml=inlines`, `-qlistfmt=html=inlines`, `-qlistfmt=xml`, or `-qlistfmt=html`, the generated compiler report includes a list of inline attempts during 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 reasons why a named function has not been successfully inlined. Some examples of these reasons are as follows:
- 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 reasons, see the Inline optimization types section of the XML schema help file named XMLContent.html in the /opt/ibm/xlf/15.1.6/listings/ directory. The Japanese and Chinese versions of the help file, XMLContent-Japanese.utf8.html and XMLContent-Chinese.utf8.html, are included in this directory as well.

**Loop transformations**

If you compile with -qhot and one of -qlistfmt=xml=transforms, -qlistfmt=html=transforms, -qlistfmt=xml or -qlistfmt=html, the generated compiler report includes a list of the transformations performed on all loops in the file during compilation. The report also lists the reasons why transformations were not performed in some cases:
- 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 named XMLContent.html in the /opt/ibm/xlf/15.1.6/listings/ directory.

**Data reorganizations**

If you compile with -qhot and one of -qlistfmt=xml=data, -qlistfmt=html=data, -qlistfmt=xml, or -qlistfmt=html, the generated compiler report 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
- Common block splitting
- 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 you compile with -qpdf2 and one of -qlistfmt=xml=pdf, -qlistfmt=html=pdf, -qlistfmt=xml, or -qlistfmt=html, the generated compiler report includes the following information:
- Loop iteration counts
- Block and call counts
- Cache misses (if compiled with -qpdf1=level=2)

Related information:

Parsing compiler reports with development tools
You can write tools to parse the compiler reports produced in XML format to help you find opportunities to improve application performance.

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 might represent performance improvement opportunities. The schema, xllisting.xsd, is located in the /opt/ibm/xlf/15.1.6/listings/ directory. This schema helps present the information from the report in a tree structure.

You can also find a schema help file named XMLContent.html that helps you understand the schema details. The Japanese and Chinese versions of the help file, XMLContent-Japanese.utf8.html and XMLContent-Chinese.utf8.html, are in the same directory.

Tracing procedures in your code
You can instruct the compiler to insert calls to the tracing procedures that you have defined to aid in debugging or timing the execution of other procedures.

To trace procedures in your program, you must specify which procedures to trace. You must also provide your own tracing procedures. If you enable tracing without providing tracing procedures, you will get linker errors about undefined symbols called __func_trace_enter, __func_trace_exit, and possibly __func_trace_catch.

Specifying which procedures to trace
The -qfunctrace compiler option controls tracing for all non-inlined user-defined procedures and all outlined compiler-generated procedures in your program. If you are interested in tracing specific external or modules procedures, you can use the -qfunctrace+ and -qfunctrace- compiler options. You can also specify the NOFUNCTRACE directive to disable the tracing of entire modules, external procedures, module procedures, or internal procedures.

What can be traced
Tracing applies to programs, external procedures, non-intrinsic module procedures, and internal procedures.

Compiler-generated procedures are not traced unless they were generated for outlined user code, such as an OpenMP program. In those cases, the name of the outlined procedure contains the name of the original user procedure as a prefix.

Inlined procedures and statement functions cannot be traced because they do not exist in the executable.

To avoid infinite recursion, user-defined tracing procedures cannot be traced. Similarly, tracing must be disabled for procedures called from user-defined tracing procedures.
How to write tracing procedures

You can implement the tracing procedures in Fortran, C, or C++.

To implement the tracing procedures in Fortran, the characteristics of the procedures must be the same as those specified in the following interface:

```
SUBROUTINE routine_name(procedure_name, file_name, line_number, id)
  USE, INTRINSIC :: iso_c_binding
  CHARACTER(*), INTENT(IN) :: procedure_name
  CHARACTER(*), INTENT(IN) :: file_name
  INTEGER(C_INT), INTENT(IN) :: line_number
  TYPE(C_PTR), INTENT(INOUT) :: id
END SUBROUTINE
```

where routine_name is the name of an external or module procedure.

You must then tell the compiler to use your subroutine as a tracing procedure in one of the following ways:

- Using the `-qfunctrace_xlf_enter`, `-qfunctrace_xlf_exit`, or `-qfunctrace_xlf_catch` compiler options.
- Using the `FUNCTRACE_XLF_ENTER`, `FUNCTRACE_XLF_EXIT`, or `FUNCTRACE_XLF_CATCH` directives.

When you specify these options or directives, XL Fortran generates wrapper procedures called `__func_trace_enter`, `__func_trace_exit`, and `__func_trace_catch` that call your corresponding tracing procedure. These wrappers allow interoperability with C and C++ by converting the dummy arguments from the C prototype to the interface described earlier. routine_name must therefore not be named `__func_trace_enter`, `__func_trace_exit`, or `__func_trace_catch`. In addition, your program must not contain more than one of each of the tracing procedures.

Writing the tracing procedures in C or C++ requires that you provide the `__func_trace_enter`, `__func_trace_exit`, and `__func_trace_catch` procedures directly. They must have the following prototypes:

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

**Note:** If you write the tracing procedures in C++, they must be declared `extern "C"`.

XL Fortran inserts calls to your tracing procedures on procedure entry and exit. It passes the name of the procedure being traced, the name of the file containing the entry or exit point being traced, and the line number. It also passes the address of a static pointer that is initialized to `C_NULL_PTR` at the beginning of the program. This pointer allows you to store arbitrary data in the entry tracing procedure and access this data in the exit and catch procedures. See the Examples section for detail. Because this pointer resides in static memory, extra steps might be needed when tracing threaded or recursive procedures.
Sample tracing procedures

XL Fortran provides sample tracing procedures in the /opt/ibm/xlf/15.1.0/samples/functrace directory. You can use these procedures for simple tracing, or you can modify them for more complex tracing.

- tracing_routines.c: Provides tracing procedures written in C. This file is useful when you do not require access to Fortran modules, and when there is a possibility of recursive input/output.
- tracing_routines.f90: Provides tracing procedures written in Fortran. This file is useful when you need access to Fortran modules or intrinsics in your tracing procedures.

The following example illustrates the use of the samples for simple tracing:

```
> cat helloworld.f
print *, 'hello world'
end
> cc -c /opt/ibm/xlf/15.1.0/samples/functrace/tracing_routines.c
> xlf95 helloworld.f -qfunctrace tracing_routines.o
**_main===End of Compilation 1===
1501-510 Compilation successful for file helloworld.f.
> ./a.out
{ _main (helloworld.f:1)
  hello world
} _main (helloworld.f:2)
>
```

Tracing limitations

The procedure tracing functionality has the following limitations:

- A procedure cannot be traced separately from its ENTRY points. Either all are traced or none are. The name of the procedure is passed to the tracing procedure even when tracing the ENTRY point. The line number helps distinguish what is being traced in this case.

- The Fortran standard requires pure procedures to have no side effects. The compiler uses this assumption when optimizing your program. If you enable tracing of a pure procedure, your tracing procedure must not change the program state in a way that creates a side effect.

- The Fortran standard imposes limits on recursive input/output. If you write your tracing procedures in Fortran, you must be careful not to break these rules. The following example has a print statement where an I/O item is the result of a function call (foo). It is illegal for the tracing procedure in this case to have I/O on an external file:

```
> cat recursive.f
integer function test()
  test = 1
end function

integer test
print *, test() ! test must not have I/O on external unit
end
> xlf95 -c /opt/ibm/xlf/15.1.0/samples/functrace/tracing_routines.f90
** my__func_trace_enter === End of Compilation 1 ===
** my__func_trace_exit === End of Compilation 2 ===
** my__func_trace_catch === End of Compilation 3 ===
1501-510 Compilation successful for file tracing_routines.f90.
> xlf95 recursive.f tracing_routines.o -qfunctrace
** test === End of Compilation 1 ===
** _main === End of Compilation 2 ===
```
Compilation successful for file recursive.f.

```
> ./a.out
{ _main (recursive.f:6)
XL Fortran (I/O initialization): I/O recursion detected.
Aborted
>
```

**Note:** You can work around this by writing the tracing procedure in C. For an example, see the tracing_routines.c sample file described in section “Sample tracing procedures” on page 31.

- When optimizing your program, the compiler reorders code and removes dead code. As a result, the line number passed to the tracing procedure might not be accurate when optimization is enabled.

**Examples**

In the following example, `-qfunctrace` is used to measure the time spent in each external procedure. The `FUNCTRACE_XLF_ENTER` and `FUNCTRACE_XLF_EXIT` directives are used to specify procedures `my_enter` and `my_exit` as the tracing procedures. The `NOFUNCTRACE` directive is used to disable tracing of `main_program`:

```
> cat example.f
!

Designate my_enter as a tracing procedure that should be called on procedure entry
!

!Libm= functrace_xlf_enter
!

subroutine my_enter(procedure_name, file_name, line_number, id)
  use, intrinsic :: iso_c_binding
  use, intrinsic :: xlfutility
  character(*), intent(in) :: procedure_name, file_name
  integer(c_int), intent(in) :: line_number
  type(c_ptr), intent(inout) :: id
    integer(kind=time_size), pointer :: enter_count
    ! Store the time we entered the procedure being traced into id.
    if (.not. c_associated(id)) then
      allocate(enter_count)
      enter_count = time()
      id = c_loc(enter_count)
    end if

    print *, 'Entered procedure ', procedure_name, ' at ( ', &
    file_name, ' :', line_number, ').'
  end subroutine
!

Designate my_exit as a tracing procedure that should be called on procedure exit
!

!Libm= functrace_xlf_exit
!

subroutine my_exit(procedure_name, file_name, line_number, id)
  use, intrinsic :: iso_c_binding
  use, intrinsic :: xlfutility
  character(*), intent(in) :: procedure_name, file_name
  integer(c_int), intent(in) :: line_number
  type(c_ptr), intent(inout) :: id
    integer(kind=time_size), pointer :: enter_count
    integer(kind=time_size) exit_count, duration
    ! id should have been associated in my_enter with the time we
    ! entered the procedure being traced. Find the elapsed time.
    if (c_associated(id)) then
      exit_count = time()
      call 'c_f_pointer(id, enter_count)
```
duration = exit_count - enter_count
else
  stop "error!"
endif

print *, 'Leaving procedure ', procedure_name, ' at ( ', &
  file_name, ' : ', line_number, ' ).'
print *, 'Spent', duration, 'seconds in', procedure_name, '.
end subroutine

! sub2 will be traced
subroutine sub2
  call sleep_(3)
end subroutine

! sub1 will be traced
subroutine sub1
  call sleep_(5)
call sub2
end subroutine

! Do not want to trace main_program
lib= nofunctrace
program main_program
  call sub1
end program
> xlf95 example.f -qfunctrace
** my_enter === End of Compilation 1 ===
** my_exit === End of Compilation 2 ===
** sub2 === End of Compilation 3 ===
** sub1 === End of Compilation 4 ===
** main_program === End of Compilation 5 ===
1501-510 Compilation successful for file example.f.
> ./a.out
  Entered procedure sub1 at ( example.f : 59 ).
  Entered procedure sub2 at ( example.f : 54 ).
  Leaving procedure sub2 at ( example.f : 55 ).
  Spent 3 seconds in sub2.
  Leaving procedure sub1 at ( example.f : 61 ).
  Spent 8 seconds in sub1.
>
Related information

- For details about the -qfunctrace compiler option, see -qfunctrace in the XL Fortran Compiler Reference.
- For details about -qfuntrace_xlf_catch, -qfuntrace_xlf_enter, or -qfuntrace_xlf_exit compiler options, see the Detailed descriptions of the XL Fortran compiler options section in the XL Fortran Compiler Reference.
- For details about the FUNCTRACE_XLF_CATCH, FUNCTRACE_XLF_ENTER, and FUNCTRACE_XLF_EXIT directives, see Detailed directive descriptions section in the XL Fortran Language Reference.
- For details about the NOFUNCTRACE directive, see NOFUNCTRACE in the XL Fortran Language Reference.

Getting more performance

The XL compiler family offers other strategies and tuning alternatives for increasing performance.

Whether you are already optimizing at -O5 or you are looking for more opportunities to increase performance without the resource costs of optimizing at higher levels, the XL compiler family offers other strategies and tuning alternatives. For more information, see the following topics:
Beyond performance: effective programming techniques

Applications that perform well begin with applications that are written well. See the following topics for information about writing better code; whether your goal is to make your code more portable, more easily optimized, or interoperable with other languages.

- Chapter 4, “Managing code size,” on page 47
- Chapter 6, “Compiler-friendly programming techniques,” on page 57
- Chapter 9, “Parallel programming with XL Fortran,” on page 85
- Chapter 11, “Interlanguage calls,” on page 307
Chapter 2. Tuning XL compiler applications

Included as part of the XL Fortran optimization suite are options you can use to instruct the compiler to generate code that executes optimally on a given processor or architecture family, and to instruct the compiler on the execution characteristics of your application.

The better you can convey those characteristics, the more precisely the compiler can tune and optimize your application. This section assumes that you have already begun optimizing your application using the strategies found in Optimizing your applications.

Tuning for your target architecture

By default, the compiler generates code that runs on all supported systems, though this code does not run optimally on all supported systems. By selecting options to target the appropriate architectures, you can optimize your application to suit the broadest possible selection of relevant processors, a range of processors within a given family, or a specific processor.

The compiler options in the Options for targeting your architecture table introduce how you can control optimizations affecting individual aspects of your target architecture. This section also goes into further detail on how you can use some of those options to ensure your application provides the best possible performance on those targets.

Table 13. Options for targeting your architecture

<table>
<thead>
<tr>
<th>Option</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>-qarch</td>
<td>Selects a family of processor architectures, or a specific architecture that the compiler will generate machine instructions for. If you specify multiple architecture settings, only the last architecture is considered valid.</td>
</tr>
<tr>
<td>-qtune</td>
<td>Focuses optimizations for execution on a given processor without restricting the processor architectures that your application can execute on. If you specify multiple architecture settings, only the last architecture is considered valid. You can also use -qtune to specify the processor SMT level that the program will execute on.</td>
</tr>
<tr>
<td>-qcache</td>
<td>Defines a specific cache or memory geometry. Selecting a predefined optimization level like -O2 sets default values for -qcache suboptions.</td>
</tr>
</tbody>
</table>

In addition to targeting the correct architecture for your application, it is important to select the right level of optimization. Combining the appropriate architecture settings with an optimization level that fits your application can vastly enhance performance. If you have not already done so, consult Optimizing your applications in addition to this section.

Using -qarch

Using -qarch you can select a machine architecture or a family of architectures on which you can run your application. Selecting the correct -qarch suboption is crucial to influencing chip-level optimization as the choice of -qarch suboption controls:
• The list of machine instructions available to the compiler when generating object code.
• The characteristics and capabilities of the hardware the compiler will model when optimizing.
• Optimization trade-offs and opportunities in individual instruction selection and instruction sequence selection
• The default setting of the -qtune option.

Architecture selection is important at all optimization levels. Even at low optimization levels like -O0 and -O2, specifying the correct target architecture can be beneficial to performance. Specifying the correct target allows the compiler to select more efficient machine instructions and generate instruction sequences that perform best for a particular machine.

The -qarch suboptions allow you to specify individual processors or a family of processors with common instruction sets or subsets. The choice of processor gives you the flexibility of compiling your application to execute optimally on a particular machine, or to execute on a wide variety of machines while still applying as much architecture-specific optimization as possible. The less specific your choice of architecture, the fewer machine instructions available to the compiler when generating code. A less specific choice can also limit the number of hardware intrinsic functions available to your application. A more specific choice of architecture, can make available more instructions and hardware intrinsic functions. The XL Fortran Compiler Reference details the specific chip architectures and architecture families available.

When compiling your application, using a consistent or compatible -qarch setting for all files will ensure that you are getting the most from your architecture targets. If you are using -qipa link-time optimizations, the architecture setting you specify on the link step overrides the compile step setting.

You must ensure that your application executes only on machines that support your -qarch settings. Executing your application on other machines can produce incorrect results, even if your application appears to run without trapping.

Using -qtune

The -qtune option focuses optimizations for execution on a given processor without restricting the processor architectures that your application can execute on, generating machine instructions consistent with your -qarch architecture choice. Using -qtune also guides the optimizer in performing transformations, such as instruction scheduling, so that the resulting code executes most efficiently on your chosen -qtune architecture. The -qtune option tunes code to run on one particular processor architecture, and includes only specific processors as suboptions. The -qtune option does not support suboptions representing families of processors.

Use -qtune to specify the most common or critical processor where your application executes.

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 may be harmful on some hardware. Note that you should verify the performance of code compiled with the -qtune=balanced option before distributing it.
You can also use `-qtune` to specify the processor SMT level that the program will execute on.

You can also use `-qtune` to specify the processor SMT level that the program will execute on.

**Using `-qcache`**

The `-qcache` option allows you to instruct the optimizer on the memory cache layout of your target architecture. There are several suboptions you can specify to describe cache characteristics such as:

- The types of cache available
- The cache size
- Cache-miss penalties

The `-qcache` option is only effective if you understand the cache characteristics of the execution environment of your application. Before using `-qcache`, look at the options section of the listing file with the `-qlist` option to see if the current cache settings are acceptable. The settings appear in the listing when you compile with `-qlistopt`. If you are unsure about how to interpret this information, do not use `-qcache`, and allow the compiler to use default cache settings.

If you do not specify `-qcache`, the compiler makes cache assumptions based on your `-qarch` and `-qtune` settings. If you compile with the `-qcachae=auto` suboption, the default at optimization levels `-O4` and `-O5`, the compiler detects the cache characteristics of your compilation machine and tunes cache optimizations for that cache layout. If you do specify `-qcache`, also specify `-qhot`, or an option such as `-O4` that implies `-qhot`. The optimizations that `-qhot` performs are designed to take advantage of your `-qcache` settings.

**Before you finish tuning**

Consult the following list to ensure that you are getting the most out of your target machine options.

- Do not specify a `-qarch` option that is incompatible with your hardware. This can produce unexpected results.
- Specify a `-qarch` setting that represents the largest common instruction set available to the machines that your application will execute on.
- If you are executing your application on multiple machines, choose the `-qtune` suboption that aligns with the machine you expect your application to run on most frequently or where performance is most important.
- If compiling with `-qcache`, specify `-qhot` as well, which can take advantage of your cache settings.

**Further option driven tuning**

You can use options to convey the characteristics of your application to the compiler, tuning the optimizations that the compiler will apply. Option driven tuning is a process that can require experimentation to find the right combination of options to increase the performance of your application.

The XL compilers support many options that allow you to assert that your application will not follow certain standard language rules in some instances. The compiler assumes language standard compliance and can perform unsafe optimizations if your application is not compliant. Standards-conforming
applications are more easily optimized and more portable, but when full compliance is not possible, use the appropriate options to ensure your code is optimized safely.

For complete compiler option syntax, see the XL Fortran Compiler Reference.

**Options for providing application characteristics**

This section provides a list of options that can dictate a wide variety of characteristics about your application to the compiler including floating-point and loop behaviors.

**Option Description**

- **-qalias**
  Supports several suboptions that can help the compiler analyze the characteristics of your application. For more information on aliasing, see [Advanced optimization concepts](#).

  - **noaryovrlp**
    Asserts that your application contains no array assignments between storage associated (overlapping) arrays.

  - **nointptr**
    Asserts that your application does not make use of integer (Cray) pointers.

  - **nopteovrlp**
    Asserts that your application does not contain pointee variables that refer to any data objects that are not pointee variables. Also, that your application does not contain two pointee variables that can refer to the same storage location.

  - **std**
    Asserts that your application follows all language rules for variable aliasing. This is the default compiler setting. Specify `-qalias=nostd` if your application does not follow all variable aliasing rules.

- **-qassert**
  Includes the following suboptions that can be useful for providing some loop characteristics of your application.

  - **nodeps**
    Asserts that the loops in your application do not contain loop carried dependencies.

  - **itercnt=number**
    Gives the optimizer a value to use when estimating the number of iterations for loops where it cannot determine that value.

- **-qddim**
  Forces the compiler to reevaluate the bounds of a pointee array each time the application references the array. Specify this option only if your application performs dynamic dimensioning of pointee arrays.

- **-qdirectstorage**
  Asserts that your application accesses write-through-enabled or cache-inhibited storage.

- **-qfloat**
  Provides the compiler with floating-point characteristics for your application. The following suboptions are particularly useful.

  - **nans**
    Asserts that your application makes use of signaling NaN
(not-a-number) floating-point values. Normal floating-point operations do not create these values, your application must create signalling NaNs.

rrm Prohibits optimization transformations that assume the floating-point rounding mode must be the default setting round-to-nearest. If your application changes the rounding mode in any way, specify this option.

-qflttrap Controls various aspects of floating-point exception handling that your application can require if it attempts to detect or handle such exceptions. If your application enables floating point trapping without using -qflttrap, you must use the -qfloat=fenv option.

-qieee Specifies the floating-point rounding mode when evaluating expressions at compile time. This option is important if your application requires a non-default rounding mode in order to have consistency between compile-time evaluation and runtime evaluation.

You can also specify -y to set the compile-time floating-point rounding mode.

-qlibansi Asserts that any external function calls in your compilation that have the same name as standard C library function calls, such as malloc or memcpy, are in fact those functions and are not a user-written function with that name.

-qlibmpi Asserts that all functions with Message Passing Interface (MPI) names are in fact MPI functions and not a user function with different semantics.

-qonetrip Asserts that all DO loops in your application will execute at least one iteration. You can also specify this behavior with -1.

-qnostrictieeeemod Relaxes certain rules required by the Fortran 2003 standard related to the use of the IEEE intrinsic modules. Specify this option if your application does not use these modules.

-qstrict_induction Prevents optimization transformations that would be unsafe if DO loop integer iteration count variables overflow and become negative. Few applications contain algorithms that require this option.

-qthreaded Informs the compiler that your application will execute in a multithreaded/SMP environment. Using an _r invocation, like xlf_r, adds this option automatically.

-qnounwind Informs the compiler that the stack will not be unwound while any routine in your application is active. The -qnounwind option enables prologue tailoring optimization, which reduces the number of saves and restores of nonvolatile registers.

-qnozerosize Asserts that this application does not require checking for zero-sized arrays when performing array operations.
Options to control optimization transformations

There are many options available to you in addition to the base set found in the Optimizing your applications section. Some of these options prevent an optimization that can be unsafe for certain applications or enable one that is safe for your application, but is not normally available as part of the optimization process.

Option Description

-qcompact
Chooses a reduction of final code size over a reduction in execution time. You can use this option to constrain the optimizations of -O2 and higher. For more information on restriction code size, see the Managing code size section.

-qfdpr Prepares your object code for additional optimization by the FDPR® object code optimizer.

-qsimd=auto
Makes use of the vector capabilities of processors.

-qfloat
This option provides a number of suboptions for controlling the optimizations to your floating-point calculations.

norsqrt
Prevents the replacement of the division of the result of a square-root calculation with a multiplication by the reciprocal of the square root.

nostRICTMAF
Prevents certain floating-point multiply-and-add instructions where the sign of signed zero value would not be preserved and rounding is in the wrong direction.

-qipa Includes many suboptions that can assist the IPA optimizations while analyzing your application. If you are using the -qipa option or higher optimization levels that imply IPA, it is to your benefit to examine the suboptions available.

-qmaxmem Limits the memory available to certain memory-intensive optimizations at low levels. Specify -qmaxmem=-1 to remove these memory limits.

-qnoprefetch Prevents the insertion of prefetching machine instructions into your application during optimization.

-qinline Exerts control over inlining optimization transformations. For more information on inlining, see the Advanced optimization concepts section.

-qsmallstack Instructs the compiler to limit the use of stack storage in your application. This can increase heap usage.

-qSMP Produces code for an SMP system. This option also searches for opportunities to increase performance by automatically parallelizing your code. The Parallel programming with XL Fortran section contains more information on writing parallel code.
-qstacktemp
Limits certain compiler temporaries allocated on the stack. Those not allocated on the stack will be allocated on the heap. This option is useful for applications that use enough stack space to exceed stack user or system limits.

-qstrict
Limits optimizations to strict adherence to implied program semantics. This often prevents the compiler from ignoring certain little-used rules in the IEEE floating-point specification that few applications require for correct behavior. For example, reordering or reassociating a sequence of floating-point calculations can cause floating-point exceptions at an unexpected location or mask them completely. The \texttt{-qstrict} option includes suboptions that refine the control of the transformations performed by the optimizers. Do not use this option unless your application requires strict adherence as \texttt{-qstrict} and its suboptions can severely inhibit optimization.

-qunroll
Independently controls loop unrolling. At \texttt{-O3} and higher, \texttt{-qunroll} is a default setting.

\section*{Options to assist with performance analysis}
The compiler provides a set of options that can help you analyze the performance aspects of your application. These options are most useful when you are selecting your level of optimization and tuning the optimization process to the particular characteristics of your application.

-\texttt{d}
Informs the compiler that you want to preserve the preprocessed versions of your compilation files. Typically these files would have a \texttt{.F} extension.

-\texttt{g}
Inserts debugging information into your object code. You can use different \texttt{-g} levels to balance between debug capability and compiler optimization.

-\texttt{p}
Inserts appropriate profiling information into your object code to make using tools for performance analysis possible. You can also specify this behavior with \texttt{-pg}.

-\texttt{qlinedebug}
An option similar to \texttt{-g}, this option inserts only minimal debugging information into your object code such as function names and line number information.

-\texttt{qlist}
Produces a listing file containing a pseudo-assembly listing of your object code.

-\texttt{qlistfmt}
Creates a compiler report to assist with finding optimization opportunities.

-\texttt{qreport}
Inserts information in the listing file showing the transformations done by certain optimizations.

-\texttt{S}
Produces a \texttt{.s} file containing the assembly version of the \texttt{.o} file produced by the compilation.

-\texttt{-qshowpdf}
Enables the optimization process to insert additional profiling information into the compiled application. You can use the \texttt{showpdf} utility to view
part of the profiling information of your application in text or XML format. For more information about profile-directed feedback (PDF), see \textit{Profile-directed feedback}.

\textbf{-qt bespoke}

Limits the amount of debugging traceback information in object files, which reduces the size of the program. Use \texttt{-qt bespoke=full} if you intend to analyze your application with a profiling utility.

\section*{Options that can inhibit performance}

Some compiler options are necessary for some applications to produce correct or repeatable results. Usually, these options instruct the compiler to enforce very strict language semantics that few applications require. Others are supported by the compiler to allow compilation of code that does not conform to language standards. Avoid these options if you are trying to increase the runtime performance of your application. In cases where these options are enabled by default, you must disable them to increase performance. You can specify \texttt{-q listopt} to show, in the listing file, the settings of each of these options.

The following list summarizes the options that can inhibit performance. Each option is described in the \textit{XL Fortran Compiler Reference}.

- \texttt{-qalias=nostd}
- \texttt{-qcompact}
- \texttt{-qfloat=nosqrt}, \texttt{-qfloat=nostictmaf}, \texttt{-qfloat=rrm}
- \texttt{-qsimd=noauto}
- \texttt{-qnoprefetch}
- \texttt{-qnounroll}
- \texttt{-qsmallstack}
- \texttt{-qstacktemp=[value other than 0 or -1]}
- \texttt{-qstrict}
- \texttt{-qstrict_induction}
- \texttt{-qstrictieemod}
- \texttt{-qunwind}
- \texttt{-qxf2008=checkpresence}
- \texttt{-qzerosize}
- \texttt{-qnoinline}
Chapter 3. Advanced optimization concepts

After you apply command-line optimizations and tuning that are appropriate to your application and the constraints of your development cycle, you have opportunities to further improve the performance of your application through aliasing and inlining.

Aliasing

An alias occurs when different variables point directly or indirectly to a single area of storage. Aliasing refers to assumptions made during optimization about which variables can point to or occupy the same storage area.

When an alias exists, or the potential for an alias occurs during the optimization process, pessimistic aliasing occurs. This can inhibit optimizations like dead store elimination and loop transformations on aliased variables. Also, pessimistic aliasing can generate additional loads and stores as the compiler must ensure that any changes to the variable that occur through the alias are not lost.

When aliasing occurs there is less opportunity for optimization transformations to occur on and around aliased variables than variables where no aliasing has taken place. For example, if variables $A$, $B$, and $C$ are all aliased, any optimization must assume that a store into or a use of $A$ is also a store or a use of $B$ and $C$, even if that is not the case. Some of the highest optimization levels can improve alias analysis and remove some pessimistic aliases. However, in all cases, when it is not proven during an optimization transformation that an alias can be removed that alias must be left in place.

Where possible, avoid programming techniques that lead to pessimistic aliasing assumptions. These aliasing assumptions are the single most limiting factor to optimization transformations. The following situations can lead to pessimistic aliasing:

- When you assign a pointer the address of any variable, the pointer can be aliased with globally visible variables and with static variables visible in the pointer's scope.
- When you call a procedure that has dummy arguments passed by reference, aliasing occurs for variables used as actual arguments, and for global variables.
- The compiler will make several worst-case aliasing assumptions concerning variables in common blocks and modules. These assumptions can inhibit optimization.

Some compiler options like `-qalias` can affect aliasing directly. For more information on how to tune the aliasing behavior in your application, see “Options for providing application characteristics” on page 38.

Inlining

Inlining is the process of replacing a subroutine or function call at the call site with the body of the subroutine or function being called. This eliminates call-linkage overhead and can expose significant optimization opportunities.
For example, with inlining, the compiler can replace the subroutine parameters in the function body with the actual arguments passed. Inlining trade-offs can include code bloat and an increase in the difficulty of debugging your source code.

If your application contains many calls to small procedures, the procedure call overhead can sometimes increase the execution time of the application considerably. Specifying the `-qinline` compiler option can reduce this overhead. Additionally, you can use the `-p` or `-pg` options and profiling tools to determine which subprograms your application calls most frequently, and use `-qinline` to list their names to ensure inlining.

The `-qinline` option can perform inlining where the calling and called procedures are in different compilation units. This applies to optimization level `-O5` only.

```
# Let the compiler decide what to inline.
xlf95 -O3 -qinline inline.f
```

```
# Encourage the compiler to inline particular subprograms.
xlf95 -O3 -qinline+called_100_times:called_1000_times inline.f
```

**Note:** `-qipa=inline` is deprecated and no longer supported; it is replaced by `-qinline`.

### Finding the right level of inlining

A common occurrence in application optimization is excessive inlining. This can actually lead to a decrease in performance because running larger programs can cause more frequent cache misses and page faults. Because the XL compilers contain safeguards to prevent excessive inlining, this can lead to situations where subprograms you want to inline are not automatically inlined when you specify `-qinline`.

Some common conditions that prevent `-qinline` from inlining particular subprograms are:

- The calling and called procedures are in different compilation units. If so, you can use the `-qinline` option in the link step to enable cross-file inlining. This applies to optimization level `-O5` only.
- After inlining expands a subprogram to a particular limit, the optimizer does not inline subsequent calls to that subprogram.
- Any interface errors, such as different numbers, sizes, or types of arguments or return values, can prevent inlining for a subprogram call. You can also use interface blocks for the procedures being called.
- Actual or potential aliasing of dummy arguments or automatic variables can limit inlining. Consider the following cases:
  - There are more than 31 arguments to the procedure your application is calling.
  - Any automatic variables in the called procedures are involved in an `EQUIVALENCE` statement
  - The same variable argument is passed more than once in the same call. For example, `CALL SUB(X,Y,X)`.
- Some procedures that use computed `GO TO` statements, where any of the corresponding statement labels are also used in an `ASSIGN` statement.

To change the size limits that control inlining, you can specify `-qinline=level=n`, where `n` is 0 through 10. Larger values allow more inlining.
It is possible to inline C/C++ functions into Fortran programs and Fortran functions into C/C++ programs during link time optimizations. You must compile the C/C++ code using the IBM XL C/C++ compilers with `-qinline` and a compatible option set to that used in the IBM XL Fortran compilation.
Chapter 4. Managing code size

Code size is often not a detriment to performance for most XL compiler programmers. For some however, generating compact object code can be as important as generating efficient code.

Oversized programs can affect overall performance by creating a conflict for real storage between pages of virtual storage containing code, and pages of virtual storage containing data. On systems with a small, combined instruction and data cache, cache collisions between code and data can also reduce performance. This section provides suggestions on how to achieve a balance between code efficiency and object-module size, while identifying compiler options that can affect object-module size. Code size tuning is most effective once you have built a stable application and run optimization at `-O2` or higher.

Reasons for tuning for code size include:

- Your application design calls for an implementation with limited real memory, instruction-cache space, or disk space.
- When loading your application, it uses enough memory to create a conflict between code areas and data areas in real memory, and both code and data are frequently paged in and out.
- There are high activity areas in your code large enough that instruction cache and instruction Translation Lookaside Buffer (TLB) misses have a major effect on performance.
- You intend your application to run on a host that serves end users, or in a batch environment with limits on real memory.

Before tuning for code size, it is important for you to determine whether code size is the actual problem. Very large applications tend to have small clusters of high activity and large sections of infrequently accessed code. If a particular code page is not accessed in a particular run, that page is never loaded into memory, and has no negative impact on performance. If you are tuning for code size due to the high activity code segments that cause instruction cache and instruction TLB misses that have a major effect on performance, this can be symptomatic of a program structure that requires improvement or hardware not suited to the resource requirements of the application.

If your data takes up more real storage than is available, reducing code size can improve performance by ensuring that fewer pages of data are paged out as code is paged in. However, data blocking strategies are likely to prove both more effective and easier to implement. Processing data in each page as completely as possible before moving on to the next page can reduce the number of data page misses.

If you are coding an application for a machine with a combined instruction and data cache, you can improve performance by applying the techniques described later in this section, but tuning for data cache management can yield better results than code-size tuning. Also note that highly tuning your code for the cache characteristics of one system can lead to undesirable performance results if you execute your application elsewhere.
Steps for reducing code size

Reducing the code size of your application can have a positive effect on the performance of your application.

Consider the following steps for reducing code size:

- Ensure that you have built a stable application that compiles at `-O2` or higher.
- Use performance analysis tools to isolate high activity code segments and tune for performance where appropriate. Basing decisions for code size tuning on an application that has already undergone performance analysis will give you more information on where your application could benefit from code size tuning.
- Use compiler options like `-gcompact` to help reduce code size. See Compiler option influences on code size for more information. Also see the following options in the XL Fortran Compiler Reference:
  - `-qinline`
  - The partition parameter for `-qipa`
  - `-qunroll`

Be aware that optimization can cause code to expand significantly through loop unrolling, invariant IF floating, inlining, and other optimizations. The higher your optimization level, the more code size can increase. For more information on finding an optimization level appropriate for your application, see Chapter 1, “Optimizing your applications,” on page 1.

Compiler option influences on code size

High optimization levels can increase code size. You can use other compiler options to influence the size of your code and improve performance.

The `-qipa` compiler option

The `-qipa` option enables interprocedural analysis (IPA) by the compiler. Interprocedural analysis analyzes the relationships between procedures and the code that references those procedures, so that more optimizations within procedures and across procedure references can take place. Interprocedural analysis can decrease code size and improve performance at the same time. In some cases however, IPA inlining can increase code size. Use with discretion.

Related reference:

See interprocedural analysis (IPA) in the Compiler Reference

The `-qinline` inlining option

Using the `-qinline` compiler option, you can specify that the compiler consider all procedures, or a particular list of procedures for inlining. Inlining procedures can increase the performance of your application. However, if your program references a procedure from many different locations in the source code, inlining that procedure can increase code size dramatically. You can use `-qnoinline` to disable procedure inlining entirely. You can also partially disable inlining with `-qinline=<procedure_name>`.

Do not assume that all inlining increases code size. When your source code references a very small procedure many times, inlining can reduce code size, because inlining eliminates control transfer and data interface code. In addition, inlining code facilitates other optimizations at the point of inlining, by providing...
information on the values of arguments referencing the procedure. If a procedure is very small and is referenced from a number of places, inlining can also increase code locality and reduce code paging.

For details about the -qinline compiler option, see -qinline in the XL Fortran Compiler Reference.

The -qhot compiler option

The loop analysis and optimization available when you specify -qhot can increase code size. If your application contains many large loops and loop optimization opportunities exist, -qhot can increase code size significantly along with performance. Specifying -qhot=level=0 will perform minimal high-order transformations if code size is an issue. The topic High-order transformation contains more information on using -qhot effectively.

The -qcompact compiler option

The -qcompact compiler option instructs the compiler to avoid certain optimizing transformations that expand the object code. Compiling with -qcompact, disables many transformations, including:

- Loop unrolling
- Expansion of fixed-point multiply by more than one instruction
- Inline expansion of some string and memory manipulation functions. In some cases -qcompact will avoid inlining opportunities entirely.

Specifying -qcompact creates a trade-off between the performance of individual routines in your application, and overall system performance. Suppressing transformations degrades the performance of individual routines, while overall system performance can increase as a more compact program can provide some or all of the following:

- Fewer instruction-cache misses
- Fewer TLB misses for pages of application code
- Fewer page faults for application code

Other influences on code size

In addition to compiler options, there are a number of ways programming and analysis can influence the size of your source code.

High activity areas

Once you apply the techniques discussed earlier in this section, your strategy for further code size reduction depends on your objective. Use profiling tools to locate hot spots in your program; then follow one of the following guidelines:

- If you want to reduce code size to reduce program paging, concentrate on minimizing branches and procedure references within those hot spots.
- If you want to reduce code size to reduce the size of your program's files on disk, concentrate on areas that are not hot spots. Remove any expansive optimizations from code that does not contain hot spots.

Computed GOTOs and CASE constructs

A sparse computed GOTO can increase code size considerably. In a sparse computed GOTO, most statement labels point to the default. Consider the following example where label 10 is the default:
Although fewer cases are shown, the following **CASE** construct is functionally equivalent to the example above. \( N \) is the value of the largest integer that the computed **GOTO** or **CASE** construct is testing.

\[
\text{INTEGER IA(10000)} \\
\text{SELECT CASE (IA(I))} \\
\text{CASE DEFAULT} \\
\text{GOTO 10} \\
\text{CASE (5)} \\
\text{GOTO 20} \\
\text{CASE (10)} \\
\text{GOTO 30} \\
\text{CASE (11)} \\
\text{GOTO 20} \\
\text{! ...} \\
\text{CASE (N-10)} \\
\text{GOTO 30} \\
\text{CASE (N-2)} \\
\text{GOTO 20} \\
\text{CASE (N)} \\
\text{GOTO 30} \\
\text{END SELECT}
\]

In both examples, the compiler builds a branch table in the object file that contains one entry for each possibility from 1 to \( N \), where \( N \) is the largest integer value tested. The data section of the program stores this branch table. If \( N \) is very large, the table can increase both the size of the object file and the effects of data-cache misses.

If you use a **CASE** construct with a small number of cases and wide gaps between the test values of the cases, the compiler selects a different algorithm to dispatch to the appropriate location, and the resulting code can be more compact than a functionally equivalent computed **GOTO**. The compiler cannot determine that a computed **GOTO** has a default branch point, so the compiler assumes that any value in the range will be selected. In a **CASE** construct, the compiler assumes that cases you do not specify in the construct are handled as default.

**Code size with dynamic or static linking**

Dynamic or static linking each affect the size of your code, and the resulting performance of your application.

**Dynamic linking and code size**

When linking your programs, dynamic linking often ensures more compact code than linking statically. Dynamic linking does not include library procedures in your object file. Instead, a reference at run time causes the operating system to locate the dynamic library that contains the procedure, and reference that procedure from the library on the system. Only one copy of the procedure is in memory, even if several programs, or copies of a single program, are accessing the procedure.
simultaneously. This can reduce paging overhead. However, any libraries your program references must be present in your application's execution environment.

Note that if your program references high performance libraries like BLAS or ESSL, these procedures are dynamically linked to your program by default.

**Static linking and code size**

Static linking binds library procedures into your application's object file. This can increase the size of your object file. If your program references only a small portion of the procedures available in a library, static linking can eliminate the need to provide the library to your users. However, static linking ties your application to one version of the library which can be detrimental in situations where your application will execute in different environments, such as different levels of the operating system.
Chapter 5. 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 might not be current if the most current value is being stored in a register. Most debuggers cannot follow 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 might 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 might 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, and then recompile it with your desired optimization options. See “Debugging in the presence of optimization” on page 54 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. For more information, see -g.

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. For example, failure can occur if the program passes an actual argument that also
appears in a common block in the called procedure, or if two or more dummy arguments are associated with the same actual argument. 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` or `-qinitalloc=hex_value` option to try to produce the incorrect results consistently. For example, using `-qinitauto=FF` gives REAL and COMPLEX 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`) might 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 such programs might fail when you optimize. Similarly, a program can appear to execute correctly after optimization, but it fails at lower optimization levels or when it is run in a different environment. You can also use the `-qcheck=unset` option and `-qinfo=unset` option 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 in effect 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 debugging 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. To generate a listing file, you must specify the `-qreport` option with at least one optimization option such as `-qhot`, `-qsmp`, `-qinline`, or `-qsimd`.

- `-qinfo=HOSTASSOCIation` Issues an informational message for an entity that is accessed by host association for the first time. For details, see `-qinfo`.

- `-qinfo=mt` Reports potential synchronization issues in parallel code. For details, see `-qinfo`.

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-qinfo=unset
Detects automatic variables that are used before they are set, and flags them with informational messages at compile time. For details, see \texttt{-qinfo}.

-qpia=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, \texttt{-qsmp=noopt} ensures that the compiler performs only the minimum transformations necessary to parallelize your code and preserves maximum debug capability.

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

-qinitialloc
Instructs the compiler to emit code that initializes all allocatable and pointer variables that are allocated but not initialized to a given value.

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

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

In addition, you can also use the \texttt{SNAPSHOT} directive to ensure that certain variables are visible to the debugger at points in your application. For details, see \texttt{SNAPSHOT}.
Chapter 6. Compiler-friendly programming techniques

Writing compiler-friendly code, with both the optimizer and portability in mind, can be as important to the performance of your application as the compilation options that you specify.

General practices

It is not necessary to hand-optimize your code, as hand-optimizing can introduce unusual constructs that can obscure the intentions of your application from the compiler and limit optimization opportunities.

Avoid breaking your program into too many small functions, as this can increase the percentage of time the program spends in dealing with call overhead. If you choose to use many small functions, compiling with -qipa can help minimize the impact on performance. Attempting to optimize an application with many small functions without the benefit of -qipa can severely limit the scope of other optimizations.

Use command invocations like xlf90 and xlf95, which use -qnosave. The -qnosave option sets the default storage class of all variables to automatic. This provides more opportunities for optimization. When the xlf invocation command is used to compile the .f, .F, .F77, or .F77 files, the default is -qsave. The f77 and fort77 invocation commands also use -qsave by default. All the other invocation commands use -qnosave by default.

Use modules to group related subroutines and functions.

Use module variables instead of common blocks for global storage.

Mark all code that accesses or manipulates data objects by independent I/O processes and independent, asynchronously interrupting processes as VOLATILE. For example, mark code that accesses shared variables and pointers to shared variables. Mark your code carefully however, as VOLATILE is a barrier to optimization as accessing a VOLATILE object forces the compiler to always load the value from storage. This prevents powerful optimizations such as constant propagation or invariant code motion.

The XL compilers support high performance libraries that can provide significant advantages over custom implementations or generic libraries.

Variables and pointers

The effective use of aliasing and of variables and pointers provides opportunities for improved performance and further optimization.

Obey all aliasing rules. Avoid specifying -qalias=nostd. For more information on aliasing and how it can affect performance, see "Aliasing" on page 43.

Avoid unnecessary use of global variables and pointers, including module variables and common blocks. When using global variables and pointers in a loop, load them into a local variable before the loop and store them back after. If you do not use the local variable somewhere other than in the loop body, the optimization
process can usually recognize what you are doing and expose more optimization opportunities. Replacing a global variable in a loop with a local variable reduces the possibilities for aliasing.

Use the INTENT statement to describe the usage of dummy arguments.

Limit the use of ALLOCATABLE objects and POINTER variables to situations demanding dynamic memory allocation.

**Arrays**

Where possible, use local variables instead of global variables for loop index variables and bounds.

Whenever possible, ensure references to arrays or array sections refer to contiguous blocks of storage. Noncontiguous memory array references, when passed as parameters, lead to copy-in and copy-out operations.

When declaring an array pointer or an assumed-shape array, you can use the CONTIGUOUS attribute to ensure that the array elements in order are stored in contiguous memory and not separated by other data objects. An array pointer with the CONTIGUOUS attribute can only be pointer associated with a contiguous target. An assumed-shape array with the CONTIGUOUS attribute is always contiguous; however, the corresponding actual argument can be contiguous or noncontiguous. If it is noncontiguous, the compiler makes it contiguous by creating a temporary contiguous argument. When the CONTIGUOUS attribute is used, the compiler can perform appropriate semantic check and detect invalid codes, which helps you write more optimized codes and enables the compiler to further optimize the runtime performance and storage layout.

Keep your array expressions simple so that the optimizer can deduce access patterns more easily and reuse index calculations in whole or in part.

Frequent use of array-to-array assignment and WHERE constructs can impact performance by increasing temporary storage and creating loops. Using -qlist or -qreport can help you understand the performance characteristics of your code, and where applying -qhot could be beneficial. If you are already optimizing with -qipa, ensure you are using the list=filename option, so that the -qlist listing file is not overwritten.

**Related information**

- The CONTIGUOUS attribute

**Choosing appropriate variable sizes**

Improve the efficiency of your application by choosing the appropriate variable sizes.

When programming SMP applications, use the CONTAINS statement only to share thread local storage.

In most cases using INTEGER(8) for scalars improves the efficiency of DO loops, subscripting, mathematical calculations and calling conventions when passing objects. However, if your code contains large arrays with values that can fit in an INTEGER(4), using smaller kind parameters can actually improve memory efficiency by reducing memory traffic to load or store data.
Use the lowest floating-point precision appropriate to your application. Higher precisions can reduce performance, so use the REAL(16), or COMPLEX(16) data types only when you require extremely high precision.

On systems with VMX, using REAL(4) and -qsimd=auto provides opportunities for short vectorization that is not available with larger floating-point types. On systems with VSX, -qsimd=auto provides opportunities for vectorization on the REAL(8) type.

**Submodules (Fortran 2008)**

The submodule feature provides more structural facilities for modules.

When you compile a source file that contains submodules, a submodule symbol file named *ancestormodulename_submodulename*.smod is generated for each submodule. These output .smod files are to be used as input when you compile the descendant submodules.

You can use a module to declare the interfaces of module procedures and the descendant submodules to implement those module procedures. If the implementation of the procedures is changed, but their interfaces remain the same, you are not required to recompile the file that contains the module. An .smod file of a submodule is the prerequisite of its descendant submodules only.

A submodule extends a module or another submodule and can have its descendant submodules. You can put entities at intermediate levels that are shared by the descendant submodules at lower levels. Changing these entities cannot change the interpretation of anything that is accessible from the module by use association. Users of modules that embody large complicated concepts can organize components of the concept into submodules. At the same time, they can prevent the privacy of entities that is shared by the submodules and that is not to be displayed to the module users. In addition, putting these shared entities at an intermediate level also prevents cascades of reprocessing and testing if some of them are changed.

Because submodules cannot be accessed by use association, two submodules of different modules can access the ancestor module of each other through use association without causing circular dependency.

**Example**

The following example illustrates four modules with their descendant submodules and a main program.

- A module m1, which has a submodule m1sub.
- A module m2, which has a submodule m2sub, which in turn has a submodule m2sub2.
- Modules m3 and m4, which do not have descendant submodules.

The module m1, m2, and m4 are defined as follows. Both m2 and m4 use m1 in host associated scope.

```
MODULE m1
  TYPE Base
    INTEGER :: i
  END TYPE

INTERFACE
```
MODULE SUBROUTINE sub1(i, b)  ! Module procedure interface body for sub1
  INTEGER, INTENT(IN) :: i
  TYPE(Base), INTENT(IN) :: b
END SUBROUTINE
END INTERFACE
END MODULE

MODULE m2
  USE m1  ! Use association of module m1
  INTERFACE
    REAL MODULE FUNCTION func1()  ! Module procedure interface body for func1
    END FUNCTION
    MODULE FUNCTION func2(b)  ! Module procedure interface body for func2
      TYPE(Base) :: b
      TYPE(Base) :: func2
    END FUNCTION
    END INTERFACE
END MODULE

MODULE m4
  USE m1  ! Use association of module m1
  TYPE, EXTENDS(Base) :: NewType
  REAL :: j
END TYPE
END MODULE

The submodule m1sub, which extends module m1, and submodule m2sub, which extends module m2, are defined as follows. The use association of module m4 in m1sub does not cause circular reference.

SUBMODULE (m1) m1sub
  USE m4  ! Use association of module m4
  CONTAINS
    MODULE SUBROUTINE sub1(i, b)  ! Implementation of sub1 declared in m1
      INTEGER, INTENT(IN) :: i
      TYPE(Base), INTENT(IN) :: b
      PRINT *, "sub1", i, b
    END SUBROUTINE
END SUBMODULE

SUBMODULE (m2) m2sub
  CONTAINS
    REAL MODULE FUNCTION func1()  ! Implementation of func1 declared in m2
      func1 = 20
    END FUNCTION
END SUBMODULE

The third level submodule m2sub2, which extends its parent submodule m2sub, is defined as follows.

SUBMODULE (m2:m2sub) m2sub2
  CONTAINS
    MODULE FUNCTION func2(b)  ! Implementation of func2 declared in m2
      TYPE(Base) :: b
      TYPE(Base) :: func2
      func2 = b
    END FUNCTION
END SUBMODULE

The module m3 is defined as follows. Type Base is still accessible by host association of m1 in m2.
MODULE m3
  INTERFACE
    SUBROUTINE interfaceSub1(i, b)
      USE m1
      INTEGER, INTENT(IN) :: i
      TYPE(Base), INTENT(IN) :: b
    END SUBROUTINE

    REAL FUNCTION interfaceFunc1()
  END FUNCTION

    FUNCTION interfaceFunc2(b)
      USE m1
      TYPE(Base) :: b
      TYPE(Base) :: interfaceFunc2
    END FUNCTION
  END INTERFACE

  TYPE Container
    PROCEDURE(interfaceSub1), NOPASS, POINTER :: pp1
    PROCEDURE(interfaceFunc1), NOPASS, POINTER :: pp2
    PROCEDURE(interfaceFunc2), NOPASS, POINTER :: pp3
  END TYPE
END MODULE

The program example, which uses m1, m2, and m3, is defined as follows.

PROGRAM example
  USE m1
  USE m2
  USE m3
  TYPE(Container) :: c1
  c1%pp1 => sub1
  c1%pp2 => func1
  c1%pp3 => func2

  CALL c1%pp1(10, Base(11))
  PRINT *, "func1", int(c1%pp2())
  PRINT *, "func2", c1%pp3(Base(5))
END PROGRAM

When you compile the source files that contain the submodules m1sub, m2sub, and m2sub2, the following submodule symbol files are generated:

m1_m1sub.smod
m2_m2sub.smod
m2_m2sub2.smod

Related information
  • Submodules
  • The SUBMODULE statement
  • XL Fortran input files
  • XL Fortran output files
Chapter 7. Exploiting POWER9 technology

Releases of IBM XL Fortran for Linux, starting from V15.1.6, provide full exploitation of the POWER9 technology. The POWER9 exploitation features include compiler options, high-performance libraries, and intrinsic procedures.

POWER9 compiler options

Use the -qarch and -qtune options to utilize the POWER9 technology.

-qarch=pwr9

Specifying -qarch=pwr9 produces object code that contains instructions that utilize the POWER9 technology.

For more information, see -qarch=pwr9

-qtune=pwr9

If you specify -qtune=pwr9, optimizations are tuned to utilize the POWER9 technology.

For more information, see -qtune=pwr9

High-performance libraries that are tuned for POWER9

Use the MASS vector library and SIMD library to exploit the POWER9 architecture.

MASS libraries

The vector library libmassvp9.a and the SIMD library libmass_simdp9.a contain functions that are tuned for the POWER9 architecture.

For how to use MASS libraries, see Using the Mathematical Acceleration Subsystem (MASS) libraries

POWER9 intrinsic procedures

A number of intrinsic procedures are available to exploit the POWER9 architecture.

Note: The following intrinsic procedures are valid only when -qarch is set to utilize the POWER9 technology.

Vector intrinsic procedures (IBM extension)

VEC_ABSD(ARG1, ARG2)

Returns a vector that contains the absolute difference of the corresponding elements of the given vectors.

This intrinsic procedure is valid only when you include the altivec.h file.

VEC_CMPNE(ARG1, ARG2)

Returns a vector containing the results of comparing each set of the corresponding elements of the given vectors for inequality.

This intrinsic procedure is valid only when you include the altivec.h file.

VEC_CMPNEZ(ARG1, ARG2)

Returns a vector that contains the results of comparing each set of the corresponding elements of the given vectors for inequality, or the results of testing the corresponding element of given vectors for the value of zero.
This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_CNTLZ(ARG1)**
Counts the most significant zero bits of each element of the given vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_CNTLZ_LSBB(ARG1)**
Counts the leading byte elements of the given vector that have a least significant bit of 0.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_CNTTZ(ARG1)**
Counts the least significant zero bits of each element of the given vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_CNTTZ_LSBB(ARG1)**
Counts the trailing byte elements of the given vector that have a least significant bit of 0.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_CONCAT(ARG1, ARG2)**
Concatenates two elements to form a vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_EXTRACT_EXP(ARG1)**
Returns a vector that contains the exponent of the given vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_EXTRACT_SIG(ARG1)**
Returns a vector that contains the significand of the given vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_FIRST_MATCH_INDEX(ARG1, ARG2)**
Compares each set of the corresponding elements of the given vectors and returns the first position of equality.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_FIRST_MATCH_OR_EOS_INDEX(ARG1, ARG2)**
Compares each set of the corresponding elements of the given vectors and returns the first position of equality or the position of the end-of-string terminator.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_FIRST_MISMATCH_INDEX(ARG1, ARG2)**
Compares each set of the corresponding elements of the given vectors and returns the first position of inequality.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_FIRST_MISMATCH_OR_EOS_INDEX(ARG1, ARG2)**
Compares each set of the corresponding elements of the given vectors and returns the first position of inequality or the position of the end-of-string terminator.

This intrinsic procedure is valid only when you include the altivec.h file.
**VEC_INSERT_EXP(ARGV1, ARG2)**

Returns a vector that combines the exponents of elements from one vector with the signs and the significands of elements from another vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_LOAD_SPLATS(ARGV1, ARG2)**

Loads a 4-byte element from the memory address specified by the displacement.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_PARITY_LSBB(ARGV1)**

Returns a vector that computes parity on the least significant bit of each byte of each element of the given vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_RLMI(ARGV1, ARG2, ARG3)**

Returns a vector that contains each element of the given vector rotated left and inserted under a mask into another vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_RLNM(ARGV1, ARG2, ARG3)**

Returns a vector that contains each element of the given vector rotated left and intersected with a mask.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_SLV (ARGV1, ARG2)**

Left shifts the elements of a given vector by a given number of bits.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_SRV (ARGV1, ARG2)**

Right-shifts the elements of a given vector by a given number of bits.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_TEST_DATA_CLASS(ARGV1, ARG2)**

Determines the data class of the elements of the given vector.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_XL_LEN(ARGV1, ARG2)**

Returns a vector that loads a given number of bytes from the given address.

This intrinsic procedure is valid only when you include the altivec.h file.

**VEC_XST_LEN(ARGV1, ARG2, ARG3)**

Stores a given byte length of a vector to a given address.

This intrinsic procedure is valid only when you include the altivec.h file.
Chapter 8. High performance libraries

XL Fortran is shipped with the following set of libraries for high-performance mathematical computing:

- Mathematical Acceleration Subsystem (MASS). It is a set of libraries of tuned mathematical intrinsic routines that provide improved performance over the corresponding standard system math library routines. MASS is described in “Using the Mathematical Acceleration Subsystem (MASS) libraries.”

- Basic Linear Algebra Subprograms (BLAS). They are a subset of routines from IBM’s Engineering and Scientific Subroutine Library (ESSL) library, which provides matrix/vector multiplication functions tuned for PowerPC architectures. The BLAS functions are described in “Using the Basic Linear Algebra Subprograms - BLAS” on page 80.

Note that if you are going to link your application with the ESSL libraries, using -qessl and IPA allows the optimizer to automatically use ESSL routines.

Using the Mathematical Acceleration Subsystem (MASS) libraries

XL Fortran 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 Fortran routines described in “Using the scalar library” on page 68, a set of vector libraries tuned for specific architectures described in “Using the vector libraries” on page 70, and a set of SIMD libraries tuned for specific architectures described in “Using the SIMD libraries” on page 74. 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 -qnostrict
- -qhot -O3 -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 vatan2, vsatan2, vdnint, vdfint, vcosisin, vscosisin, vqdrf, vsqdrf, vrqdrf, vsrqdrf, vpopcnt4, vpopcnt8, vexp2, vexp2m1, vsexp2, vsexp2m1, vlog2, vlog21p, vslog2, and vslog21p). 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 79 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.

Related external information


Using the scalar library

The MASS scalar library libmass.a contains 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 you explicitly link libmass.a.

If you want to explicitly call the MASS scalar functions, you can take the following steps:

1. Link the MASS scalar library libmass.a with your application. For instructions, see “Compiling and linking a program with MASS” on page 79

2. All the MASS scalar routines, except those listed in step 3, are recognized by XL Fortran as intrinsic functions, so no explicit interface block is needed. To provide an interface block for the functions listed in step 3, include mass.include in your source file.

3. Include mass.include in your source file for the following functions:
   - acosf, acoshf, asinf, asinhf, atan2f, atanf, atanhf, cbtf, cbtf, copysign, copysignf, cosf, coshf, cosisin, erff, erfcb, expf, expmlf, hypotf, lgammaf, logf, log10f, log1pf, rsqrt, sinf, sinhf, tanf, tanhf, and x**y

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 14.

<table>
<thead>
<tr>
<th>Double-precision function</th>
<th>Single-precision function</th>
<th>Arguments</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>acos</td>
<td>acosf</td>
<td>(x)</td>
<td>Returns the arccosine of x</td>
</tr>
<tr>
<td>acosh</td>
<td>acoshf</td>
<td>(x)</td>
<td>Returns the hyperbolic arccosine of x</td>
</tr>
<tr>
<td>anint</td>
<td>asinf</td>
<td>(x)</td>
<td>Returns the rounded integer value of x</td>
</tr>
<tr>
<td>asin</td>
<td>asinf</td>
<td>(x)</td>
<td>Returns the arcsine of x</td>
</tr>
<tr>
<td>asinh</td>
<td>asinhf</td>
<td>(x)</td>
<td>Returns the hyperbolic arcsine of x</td>
</tr>
<tr>
<td>atan2</td>
<td>atan2f</td>
<td>(x,y)</td>
<td>Returns the arctangent of x/y</td>
</tr>
<tr>
<td>atan</td>
<td>atanf</td>
<td>(x)</td>
<td>Returns the arctangent of x</td>
</tr>
<tr>
<td>atanh</td>
<td>atanhf</td>
<td>(x)</td>
<td>Returns the hyperbolic arctangent of x</td>
</tr>
<tr>
<td>cbtf</td>
<td>cbtff</td>
<td>(x)</td>
<td>Returns the cube root of x</td>
</tr>
<tr>
<td>copysign</td>
<td>copysignf</td>
<td>(x,y)</td>
<td>Returns x with the sign of y</td>
</tr>
</tbody>
</table>
### Table 14. MASS scalar functions (continued)

<table>
<thead>
<tr>
<th>Double-precision function</th>
<th>Single-precision function</th>
<th>Arguments</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cos</td>
<td>cosf</td>
<td>(x)</td>
<td>Returns the cosine of x</td>
</tr>
<tr>
<td>cosh</td>
<td>coshf</td>
<td>(x)</td>
<td>Returns the hyperbolic cosine of x</td>
</tr>
<tr>
<td>cossin</td>
<td></td>
<td>(x)</td>
<td>Returns a complex number with the real part the cosine of x and the imaginary part the sine of x.</td>
</tr>
<tr>
<td>dnint</td>
<td></td>
<td>(x)</td>
<td>Returns the nearest integer to x (as a double)</td>
</tr>
<tr>
<td>erf</td>
<td>erf</td>
<td>(x)</td>
<td>Returns the error function of x</td>
</tr>
<tr>
<td>erfc</td>
<td>erfcf</td>
<td>(x)</td>
<td>Returns the complementary error function of x</td>
</tr>
<tr>
<td>exp</td>
<td>expf</td>
<td>(x)</td>
<td>Returns the exponential function of x</td>
</tr>
<tr>
<td>expm1</td>
<td>expmf</td>
<td>(x)</td>
<td>Returns (the exponential function of x) - 1</td>
</tr>
<tr>
<td>hypot</td>
<td>hypotf</td>
<td>(x,y)</td>
<td>Returns the square root of (x^2 + y^2)</td>
</tr>
<tr>
<td>lgamma</td>
<td>lgammalf</td>
<td>(x)</td>
<td>Returns the natural logarithm of the absolute value of the Gamma function of x</td>
</tr>
<tr>
<td>log</td>
<td>logf</td>
<td>(x)</td>
<td>Returns the natural logarithm of x</td>
</tr>
<tr>
<td>log10</td>
<td>log10f</td>
<td>(x)</td>
<td>Returns the base 10 logarithm of x</td>
</tr>
<tr>
<td>log1p</td>
<td>log1pf</td>
<td>(x)</td>
<td>Returns the natural logarithm of ((x + 1))</td>
</tr>
<tr>
<td>rsqrt</td>
<td></td>
<td>(x)</td>
<td>Returns the reciprocal of the square root of x</td>
</tr>
<tr>
<td>sin</td>
<td>sinf</td>
<td>(x)</td>
<td>Returns the sine of x</td>
</tr>
<tr>
<td>sincos</td>
<td></td>
<td>(x,s,c)</td>
<td>Sets s to the sine of x and c to the cosine of x</td>
</tr>
<tr>
<td>sinh</td>
<td>sinhf</td>
<td>(x)</td>
<td>Returns the hyperbolic sine of x</td>
</tr>
<tr>
<td>sqrt</td>
<td></td>
<td>(x)</td>
<td>Returns the square root of x</td>
</tr>
<tr>
<td>tan</td>
<td>tanf</td>
<td>(x)</td>
<td>Returns the tangent of x</td>
</tr>
<tr>
<td>tanh</td>
<td>tanhf</td>
<td>(x)</td>
<td>Returns the hyperbolic tangent of x</td>
</tr>
<tr>
<td>(x^y)</td>
<td></td>
<td>(x,y)</td>
<td>Returns x raised to the power y</td>
</tr>
</tbody>
</table>

The MASS library interfaces include the following features:

- The scalar functions have generic interfaces so that the same name (the name used for the real*8 function in previous versions) can be called with either real*4 or real*8 arguments.
- The scalar functions are marked pure. You can call them from pure procedures.
- The scalar functions are marked elemental. You can call them with an array argument and apply them to all the array elements.
- The intent of the argument is specified to assist in compiler error checking.

The following example shows the XL Fortran interface declaration of the acos and acosf scalar functions:

```fortran
INTERFACE acos
  PURE ELEMENTAL REAL*8 FUNCTION acos (x)
  REAL*8, VALUE :: x
END INTERFACE
```
END FUNCTION

PURE ELEMENTAL REAL*4 FUNCTION acosf(x)
REAL*4, value :: x
END FUNCTION
END INTERFACE

The following example shows the XL Fortran interface declaration for the rsqrt scalar function:

INTERFACE
! Returns the reciprocal of the square root of x.
REAL(8) FUNCTION rsqrt(x)
REAL(8), value :: x
END FUNCTION
END INTERFACE

Although most of the scalar MASS functions have separate implementations tuned for optimal performance with real*4 and real*8 arguments, the functions cosisin, rsqrt, and sincos have only real*8 versions. These functions have only the real*8 interface in mass.include, but they can be called with real*4 or real*8 arguments and will operate correctly.

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).
- For accuracy comparisons with libm.a, see Product documentation (manuals) in the Product support content section of the [Mathematical Acceleration Subsystem website](http://www.ibm.com/software/awdtools/mass/).

Related external information

Using the vector libraries

If you want to explicitly call any of the MASS vector functions, you can do so by including massv.include 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 79.

The vector libraries shipped with XL Fortran are listed below:

libmassv.a
The generic vector library that runs on any supported POWER® processor. Unless your application requires this portability, use the appropriate architecture-specific library below for maximum performance.

libmassvp8.a
Contains functions that are tuned for the POWER8® architecture.

libmassvp9.a
Contains functions that are tuned for the POWER9 architecture.

The single-precision and double-precision floating-point functions contained in the vector libraries are summarized in [Table 15 on page 71](#). The integer functions contained in the vector libraries are summarized in [Table 16 on page 73](#).
With the exception of a few functions (described in the following paragraph), all of the floating-point functions in the vector libraries accept three arguments:

- A double-precision (for double-precision functions) or single-precision (for single-precision functions) vector output argument.
- A double-precision (for double-precision functions) or single-precision (for single-precision functions) vector input argument.
- An integer vector-length argument.

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 arguments `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 outputs a vector `y` of length 500 whose elements are \( \exp(x(i)) \), where \( i=1,\ldots,500 \):

```c
#include 'massv.include'
real(8) x(500), y(500)
integer n
n = 500
...
call vexp (y, x, n)
```

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 \( i=1,\ldots,n \). The function `vpow` outputs a vector `z` whose elements are \( x(i)^{y(i)} \), where \( i=1,\ldots,n \). The function `vatan2` outputs a vector `z` whose elements are \( \tan(x(i)/y(i)) \), where \( i=1,\ldots,n \). 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(8) (for `vcosisin`) or complex(4) (for `vscosisin`) elements of the form \((\cos(x(i)), \sin(x(i)))\).

<table>
<thead>
<tr>
<th>Double-precision function</th>
<th>Single-precision function</th>
<th>Arguments</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>vacos</code></td>
<td><code>vsacos</code></td>
<td>((y, x, n))</td>
<td>Sets <code>y(i)</code> to the arc cosine of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vacosh</code></td>
<td><code>vsacosh</code></td>
<td>((y, x, n))</td>
<td>Sets <code>y(i)</code> to the hyperbolic arc cosine of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vasin</code></td>
<td><code>vsasin</code></td>
<td>((y, x, n))</td>
<td>Sets <code>y(i)</code> to the arc sine of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vasinh</code></td>
<td><code>vsasinh</code></td>
<td>((y, x, n))</td>
<td>Sets <code>y(i)</code> to the arc hyperbolic sine of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vatan2</code></td>
<td><code>vsatan2</code></td>
<td>((y, z, x, n))</td>
<td>Sets <code>z(i)</code> to the arc tangent of <code>x(i)/y(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vatanh</code></td>
<td><code>vsatanh</code></td>
<td>((y, x, n))</td>
<td>Sets <code>y(i)</code> to the arc hyperbolic tangent of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vcbrt</code></td>
<td><code>vcbbrt</code></td>
<td>((y, x, n))</td>
<td>Sets <code>y(i)</code> to the cube root of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vcos</code></td>
<td><code>vscos</code></td>
<td>((y, x, n))</td>
<td>Sets <code>y(i)</code> to the cosine of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vcosh</code></td>
<td><code>vscosh</code></td>
<td>((y, x, n))</td>
<td>Sets <code>y(i)</code> to the hyperbolic cosine of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
<tr>
<td><code>vcosisin</code></td>
<td><code>vscosisin</code></td>
<td>((y, x, n))</td>
<td>Sets the real part of <code>y(i)</code> to the cosine of <code>x(i)</code> and the imaginary part of <code>y(i)</code> to the sine of <code>x(i)</code>, for (i=1,\ldots,n)</td>
</tr>
</tbody>
</table>
Table 15. MASS floating-point vector library functions (continued)

<table>
<thead>
<tr>
<th>Double-precision function</th>
<th>Single-precision function</th>
<th>Arguments</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>vdint</td>
<td></td>
<td>(y,x,n)</td>
<td>Sets y(i) to the integer truncation of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vdiv</td>
<td>vsdiv</td>
<td>(z,x,y,n)</td>
<td>Sets z(i) to x(i)/y(i), for i=1,...,n</td>
</tr>
<tr>
<td>vdnint</td>
<td></td>
<td>(y,x,n)</td>
<td>Sets y(i) to the nearest integer to x(i), for i=1,...,n</td>
</tr>
<tr>
<td>verf</td>
<td>vserf</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the error function of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>verfc</td>
<td>vserfc</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the complimentary error function of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vexp</td>
<td>vsexp</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the exponential function of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vexp2</td>
<td>vsexp2</td>
<td>(y,x,n)</td>
<td>Sets y(i) to 2 raised to the power of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vexpm1</td>
<td>vsepxm1</td>
<td>(y,x,n)</td>
<td>Sets y(i) to (the exponential function of x(i)) -1, for i=1,...,n</td>
</tr>
<tr>
<td>vexp2m1</td>
<td>vsepxp2m1</td>
<td>(y,x,n)</td>
<td>Sets y(i) to (2 raised to the power of x(i)) -1, for i=1,...,n</td>
</tr>
<tr>
<td>vhypot</td>
<td>vshypot</td>
<td>(z,x,y,n)</td>
<td>Sets z(i) to the square root of the sum of the squares of x(i) and y(i), for i=1,...,n</td>
</tr>
<tr>
<td>vlog</td>
<td>vslog</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the natural logarithm of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vlog2</td>
<td>vslog2</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the base-2 logarithm of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vlog10</td>
<td>vslog10</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the base-10 logarithm of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vlog2lp</td>
<td>vslog2lp</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the base-2 logarithm of (x(i)+1), for i=1,...,n</td>
</tr>
<tr>
<td>vpow</td>
<td>vspow</td>
<td>(z,x,y,n)</td>
<td>Sets z(i) to x(i) raised to the power y(i), for i=1,...,n</td>
</tr>
<tr>
<td>vqdrtr</td>
<td>vsqdrtr</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the 4th root of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vrcbrt</td>
<td>vsrccbrt</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the reciprocal of the cube root of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vrec</td>
<td>vsrec</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the reciprocal of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vrqdrtr</td>
<td>vsrqdrtr</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the reciprocal of the 4th root of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vrsqrt</td>
<td>vsrsqrt</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the reciprocal of the square root of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vsin</td>
<td>vssin</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the sine of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vsincos</td>
<td>vssincos</td>
<td>(y,z,x,n)</td>
<td>Sets y(i) to the sine of x(i) and z(i) to the cosine of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vsinh</td>
<td>vssinh</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the hyperbolic sine of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vsqrt</td>
<td>vssqrt</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the square root of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>vtan</td>
<td>vstan</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the tangent of x(i), for i=1,...,n</td>
</tr>
<tr>
<td>v tanh</td>
<td>vstanh</td>
<td>(y,x,n)</td>
<td>Sets y(i) to the hyperbolic tangent of x(i), for i=1,...,n</td>
</tr>
</tbody>
</table>

Integer functions are of the form \textit{function\_name} \((x,\ n)\), where \(x\) is a vector of 4-byte (for \textit{vpopcnt4}) or 8-byte (for \textit{vpopcnt8}) numeric objects (integer or floating-point), and \(n\) is the vector length.
Table 16. MASS integer vector library functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>vpopcnt4</td>
<td>Returns the total number of 1 bits in the concatenation of the binary representation of x(i), for i=1,...,n, where x is vector of 32-bit objects</td>
<td>integer<em>4 function vpopcnt4 (x, n) integer</em>4 x(*) , n</td>
</tr>
<tr>
<td>vpopcnt8</td>
<td>Returns the total number of 1 bits in the concatenation of the binary representation of x(i), for i=1,...,n, where x is vector of 64-bit objects</td>
<td>integer<em>4 function vpopcnt8 (x, n) integer</em>8 x(<em>) , integer</em>4 n</td>
</tr>
</tbody>
</table>

The following example shows XL Fortran interface declarations for some of the MASS single-precision and double-precision functions:

```fortran
INTERFACE vsqrt
  ! Sets y(i) to the square root of x(i), for i=1,...,n
  PURE SUBROUTINE vsqrt (y, x, n)
    REAL*8, INTENT(OUT) :: y(*)
    REAL*8, INTENT(IN) :: x(*)
    INTEGER*4, INTENT(IN) :: n
  END SUBROUTINE

  PURE SUBROUTINE vssqrt (y, x, n)
    REAL*4, INTENT(OUT) :: y(*)
    REAL*4, INTENT(IN) :: x(*)
    INTEGER*4, INTENT(IN) :: n
  END SUBROUTINE
END INTERFACE
```

**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 might 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(1:n) and y(1:n) must be either disjoint or identical, or unexpected results might 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(1:n) and x1(1:n) must be either disjoint or identical; and y(1:n) and x2(1:n) 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(1:n) and x(1:n) must be either disjoint or identical; and y2(1:n) and x(1:n) must be either disjoint or identical. Also, the vectors y1(1:n) and y2(1:n) must be disjoint.

**Alignment of input and output vectors**

To get the best performance from the vector libraries, align the input and output vectors on 8-byte (or better, 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 external information


Using the SIMD libraries

The MASS SIMD library contains a set of frequently used math intrinsic functions that provide improved performance over the corresponding standard system library functions.

The SIMD libraries shipped with XL Fortran are listed below:

libmass_simdp8.a
Contains functions that are tuned for the POWER8 architecture.

libmass_simdp9.a
Contains functions that are tuned for the POWER9 architecture.

If you want to use the MASS SIMD functions, follow the procedure below:
1. Provide the interfaces for the functions by including mass_simd.include in your source files.
2. Link the MASS SIMD library libmass_simdp8.a with your application. For instructions, see “Compiling and linking a program with MASS” on page 79.

The single-precision MASS SIMD functions accept single-precision arguments and return single-precision results. Likewise, the double-precision MASS SIMD functions accept double-precision arguments and return double-precision results. They are summarized in Table 17.

Table 17. MASS SIMD functions

<table>
<thead>
<tr>
<th>Double-precision function</th>
<th>Single-precision function</th>
<th>Description</th>
<th>Double-precision function interface</th>
<th>Single-precision function interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>acosd2</td>
<td>acos4</td>
<td>Computes the arc cosine of each element of vx.</td>
<td>vector(real(8)) function acosd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function acosf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>acoshd2</td>
<td>acosh4</td>
<td>Computes the arc hyperbolic cosine of each element of vx.</td>
<td>vector(real(8)) function acoshd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function acoshf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>asind2</td>
<td>asinf4</td>
<td>Computes the arc sine of each element of vx.</td>
<td>vector(real(8)) function asind2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function asinf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>asinhd2</td>
<td>asinhf4</td>
<td>Computes the arc hyperbolic sine of each element of vx.</td>
<td>vector(real(8)) function asinhd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function asinhf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>Double-precision function</td>
<td>Single-precision function</td>
<td>Description</td>
<td>Double-precision function interface</td>
<td>Single-precision function interface</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------------------</td>
<td>--------------------------------------------------</td>
<td>--------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>atand2</td>
<td>atanf4</td>
<td>Computes the arc tangent of each element of vx.</td>
<td>vector(real(8)) function atand2(vx)</td>
<td>vector(real(4)) function atanf4(vx)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vector(real(8)), value :: vx</td>
<td>vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>atan2d2</td>
<td>atan2f4</td>
<td>Computes the arc tangent of each element of vx/vy</td>
<td>vector(real(8)) function atan2d2(vx,vy)</td>
<td>vector(real(4)) function atan2f4(vx,vy)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vector(real(8)), value :: vx, vy</td>
<td>vector(real(4)), value :: vx, vy</td>
</tr>
<tr>
<td>atanh2d2</td>
<td>atanhf4</td>
<td>Computes the arc hyperbolic tangent of each element of vx.</td>
<td>vector(real(8)) function atanh2d2(vx)</td>
<td>vector(real(4)) function atanhf4(vx)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vector(real(8)), value :: vx</td>
<td>vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>cbtd2</td>
<td>cbtf4</td>
<td>Computes the cube root of each element of vx</td>
<td>vector(real(8)) function cbtd2(vx)</td>
<td>vector(real(4)) function cbtf4(vx)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vector(real(8)), value :: vx</td>
<td>vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>cosd2</td>
<td>cosf4</td>
<td>Computes the cosine of each element of vx.</td>
<td>vector(real(8)) function cosd2(vx)</td>
<td>vector(real(4)) function cosf4(vx)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vector(real(8)), value :: vx</td>
<td>vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>coshd2</td>
<td>coshf4</td>
<td>Computes the hyperbolic cosine of each element of vx.</td>
<td>vector(real(8)) function coshd2(vx)</td>
<td>vector(real(4)) function coshf4(vx)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vector(real(8)), value :: vx</td>
<td>vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>Double-precision function</td>
<td>Single-precision function</td>
<td>Description</td>
<td>Double-precision function interface</td>
<td>Single-precision function interface</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------------------</td>
<td>-------------</td>
<td>-------------------------------------</td>
<td>-------------------------------------</td>
</tr>
</tbody>
</table>
| cosisind2                 | cosisinf4                | Computes the cosine and sine of each element of \( x \), and stores the results in \( y \) and \( z \) as follows: \[
\text{cosisind2} (x, y, z) \text{ sets the elements of } y \text{ to } \cos(x_1), \sin(x_1), \text{ and the elements of } \sin(x_2), \cos(x_2), \text{ where } x_1, x_2 \text{ are the elements of } x. \\
\text{cosisinf4} (x, y, z) \text{ sets the elements of } y \text{ to } \cos(x_1), \sin(x_1), \cos(x_2), \sin(x_2), \text{ and the elements of } y \text{ to } \cos(x_3), \sin(x_3), \cos(x_4), \sin(x_4), \text{ where } x_1, x_2, x_3, x_4 \text{ are the elements of } x. 
\]
<p>| subroutine cosisind2 ((x, y, z)) vector(real(8)), value :: (x) vector(real(8)) (y, z) | subroutine cosisinf4 ((x, y, z)) vector(real(4)), value :: (x) vector(real(4)) (y, z) |
| divd2                     | divf4                     | Computes the quotient (vx/)vy. | vector(real(8)) function divd2(vx, vy) vector(real(8)), value :: (vx, vy) | vector(real(4)) function divf4(vx, vy) vector(real(4)), value :: (vx, vy) |
| erfcd2                    | erfcf4                    | Computes the complementary error function of each element of (vx). | vector(real(8)) function erfcd2(vx) vector(real(8)), value :: (vx) | vector(real(4)) function erfcf4(vx) vector(real(4)), value :: (vx) |
| erf2d                     | erff4                     | Computes the error function of each element of (vx). | vector(real(8)) function erf2d(vx) vector(real(8)), value :: (vx) | vector(real(4)) function erff4(vx) vector(real(4)), value :: (vx) |
| expd2                     | expf4                     | Computes the exponential function of each element of (vx). | vector(real(8)) function expd2(vx) vector(real(8)), value :: (vx) | vector(real(4)) function expf4(vx) vector(real(4)), value :: (vx) |</p>
<table>
<thead>
<tr>
<th>Double-precision function</th>
<th>Single-precision function</th>
<th>Description</th>
<th>Double-precision function interface</th>
<th>Single-precision function interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>exp2d2</td>
<td>exp2f4</td>
<td>Computes 2 raised to the power of each element of vx.</td>
<td>vector(real(8)) function exp2d2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function exp2f4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>expm1d2</td>
<td>expm1f4</td>
<td>Computes (the exponential function of each element of vx) - 1.</td>
<td>vector(real(8)) function expm1d2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function expm1f4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>exp2m1d2</td>
<td>exp2m1f4</td>
<td>Computes (2 raised to the power of each element of vx) - 1.</td>
<td>vector(real(8)) function exp2m1d2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function exp2m1f4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>hypotd2</td>
<td>hypotf4</td>
<td>For each element of vx and the corresponding element of vy, computes sqrt(vx<em>vx +vy</em>vy).</td>
<td>vector(real(8)) function hypotd2(vx,vy) vector(real(8)), value :: vx, vy</td>
<td>vector(real(4)) function hypotf4(vx,vy) vector(real(4)), value :: vx, vy</td>
</tr>
<tr>
<td>lgammad2</td>
<td>lgammaf4</td>
<td>Computes the natural logarithm of the absolute value of the Gamma function of each element of vx.</td>
<td>vector(real(8)) function lgammad2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function lgammaf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>logd2</td>
<td>logf4</td>
<td>Computes the natural logarithm of each element of vx.</td>
<td>vector(real(8)) function logd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function logf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>log2d2</td>
<td>log2f4</td>
<td>Computes the base-2 logarithm of each element of vx.</td>
<td>vector(real(8)) function log2d2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function log2f4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>log10d2</td>
<td>log10f4</td>
<td>Computes the base-10 logarithm of each element of vx.</td>
<td>vector(real(8)) function log10d2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function log10f4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>log1pd2</td>
<td>log1pf4</td>
<td>Computes the natural logarithm of each element of (vx +1).</td>
<td>vector(real(8)) function log1pd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function log1pf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>Double-precision function</td>
<td>Single-precision function</td>
<td>Description</td>
<td>Double-precision function interface</td>
<td>Single-precision function interface</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------------</td>
<td>-------------</td>
<td>-------------------------------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>log21pd2</td>
<td>log21pf4</td>
<td>Computes the base-2 logarithm of each element of ((vx+1)).</td>
<td>vector(real(8)) function log21pd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function log21pf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>powd2</td>
<td>powf4</td>
<td>Computes each element of (vx) raised to the power of the corresponding element of (vy).</td>
<td>vector(real(8)) function powd2(vx, vy) vector(real(8)), value :: vx, vy</td>
<td>vector(real(4)) function powf4(vx, vy) vector(real(4)), value :: vx, vy</td>
</tr>
<tr>
<td>qdrtd2</td>
<td>qdrtf4</td>
<td>Computes the quad root of each element of (vx).</td>
<td>vector(real(8)) function qdrtd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function qdrtf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>rcbtd2</td>
<td>rcbrtf4</td>
<td>Computes the reciprocal of the cube root of each element of (vx).</td>
<td>vector(real(8)) function rcbtd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function rcbrtf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>recip2d</td>
<td>recipf4</td>
<td>Computes the reciprocal of each element of (vx).</td>
<td>vector(real(8)) function recipd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function recipf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>rqdrtd2</td>
<td>rqdrtf4</td>
<td>Computes the reciprocal of the quad root of each element of (vx).</td>
<td>vector(real(8)) function rqdrtd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function rqdrtf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>rsqrtd2</td>
<td>rsqrtf4</td>
<td>Computes the reciprocal of the square root of each element of (vx).</td>
<td>vector(real(8)) function rsqrtd2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function rsqrtf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>sind2</td>
<td>sinf4</td>
<td>Computes the sine of each element of (vx).</td>
<td>subroutine sind2(vx, vs, vc) vector(real(8)), value :: vx vector(real(8)) vs, vc</td>
<td>subroutine sinf4(vx, vs, vc) vector(real(4)), value :: vx vector(real(4)) vs, vc</td>
</tr>
<tr>
<td>sinh2</td>
<td>sinhf4</td>
<td>Computes the hyperbolic sine of each element of (vx).</td>
<td>vector(real(8)) function sinh2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function sinhf4(vx) vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>sqrt2</td>
<td>sqrtf4</td>
<td>Computes the square root of each element of (vx).</td>
<td>vector(real(8)) function sqrt2(vx) vector(real(8)), value :: vx</td>
<td>vector(real(4)) function sqrtf4(vx) vector(real(4)), value :: vx</td>
</tr>
</tbody>
</table>
Table 17. MASS SIMD functions (continued)

<table>
<thead>
<tr>
<th>Double-precision function</th>
<th>Single-precision function</th>
<th>Description</th>
<th>Double-precision function interface</th>
<th>Single-precision function interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>tand2</td>
<td>tanf4</td>
<td>Computes the tangent of each element of vx.</td>
<td>vector(real(8)) function tand2(vx)</td>
<td>vector(real(4)) function tanf4(vx)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vector(real(8)), value :: vx</td>
<td>vector(real(4)), value :: vx</td>
</tr>
<tr>
<td>tanhd2</td>
<td>tanhf4</td>
<td>Computes the hyperbolic tangent of each element of vx.</td>
<td>vector(real(8)) function tanhd2(vx)</td>
<td>vector(real(4)) function tanhf4(vx)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vector(real(8)), value :: vx</td>
<td>vector(real(4)), value :: vx</td>
</tr>
</tbody>
</table>

The MASS SIMD library interfaces include the following features:
- The SIMD functions are marked pure. You can call them from pure procedures.
- The intent of the argument is specified to assist in compiler error checking.

The following example shows the XL Fortran interface declarations of some of MASS SIMD library functions:

```fortran
INTERFACE
   PURE VECTOR(REAL*4) FUNCTION acosf4 (x)
   VECTOR(REAL*4), value :: x
END FUNCTION

PURE VECTOR(REAL*4) FUNCTION atan2f4 (x,y)
   VECTOR(REAL*4), value :: x,y
END FUNCTION

PURE SUBROUTINE sincosf4 (x,s,c)
   VECTOR(REAL*4), value :: x
   VECTOR(REAL*4), INTENT(OUT) :: s,c
END SUBROUTINE
END INTERFACE
```

**Compiling and linking a program with MASS**

To compile an application that calls the functions in the following MASS libraries, specify the corresponding library names on the -l link option.

Table 18. The scalar, vector, and SIMD MASS library

<table>
<thead>
<tr>
<th>MASS library</th>
<th>Library name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalar library</td>
<td>mass</td>
</tr>
<tr>
<td>Vector library</td>
<td>massv, massvp8, or massvp9</td>
</tr>
<tr>
<td>SIMD library</td>
<td>mass_simdp8 or mass_simdp9</td>
</tr>
</tbody>
</table>

For example, if the MASS libraries are installed in the default directory, you can use one of the following commands:

**Link object file progf with scalar library libmass.a and vector library libmassv.a**

```
xlf progf.f -o progf -lmass -lmassv
```

**Link object file progf with SIMD library libmass_simdp9.a**

```
xlf progf.f -o progf -lmass_simdp9
```
Using libmass.a with the math system library

If you want to use the libmass.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. Find the object file name of the function that you want to use from libmass.a.
   The file name starts with the name of the function and has a .o suffix.
   For example, to find the tanf function, you can use the following command if XL Fortran is installed to the default location:

   ```
   nm /opt/ibm/x1mass/8.1.6/lib/libmass.a | grep "^tan.*\.o"
   ```

   The output is as follows:

   ```
   tand2_8xs.s64.o:  
tanhd2_8xs.s64.o:  
tanf.s64.o:  
tanhf.s64.o:  
   ```

   Among the listed object files, the object file name for the tanf function is `tanf.s64.o`.

2. Use the `ar` command to extract the object files of the wanted functions from libmass.a.
   For example, to extract the object file for the tanf function, use the following command:

   ```
   ar -x tanf.s64.o /opt/ibm/x1mass/8.1.6/lib/libmass.a
   ```

3. Archive the extracted object files into another library:

   ```
   ar -qv libfasttanf.a tanf.s64.o
   ranlib libfasttanf.a
   ```

4. Create the final executable using `xlf`, specifying `-lfasttanf` instead of `-lmass`:

   ```
   xlf sample.f -o sample -Ldir_containing_libfasttanf -lfasttanf
   ```

   This links only the tanf function from MASS (now in libfasttanf.a) and the remainder of the math functions from the standard system library.

Exception:

1. For the XL Fortran ** (exponentiation) operator, search for pow (for double-precision operands) or powf (for single-precision operands).

Using the Basic Linear Algebra Subprograms - BLAS

Four Basic Linear Algebra Subprograms (BLAS) functions are shipped with XL Fortran 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

Note: Some error-handling code has been removed from the BLAS functions in libxlopt, and no error messages are emitted for calls to the these functions.

"BLAS function syntax" on page 81 describes the interfaces for the XL Fortran BLAS functions, which are similar to those of the equivalent BLAS functions.
shipped in IBM’s Engineering and Scientific Subroutine Library (ESSL); for more
detailed information and examples of usage of these functions, you may want to
consult the 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 83 describes how to link to the XL Fortran
libxlopt library if you are also using a third-party BLAS library.

**BLAS function syntax**

The interfaces for the SGEMV and DGEMV functions are as follows:

```plaintext
CALL SGEMV(trans, m, n, alpha, a, lda, x, incx, beta, y, incy)
CALL DGEMV(trans, m, n, alpha, a, lda, x, incx, beta, y, 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 or equal to 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 `α`

- **a**
  - is the input matrix of single-precision (for SGEMV) or double-precision (for DGEMV) real values

- **lda**
  - is the leading dimension of the array specified by `a`. 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`).

- **x**
  - is the input vector of single-precision (for SGEMV) or double-precision (for DGEMV) real values.

- **incy**
  - is the stride for vector `x`. It can have any value.

- **beta**
  - is the scaling constant `β`

- **y**
  - is the output vector of single-precision (for SGEMV) or double-precision (for DGEMV) real 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:
CALL SGEMM(transa, transb, l, n, m, alpha, a, lda, b, ldb, beta, c, ldc)
CALL DGEMM(transa, transb, l, n, m, alpha, a, lda, b, ldb, beta, c, ldc)

The parameters are as follows:

trans a
   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

trans b
   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 less than or equal to 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 α

a   is the input matrix a of single-precision (for SGEMM) or double-precision (for DGEMM) real 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 single-precision (for SGEMM) or double-precision (for DGEMM) real 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 \( n \).

\[ beta \]
\begin{align*}
\text{is the scaling constant } \beta \\
\end{align*}

\[ c \]
\begin{align*}
\text{is the output matrix } c \text{ of single-precision (for SGEMM) or double-precision (for DGEMM) real values.}
\end{align*}

\[ ldc \]
\begin{align*}
\text{is the leading dimension of the array specified by } c. \text{ The leading dimension must be greater than zero. If } transb \text{ is specified as 'N' or 'n', the leading dimension must be greater than or equal to the value specified in } l.
\end{align*}

**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 XL Fortran. 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, you would compile your code with the following command:

```
xlf app.f -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 library.
Chapter 9. Parallel programming with XL Fortran

Parallel programming with XL Fortran involves a combination of compiling, setting of runtime options, and optimization of your code, by incorporating SMP directives and by using the pthreads library module.

XL Fortran supports the OpenMP specification, as understood and interpreted by IBM as well as the POSIX 1003.1-1996 standard.

**Note:** IBM implementation of OpenMP in XL Fortran is an extension to the standard Fortran language.

Compiling your parallelized code

To compile parallelized code, you must specify the `-qsmp` compiler option. When compiling with `-qsmp`, the driver links the libraries found on the `smplibraries` line in the active stanza of your configuration file.

If you specify `-qsmp`, you must use an appropriate invocation command. Use any of the following invocations to compile SMP code or to ensure that the compiler links threadsafe libraries:

- `xlf_r`
- `xlf90_r`
- `xlf95_r`
- `xlf2003_r`
- `xlf2008_r`
- `CUDA Fortran xcluf CUDA Fortran`

Related reference:

See `-qsmp` in the Compiler Reference

The `_OPENMP C preprocessor macro and conditional compilation`

You can use sentinels to mark specific lines of an XL Fortran program for conditional compilation. This allows you to port code that contains statements that are only valid or applicable in an SMP environment to a non-SMP environment. You can do this using conditional compilation lines, or the `_OPENMP C preprocessor macro. This macro is defined when the C preprocessor is invoked and you specify the `-qsmp=omp` compiler option. See Passing Fortran files through the C preprocessor in the Editing, Compiling, Linking, and Running XL Fortran Programs section of the XL Fortran Compiler Reference for an example of using this macro.

The following example uses conditional compilation lines to hide OpenMP runtime routines. You cannot easily compile code that calls OpenMP runtime routines in a non-OpenMP environment without using conditional compilation. Since calls to the runtime routines are not directives, they cannot be hidden by the `!$OMP` trigger. If you do not compile the example with `-qsmp=omp`, the variable that stores the number of threads is assigned the value of 8.

Example of conditional compilation lines
PROGRAM PAR_MAT_MUL
!$ USE OMP_LIB
IMPLICIT NONE
INTEGER(KIND=8) :: I,J,NTHREADS
INTEGER(KIND=8), PARAMETER :: N=60
INTEGER(KIND=8), DIMENSION(N,N) :: AI,BI,CI
INTEGER(KIND=8) :: SUMI
COMMON/DATA/ AI,BI,CI
!$OMP THREADPRIVATE (/DATA/) $OMP
!$OMP PARALLEL $OMP
FORALL(I=1:N,J=1:N) AI(I,J) = (I-N/2)**2+(J+N/2)
FORALL(I=1:N,J=1:N) BI(I,J) = 3-((I/2)+(J-N/2)**2)
!$OMP MASTER $OMP
NTHREADS=8
!$OMP END MASTER
!$OMP END PARALLEL
!$OMP PARALLEL DEFAULT(PRIVATE), COPYIN(AI,BI), SHARED(NTHREADS)
!$OMP DO
DO I=1,NTHREADS
CALL IMAT_MUL(SUMI)
ENDDO
!$OMP END DO
!$OMP END PARALLEL
END

For information on using sentinels, see Conditional compilation in the XL Fortran Language Reference.

Setting runtime options

When you write parallel code, set the necessary XLSMPOPTS environment variables, and the environment variables for OpenMP.

XLSMPOPTS

The XLSMPOPTS environment variable allows you to specify options that affect SMP execution. You can declare XLSMPOPTS by using the following bash command format:

```
XLSMPOPTS="runtime_option_name = option_setting"
```

You can specify option names and settings in uppercase or lowercase. You can add blanks before and after the colons and equal signs to improve readability. However, if the XLSMPOPTS option string contains imbedded blanks, you must enclose the entire option string in double quotation marks (" ).

You can specify the following runtime options with the XLSMPOPTS environment variable.

- "Scheduling options" on page 87
- "Parallel execution options" on page 88
- "Options to offload computations to target devices" on page 89
- "Performance tuning options" on page 90
Scheduling options

When the SMP run time is used to divide the iteration space of a loop through auto-parallelization, a scheduling algorithm is used to assign iterations to the threads in the parallel region. Each thread receives and executes a contiguous range of iterations, which is called a block or a chunk. Threads might finish their blocks of work at different speeds. After completing the assigned work, threads can be assigned more work or go to sleep. The chunk size can be controlled in some algorithms; doing so is a trade-off between overhead and load balancing.

Note: Use the OMP_SCHEDULE environment variable for loops that are explicitly assigned to runtime schedule type with the OpenMP schedule clause.

schedule=static[=n]

The iteration space is divided into blocks of n contiguous iterations. The final block might have fewer than n iterations. If n is unspecified, its default value is FLOOR(number_of_iterations / number_of_threads). The first REMAINDER(number_of_iterations/number_of_threads) chunks have one more iteration. Each thread is assigned a separate chunk.

The blocks are assigned in a round-robin fashion to threads in the parallel region until there are no remaining blocks. A thread that completes all its blocks goes to sleep. This is also known as block-cyclic scheduling, or cyclic scheduling when n has the value 1.

schedule=dynamic[=n]

The iteration space is divided into chunks that contain n contiguous iterations each. The final chunk might contain fewer than n iterations. If n is not specified, the chunk contains one iteration.

Each thread is initially assigned one chunk. After threads complete their assigned chunks, they are assigned remaining chunks on a "first-come, first-do" basis.

schedule=affinity[=n]

The iteration space is divided into number-of-thread-in-parallel-region partitions. Each partition has CEILING(number-of-iterations / number-of-thread-in-parallel-region) contiguous iterations. The final partition might have fewer iterations. The partitions are further divided into blocks, each with n iterations. If n is unspecified, its default value is CEILING( number-of-iterations-in-partition / 2 ); that is, each partition is divided into two blocks.

Each thread is assigned a partition. Each thread completes blocks within its local partition until no blocks remain in its partition. If blocks remain in other partitions, but a thread completes all blocks in its local partition, the thread might complete blocks in another thread’s partition. A thread goes to sleep if it completes its blocks and no blocks remain.

Note: This option has been deprecated and might be removed in a future release. Instead, you can use the guided option.

schedule=guided[=n]

The iteration space is divided into blocks of successively smaller size. Each block is sized to the larger of n and CEILING( number-of-iterations-
remaining / number-of-thread-in-parallel-region). The final chunk might contain fewer than \( n \) iterations. If \( n \) is unspecified, its default value is 1.

Each thread is initially assigned one block. As threads complete their work, they are assigned remaining blocks on a “first-come, first-serve” basis. A thread goes to sleep if it completes its blocks and no blocks remain.

**schedule=auto**

The compiler and runtime might select any algorithm to assign work to threads. A different algorithm might be selected for different loops. In addition, a different algorithm might be selected if the run time is updated.

The OMP_SCHEDULE environment variable affects only the constructs with a schedule (runtime) clause specified.

### Parallel execution options

**parthds=\( num \)**

Specifies the number of threads (\( num \)) to be used for parallel execution of code that you compiled with the -qsmp option. By default, this is equal to the number of online processors. There are some applications that cannot use more than some maximum number of processors. There are also some applications that can achieve performance gains if they use more threads than there are processors.

This option allows you full control over the number of execution threads. The default value for \( num \) is 1 if you did not specify -qsmp. Otherwise, it is the number of online processors on the machine. For more information, see the NUM_PARTHDS intrinsic function in the XL Fortran Language Reference.

**Note:** This option has been deprecated and might be removed in a future release.

**usrthds=\( num \)**

Specifies the maximum number of threads (\( num \)) that you expect your code will explicitly create if the code does explicit thread creation. The default value for \( num \) is 0. For more information, see the NUM_PARTHDS intrinsic function in the XL Fortran Language Reference.

**Note:** This option has been deprecated and might be removed in a future release.

**stack=\( num \)**

Specifies the largest amount of space in bytes (\( num \)) that a thread’s stack will need. The default value for \( num \) is 4194304.

Set stack=\( num \) so it is within the acceptable upper limit. \( num \) can be up to the limit imposed by system resources or the stack size ulimit, whichever is smaller. An application that exceeds the upper limit may cause a segmentation fault.

**Note:** This option has been deprecated and might be removed in a future release. Instead, you can use the OMP_STACKSIZE environment variable.

**stackcheck[=\( num \)]**

Enables stack overflow checking for worker threads at runtime. \( num \) is the size in bytes that you specify, and it must be a nonnull positive number. When the remaining stack size is less than \( num \), a runtime warning
message is issued. If you do not specify a value for num, the default value is 4096 bytes. Note that this option only has an effect when \texttt{-qsmp=stackcheck} has also been specified at compile time. See \texttt{-qsmp} in the \textit{XL Fortran Compiler Reference} for more information.

\texttt{startproc=cpu\_id}
Enables thread binding and specifies the cpu\_id to which the first thread binds. If the value provided is outside the range of available processors, the SMP run time issues a warning message and no threads are bound.

Note: This option has been deprecated and might be removed in a future release. Instead, you can use the \texttt{OMP\_PLACES} environment variable.

\texttt{procs=cpu\_id[,cpu\_id,...]}
Enables thread binding and specifies a list of cpu\_id to which the threads are bound.

Note: This option has been deprecated and might be removed in a future release. Instead, you can use the \texttt{OMP\_PLACES} environment variable.

\texttt{stride=num}
Specifies the increment used to determine the cpu\_id to which subsequent threads bind. num must be greater than or equal to 1. If the value provided causes a thread to bind to a CPU outside the range of available processors, a warning message is issued and no threads are bound.

Note: This option has been deprecated and might be removed in a future release. Instead, you can use the \texttt{OMP\_PLACES} environment variable.

Options to offload computations to target devices

\textbf{GPU}

Use the following options to control which device to execute target regions on.

\texttt{target=mandatory}
Forces target regions directed at a target device to execute on the target device. Program aborts if target regions cannot execute on the target device. This is the default value for machines with devices.

\texttt{target=default}
Executes target regions directed at a target device on the target device when the device and binaries are available. If a target region fails in executing on the target device, all subsequent target regions will execute on the host device.

\texttt{target=disabled}
Executes all target regions on the host device. This is the default value for machines without devices.

Use the following options to control whether to disable the check for pinned memory in the runtime.

\texttt{cudamemcheckfriendly=off}
Enables the check for pinned memory in the runtime. This is the default value.
**cudamemcheckfriendly=on**

Disables the check for pinned memory in the runtime. Specify this suboption if you want to run the cuda-memcheck tool from the NVIDIA CUDA Toolkit on your application.

---

**Performance tuning options**

When a thread completes its work and there is no new work to do, it can go into either a "busy-wait" state or a "sleep" state. In "busy-wait", the thread keeps executing in a tight loop looking for additional new work. This state is highly responsive but harms the overall utilization of the system. When a thread sleeps, it completely suspends execution until another thread signals it that there is work to do. This state provides better utilization of the system but introduces extra overhead for the application.

The *xlsmp* runtime library routines use both "busy-wait" and "sleep" states in their approach to waiting for work. You can control these states with the **spins**, **yields**, and **delays** options.

During the busy-wait search for work, the thread repeatedly scans the work queue up to *num* times, where *num* is the value that you specified for the option **spins**. If a thread cannot find work during a given scan, it intentionally wastes cycles in a delay loop that executes *num* times, where *num* is the value that you specified for the option **delays**. This delay loop consists of a single meaningless iteration. The length of actual time this takes will vary among processors. If the value **spins** is exceeded and the thread still cannot find work, the thread will yield the current time slice (time allocated by the processor to that thread) to the other threads. The thread will yield its time slice up to *num* times, where *num* is the number that you specified for the option **yields**. If this value *num* is exceeded, the thread will go to sleep.

In summary, the ordered approach to looking for work consists of the following steps:

1. Scan the work queue for up to **spins** number of times. If no work is found in a scan, then loop **delays** number of times before starting a new scan.
2. If work has not been found, then yield the current time slice.
3. Repeat the above steps up to **yields** number of times.
4. If work has still not been found, then go to sleep.

The syntax for specifying these options is as follows:

- **spins[=num]**
  - where *num* is the number of spins before a yield. The default value for **spins** is 100.

- **yields[=num]**
  - where *num* is the number of yields before a sleep. The default value for **yields** is 10.

- **delays[=num]**
  - where *num* is the number of delays while busy-waiting. The default value for **delays** is 500.
Zero is a special value for \texttt{spins} and \texttt{yields}, as it can be used to force complete busy-waiting. Normally, in a benchmark test on a dedicated system, you would set both options to zero. However, you can set them individually to achieve other effects.

For instance, on a dedicated 8-way SMP, setting these options to the following:
\begin{verbatim}
parthds=8 : schedule=dynamic=10 : spins=0 : yields=0
\end{verbatim}
results in one thread per CPU, with each thread assigned chunks consisting of 10 iterations each, with busy-waiting when there is no immediate work to do.

\section*{Options to enable and control dynamic profiling}

You can use dynamic profiling to reevaluate the compiler's decision to parallelize loops in a program. The three options you can use to do this are: \texttt{parthreshold}, \texttt{seqthreshold}, and \texttt{profilefreq}.

\texttt{parthreshold=\texttt{num}}

Specifies the time, in milliseconds, below which each loop must execute serially. If you set \texttt{parthreshold} to 0, every loop that has been parallelized by the compiler will execute in parallel. The default setting is 0.2 milliseconds, meaning that if a loop requires fewer than 0.2 milliseconds to execute in parallel, it should be serialized.

Typically, \texttt{parthreshold} is set to be equal to the parallelization overhead. If the computation in a parallelized loop is very small and the time taken to execute these loops is spent primarily in the setting up of parallelization, these loops should be executed sequentially for better performance.

\texttt{seqthreshold=\texttt{num}}

Specifies the time, in milliseconds, beyond which a loop that was previously serialized by the dynamic profiler should revert to being a parallel loop. The default setting is 5 milliseconds, meaning that if a loop requires more than 5 milliseconds to execute serially, it should be parallelized.

\texttt{seqthreshold} acts as the reverse of \texttt{parthreshold}.

\texttt{profilefreq=\texttt{num}}

Specifies the frequency with which a loop should be revisited by the dynamic profiler to determine its appropriateness for parallel or serial execution. Loops in a program can be data dependent. The loop that was chosen to execute serially with a pass of dynamic profiling may benefit from parallelization in subsequent executions of the loop, due to different data input. Therefore, you need to examine these loops periodically to reevaluate the decision to serialize a parallel loop at run time.

The allowed values for this option are the numbers from 0 to 32. If you set \texttt{profilefreq} to one of these values, the following results will occur.

\begin{itemize}
  \item If \texttt{profilefreq} is 0, all profiling is turned off, regardless of other settings. The overheads that occur because of profiling will not be present.
  \item If \texttt{profilefreq} is 1, loops parallelized automatically by the compiler will be monitored every time they are executed.
  \item If \texttt{profilefreq} is 2, loops parallelized automatically by the compiler will be monitored every other time they are executed.
  \item If \texttt{profilefreq} is greater than or equal to 2 but less than or equal to 32, each loop will be monitored once every \texttt{rth} time it is executed.
  \item If \texttt{profilefreq} is greater than 32, then 32 is assumed.
\end{itemize}
It is important to note that dynamic profiling is not applicable to user-specified parallel loops (for example, loops for which you specified the PARALLEL DO directive).

Related information:
“OMP_PLACES” on page 98
“OMP_STACKSIZE” on page 104

Environment variables for OpenMP

The following environment variables, which are included in the OpenMP standard, allow you to control the execution of parallel code.

Note: If you specify both the XLSPORTS environment variable and an OpenMP environment variable, the OpenMP environment variable takes precedence.

**OMP_DEFAULT_DEVICE**

The OMP_DEFAULT_DEVICE environment variable controls the device number to be used in device constructs by setting the initial value of the default-device-var internal control variable (ICV).

►►OMP_DEFAULT_DEVICE=—n—►◄

n Is a non-negative integer value that is less than the value of the omp_get_num_devices routine.

Related reference:
“omp_get_num_devices()” on page 227

Related information:
“OpenMP device constructs” on page 108

**OMP_DISPLAY_ENV**

When a program that uses the OpenMP runtime library is invoked and the OMP_DISPLAY_ENV environment variable is set, the OpenMP runtime library displays the values of the internal control variables (ICVs) associated with the environment variables and the build-specific information about the runtime library.

OMP_DISPLAY_ENV is useful in the following cases:

- When the runtime library is statically linked with an OpenMP program, you can use OMP_DISPLAY_ENV to check the version of the library that is used during link time.
- When the runtime library is dynamically linked with an OpenMP program, you can use OMP_DISPLAY_ENV to check the library that is used at run time.
- You can use OMP_DISPLAY_ENV to check the current setting of the runtime environment.

By default, no information is displayed.

The syntax of this environment variable is as follows:

►►OMP_DISPLAY_ENV—TRUE—FALSE—VERBOSE—►◄
Note: The values TRUE, FALSE, VERBOSE are not case-sensitive.

TRUE
Displays the OpenMP version number defined by the _OPENMP macro and the initial ICV values for the OpenMP environment variables.

FALSE
Instructs the runtime environment not to display any information.

VERBOSE
Displays build-specific information, ICV values associated with OpenMP environment variables, and the setting of the XLSMPOPTS environment variable.

Usage

When OMP_DISPLAY_ENV is TRUE, the initial ICV values for the OpenMP environment variables are displayed. If OMP_PLACES is set to cores or threads, the OMP_PLACES value is displayed in the format of cores or threads followed by the number of places in brackets; for example, OMP_PLACES='cores(4)'. For custom OMP_PLACES, each resource is displayed individually in each place, followed by the keyword custom; for example, OMP_PLACES='\{4,5,6,7\},\{8,9,10,11\}' custom.

When OMP_DISPLAY_ENV is VERBOSE, the output includes a section that is delineated by the lines OPENMP DISPLAY AFFINITY BEGIN and OPENMP DISPLAY AFFINITY END. This section includes a verbose display of the OMP_PLACES value, where each resource for each place is displayed individually, followed by cores, threads, or custom as appropriate. This section also displays information on THREADS_PER_PLACE in the format of a comma-separated list of the individual THREADS_PER_PLACE value for each place; for example, THREADS_PER_PLACE='\{2\},\{2\}'

Examples

Example 1

If you enter the export OMP_DISPLAY_ENV=TRUE command, you get output similar to the following example:

OPENMP DISPLAY ENVIRONMENT BEGIN
OMP_DISPLAY_ENV='TRUE'

_OPENMP='201107'
OMP_DYNAMIC='FALSE'
OMP_MAX_ACTIVE_LEVELS='5'
OMP_NESTED='FALSE'
OMP_NUM_THREADS='96'
OMP_PROC_BIND='FALSE'
OMP_SCHEDULE='STATIC,0'
OMP_STACKSIZE='4194304'
OMP_THREAD_LIMIT='96'
OMP_WAIT_POLICY='PASSIVE'
OPENMP DISPLAY ENVIRONMENT END

Example 2

If you enter the export OMP_DISPLAY_ENV=VERBOSE command, you will get output that is similar to the following example:
OPENMP DISPLAY AFFINITY BEGIN
OMP_PLACES="\{0\},\{1\},\{2\},\{3\},\{4\},\{5\},\{6\},\{7\},\{8\},\{9\},\{10\}" cores
THREADS_PER_PLACE="\{1\},\{1\},\{1\},\{1\},\{1\},\{1\},\{1\},\{1\}" cores
OPENMP DISPLAY AFFINITY END

Related information

"XLSMPOPTS" on page 86
"OMP_PLACES" on page 98
"OMP_PROC_BIND" on page 99

OMP_DYNAMIC

The OMP_DYNAMIC environment variable controls dynamic adjustment of the number of threads available for the execution of parallel regions.

```
OMP_DYNAMIC = TRUE
```

When OMP_DYNAMIC is set to TRUE, the number of threads that are created and then assigned to a place must not exceed the value of THREADS_PER_PLACE. The thread number includes the currently allocated threads of all active parallel regions. Under a given OMP_PROC_BIND policy, THREADS_PER_PLACE takes precedence in all situations.

When OMP_DYNAMIC is set to FALSE, if an application requires more threads than the value of THREADS_PER_PLACE in any place under a given OMP_PROC_BIND policy, the excess threads beyond the value of THREADS_PER_PLACE for all such places are assigned with priority to the following places:
1. Places that have not reached THREADS_PER_PLACE.
2. Places where the master thread is not running.

Examples

Example 1

Suppose OMP_THREAD_LIMIT=48 and
OMP_PLACES=\{0,1,2,3,4,5,6,7\},\{8,9,10,11,12,13,14,15\},\{16,17,18,19\}, the THREADS_PER_PLACE values are calculated as follows:

P0=\{0,1,2,3,4,5,6,7\}: size = 8, total size = 20, THREADS_PER_PLACE = floor((8/20)*48) = floor(19.2) = 19

P1=\{8,9,10,11,12,13,14,15\}: size = 8, total size = 20, THREADS_PER_PLACE = floor((8/20)*48) = floor(19.2) = 19

P2=\{16,17,18,19\}: size = 4, total size = 20, THREADS_PER_PLACE = floor((4/20)*48) = floor(9.6) = 9

The number of total allocated threads is 47. Threads are allocated by place size. Because P0 and P1 have the same largest size and P0 comes first in
**OMP_PLACES**, threads are allocated starting with P0. The thread allocation order is: P0, P1, P2. Only one thread is unallocated, so it is allocated to P0. Therefore, **THREADS_PER_PLACE**={20}, {19}, {9}.

**Example 2**

Suppose **OMP_THREAD_LIMIT**=17 and **OMP_PLACES**={0,1,2,3,0,1,2,3}, {4,5,6,7}, {8,9,10,11}, the **THREADS_PER_PLACE** values are calculated as follows:

- P0={0,1,2,3,0,1,2,3}: size = 8, total size = 16, **THREADS_PER_PLACE** = floor((8/16)*17) = floor(8.5) = 8
- P1={4,5,6,7}: size = 4, total size = 16, **THREADS_PER_PLACE** = floor((4/16)*17) = floor(4.25) = 4
- P2={8,9,10,11}: size = 4, total size = 16, **THREADS_PER_PLACE** = floor((4/16)*17) = floor(4.25) = 4

The number of total allocated threads is 16. Threads are allocated by place size, so the thread allocation order is: P0, P1, P2. Only one thread is unallocated, so it is allocated to P0. Therefore, **THREADS_PER_PLACE**={9}, {4}, {4}.

**Example 3**

Suppose **OMP_THREAD_LIMIT**=394 and **OMP_PLACES**={0,1}, {2,3,4,5}, {6,7,8,9,10,11}, {12,13,14,15}, {16,17,18,19,20,21,22,23}, the **THREADS_PER_PLACE** values are calculated as follows:

- P0={0,1}: size = 2, total size = 24, **THREADS_PER_PLACE** = floor((2/24)*394) = floor(32.8) = 32
- P1={2,3,4,5}: size = 4, total size = 24, **THREADS_PER_PLACE** = floor((4/24)*394) = floor(65.7) = 65
- P2={6,7,8,9,10,11}: size = 6, total size = 24, **THREADS_PER_PLACE** = floor((6/24)*394) = floor(98.5) = 98
- P3={12,13,14,15}: size = 4, total size = 24, **THREADS_PER_PLACE** = floor((4/24)*394) = floor(56.7) = 65
- P4={16,17,18,19,20,21,22,23}: size = 8, total size = 24, **THREADS_PER_PLACE** = floor((8/24)*394) = floor(131.3) = 131

The number of total allocated threads is 391. Threads are allocated by place size, so the thread allocation order is: P4, P2, P1, P3, P0. Three threads are unallocated, so the **THREADS_PER_PLACE** values of P4, P2, and P1 are increased by one each. Therefore, **THREADS_PER_PLACE**={32}, {66}, {99}, {65}, {132}.

**Related information**

“OMP_PLACES” on page 98

“OMP_PROC_BIND” on page 99
OMP_MAX_ACTIVE_LEVELS
The OMP_MAX_ACTIVE_LEVELS environment variable controls the maximum number of nested active parallel regions. The syntax is as follows:

\[ \text{OMP_MAX_ACTIVE_LEVELS}=n \]

\( n \) is the maximum number of nested active parallel regions. It must be a positive scalar integer. The maximum number that you can specify is 5.

OMP_NESTED
The OMP_NESTED environment variable enables or disables nested parallelism. The syntax is as follows:

\[ \text{OMP_NESTED} \]

If you set this environment variable to TRUE, nested parallelism is enabled, which means that the runtime environment might deploy extra threads to form the team of threads for the nested parallel region. If you set this environment variable to FALSE, nested parallelism is disabled, which means nested parallel regions are serialized and run in the current thread.

The default value for OMP_NESTED is FALSE.

The setting of the omp_set_nested subroutine overrides the OMP_NESTED setting.

Note: If the number of threads from all regions exceeds the number of available processors, your program might suffer performance degradation.

OMP_NUM_THREADS
The OMP_NUM_THREADS environment variable sets the number of threads to use for parallel regions. The syntax of the environment variable is as follows:

\[ \text{OMP_NUM_THREADS}=\text{num_list} \]

\( \text{num_list} \)
A list of one or more positive integer values separated by commas.

If you do not set the OMP_NUM_THREADS environment variable, the number of processors available is the default value to form a new team for the first encountered parallel construct. By default, any nested constructs are run by one thread.

If \( \text{num_list} \) contains a single value, dynamic adjustment of the number of threads is enabled (OMP_DYNAMIC is set to true), a parallel construct without a NUM_THREADS clause is encountered, the value is the maximum number of threads that can be used to form a new team for the encountered parallel construct.

If \( \text{num_list} \) contains a single value, dynamic adjustment of the number of threads is not enabled (OMP_DYNAMIC is set to false), a parallel construct without a NUM_THREADS clause is encountered, the value is the exact number of threads that can be used to form a new team for the encountered parallel construct.
If `num_list` contains multiple values, dynamic adjustment of the number of threads is enabled (OMP_DYNAMIC is set to true), a parallel construct without a NUM_THREADS clause is encountered, the first value is the maximum number of threads that can be used to form a new team for the encountered parallel construct. After the encountered construct is entered, the first value is removed and the remaining values form a new `num_list`. The new `num_list` is in turn used in the same way for any closely nested parallel constructs inside the encountered parallel construct.

If `num_list` contains multiple values, dynamic adjustment of the number of threads is not enabled (OMP_DYNAMIC is set to false), a parallel construct without a NUM_THREADS clause is encountered, the first value is the exact number of threads that can be used to form a new team for the encountered parallel construct. After the encountered construct is entered, the first value is removed and the remaining values form a new `num_list`. The new `num_list` is in turn used in the same way for any closely nested parallel constructs inside the encountered parallel construct.

**Note:** If the number of parallel regions is equal to or greater than the number of values in `num_list`, the `omp_get_max_threads` routine returns the last value of `num_list` in the parallel region.

If the number of threads requested exceeds the system resources available, the program stops.

The `omp_set_num_threads` routine sets the first value of `num_list`. The `omp_get_max_threads` routine returns the first value of `num_list`.

If you specify the number of threads for a given parallel region more than once with different settings, the compiler uses the following precedence order to determine which setting takes effect:

1. The number of threads set using the NUM_THREADS clause takes precedence over that set using the `omp_set_num_threads` routine.
2. The number of threads set using the `omp_set_num_threads` routine takes precedence over that set using the OMP_NUM_THREADS environment variable.
3. The number of threads set using the OMP_NUM_THREADS environment variable takes precedence over that set using the PARTHDS suboption of the XLSMPOPTS environment variable.

**Note:** The PARTHDS suboption of the XLSMPOPTS environment variable is deprecated.

**Note:** In a given parallel region, the `omp_get_max_threads` routine returns the first value of `num_list`, even though the actual number of threads running that parallel region might be different from the first value of `num_list`.

The following example shows how you can set the OMP_NUM_THREADS environment variable.

```bash
export OMP_NUM_THREADS=5,10
export OMP_DYNAMIC=false

! OMP_GET_MAX_THREADS() returns 5 threads
 !$omp parallel
  ! OMP_GET_MAX_THREADS() returns 10 threads
  !$omp parallel
```

Chapter 9. Parallel programming with XL Fortran  97
OMP_GET_MAX_THREADS() returns 10 threads
$omp parallel
OMP_GET_MAX_THREADS() returns 10 threads
$omp end parallel
$omp end parallel
$omp end parallel
$omp end parallel

OMP_PLACES
The OMP_PLACES environment variable specifies a list of places that are available when the OpenMP program is executed. The value of OMP_PLACES can be either one of the following values:
  • An abstract name that describes a set of places
  • An explicit list of places that are described by non-negative numbers

OMP_PLACES syntax

OMP_PLACES=place_list

where place_list takes one of the following syntax forms:

place_list syntax: form 1

lower_bound:length:stride

place_list syntax: form 2

lower_bound:length:num_places:multiplier

where lower_bound, length, stride, num, num_places, and multiplier are positive integers that represent the units of execution that are exposed to the execution environment. The thread number in each place starts with the value that is a multiple of multiplier. An exclusion operator ! excludes the number or place that follows the operator immediately.

place_name syntax

cores:threads

threads Each place contains a hardware thread.
cores Each place contains a core. If OMP_PLACES is not set, the default setting is cores.
num_places Is the number of places.
Usage

When requested places are fewer than that are available on the system, the execution environment assigns places in the order of the place list at run time. When requested places are more than that are available on the system, the execution environment assigns the maximum number of places that the system supports at run time.

For a program that contains both OpenMP and OpenMPI code, the OpenMP runtime detects the existence of OpenMPI code by the presence of the `OMPI_COMM_WORLD_RANK` environment variable. If you do not set `OMP_PLACES` explicitly, the compiler sets `OMP_PLACES` to `cores` and removes any unavailable resources from `OMP_PLACES` based on the OpenMPI affinity policy. In addition, `OMP_PROC_BIND` is set to `TRUE`.

For examples on how to set the `OMP_PLACES` environment variable, see examples in `OMP_PROC_BIND`.

**OMP_PROC_BIND**
The `OMP_PROC_BIND` environment variable controls the thread affinity policy and whether OpenMP threads can be moved between places. With the thread affinity feature, you can have a fine-grained control of how threads are bound and distributed to places. Three thread affinity policies exist: `MASTER`, `CLOSE`, and `SPREAD`.

**OMP_PROC_BIND syntax**

```
OMP_PROC_BIND=<TRUE|FALSE|MASTER|CLOSE|SPREAD>
```

- **TRUE**
  Binds the threads to places.

- **FALSE**
  Allows threads to be moved between places and disables thread affinity.

- **MASTER**
  Instructs the execution environment to assign the threads in the team to the same place as the master thread.

- **CLOSE**
  Instructs the execution environment to assign the threads in the team to the places that are close to the place of the parent thread. The place partition is not changed by this policy. Each implicit task inherits the `place-partition-var` ICV of the parent implicit task. Suppose T threads in the team are assigned to P places in the parent's place partition, the threads are assigned as follows:
  - If T is less than or equal to P, the master thread executes on the place of the parent thread. The thread with the next smallest thread number executes on the next place in the place partition, and so on, with wrap around with respect to the place partition of the master thread.
  - If T is greater than P, each place contains at least S = floor(T/P) consecutive threads. The first S threads with the smallest thread number (including the master thread) are assigned to the place of the parent thread. The next S
threads with the next smallest thread numbers are assigned to the next place in the place partition, and so on, with wrap around with respect to the place partition of the master thread. When P does not divide T evenly, each remaining thread is assigned to a subpartition in the order of the place list.

**SPREAD**

Instructs the execution environment to spread a set of T threads as evenly as possible among P places of the parent’s place partition at run time. The thread distribution mechanism is as follows:

- If T is less than or equal to P, the parent partition is divided into T subpartitions, where each subpartition contains at least $S = \lfloor \frac{P}{T} \rfloor$ consecutive places. A single thread is assigned to each subpartition. The master thread executes on the place of the parent thread and is assigned to the subpartition that includes that place. The thread with the next smallest thread number is assigned to the first place in the next subpartition, and so on, with wrap around with respect to the original place partition of the master thread.

- If T is greater than P, the parent’s partition is divided into P subpartitions, where each subpartition contains a single place. Each place contains at least $S = \lfloor \frac{T}{P} \rfloor$ consecutive threads. The first S threads with the smallest thread number (including the master thread) are assigned to the subpartition that contains the place of the parent thread. The next S threads with the next smallest thread numbers are assigned to the next place in the place partition, and so on, with wrap around with respect to the original place partition of the master thread. When P does not divide T evenly, each remaining thread is assigned to a subpartition in the order of the place list.

where,

**Place**

is a hardware unit that holds an unordered set of processors on which one or more threads can execute.

**Place list**

is an ordered list that describes all places that are available to the applications.

**Place partition**

is an ordered list that corresponds to a contiguous interval in the place list. The places in the partition are available for a given parallel region.

When OMP_PROC_BIND is set to TRUE, MASTER, CLOSE, or SPREAD, a place can be assigned with up to THREADS_PER_PLACE threads. Each remaining thread is assigned to a place in the order of the place list.

For each place in OMP PLACES, THREADS_PER_PLACE is a positive integer and is calculated in the following way:

$$\text{THREADS\_PER\_PLACE} = \lfloor \left( \frac{\text{the number of resources in that place}}{\text{the total number of resources (including duplicated resources)}} \right) \times \text{OMP\_THREAD\_LIMIT} \rfloor$$

After THREADS_PER_PLACE is calculated for each place in this manner, if the sum of all the THREADS_PER_PLACE values is less than OMP_THREAD_LIMIT, each THREADS_PER_PLACE is increased by one, starting from the largest place to the smallest place, until OMP_THREAD_LIMIT is reached. Places that are equivalent in size are ordered according to their order in OMP PLACES.
Usage

By default, the **OMP_PROC_BIND** environment variable is not set.

If the initial thread cannot be bound to the first place in the OpenMP place list, the runtime execution environment issues a message and assigns threads according to the default place list.

The **OMP_PROC_BIND** and **XLSMPOPTS** environment variables interact with each other according to the following rules:

Table 19. Thread binding rule summary

<table>
<thead>
<tr>
<th><strong>OMP_PROC_BIND</strong> settings</th>
<th><strong>XLSMPOPTS</strong> settings</th>
<th>Thread binding results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OMP_PROC_BIND</strong> is not set</td>
<td><strong>XLSMPOPTS</strong> is not set</td>
<td>Threads are not bound.</td>
</tr>
<tr>
<td><strong>XLSMPOPTS</strong> is set to startproc/stride or proc2</td>
<td><strong>XLSMPOPTS</strong> setting is invalid</td>
<td>Threads are bound according to the settings in <strong>XLSMPOPTS</strong>.</td>
</tr>
<tr>
<td><strong>XLSMPOPTS</strong> setting is invalid</td>
<td>Threads are not bound.</td>
<td></td>
</tr>
<tr>
<td><strong>OMP_PROC_BIND = TRUE</strong></td>
<td><strong>XLSMPOPTS</strong> is not set</td>
<td>Threads are bound.</td>
</tr>
<tr>
<td><strong>XLSMPOPTS</strong> is set to startproc/stride or proc2</td>
<td><strong>XLSMPOPTS</strong> setting is invalid</td>
<td>Threads are bound according to the settings in <strong>XLSMPOPTS</strong>.</td>
</tr>
<tr>
<td><strong>OMP_PROC_BIND = FALSE</strong></td>
<td><strong>XLSMPOPTS</strong> is not set</td>
<td>Threads are not bound.</td>
</tr>
<tr>
<td><strong>XLSMPOPTS</strong> is set (startproc/stride or proc2)</td>
<td><strong>XLSMPOPTS</strong> setting is invalid</td>
<td></td>
</tr>
</tbody>
</table>

Note:

1. If **procs** is set and the number of CPU IDs specified is smaller than the number of threads that are used by the program, the remaining threads are also bound to the listed CPU IDs but not in any particular order. If **XLSMPOPTS=startproc** is used, the value specified by **startproc** is smaller than the number of CPUs, and the value that is specified by **stride** causes a thread to bind to a CPU outside the range of available places, some of the threads are bound and some are not.

2. The **startproc/stride** and **procs** suboptions of **XLSMPOPTS** are deprecated.

The **OMP_PROC_BIND** environment variable provides a portable way to control whether OpenMP threads can be migrated. The **startproc/stride** or **procs** suboption of the **XLSMPOPTS** environment variable, which is an IBM extension, provides a finer control to bind OpenMP threads to places. If portability of your application is important, use only the **OMP_PROC_BIND** environment variable to control thread binding.

When **OMP_PROC_BIND** is set to **MASTER**, **CLOSE**, or **SPREAD**, the suboption settings **startproc/stride** or **procs** of **XLSMPOPTS** are ignored.

For a program that contains both OpenMP and OpenMPI code, the OpenMP runtime detects the existence of OpenMPI code by the presence of the **OMPI_COMM_WORLD_RANK** environment variable. If you do not set **OMP_PLACES** explicitly, the compiler sets **OMP_PROC_BIND** to be **TRUE**.
Examples

The following examples demonstrate the thread binding and thread affinity results when you compile myprogram.f with different environment variable settings.

myprogram.f
PROGRAM MYPROGRAM
    !... ...!
END PROGRAM MYPROGRAM

Environment variable settings 1
OMP_NUM_THREADS=4;
OMP_PROC_BIND=MASTER;
OMP_PLACES='\{0:4\},\{4:4\},\{8:4\},\{12:4\},\{16:4\},\{20:4\},\{24:4\},\{28:4\}'

Results 1: Every thread in the team is assigned to the place on which the master executes. Four threads are assigned to place 0.

Environment variable settings 2
OMP_NUM_THREADS=4;
OMP_PROC_BIND=close;
OMP_PLACES='\{0:4\},\{4:4\},\{8:4\},\{12:4\},\{16:4\},\{20:4\},\{24:4\},\{28:4\}'

Results 2: The thread is assigned to a place that is close to the place of the parent thread. The thread assignment is as follows:
• OMP thread 0 is assigned to place 0
• OMP thread 1 is assigned to place 1
• OMP thread 2 is assigned to place 2
• OMP thread 3 is assigned to place 3

Environment variable settings 3
OMP_NUM_THREADS=4;
OMP_PROC_BIND=spread;
OMP_PLACES='\{0:4\},\{4:4\},\{8:4\},\{12:4\},\{16:4\},\{20:4\},\{24:4\},\{28:4\}'

Results 3: The number of threads 4 is smaller than the number of places 8, so four subpartitions are formed. 8 is evenly divided by 4, so the thread assignment is as follows:
• OMP thread 0 is assigned to place 0
• OMP thread 1 is assigned to place 2
• OMP thread 2 is assigned to place 4
• OMP thread 3 is assigned to place 6

Environment variable settings 4
OMP_NUM_THREADS=5;
OMP_PROC_BIND=spread;
OMP_PLACES='\{0:4\},\{4:4\},\{8:4\},\{12:4\},\{16:4\},\{20:4\},\{24:4\},\{28:4\}'

Results 4: The number of threads 5 is smaller than the number of places 8, so five subpartitions are formed. 8 is not evenly divided by 5, so threads are assigned to the places in order. The thread assignment is as follows:
• OMP thread 0 is assigned to place 0
• OMP thread 1 is assigned to place 2
• OMP thread 2 is assigned to place 4
OMP thread 3 is assigned to place 6
OMP thread 4 is assigned to place 7

Environment variable settings 5
OMP_NUM_THREADS=8;
OMP_PROC_BIND=spread;
OMP_PLACES='(0:4),(4:4),(8:4),(12:4)'

Results 5: The number of threads 8 is greater than the number of places 4, so four subpartitions are formed. 8 is evenly divided by 4, so two threads are assigned to each subpartition. The thread assignment is as follows:
• OMP thread 0 and thread 1 are assigned to place 0
• OMP thread 2 and thread 3 are assigned to place 1
• OMP thread 4 and thread 5 are assigned to place 2
• OMP thread 6 and thread 7 are assigned to place 3

Environment variable settings 6
OMP_NUM_THREADS=7;
OMP_PROC_BIND=spread;
OMP_PLACES='(0:4),(4:4),(8:4),(12:4)'

Results 6: The number of threads 7 is greater than the number of places 4, so four subpartitions are formed. 7 is not evenly divided by 4, so one thread (\(\text{floor}(7/4)=1\)) is assigned to each subpartition. The thread assignment is as follows:
• OMP thread 0 is assigned to place 0
• OMP thread 1 and thread 2 are assigned to place 1
• OMP thread 3 and thread 4 are assigned to place 2
• OMP thread 5 and thread 6 are assigned to place 3

Related reference:
“PROC_BIND” on page 216
“omp_get_proc_bind()” on page 232

Related information:
“XLSMPOPTS” on page 86
“OMP_PLACES” on page 98

OMP_SCHEDULE
The OMP_SCHEDULE environment variable applies to the PARALLEL DO and work-sharing DO directives that have a schedule type of RUNTIME. The syntax is as follows:

\[\text{OMP_SCHEDULE}=\text{sched_type},\text{chunk_size}\]

sched_type
is either AUTO, DYNAMIC, GUIDED, or STATIC. See the “SCHEDULE” on page 217 clause for a description of these scheduling parameters.

chunk_size
is a positive, scalar integer that represents the chunk size.

This environment variable is ignored for the PARALLEL DO and work-sharing DO directives that have a schedule type other than RUNTIME.
If you do not specify a schedule type either at compile time through a directive, or
at run time through the OMP_SCHEDULE environment variable or the
SCHEDULE option of the XLSMPOPTS environment variable, the default
schedule type is AUTO, which delegates scheduling decision to the compiler and
runtime system. You cannot specify chunk_size when the schedule type is set to
AUTO.

If you specify both the SCHEDULE option of the XLSMPOPTS environment
variable and the OMP_SCHEDULE environment variable, the OMP_SCHEDULE
environment variable takes precedence.

The following examples show how you can set the OMP_SCHEDULE
environment variable:

```
export OMP_SCHEDULE="DYNAMIC"
export OMP_SCHEDULE="GUIDED,4*
export OMP_SCHEDULE="STATIC"
export OMP_SCHEDULE="AUTO"
```

**OMP_STACKSIZE**

The OMP_STACKSIZE environment variable specifies the size of the stack for
threads created by the OpenMP run time. The syntax is as follows:

```
OMP_STACKSIZE=size
```

- `size` is a positive integer that specifies the size of the stack for threads that are
  created by the OpenMP run time.

- "B", "K", "M", "G"
  - are letters that specify whether the given size is in Bytes, Kilobytes,
    Megabytes, or Gigabytes.

If only size is specified and none of "B", "K", "M", "G" is specified, size is in
Kilobytes by default. This environment variable does not control the size of the
stack for the initial thread.

The value assigned to the OMP_STACKSIZE environment variable is case
insensitive and might have leading and trailing white space. The following
examples show how you can set the OMP_STACKSIZE environment variable.

```
export OMP_STACKSIZE="10M"
export OMP_STACKSIZE=" 10 M "
```

If the value of OMP_STACKSIZE is not set, the initial value is set to the default
value. (up to the limit that is imposed by system resources).

If the compiler cannot deliver the stack size specified by the environment variable,
or if OMP_STACKSIZE does not conform to the valid format, the compiler sets
the environment variable to the default value.

The OMP_STACKSIZE environment variable takes precedence over the stack
suboption of the XLSMPOPTS environment variable.
The **OMP_THREAD_LIMIT** environment variable sets the number of OpenMP threads to use for the whole program. The syntax is as follows:

\[ \text{OMP_THREAD_LIMIT} = n \]

- **n**: The number of OpenMP threads to use for the whole program. It must be a positive scalar integer that is less than 65536.

**Usage**

When **OMP_THREAD_LIMIT**=1, the parallel regions are run sequentially rather than in parallel. However, when **OMP_THREAD_LIMIT** is much smaller than the number of threads that are required in the program, the parallel region might still run in parallel but with less number of threads. When there are nested parallel regions, some parallel regions might run in parallel, some might run sequentially, and some might run in parallel but with threads that are recycled from other regions.

If **OMP_THREAD_LIMIT** is not defined and **OMP_NESTED**=TRUE, the default value of **OMP_THREAD_LIMIT** is the greater value of either the multiplication of all **OMP_NUM_THREADS** levels or the number of total resources in **OMP_PLACES**.

If **OMP_THREAD_LIMIT** is not defined and **OMP_NESTED**=FALSE, the default value of **OMP_THREAD_LIMIT** is the greater value of either the first level of **OMP_NUM_THREADS** or the number of total resources in **OMP_PLACES**.

If neither **OMP_THREAD_LIMIT** nor **OMP_NESTED** is defined, the default value of **OMP_THREAD_LIMIT** is the number of total resources in **OMP_PLACES**.

**Examples**

Suppose **OMP_THREAD_LIMIT** is not defined and **OMP_PLACES**={0,1,2,3,4,5,6,7}, {8,9,10,11,12,13,14,15}. The number of total resources in **OMP_PLACES** is 16.

**Example 1**

When **OMP_NESTED**=TRUE and **OMP_NUM_THREADS**=2,12, the default value of **OMP_THREAD_LIMIT** is 24, because the multiplication of all **OMP_NUM_THREADS** levels is 24 and 24 is greater than 16.

**Example 2**

When **OMP_NESTED**=FALSE and **OMP_NUM_THREADS**=2,4, the default value of **OMP_THREAD_LIMIT** is 16, because the first level of **OMP_NUM_THREADS** is 2 and 16 is greater than 2.

**Related information**

- "OMP_PLACES” on page 98
- "OMP_NUM_THREADS” on page 96
OMP_WAIT_POLICY

The OMP_WAIT_POLICY environment variable provides hints about the preferred behavior of waiting threads during program execution. The syntax is as follows:

```
OMP_WAIT_POLICY=PASSIVE
```

Use ACTIVE if you want waiting threads to mostly be active. That is, the threads consume processor cycles while waiting. For example, waiting threads can spin while waiting. The ACTIVE wait policy is recommended for maximum performance on the dedicated machine.

Use PASSIVE if you want waiting threads to mostly be passive. That is, the threads do not consume processor cycles while waiting. For example, waiting threads can sleep or yield the processor to other threads.

The default value of OMP_WAIT_POLICY is PASSIVE.

Note: If you set the OMP_WAIT_POLICY environment variable and specify the SPINS, YIELDS, or DELAYS suboptions of the XLSMPOPTS environment variable, OMP_WAIT_POLICY takes precedence.

Optimizing your SMP code

Most IBM processors are capable of shared-memory parallel processing. Compile with -qsmp to generate the threaded code needed to exploit this capability. The option implies a -O2 optimization level. The default behavior for the option without suboptions is to do automatic parallelization with optimization.

The most commonly used -qsmp suboptions are summarized in the following table.

<table>
<thead>
<tr>
<th>Suboption</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>auto</td>
<td>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 -qsmp suboptions, and it also implies the opt suboption.</td>
</tr>
<tr>
<td>omp</td>
<td>Parallelizes only program code that is explicitly annotated with OpenMP directives.</td>
</tr>
<tr>
<td>opt</td>
<td>Enables optimization of parallelized program code. The optimization is equivalent to -O2 -qhot in the absence of other optimization options. The default setting of -qsmp is -qsmp=auto:noomp:opt.</td>
</tr>
<tr>
<td>noopt</td>
<td>Performs the smallest amount of optimization that is required to parallelize the code. During development, it can be useful to turn off optimization to facilitate debugging.</td>
</tr>
<tr>
<td>fine_tuning</td>
<td>Other values for the suboption provide control over thread scheduling, nested parallelism, locking, and so on.</td>
</tr>
</tbody>
</table>

Related information in the XL Fortran Compiler Reference

- `-O, -qoptimize`
- `-qsmp`
Developing and running SMP applications

- By default, the parallelization performed is both user-directed and automatic. Use `-qsmp=omp:noauto` if you are compiling an OpenMP program and do not want automatic parallelization.
- Before using `-qsmp` with automatic parallelization, test your programs using optimization and `-qhot` in a single-threaded manner.
- Always use the reentrant compiler invocations (the `_r` command invocations, like `xlf_r`) when using `-qsmp`.
- By default, the run time uses all available processors. Do not set the `XLSMPOPTS=PARTHDS` or `OMP_NUM_THREADS` 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.

**Note:** The `XLSMPOPTS=PARTHDS` variable is deprecated.

- If you are using a dedicated machine or node, consider setting `OMP_WAIT_POLICY` to `ACTIVE` or setting the `SPINS` and `YIELDS` variables (suboptions of `XLSMPOPTS`) to 0. Doing so prevents the operating system from intervening in the scheduling of threads across synchronization boundaries such as barriers.
- When debugging an SMP program, try using `-qsmp=noopt` (without `-O`) to make the debugging information produced by the compiler more precise. You can also use the `SNAPSHOT` directive to create additional program points for storage visibility by flushing registers to memory.

### Parallelization directives

You can use directives introduced in this section to exert control over parallelization. For example, you can specify the `PARALLEL DO` directive to indicate that the loop immediately follows the directive should be run in parallel. All parallelization directives are comment form directives.

For more information on rules and syntax for comment form directives, see "Comment and noncomment form directives" in the *XL Fortran Language Reference*.

XL Fortran supports a number of parallelization directives, divided as listed in "Summary of supported parallelization directives." To ensure the greatest portability of code, OpenMP directives are recommended where possible. Use the OpenMP `trigger_constant`, `$OMP` for OpenMP directives, but do not use this `trigger_constant` with any other directive. OpenMP directives must not appear in `PURE` and `ELEMENTAL` procedures.

To enable parallelization directives, you must specify the `-qsmp` option. For more information, see topic `-qsmp` in the *XL Fortran Compiler Reference*.

### Summary of supported parallelization directives

This section categorizes all parallelization directives that are supported by XL Fortran.

**OpenMP parallel region construct**

Parallel constructs form the foundation of OpenMP based parallel execution in XL Fortran. The `[PARALLEL/END PARALLEL]` directive pair forms a basic parallel construct. Each time an executing thread enters a parallel region, it creates a team
of threads and becomes master of that team. This allows parallel execution to take place within that construct by the threads in that team. The following directives are necessary for a parallel region:

```
PARALLEL
END PARALLEL
```

**OpenMP work-sharing constructs**

Work-sharing constructs divide the execution of code enclosed by the construct between threads in a team. For work-sharing to take place, the construct must be enclosed within the dynamic extent of a parallel region. For further information on work-sharing constructs, see the following directives:

```
DO
END DO
SECTIONS
END SECTIONS
WORKSHARE
END WORKSHARE
SINGLE
END SINGLE
```

**OpenMP SIMD constructs**

SIMD constructs indicate that multiple iterations of a loop can be executed concurrently using SIMD instructions. For further information on SIMD constructs, see the following directives:

```
SIMD
END SIMD
DO SIMD
END DO SIMD
```

**OpenMP device constructs**

You can use the following OpenMP directives to manage device data environments and inside variables and to offload computations to devices:

```
TARGET DATA
END TARGET DATA
TARGET ENTER DATA
TARGET EXIT DATA
TARGET
END TARGET
TARGET UPDATE
DECLARE TARGET
TEAMS
END TEAMS
DISTRIBUTE
END DISTRIBUTE
DISTRIBUTE SIMD
END DISTRIBUTE SIMD
DISTRIBUTE PARALLEL DO
END DISTRIBUTE PARALLEL DO
DISTRIBUTE PARALLEL DO SIMD
END DISTRIBUTE PARALLEL DO SIMD
```

**OpenMP synchronization constructs**

You can use the following directives to synchronize the execution of a parallel region by multiple threads in a team:

```
ATOMIC
BARRIER
CRITICAL
END CRITICAL
```
OpenMP combined constructs

Combined constructs are shortcuts for specifying one construct immediately nested inside another construct. Specifying a combined construct is semantically identical to specifying the first construct that encloses an instance of the second construct and no other statements.

Some combined constructs have clauses that are permitted on both individual constructs that were combined. If you specify a clause that is permitted on both of the individual constructs, the clause applies to one or both constructs.

You can use the following combined constructs:

<table>
<thead>
<tr>
<th>PARALLEL DO</th>
<th>END PARALLEL DO</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARALLEL DO SIMD</td>
<td>END PARALLEL DO SIMD</td>
</tr>
<tr>
<td>PARALLEL SECTIONS</td>
<td>END PARALLEL SECTIONS</td>
</tr>
<tr>
<td>PARALLEL WORKSHARE</td>
<td>END PARALLEL WORKSHARE</td>
</tr>
<tr>
<td>TARGET PARALLEL DO</td>
<td>END TARGET PARALLEL DO</td>
</tr>
<tr>
<td>TARGET PARALLEL DO SIMD</td>
<td>END TARGET PARALLEL DO SIMD</td>
</tr>
<tr>
<td>TARGET SIMD</td>
<td>END TARGET SIMD</td>
</tr>
<tr>
<td>TARGET TEAMS</td>
<td>END TARGET TEAMS</td>
</tr>
<tr>
<td>TARGET TEAMS DISTRIBUTE</td>
<td>END TARGET TEAMS DISTRIBUTE</td>
</tr>
<tr>
<td>TARGET TEAMS DISTRIBUTE PARALLEL DO</td>
<td>END TARGET TEAMS DISTRIBUTE PARALLEL DO</td>
</tr>
<tr>
<td>TARGET TEAMS DISTRIBUTE PARALLEL DO SIMD</td>
<td>END TARGET TEAMS DISTRIBUTE PARALLEL DO SIMD</td>
</tr>
<tr>
<td>TARGET TEAMS DISTRIBUTE SIMD</td>
<td>END TARGET TEAMS DISTRIBUTE SIMD</td>
</tr>
<tr>
<td>TEAMS DISTRIBUTE</td>
<td>END TEAMS DISTRIBUTE</td>
</tr>
<tr>
<td>TEAMS DISTRIBUTE PARALLEL DO</td>
<td>END TEAMS DISTRIBUTE PARALLEL DO</td>
</tr>
<tr>
<td>TEAMS DISTRIBUTE PARALLEL DO SIMD</td>
<td>END TEAMS DISTRIBUTE PARALLEL DO SIMD</td>
</tr>
<tr>
<td>TEAMS DISTRIBUTE SIMD</td>
<td>END TEAMS DISTRIBUTE SIMD</td>
</tr>
</tbody>
</table>

Related reference:

“PARALLEL DO / END PARALLEL DO” on page 142
“PARALLEL SECTIONS / END PARALLEL SECTIONS” on page 146
“PARALLEL WORKSHARE / END PARALLEL WORKSHARE” on page 148

Other OpenMP constructs

You can use the following OpenMP directives that provide additional control over parallelization:

<table>
<thead>
<tr>
<th>MASTER</th>
<th>END MASTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>TASK</td>
<td>END TASK</td>
</tr>
</tbody>
</table>
SMP directives
The following directives provide additional SMP functionality:

- **DO SERIAL**
- **SCHEDULE**
- **THREADLOCAL**

Deprecated directive
The SMP directive listed in the following table has been deprecated and might be removed in a future release. Use the corresponding OpenMP directive or clause to obtain the same behavior.

<table>
<thead>
<tr>
<th>SMP directive</th>
<th>OpenMP clause</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCHEDULE</td>
<td>SCHEDULE</td>
</tr>
</tbody>
</table>

The following example shows how to replace the deprecated SMP SCHEDULE directive with the OpenMP SCHEDULE clause.

The original code that uses the SMP SCHEDULE directive is as follows:

```fortran
program loop
  integer, parameter :: N=500
  integer :: i
  real :: arr(N)

  !SMP$ SCHEDULE(STATIC)
  !SMP$ parallel do
  do i=1, N
    arr(i) = real(i-1)
  enddo
end program
```

To obtain the same behavior, you can use the OpenMP SCHEDULE clause, as shown below:

```fortran
program loop
  integer, parameter :: N=500
  integer :: i
  real :: arr(N)

  !$OMP parallel do schedule(static)
  do i=1, N
    arr(i) = real(i-1)
  enddo
end program
```

**Detailed descriptions of parallelization directives**
This section describes selected parallelization directives that are supported by XL Fortran in detail.

You can find information that is specific to each directive in this section. For general information about directive clauses, see “Directive clauses” on page 195.
**ATOMIC**  
**Purpose**

You can use the ATOMIC directive to access a specific memory location safely within a parallel region. When you use the ATOMIC directive, the compiler generates code to ensure that only one thread is accessing the memory location at a time to avoid errors that might occur from simultaneous reads or writes to the same memory location.

Atomic operations are useful when you create multithreaded or concurrent algorithms and data structures. Using atomic constructs, you can write more efficient concurrent algorithms with fewer locks.

An atomic construct supports the following kinds of atomic access:

- **Atomic update**
  Updates the value of a variable atomically. Allows only one thread to write to a shared variable at a time, avoiding errors from simultaneous writes to the same variable.

- **Atomic read**
  Reads the value of a variable atomically. The value of a shared variable can be read safely, avoiding the danger of reading an intermediate value of the variable when it is accessed simultaneously by a concurrent thread.

- **Atomic write**
  Writes the value of a variable atomically. The value of a shared variable can be written exclusively to avoid errors from simultaneous writes.

- **Atomic capture**
  Updates the value of a variable while capturing the original or final value of the variable atomically.

**Notes:**

1. The atomic operations are not interoperable between V15.1.1 and V15.1.2. The atomic implementation of V15.1.2 is more efficient.
2. The ATOMIC directive is not supported on a target device.

**Required option**

-qsmp
Syntax

Atomic update

```
ATOMI<UPDATE> seq_cst

atomic_update_statement

END ATOMIC
```

Atomic read

```
ATOMI<READ> seq_cst

atomic_capture_statement

END ATOMIC
```

Atomic write

```
ATOMI<WRITE> seq_cst

atomic_write_statement

END ATOMIC
```
Atomic capture

where:

atomic_update_statement
    is one of the following forms:

Note: The last form is to support atomic swap operations.
update_variable = update_variable operator expression
update_variable = expression operator update_variable
update_variable = intrinsic(update_variable, expression_list)
update_variable = intrinsic(expression_list, update_variable)

atomic_write_statement
    has the following form:
    update_variable = expression

atomic_capture_statement
    has the following form:
    capture_variable = update_variable

seq_cst
    is a clause that supports sequentially atomic operations. It forces atomically
    performed operations to include an implicit flush operation without a list.

where:
update_variable, capture_variable
    are both nonpointer, nonallocatable scalar variables of intrinsic type.
intrinsic
    is one of \texttt{MAX}, \texttt{MIN}, \texttt{IAND}, \texttt{IOR} or \texttt{IEOR}.
operator
    is one of \texttt{+}, \texttt{-}, \texttt{*}, \texttt{/}, \texttt{.AND.}, \texttt{.OR.}, \texttt{.EQV.}, \texttt{.NEQV.} or \texttt{.XOR.}.
expression
    is a scalar expression that does not reference \texttt{update_variable}.
expression_list
    is a comma-separated, non-empty list of scalar expressions that do not
    reference \texttt{update_variable}.

\textbf{Note:} If the intrinsic is \texttt{IAND}, \texttt{IOR}, or \texttt{IEOR}, \texttt{expression_list} can only
    contain one expression.

\section*{Rules}

An \texttt{ATOMIC} directive without a clause is equivalent to atomic update, and applies
only to the statement that immediately follows it.

All accesses to a certain storage location throughout a concurrent program must be
atomic. A non-atomic access to a memory location might break the expected atomic
behavior of all atomic accesses to that storage location.

The \texttt{expression} in an atomic statement is not evaluated atomically. You must ensure
that no race conditions exist in the calculation.

Within the entire program, if you use the \texttt{ATOMIC} directive to make references to
the storage location of an \texttt{update_variable}, all these references must have the same
\texttt{type} and \texttt{type parameters}.

capture_variable, expression, and \texttt{expression_list} must not access the same storage
location as \texttt{update_variable}.

For atomic capture access, the operation of writing the captured value to the
storage location represented by \texttt{capture_variable} is not atomic.
The function *intrinsic*, the operator *operator*, and the assignment must be the intrinsic function, operator and assignment, and not a redefined intrinsic function, defined operator or defined assignment.

**Examples**

**Example 1:** In this example, multiple threads are updating a counter. *ATOMIC* is used to ensure that no updates are lost.

```fortran
PROGRAM P
  R = 0.0
!$OMP PARALLEL DO SHARED(R)
  DO I = 1, 10
    !$OMP ATOMIC
    R = R + 1.0
  END DO
  PRINT *, R
END PROGRAM P
```

Expected output:

10.0

**Example 2:** In this example, an *ATOMIC* directive is required, because it is uncertain which element of array *Y* is updated in each iteration.

```fortran
PROGRAM P
  INTEGER, DIMENSION(10) :: Y, INDEX
  INTEGER B

  Y = 5
  READ(*,*) INDEX, B
!$OMP PARALLEL DO SHARED(Y)
  DO I = 1, 10
    !$OMP ATOMIC
    Y(INDEX(I)) = MIN(Y(INDEX(I)), B)
  END DO
  PRINT *, Y
END PROGRAM P
```

Input data:

```
10 10 8 8 6 6 4 4 2 2
```

Expected output:

```
5 4 5 4 5 4 5 4 5 4
```

**Example 3:** This example demonstrates the usage of atomic capture.

```fortran
FUNCTION fnc(upper) RESULT(ret)
  INTEGER, INTENT(IN) :: upper
  INTEGER :: ret
  INTEGER, SAVE :: iter = 0

!$OMP ATOMIC CAPTURE
  iter = iter + 1
  ret = iter
!$OMP END ATOMIC

  IF (ret .GT. upper) THEN
    ret = -1
  ENDIF
END FUNCTION fnc
```

**Related reference:**

“CRITICAL / END CRITICAL” on page 117
BARRIER

Purpose

The BARRIER directive enables you to synchronize all threads of a team. When a thread encounters a BARRIER directive, it will not execute beyond the BARRIER until all other threads in the team complete all explicit tasks in the region.

Required option

-qsmp

Syntax

```
$OMP BARRIER
```

Rules

A BARRIER region binds to the closest enclosing PARALLEL region.

A BARRIER region must not be closely nested inside a CRITICAL, MASTER, ORDERED, TASK or work-sharing region.

All threads of the team which are executing the binding parallel region must execute the BARRIER region, and they must not continue execution beyond the BARRIER until they complete execution of all explicit tasks that are bound to this parallel region.

All BARRIER regions and work-sharing region must be encountered in the same order by all threads in the team.

Each BARRIER region must be encountered by all threads in a team or by none at all.

In addition to synchronizing the threads in a team, the BARRIER directive implies the FLUSH directive without the variable_name_list.

Examples

An example of the BARRIER construct binding to the PARALLEL construct. Note: To calculate $C$, we need to ensure that $A$ and $B$ have been completely assigned to, so threads need to wait.

```fortran
SUBROUTINE SUB1
  INTEGER A(1000), B(1000), C(1000)
  !$OMP PARALLEL
  !$OMP DO
    DO I = 1, 1000
      A(I) = SIN(I*2.5)
    END DO
  !$OMP END DO NONWAIT
  !$OMP DO
    DO J = 1, 10000
```

XL Fortran: Optimization and Programming Guide for Little Endian Distributions
\[ B(j) = X + \cos(j*5.5) \]

END DO
!

\$OMP END DO NOWAIT

...
!

\$OMP BARRIER
C = A + B
!

\$OMP END PARALLEL
END

Related reference:
“FLUSH” on page 133
“PARALLEL / END PARALLEL” on page 139

See -qsmp in the Compiler Reference

CRITICAL / END CRITICAL

Purpose

The CRITICAL construct allows you to define independent blocks of code that are to be run by at most one thread at a time. It includes a CRITICAL directive that is followed by a block of code and ends with an END CRITICAL directive.

Required option

-qsmp

Syntax

\[ \text{CRITICAL} \left( \text{-lock_name-} \right) \]

\[ \text{block} \]

\[ \text{END CRITICAL} \left( \text{-lock_name-} \right) \]

lock_name provides a way of distinguishing different CRITICAL constructs of code.

block represents the block of code to be executed by at most one thread at a time.

Rules

The optional lock_name is a name with global scope. You must not use the lock_name to identify any other global entity in the same executable program.

If you specify the lock_name on the CRITICAL directive, you must specify the same lock_name on the corresponding END CRITICAL directive.
If you specify the same lock_name for more than one CRITICAL construct, the compiler will allow only one thread to execute any one of these CRITICAL constructs at any one time. CRITICAL constructs that have different lock_names may be run in parallel.

The same lock protects all CRITICAL constructs that do not have an explicit lock_name. In other words, the compiler will assign the same lock_name, thereby ensuring that only one thread enters any unnamed CRITICAL construct at a time.

The lock_name must not share the same name as any local entity of category 1.

It is illegal to branch into or out of a CRITICAL construct.

The CRITICAL construct may appear anywhere in a program.

Although it is possible to nest a CRITICAL construct within a CRITICAL region, a deadlock situation may result. The -qsmp=rec_locks compiler option can be used to prevent deadlocks. See the XL Fortran Compiler Reference for more information.

The OpenMP API does not allow nested CRITICAL regions to have the same name.

CRITICAL and END CRITICAL directives imply the FLUSH directive without the variable_name_list.

A CYCLE statement must not appear within a CRITICAL construct if it belongs to an outer construct.

An EXIT statement must not appear within a CRITICAL construct if it belongs to that construct or an outer construct.

Examples

Example 1: This example illustrates the use of a CRITICAL construct to update a shared variable inside a parallel region. The CRITICAL construct restricts only one thread to execute the code at a time.

```
EXPR=0
!$OMP PARALLEL DO PRIVATE (I)
DO I = 1, 100
!$OMP CRITICAL
    EXPR = EXPR + A(I) * I
!$OMP END CRITICAL
END DO
```

Example 2: An example specifying a lock_name on the CRITICAL construct.

```
!$OMP PARALLEL DO PRIVATE(T)
DO I = 1, 100
    T = B(I) * B(I-1)
!$OMP CRITICAL (LOCK)
    SUM = SUM + T
!$OMP END CRITICAL (LOCK)
END DO
```

Related reference:

"ATOMIC" on page 111
"FLUSH" on page 133

See Global entity in the Language Reference.
DECLARE TARGET

Purpose

The DECLARE TARGET directive specifies that variables, functions, and subroutines are mapped to a device so that these variables, functions, and subroutines can be accessed or executed on the device.

Required option

-qsm

Syntax

Syntax form 1

DECLARE TARGET (extended-list)

Syntax form 2

DECLARE TARGET clause

where clause is one of the following clauses:

• TO(extended-list)
• LINK(list)

The list is a comma-separated list of one or more list items. A list item is a variable or a common block.

The extended-list is a comma-separated list of one or more extended list items. An extended list item is a list item or a procedure.

If extended-list is present with no clause, the TO clause is implied.

Rules

Declarations for global variables and functions in a DECLARE TARGET directive create device versions of the variables and functions and allocate storage on the device environment. Device variables can be accessed from target regions either directly or through a DECLARE TARGET function.

Variables are mapped for all device executions, or for specific device executions through a LINK clause. The TO clause maps the items when the device is initialized, whereas the LINK clause maps the items when they are first accessed on the device and maps only for the target regions that reference the variable.
If a **DECLARE TARGET** directive does not have any clauses, an implicit extended list to an implicit **TO** clause of one item is formed from the name of the enclosing subroutine subprogram, function subprogram, or interface body to which it applies.

**Restrictions**

- You cannot specify the following items in a **DECLARE TARGET** directive:
  - A variable that is part of a common block, **EQUIVALENCE** statement, or another variable such as an array
  - A function whose name is a generic name, procedure pointer, or entry name
  - A blank common block
- You cannot specify the same item more than once.
- A variable type must be one of the allowed types in the **MAP** clause on target regions. For more information, see the *OpenMP Application Program Interface Language Specification*, which is available at [http://www.openmp.org](http://www.openmp.org)
- A variable that appears in a **DECLARE TARGET** directive must be either of the following variables:
  - A module variable
  - A static variable for which the **SAVE** attribute is implicitly or explicitly specified
- A variable or common block can be specified in a **DECLARE TARGET** directive only in the same scope in which the variable or common block is declared.
- If a common block name appears in a **DECLARE TARGET** directive, the common block name must be declared in a **DECLARE TARGET** directive in every scope where the common block is declared. In addition, the directive must appear after the last **COMMON** statement in the program unit.
- For external type-bound procedures of derived types, the **DECLARE TARGET** directive must appear in the definition and the interface.
- If a procedure is declared using a procedure declaration statement that is not in the type-bound procedure part of a derived-type definition, any **DECLARE TARGET** procedure name must appear in the same specification part.
- A **DECLARE TARGET** directive with clauses, which is **Syntax form 2**, must appear in the specification part of a subroutine subprogram, function subprogram, or module.
- A **DECLARE TARGET** directive without clauses, which is **Syntax form 1**, must appear in the specification part of a subroutine subprogram, function subprogram, or interface body with which the directive is associated.
- If an item has the **BIND** attribute, the corresponding C items must also be specified in a **DECLARE TARGET** directive in the C program.
- Items in the **TO** clause and the **LINK** clause are mutually exclusive.
- The **DECLARE TARGET** and **THREADPRIVATE** directives are mutually exclusive.

**Restriction**

The **ENTRY** statement cannot be used inside the **DECLARE TARGET** directive.

**Example**

The following example shows how to specify variables and functions in a **DECLARE TARGET** directive.
Module m
    TYPE vector
        INTEGER :: x, y
    END TYPE
    TYPE(vector) :: v1 = vector(1, 1)
!$OMP DECLARE TARGET (v1)

Contains
    FUNCTION dot(a, b) RESULT (res)
        TYPE(vector) :: a, b
        INTEGER :: res
    !$OMP DECLARE TARGET
    res = a%x * b%x + a%y * b%y
    END FUNCTION dot
End Module m

Use m
    TYPE(vector) :: v2 = vector(1, 3)
    INTEGER :: result
!$OMP TARGET MAP(FROM: result)
    result = dot(v1, v2)
!$OMP END TARGET
    PRINT *, v1%x, v2%x, v1%y, v2%y, result
END

The module function dot and module variable v1 are declared in the DECLARE TARGET directive. Hence, a device copy of each variable and function is created based on the host version. On entry to the target region, the variable v2 is implicitly mapped to and from the device, while the device copy of the variable v1 is accessed directly. The device version of the function dot is invoked and the result is stored in the mapped variable result.

Related reference:

See -qsmp in the Compiler Reference

DISTRIBUTE / END DISTRIBUTE

Purpose

The DISTRIBUTE directive specifies that the iterations of one or more loops will be executed by the thread teams in the context of their implicit tasks. The iterations are distributed across the master threads of all teams that execute the teams region to which the distribute region binds.

Required options

-qsmp and -qoffload
**Syntax**

where `distribute_clause` is:

```
<table>
<thead>
<tr>
<th>collapse_clause</th>
</tr>
</thead>
<tbody>
<tr>
<td>dist_schedule_clause</td>
</tr>
<tr>
<td>firstprivate_clause</td>
</tr>
<tr>
<td>private_clause</td>
</tr>
<tr>
<td>lastprivate_clause</td>
</tr>
</tbody>
</table>
```

**collapse_clause**

Specifies the number of loops that the `DISTRIBUTE` directive applies to. The syntax is `COLLAPSE(scalar-integer-expression)`. The `scalar-integer-expression` must evaluate to a constant positive integer value. If no `COLLAPSE` is specified, the `DISTRIBUTE` directive applies only to the immediately following loop.

**dist_schedule_clause**

Specifies the way that groups of `chunk_size` iterations are assigned. The syntax is `DIST_SCHEDULE(STATIC[,chunk_size])`.

- If `DIST_SCHEDULE` is specified:
  - If `chunk_size` is specified, groups of `chunk_size` iterations are assigned in a round-robin fashion to each participating team.
  - If no `chunk_size` is specified, the iteration space is divided into approximately equal-sized chunks, and each chunk is assigned to each team. At most one chunk is assigned to each team.
- If `DIST_SCHEDULE` is not specified, iterations are distributed as if `DIST_SCHEDULE(STATIC)` is specified.

**firstprivate_clause**

Similar to `private_clause`, except that the private copy is initialized with the value of the original variable. The syntax is `FIRSTPRIVATE(list)`.

**lastprivate_clause**

Similar to `private_clause`. In addition, the value of each new list item from the sequentially last iteration of the distribute loop is assigned back to the original list item. The syntax is `LASTPRIVATE(list)`.

**private_clause**

 Declares one or more list items to be private to the team in the enclosing team region. For every list item, a local copy is created for each team. All
references to the original list item in the teams region are replaced with references to the private copy. A copy is created per team; hence, the copy is shared among the threads in the team. The syntax is \texttt{PRIVATE(list)}.

**Rules**

Use the \texttt{DISTRIBUTE} directive only on loops that are strictly nested within a teams region. There is no implicit barrier at the end of a \texttt{DISTRIBUTE} directive.

**Example**

```fortran
PROGRAM main
INTEGER, PARAMETER :: n = 8
INTEGER :: a(n)

!$OMP TARGET MAP(TO:n) MAP(TOFROM:a)
!$OMP TEAMS NUM_TEAMS(2) THREAD_LIMIT(n/2)
!$OMP DISTRIBUTED
DO i=1,n,1
   a(i) = omp_get_team_num()
END DO
!$OMP END DISTRIBUTED
!$OMP END TEAMS
!$OMP END TARGET
END PROGRAM main
```

This target region contains a teams region that consists of two teams. The iterations of the closely nested distribute loop are assigned to these two teams, with the master thread of either team executing \(N/2\) iterations.

**Related reference:**

- "\texttt{TEAMS / END TEAMS}“ on page 180
- See \texttt{-qsmp} in the Compiler Reference
- See \texttt{-qoffload} in the Compiler Reference

**DISTRIBUTE PARALLEL DO / END DISTRIBUTE PARALLEL DO**

**Purpose**

The \texttt{DISTRIBUTE PARALLEL DO} directive executes a loop using multiple teams where each team typically consists of several threads. The loop iterations are distributed across the teams in chunks in round robin fashion.

The \texttt{DISTRIBUTE PARALLEL DO} construct is a composite construct.

**Required option**

- \texttt{-qsmp} and \texttt{-qoffload}
Syntax

where clause can be any of the clauses that are accepted by the `DISTRIBUTE` or `PARALLEL DO` directive except the LINEAR and ORDERED clauses. The specified clause has identical meanings and restrictions applied as used in the `DISTRIBUTE` or `PARALLEL DO` directive.

Rules

If any specified clause except the COLLAPSE clause is applicable to both the `DISTRIBUTE` and `PARALLEL DO` directives, it is applied twice; the COLLAPSE clause is applied only once.

The iterations of the loops that are associated with the `DISTRIBUTE PARALLEL DO` directive are distributed across the teams that bind to the loop construct. Each team is assigned a chunk of the loop iterations. The size of the chunks is determined according to the clauses that apply to the `DISTRIBUTE` directive. Each chunk forms a parallel loop, and the parallel loop is distributed across the threads that participate in the team region according to the clauses that apply to the `PARALLEL DO` directive.

Examples

```fortran
INTEGER, PARAMETER :: N = 8
INTEGER :: a(N), b(N), c(N)
INTEGER :: k = 4, nteams = 16
INTEGER :: block_threads = 2
DO i = 1, N, 1
  a(i) = 0
  b(i) = i
  c(i) = 3*i
END DO
!$OMP TARGET MAP(TOFROM: a) MAP( TO: b, c)
!$OMP TEAMS NUM_TEAMS(nteams)
!$OMP DISTRIBUTE PARALLEL DO DIST_SCHEDULE(STATIC, block_threads)
DO i = 1, N, 1
  a(i) = b(i) + k*c(i)
END DO
!$OMP END TEAMS
!$OMP END TARGET
```

In the beginning, the arrays a, b, and c and the scalar variables k, nteams, and block_threads are declared and initialized in the host environment.
Then, a target region is declared, and the arrays a, b, and c are explicitly mapped into the device environment. At the start of the target region, storage for a, b, and c is allocated on the device. The device copy of each array is then initialized with the content of the corresponding array on the host. The scalar variables k, nteams, and block_threads are implicitly mapped by the compiler as FIRSTPRIVATE because they are not explicitly mapped and the DEFAULTMAP(TOFROM:SCALAR) clause is not present.

The target region is executed by the nteams teams of threads.

The loop iterations are first distributed across the teams in chunks of size equal to the value of the block_threads variable. Each chunk of iterations is further distributed across the threads in each team.

At the end of the target region, the copy of array a on the device is copied back into the host environment.

Related reference:

- See -qsmp in the Compiler Reference
- See -qoffload in the Compiler Reference

DISTRIBUTE PARALLEL DO SIMD / END DISTRIBUTE PARALLEL DO SIMD

Purpose

The DISTRIBUTE PARALLEL DO SIMD directive distributes loop iterations to each master thread, further redistributes those iterations among the threads of each team, and then applies SIMD vectorization to each iteration.

The DISTRIBUTE PARALLEL DO SIMD construct is a composite construct.

Required option

-qsmp and -qoffload

Syntax

```
DISTRIBUTE PARALLEL DO SIMD / END DISTRIBUTE PARALLEL DO SIMD

do_loops

where clause can be any of the clauses that are accepted by the DISTRIBUTE or PARALLEL DO SIMD directive with identical meanings and restrictions.
```
Rules

If any specified clause except the COLLAPSE clause is applicable to both the DISTRIBUTED and PARALLEL DO SIMD directives, it is applied twice; the COLLAPSE clause is applied only once.

You can specify only loop iteration variables on the LINEAR clause.

Examples

```fortran
INTEGER, PARAMETER:: N = 8
INTEGER :: a(N)
!$OMP TARGET MAP(TO:N) MAP(TOFROM:a)
!$OMP TEAMS NUM_TEAMS(2) THREAD_LIMIT(N/2)
!$OMP DISTRIBUTED PARALLEL DO SIMD
   DO i = 1, N, 1
       a(i) = N
   END DO
!$OMP END DISTRIBUTED PARALLEL DO SIMD
!$OMP END TEAMS
!$OMP END TARGET
```

In this example, the target region contains a teams region that consists of two teams. With the DISTRIBUTED PARALLEL DO SIMD directive, the iterations of the closely nested distribute loop are assigned to the teams that are actually created, and the master thread of each team executes the distributed iterations. Each parallel-do chunk is further redistributed among threads of each team, and SIMD vectorization is applied to each iteration of the SIMD chunks.

Related reference:

- See `-qsmp` in the Compiler Reference
- See `-qoffload` in the Compiler Reference

DISTRIBUTED SIMD / END DISTRIBUTED SIMD

Purpose

The DISTRIBUTED SIMD directive distributes loop iterations to each master thread and then executes each set of distributed iterations concurrently by using SIMD instructions.

The DISTRIBUTED SIMD construct is a composite construct.

Required option

- `-qsmp` and `-qoffload`
where \textit{clause} can be any of the clauses that are accepted by the \texttt{DISTRIBUTE} or \texttt{SIMD} directive with identical meanings and restrictions.

**Rules**

If any specified clause except the \texttt{COLLAPSE} clause is applicable to both the \texttt{DISTRIBUTE} and \texttt{SIMD} directives, it is applied twice; the \texttt{COLLAPSE} clause is applied only once.

You can specify only loop iteration variables on the \texttt{LINEAR} clause.

**Examples**

```fortran
INTEGER, PARAMETER :: n = 8
INTEGER :: a(n)
!$OMP TARGET MAP(TO:n) MAP( TOFROM:a)  
!$OMP TEAMS NUM_TEAMS(2) THREAD_LIMIT(n/2) 
!$OMP DISTRIBUTE SIMD  
  DO i = 1, n, 1  
    a(i) = n  
  END DO  
!$OMP END DISTRIBUTE SIMD  
!$OMP END TEAMS  
!$OMP END TARGET
```

In this example, the target region contains a teams region that consists of two teams. The iterations of the closely nested distribute loop are assigned to the teams that are actually created. With the \texttt{DISTRIBUTE SIMD} directive, the master thread of each team executes each set of distributed iterations concurrently by using SIMD instructions.

**Related reference:**

- See -qsmp in the Compiler Reference
- See -qoffload in the Compiler Reference

**DO / END DO**

**Purpose**

The \texttt{DO} (work-sharing) construct enables you to divide the execution of the loop among the members of the team that encounter it. The \texttt{END DO} directive enables
you to indicate the end of a DO loop that is specified by the DO (work-sharing) directive.

**Required option**

-qsmp

**Syntax**

where `do_clause` is:

```
collapse_clause
  | firstprivate_clause
  | lastprivate_clause
  | ordered_clause
  | private_clause
  | reduction_clause
  | schedule_clause
```

- `collapse_clause`
  See — "COLLAPSE" on page 209.

- `firstprivate_clause`
  See — "FIRSTPRIVATE" on page 202.

- `lastprivate_clause`
  See — "LASTPRIVATE" on page 204.

- `ordered_clause`
  See — "ORDERED" on page 216

- `private_clause`
  See — "PRIVATE" on page 200.

- `reduction_clause`
  See — "REDUCTION" on page 206.

- `schedule_clause`
  See — "SCHEDULE" on page 217.
Rules

The first noncomment line (not including other directives) that follows the DO (work-sharing) directive must be a DO loop. This line cannot be an infinite DO or DO WHILE loop. The DO (work-sharing) directive applies only to the DO loop that is immediately following the directive, and not to any nested DO loops, unless the COLLAPSE clause is specified.

The END DO directive is optional. If you use the END DO directive, it must immediately follow the end of the DO loop.

You may have a DO construct that contains several DO statements. If the DO statements share the same DO termination statement, and an END DO directive follows the construct, you can only specify a work-sharing DO directive for the outermost DO statement of the construct.

If you specify NOWAIT on the END DO directive, a thread that completes its iterations of the loop early will proceed to the instructions following the loop. The thread will not wait for the other threads of the team to complete the DO loop. If you do not specify NOWAIT on the END DO directive, each thread will wait for all other threads within the same team at the end of the DO loop.

If you do not specify the NOWAIT clause, the END DO directive implies the FLUSH directive without the variable_name_list.

All threads in the team must encounter the DO (work-sharing) directive if any thread encounters it. A DO loop must have the same loop boundary and step value for each thread in the team. All work-sharing constructs and BARRIER directives that are encountered must be encountered in the same order by all threads in the team.

A DO (work-sharing) directive must not appear within a CRITICAL, MASTER, or ORDERED region. In addition, it must not appear within a work-sharing region or a TASK region unless it is bound to another parallel region.

You cannot follow a DO (work-sharing) directive by another DO (work-sharing) directive. You can only specify one DO (work-sharing) directive for a given DO loop.

The DO (work-sharing) directive cannot appear with either an INDEPENDENT or DO SERIAL directive for a given DO loop.

To ensure that the same assignment of logical iteration numbers to threads is used in two work-sharing loop regions, you can use the STATIC schedule of the SCHEDULE clause. For details, see “SCHEDULE” on page 217.

Examples

Example 1: An example of several independent DO loops within a PARALLEL construct. No synchronization is performed after the first work-sharing DO loop, because NOWAIT is specified on the END DO directive.

```fortran
!$OMP PARALLEL
!$OMP DO
   DO I = 2, N
      B(I) = (A(I) + A(I-1)) / 2.0
   END DO
!$OMP END DO NOWAIT
```

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Example 2: An example of \texttt{SHARED}, and \texttt{SCHEDULE} clauses.

\begin{verbatim}
!$OMP PARALLEL
!$OMP SHARED(A)
!$OMP DO SCHEDULE(STATIC,10)
    DO I = 1, 1000
        A(I) = I * 4
    END DO
!$OMP END DO
!$OMP END PARALLEL
\end{verbatim}

Example 3: An example of both a \texttt{MASTER} and a \texttt{DO} (work-sharing) directive that bind to the closest enclosing \texttt{PARALLEL} directive.

\begin{verbatim}
!$OMP PARALLEL DEFAULT(PRIVATE), SHARED(X)
    Y = 100
!$OMP MASTER
    PRINT *, Y
!$OMP END MASTER
!$OMP DO
    DO I = 1, 10
        X(I) = I
        X(I) = X(I) + Y
    END DO
!$OMP END PARALLEL
\end{verbatim}

Example 4: An example of both the \texttt{FIRSTPRIVATE} and the \texttt{LASTPRIVATE} clauses on \texttt{DO} (work-sharing) directives.

\begin{verbatim}
X = 100
!$OMP PARALLEL PRIVATE(I), SHARED(X,Y)
!$OMP DO FIRSTPRIVATE(X), LASTPRIVATE(X)
    DO I = 1, 80
        Y(I) = X + I
        X = I
    END DO
!$OMP END PARALLEL
\end{verbatim}

Related reference:

- "COLLAPSE" on page 209
- See \texttt{DO} in the Language Reference
- "DO SERIAL" on page 131
- "FLUSH" on page 133
- See \texttt{INDEPENDENT} in the Language Reference
- "ORDERED / END ORDERED" on page 137
- "PARALLEL / END PARALLEL" on page 139
- "PARALLEL DO / END PARALLEL DO" on page 142
DO SERIAL

Purpose

The DO SERIAL directive indicates to the compiler that the DO loop that is immediately following the directive must not be parallelized. This directive is useful in blocking automatic parallelization for a particular DO loop.

Required option

-qsmp

Syntax

```
DO SERIAL
```

Rules

The first noncomment line (not including other directives) that is following the DO SERIAL directive must be a DO loop. The DO SERIAL directive applies only to the DO loop that immediately follows the directive and not to any loops that are nested within that loop.

You can only specify one DO SERIAL directive for a given DO loop. The DO SERIAL directive must not appear with the DO (work-sharing), or PARALLEL DO directive on the same DO loop.

White space is optional between DO and SERIAL.

You should not use the OpenMP trigger constant with this directive.

Examples

Example 1: An example with nested DO loops where the inner loop (the J loop) is not parallelized.

```
!$OMP PARALLEL DO PRIVATE(S,I), SHARED(A)
   DO I=1, 500
      S=0
      !$OMP DO SERIAL
      DO J=1, 500
         S=S+1
      ENDDO
      A(I)=S+I
   ENDDO
```

Example 2: An example with the DOSERIAL directive applied in nested loops. In this case, if automatic parallelization is enabled the I or K loop may be parallelized.

```
DO I=1, 100
   !$OMP DO SERIAL
   DO J=1, 100
      DO K=1, 100
         ARR(I,J,K)=I+J+K
      ENDDO
   ENDDO
ENDDO
```
DO SIMD / END DO SIMD

Purpose

The **DO SIMD** directive distributes the iterations of one or more associated loops across the threads that already exist in the team and indicates that the iterations executed by each thread can be executed concurrently using SIMD instructions.

The **DO SIMD** construct is a composite construct.

Syntax

```
   DO SIMD
       clause
       do_loops
   END DO SIMD
   NOWAIT
```

where **clause** can be any of the clauses that are accepted by the **DO** or **SIMD** directive. The specified **clause** has identical meanings and restrictions applied as used in the **DO** or **SIMD** directive.

Rules

If any specified clause except the **COLLAPSE** clause is applicable to both the **DO** and **SIMD** directives, it is applied twice; the **COLLAPSE** clause is applied only once.

A list item can only appear in a **LINEAR** or **FIRSTPRIVATE** clause, but not both.

The iterations of the loops that are associated with the **DO SIMD** directive are distributed across the teams that bind to the loop construct, with any clauses that apply to the **DO** directive in effect. The resulting chunks of iterations then are converted to a SIMD loop, with any clauses that apply to the **SIMD** directive in effect.
Usage

You can take advantage of the DO SIMD directive by nesting it inside the PARALLEL construct or using the combined construct PARALLEL DO SIMD.

Examples

```
INTEGER, PARAMETER :: N = 8
INTEGER :: a(N)
!$OMP TARGET MAP(TO:N) MAP(TOFROM:a)
!$OMP PARALLEL DO SIMD
  DO i = 1, N, 1
    a(i) = N
  END DO
!$OMP END PARALLEL DO SIMD
!$OMP END TARGET
```

In this example, the PARALLEL DO SIMD directive distributes the iterations of the loop across the threads and executes the iterations in parallel. Then, the iterations are allowed to be executed by each thread concurrently by using SIMD instructions.

**FLUSH**

**Purpose**

The FLUSH directive ensures that each thread has access to data generated by other threads. This directive is required because the compiler may keep values in processor registers if a program is optimized. The FLUSH directive ensures that the memory images that each thread views are consistent.

You might be able to improve the performance of your program by using the FLUSH directive instead of the VOLATILE attribute. The VOLATILE attribute causes variables to be flushed after every update and before every use, while FLUSH causes variables to be written to or read from memory only when specified.

**Required option**

-qsmp

**Syntax**

```
$ FLUSH (variable_name_list)
```

**Rules**

You can specify this directive anywhere in your code; however, if you specify it outside a parallel region, it is ignored.

If you specify a variable_name_list, only the variables in that list are written to or read from memory (assuming that they have not been written or read already). All variables in the variable_name_list must be at the current scope and must be thread visible. Thread visible variables can be any of the following:
- Globally visible variables (common blocks and module data)
- Local and host-associated variables with the SAVE attribute
- Local variables without the SAVE attribute that are specified in a SHARED clause in a parallel region within the subprogram
- Local variables without the SAVE attribute that have had their addresses taken
- All pointer dereferences
- Dummy arguments

If an item or a subobject of an item in the variable_name_list has the POINTER attribute, the allocation and association status of the POINTER item is flushed, but the pointer target is not.

If an item in the variable_name_list is an integer pointer, the pointer is flushed, but the object to which it points is not.

If an item in the variable_name_list has the ALLOCATABLE attribute and the item is allocated, the allocated object is flushed; otherwise, the allocation status is flushed.

If an item in the variable_name_list is of type C_PTR, the variable is flushed, but the storage that corresponds to that address is not flushed.

If you do not specify a variable_name_list, all thread visible variables are written to or read from memory.

When a thread encounters the FLUSH directive, it writes into memory the modifications to the affected variables. The thread also reads the latest copies of the variables from memory if it has local copies of those variables: for example, if it has copies of the variables in registers.

It is not mandatory for all threads in a team to use the FLUSH directive. However, to guarantee that all thread visible variables are current, any thread that modifies a thread visible variable should use the FLUSH directive to update the value of that variable in memory. If you do not use FLUSH or one of the directives that implies FLUSH (see below), the value of the variable might not be the most recent one.

The FLUSH directive does not imply any ordering between the directive and operations on variables not in the variable_name_list. The FLUSH directive does not imply any ordering between two or more FLUSH constructs if the constructs do not have any variables in common in the variable_name_list.

Note that FLUSH is not atomic. You must FLUSH shared variables that are controlled by a shared lock variable with one directive and then FLUSH the lock variable with another. This guarantees that the shared variables are written before the lock variable.

The following directives imply a FLUSH directive without the variable_name_list unless you specify a NOWAIT clause for those directives to which it applies:

- BARRIER
- CRITICAL/END CRITICAL
- END DO
- END SECTIONS
- END SINGLE
The ATOMIC directive implies a FLUSH directive with the variable_name_list. The variable_name_list contains only the object updated in the ATOMIC construct.

The following routines imply a FLUSH directive without the variable_name_list:
- During `OMP_SET_LOCK` and `OMP_UNSET_LOCK` regions.
- During `OMP_TEST_LOCK`, `OMP_SET_NEST_LOCK`, `OMP_UNSET_NEST_LOCK` and `OMP_TEST_NEST_LOCK` regions, if the region causes the lock to be set or unset.

Examples

In the following example, two threads perform calculations in parallel and are synchronized when the calculations are complete:

```fortran
PROGRAM P
USE OMP_LIB
INTEGER INSYNC(0:1), IAM

!$OMP PARALLEL DEFAULT(PRIVATE) SHARED(INSYNC) NUM_THREADS(2)
IAM = OMP_GET_THREAD_NUM()
INSYNC(IAM) = 0
!$OMP BARRIER
CALL WORK  
!$OMP FLUSH(INSYNC)
  INSYNC(IAM) = 1  ! Each thread sets a flag
  ! once it has
!$OMP FLUSH(INSYNC)
  ! completed its work.
DO WHILE (INSYNC(1-IAM) .eq. 0)  ! One thread waits for
  ! another to complete
!$OMP FLUSH(INSYNC)
  ! its work.
END DO
!$OMP END PARALLEL
END PROGRAM P

SUBROUTINE WORK  ! Each thread does indep-
  ! endent calculations.
  !...
  !$OMP FLUSH  ! flush work variables
  ! before INSYNC
  ! is flushed.
END SUBROUTINE WORK

MASTER / END MASTER

Purpose

The MASTER construct enables you to define a block of code that will be run by only the master thread of the team. It includes a MASTER directive that precedes a block of code and ends with an END MASTER directive.
Required option

-qsmp

Syntax

```
MASTER

block

END MASTER
```

*block* represents the block of code that will be run by the master thread of the team.

**Rules**

It is illegal to branch into or out of a **MASTER** construct.

A **MASTER** directive binds to the closest enclosing **PARALLEL** region, if one exists.

A **MASTER** directive cannot appear within a work-sharing region or a **TASK** region.

No implied barrier exists on entry to, or exit from, the **MASTER** construct.

**Examples**

**Example 1:** An example of the **MASTER** directive binding to the **PARALLEL** directive.

```
!$OMP PARALLEL DEFAULT(SHARED)
!$OMP MASTER
    Y = 10.0
    X = 0.0
    DO I = 1, 4
        X = X + COS(Y) + I
    END DO
!$OMP END MASTER
!$OMP BARRIER
!$OMP DO PRIVATE(J)
    DO J = 1, 10000
        A(J) = X + SIN(J*2.5)
    END DO
!$OMP END DO
!$OMP END PARALLEL
END
```

**Related reference:**

- See -qsmp in the Compiler Reference
- "PARALLEL / END PARALLEL" on page 139
- "DO / END DO" on page 127
**ORDERED / END ORDERED**

**Purpose**

The ORDERED / END ORDERED directives cause the iterations of a block of code within a parallel loop to be executed in the order that the loop would execute in if it was run sequentially. You can force the code inside the ORDERED construct to run in a predictable order while code outside of the construct runs in parallel.

**Required option**

-qsm

**Syntax**

**Syntax form 1**

```
ORDERED
  block
END ORDERED
```

*block* represents the block of code that will be executed in sequence.

**Syntax form 2**

```
ORDERED clause
```

where *clause* is DEPEND. DEPEND clauses specify the order in which threads in a team execute ORDERED regions. The DEPEND clause takes one of the following forms:

**DEPEND(SOURCE)**

SOURCE specifies the satisfaction of cross-iteration dependences that arise from the current iteration.

**DEPEND(SINK : vec)**

SINK specifies a cross-iteration dependence, where the iteration vector *vec* indicates the iteration that satisfies the dependence. *vec* has the following form:

\[ x_1 [\pm d_1], x_2 [\pm d_2], \ldots, x_n [\pm d_n] \]
where \( n \) is the value specified by the **ORDERED** clause in the loop directive, \( x_i \) denotes the loop iteration variable of the \( i \)-th nested loop associated with the loop directive, and \( d_i \) is a constant non-negative integer.

**Rules**

The **ORDERED** directive can only appear in the dynamic extent of a **DO** or **PARALLEL DO** directive. It is illegal to branch into or out of an **ORDERED** construct.

The **ORDERED** directive binds to the nearest dynamically enclosing **DO** or **PARALLEL DO** directive. You must specify the **ORDERED** clause on the **DO** or **PARALLEL DO** directive to which the **ORDERED** construct binds.

**ORDERED** constructs that bind to different **DO** directives are independent of each other.

Only one thread can execute an **ORDERED** construct at a time. Threads enter the **ORDERED** construct in the order of the loop iterations. A thread will enter the **ORDERED** construct if all of the previous iterations have either executed the construct or will never execute the construct.

Each iteration of a parallel loop with an **ORDERED** construct can only execute that **ORDERED** construct once. Each iteration of a parallel loop can execute at most one **ORDERED** directive. An **ORDERED** construct cannot appear within the dynamic extent of a **CRITICAL** construct.

The **END ORDERED** directive implies the **FLUSH** directive without the **variable_name_list**

**Examples**

**Example 1:** In this example, an **ORDERED** parallel loop counts down.

```
PROGRAM P
!$OMP PARALLEL DO ORDERED
  DO I = 3, 1, -1
!$OMP ORDERED
    CALL C_PRINT(I) ! print I using routine written in C
!$OMP END ORDERED
END DO
END PROGRAM P
```

The expected output of this program is:

3
2
1

**Example 2:** This example shows a program with two **ORDERED** constructs in a parallel loop. Each iteration can only execute a single section.

```
PROGRAM P
!$OMP PARALLEL DO ORDERED
  DO I = 1, 3
    IF (MOD(I,2) == 0) THEN
!$OMP ORDERED
      CALL C_PRINT(I*10) ! print I*10 using routine written in C
!$OMP END ORDERED
    END ORDERED
  ELSE
    !$OMP END ORDERED
  END DO
END PROGRAM P
```
The expected output of this program is:
1
20
3

Example 3: In this example, the program computes the sum of all elements of an array that are greater than a threshold. ORDERED is used to ensure that the results are always reproducible: roundoff will take place in the same order every time the program is executed, so the program will always produce the same results.

PROGRAM P
    REAL :: A(1000)
    REAL :: THRESHOLD = 999.9
    REAL :: SUM = 0.0
!
!$OMP PARALLEL DO ORDERED
    !$OMP ORDERED
    SUM = SUM + A(I)
!$OMP END ORDERED
    END IF
END DO
END PROGRAM P

Note: To avoid bottleneck situations when using the ORDERED clause, you can try using DYNAMIC scheduling or STATIC scheduling with a small chunk size. For more information on scheduling parameters, see the “SCHEDULE” on page 217 clause.

Related reference:
See -qsmp in the Compiler Reference

“PARALLEL DO / END PARALLEL DO” on page 142
“DO / END DO” on page 127
“CRITICAL / END CRITICAL” on page 117

PARALLEL / END PARALLEL

Purpose

The PARALLEL construct enables you to define a block of code that can be executed by a team of threads concurrently. The PARALLEL construct includes a PARALLEL directive that is followed by one or more blocks of code, and ends with an END PARALLEL directive.

Required option

-qsm
where `parallel_clause` is:

- `copyin clause`
  See — “COPYIN” on page 211
- `default clause`
  See — “DEFAULT” on page 196
- `if clause`
  See — “IF” on page 214
- `firstprivate clause`
  See — “FIRSTPRIVATE” on page 202
- `num_threads clause`
  See — “NUM_THREADS” on page 215
- `private clause`
  See — “PRIVATE” on page 200
- `proc_bind clause`
  See — “PROC_BIND” on page 216
- `reduction clause`
  See — “REDUCTION” on page 206
- `shared clause`
  See — “SHARED” on page 198
Rules

It is illegal to branch into or out of a PARALLEL construct.

The IF and DEFAULT clauses can appear at most once in a PARALLEL directive.

You should be careful when you perform input/output operations in a parallel region. If multiple threads execute a Fortran I/O statement on the same unit, you should make sure that the threads are synchronized. If you do not, the behavior is undefined. See “Parallel I/O issues” on page 341 for more information. Also note that although in the XL Fortran implementation each thread has exclusive access to the I/O unit, the OpenMP specification does not require exclusive access.

Directives that bind to a parallel region will bind to that parallel region even if it is serialized.

The END PARALLEL directive implies the FLUSH directive without the variable_name_list and a BARRIER directive.

Examples

Example 1: An example of an outer PARALLEL directive with the PRIVATE clause enclosing the PARALLEL construct. Note: The SHARED clause is present on the inner PARALLEL construct.

```fortran
!$OMP PARALLEL PRIVATE(X)
!$OMP DO
  DO I = 1, 10
    X(I) = I
  END DO
!$OMP PARALLEL SHARED (X,Y)
!$OMP DO
  DO K = 1, 10
    Y(K,I) = K * X(I)
  END DO
END DO
!$OMP END PARALLEL
!$OMP END DO
!$OMP END PARALLEL
```

Example 2: This example demonstrates the use of the COPYIN clause. Each thread created by the PARALLEL directive has its own copy of the common block BLOCK. The COPYIN clause causes the initial value of FCTR to be copied into the threads that execute iterations of the DO loop.

```fortran
PROGRAM TT
COMMON /BLOCK/ FCTR
INTEGER :: I, FCTR
!$OMP THREADPRIVATE(/BLOCK/)
  INTEGER :: A(100)
  FCTR = -1
  A = 0
!$OMP PARALLEL COPYIN(FCTR)
!$OMP DO
  DO I = 1, 100
    FCTR = FCTR + I
    CALL SUB(A(I), I)
  ENDDO
!$OMP END PARALLEL
PRINT *, A
```
SUBROUTINE SUB(AA, J)
  INTEGER :: FCTR, AA, J
  COMMON /BLOCK/ FCTR
  !$OMP THREADPRIVATE(/BLOCK/) ! EACH THREAD GETS ITS OWN COPY
  ! OF BLOCK.
  AA = FCTR
  FCTR = FCTR - J
END SUBROUTINE SUB

The expected output is:
0 1 2 3 ... 96 97 98 99

Related reference:
"FLUSH" on page 133
"PARALLEL DO / END PARALLEL DO"

See INDEPENDENT in the Language Reference
"THREADPRIVATE" on page 185
"DO / END DO" on page 127

See -directive in the Compiler Reference
See -qsmp in the Compiler Reference

PARALLEL DO / END PARALLEL DO

Purpose

The PARALLEL DO directive enables you to specify which loops the compiler should parallelize. This is semantically equivalent to:

$OMP PARALLEL
$OMP DO
...
$OMP END DO
$OMP END PARALLEL

and is a convenient way of parallelizing loops. The END PARALLEL DO directive allows you to indicate the end of a DO loop that is specified by the PARALLEL DO directive.

Required option

-qsmp
Syntax

where parallel_do_clause is:

```
collapse_clause
copyin_clause
default_clause
firstprivate_clause
if_clause
lastprivate_clause
num_threads_clause
ordered_clause
private_clause
reduction_clause
schedule_clause
shared_clause
```

collapse_clause
See — “COLLAPSE” on page 209

copyin_clause
See — “COPYIN” on page 211

default_clause
See — “DEFAULT” on page 196

if_clause
See — “IF” on page 214

firstprivate_clause
See — “FIRSTPRIVATE” on page 202

lastprivate_clause
See — “LASTPRIVATE” on page 204

num_threads_clause
See — “NUM_THREADS” on page 215

ordered_clause
See — “ORDERED” on page 216

private_clause
See — “PRIVATE” on page 200
**Rules**

The first noncomment line (not including other directives) that is following the PARALLEL DO directive must be a DO loop. This line cannot be an infinite DO or DO WHILE loop. The PARALLEL DO directive applies only to the DO loop that is immediately following the directive, and not to any nested DO loops, unless the COLLAPSE clause is specified.

If you specify a DO loop by a PARALLEL DO directive, the END PARALLEL DO directive is optional. If you use the END PARALLEL DO directive, it must immediately follow the end of the DO loop.

You may have a DO construct that contains several DO statements. If the DO statements share the same DO termination statement, and an END PARALLEL DO directive follows the construct, you can only specify a PARALLEL DO directive for the outermost DO statement of the construct.

You must not follow the PARALLEL DO directive by a DO (work-sharing) or DO SERIAL directive. You can specify only one PARALLEL DO directive for a given DO loop.

All work-sharing constructs and BARRIER directives that are encountered must be encountered in the same order by all threads in the team.

The PARALLEL DO directive must not appear with the INDEPENDENT directive for a given DO loop.

**Note:** You should use the PARALLEL DO directive for maximum portability across multiple vendors. The PARALLEL DO directive is a prescriptive directive, while the INDEPENDENT directive is an assertion about the characteristics of the loop. (See the INDEPENDENT directive in the XL Fortran Language Reference for more information.)

The IF clause may appear at most once in a PARALLEL DO directive.

An IF expression is evaluated outside of the context of the parallel construct. Any function reference in the IF expression must not have side effects.

By default, a nested parallel loop is serialized, regardless of the setting of the IF clause. You can change this default by using the -qsmp=nestoPar compiler option.

If the REDUCTION variable of an inner DO loop appears in the PRIVATE or LASTPRIVATE clause of an enclosing DO loop or PARALLEL SECTIONS construct, the variable must be initialized before the inner DO loop.
A variable that appears in the REDUCTION clause of an INDEPENDENT directive of an enclosing DO loop must not also appear in the data_scope_entity_list of the PRIVATE or LASTPRIVATE clause.

Within a PARALLEL DO construct, variables that do not appear in the PRIVATE clause are assumed to be shared by default.

You should be careful when you perform input/output operations in a parallel region. If multiple threads execute a Fortran I/O statement on the same unit, you should make sure that the threads are synchronized. If you do not, the behavior is undefined. Also note that although in the XL Fortran implementation each thread has exclusive access to the I/O unit, the OpenMP specification does not require exclusive access.

Directives that bind to a parallel region will bind to that parallel region even if it is serialized.

The END PARALLEL DO directive implies the FLUSH directive without the variable_name_list and a BARRIER directive.

Examples

Example 1: A valid example with the LASTPRIVATE clause.

```fortran
!$OMP PARALLEL DO PRIVATE(I), LASTPRIVATE (X)
  DO I = 1,10
    X = I * I
    A(I) = X * B(I)
  END DO
  PRINT *, X ! X has the value 100

Example 2: A valid example with the REDUCTION clause.

```fortran
!$OMP PARALLEL DO PRIVATE(I), REDUCTION(:MYSUM)
  DO I = 1, 10
    MYSUM = MYSUM + IARR(I)
  END DO
```fortran

Example 3: A valid example where more than one thread accesses a variable that is marked as SHARED, but the variable is used only in a CRITICAL construct.

```fortran
!$OMP PARALLEL DO SHARED (X)
  DO I = 1, 10
    A(I) = A(I) * I
  END DO
  !$OMP CRITICAL
    X = X + A(I)
  !$OMP END CRITICAL
  END DO
```fortran

Example 4: A valid example of the END PARALLEL DO directive.

```fortran
REAL A(100), B(2:100), C(100)
!$OMP PARALLEL DO
  DO I = 2, 100
    B(I) = (A(I) + A(I-1))/2.0
  END DO
!$OMP END PARALLEL DO
!$OMP PARALLEL DO
  DO J = 1, 100
    C(J) = X + COS(J*5.5)
  END DO
!$OMP END PARALLEL DO
END
```
PARALLEL SECTIONS / END PARALLEL SECTIONS

Purpose

The PARALLEL SECTIONS construct provides a short form method for including SECTIONS directive inside a PARALLEL construct.

Required option

-qsm

Syntax

where parallel_sections_clause is:
copyin clause
See — “COPYIN” on page 21

default clause
See — “DEFAULT” on page 19

firstprivate clause
See — “FIRSTPRIVATE” on page 20

if clause
See — “IF” on page 21

lastprivate clause
See — “LASTPRIVATE” on page 20

num_threads clause
See — “NUM_THREADS” on page 21

private clause
See — “PRIVATE” on page 20

proc_bind clause
See — “PROC_BIND” on page 21

reduction clause
See — “REDUCTION” on page 20

shared clause
See — “SHARED” on page 19

Rules
See the Rules section in “SECTIONS / END SECTIONS” on page 15

In a PARALLEL SECTIONS construct, a variable that appears in the
REDUCTION clause of an INDEPENDENT directive or the PARALLEL DO
directive of an enclosing DO loop must not also appear in the data_scope_entity_list
of the PRIVATE clause.

If the REDUCTION variable of the inner PARALLEL SECTIONS construct
appears in the PRIVATE clause of an enclosing DO loop or PARALLEL
SECTIONS construct, the variable must be initialized before the inner PARALLEL
SECTIONS construct.

Examples

Example 1:
Example 2: In this example, the index variable I is declared as PRIVATE. Note also that the first optional SECTION directive has been omitted.

```fortran
!$OMP PARALLEL SECTIONS PRIVATE(I)
  DO I = 1, 100
    A(I) = A(I) * I
  END DO
!$OMP SECTION
  CALL NORMALIZE (B)
  DO I = 1, 100
    B(I) = B(I) + 1.0
  END DO
!$OMP SECTION
  DO I = 1, 100
    C(I) = C(I) * C(I)
  END DO
!$OMP END PARALLEL SECTIONS
```

Related reference:
- "PARALLEL / END PARALLEL" on page 139
- "SECTIONS / END SECTIONS" on page 152
- See INDEPENDENT in the Language Reference
- See -qdirective in the Compiler Reference
- See -qsmp in the Compiler Reference

**PARALLEL WORKSHARE / END PARALLEL WORKSHARE**

**Purpose**

The PARALLEL WORKSHARE construct provides a short form method for including a WORKSHARE directive inside a PARALLEL construct.

**Required option**

-qsmp
Syntax

\[ \text{PARALLEL WORKSHARE} \]
\[ \text{parallel_workshare_clause} \]
\[ \text{block} \]
\[ \text{END PARALLEL WORKSHARE} \]

where \textit{parallel_workshare_clause} is any of the directives accepted by either the \textit{PARALLEL} or \textit{WORKSHARE} directives.

Related reference:
“\text{PARALLEL / END PARALLEL}” on page 139
“\text{WORKSHARE / END WORKSHARE}” on page 190

**SCHEDULE**

**Purpose**

Note: The \textit{SCHEDULE} directive has been deprecated and might be removed in a future release. Use the corresponding OpenMP \textit{SCHEDULE} clause. For more information about the deprecated SMP directives and deprecation examples, see “Deprecation directive” on page 110.

The \textit{SCHEDULE} directive allows the user to specify the chunking method for parallelization. Work is assigned to threads in different manners depending on the scheduling type or chunk size used.

**Required option**

- \texttt{-qsmp}

**Syntax**

\[ \text{SCHEDULE}(\texttt{-sched_type}, \texttt{n}) \]

\( n \)  
\( n \) must be a positive, specification expression. You must not specify \( n \) for the \textit{sched_type} \textit{RUNTIME}.

\( \textit{sched_type} \)  
is \textit{AFFINITY}, \textit{DYNAMIC}, \textit{GUIDED}, \textit{RUNTIME}, or \textit{STATIC}.

For more information on \textit{sched_type} parameters, see the \textit{SCHEDULE clause}.

\( \text{number_of_iterations} \)  
is the number of iterations in the loop to be parallelized.
*number_of_threads*

is the number of threads used by the program.

**Rules**

The **SCHEDULE** directive must appear in the specification part of a scoping unit.

Only one **SCHEDULE** directive may appear in the specification part of a scoping unit.

The **SCHEDULE** directive applies to the situation when all loops in the scoping unit do not already have explicit scheduling types specified. Individual loops can have scheduling types specified using the **SCHEDULE** clause of the **PARALLEL DO** directive.

Any dummy arguments appearing or referenced in the specification expression for the chunk size \( n \) must also appear in the **SUBROUTINE** or **FUNCTION** statement and in all **ENTRY** statements appearing in the given subprogram.

If the specified chunk size \( n \) is greater than the number of iterations, the loop will not be parallelized and will execute on a single thread.

If you specify more than one method of determining the chunking algorithm, the compiler will follow, in order of precedence:

1. **SCHEDULE** clause to the **PARALLEL DO** directive.
2. **SCHEDULE** directive.
3. **schedule** suboption to the **-qsmp** compiler option. See the **-qsmp option** in the XL Fortran Compiler Reference.
4. **XLSMPOPTS** runtime option. See "**XLSMPOPTS**" on page 86.
5. runtime default (that is, **STATIC**).

**Examples**

**Example 1.** Given the following information:

number of iterations = 1000
number of threads = 4

and using the **GUIDED** scheduling type, the chunk sizes would be as follows:

250 188 141 106 79 59 45 33 25 19 14 11 8 6 4 3 2 1 1 1 1

The iterations would then be divided into the following chunks:

chunk 1 = iterations 1 to 250
chunk 2 = iterations 251 to 438
chunk 3 = iterations 439 to 579
chunk 4 = iterations 580 to 685
chunk 5 = iterations 686 to 764
chunk 6 = iterations 765 to 823
chunk 7 = iterations 824 to 868
chunk 8 = iterations 869 to 901
chunk 9 = iterations 902 to 926
chunk 10 = iterations 927 to 945
chunk 11 = iterations 946 to 959
chunk 12 = iterations 960 to 970
chunk 13 = iterations 971 to 978
chunk 14 = iterations 979 to 984
chunk 15 = iterations 985 to 988
chunk 16 = iterations 989 to 991
chunk 17 = iterations 992 to 994
chunk 18 = iterations 995 to 996
chunk 19 = iterations 997 to 997
chunk 20 = iterations 998 to 998
chunk 21 = iterations 999 to 999
chunk 22 = iterations 1000 to 1000

A possible scenario for the division of work could be:

thread 1 executes chunks 1 5 10 13 18 20
thread 2 executes chunks 2 7 9 14 16 22
thread 3 executes chunks 3 6 12 15 19
thread 4 executes chunks 4 8 11 17 21

Example 2. Given the following information:

number of iterations = 100
number of threads = 4

and using the AFFINITY scheduling type, the iterations would be divided into the following partitions:

partition 1 = iterations 1 to 25
partition 2 = iterations 26 to 50
partition 3 = iterations 51 to 75
partition 4 = iterations 76 to 100

The partitions would be divided into the following chunks:

chunk 1a = iterations 1 to 13
chunk 1b = iterations 14 to 19
chunk 1c = iterations 20 to 22
chunk 1d = iterations 23 to 24
chunk 1e = iterations 25 to 25

chunk 2a = iterations 26 to 38
chunk 2b = iterations 39 to 44
chunk 2c = iterations 45 to 47
chunk 2d = iterations 48 to 49
chunk 2e = iterations 50 to 50

chunk 3a = iterations 51 to 63
chunk 3b = iterations 64 to 69
chunk 3c = iterations 70 to 72
chunk 3d = iterations 73 to 74
chunk 3e = iterations 75 to 75

chunk 4a = iterations 76 to 88
chunk 4b = iterations 89 to 94
chunk 4c = iterations 95 to 97
chunk 4d = iterations 98 to 99
chunk 4e = iterations 100 to 100

A possible scenario for the division of work could be:

thread 1 executes chunks 1a 1b 1c 1d 1e 4d
thread 2 executes chunks 2a 2b 2c 2d
thread 3 executes chunks 3a 3b 3c 3d 3e 2e
thread 4 executes chunks 4a 4b 4c 4e

In this scenario, thread 1 finished executing all the chunks in its partition and then grabbed an available chunk from the partition of thread 4. Similarly, thread 3 finished executing all the chunks in its partition and then grabbed an available chunk from the partition of thread 2.

Example 3. Given the following information:
number of iterations = 1000
number of threads = 4

and using the DYNAMIC scheduling type and chunk size of 100, the chunk sizes would be as follows:
100 100 100 100 100 100 100 100 100 100

The iterations would be divided into the following chunks:
chunk 1 = iterations 1 to 100
chunk 2 = iterations 101 to 200
chunk 3 = iterations 201 to 300
chunk 4 = iterations 301 to 400
chunk 5 = iterations 401 to 500
chunk 6 = iterations 501 to 600
chunk 7 = iterations 601 to 700
chunk 8 = iterations 701 to 800
chunk 9 = iterations 801 to 900
chunk 10 = iterations 901 to 1000

A possible scenario for the division of work could be:
thread 1 executes chunks 1 5 9
thread 2 executes chunks 2 8
thread 3 executes chunks 3 6 10
thread 4 executes chunks 4 7

Example 4. Given the following information:
number of iterations = 100
number of threads = 4

and using the STATIC scheduling type, the iterations would be divided into the following chunks:
chunk 1 = iterations 1 to 25
chunk 2 = iterations 26 to 50
chunk 3 = iterations 51 to 75
chunk 4 = iterations 76 to 100

A possible scenario for the division of work could be:
thread 1 executes chunks 1
thread 2 executes chunks 2
thread 3 executes chunks 3
thread 4 executes chunks 4

Related reference:

See DO in the Language Reference

SECTIONS / END SECTIONS

Purpose

The SECTIONS construct defines distinct blocks of code to be executed in parallel by threads in the team.

Required option

-qsm
Syntax

where sections_clause is:

firstprivate_clause
See — “FIRSTPRIVATE” on page 202.

lastprivate_clause
See — “LASTPRIVATE” on page 204.

private_clause
See — “PRIVATE” on page 200.

reduction_clause
See — “REDUCTION” on page 206

Rules

The SECTIONS construct must be encountered by all threads in a team or by none of the threads in a team. All work-sharing constructs and BARRIER directives that are encountered must be encountered in the same order by all threads in the team.

The SECTIONS construct includes the delimiting directives, and the blocks of code they enclose. At least one block of code must appear in the construct.

You must specify the SECTION directive at the beginning of each block of code except for the first. The end of a block is delimited by either another SECTION directive or by the END SECTIONS directive.

It is illegal to branch into or out of any block of code that is enclosed in the SECTIONS construct. All SECTION directives must appear within the lexical extent of the SECTIONS/END SECTIONS directive pair.
The scheduling of structured blocks among threads in the team is set so that the first thread arriving is the first thread to execute the block. The compiler determines how to divide the work among the threads based on a number of factors, such as the number of threads in the team and the number of sections to be executed in parallel. In a SECTIONS construct, a single thread might execute more than one SECTION. It is also possible that a thread in the team might not execute any SECTION.

In order for the directive to execute in parallel, you must place the SECTIONS/END SECTIONS pair within a parallel region. Otherwise, the blocks will be executed serially.

If you specify NOWAIT on the SECTIONS directive, a thread that completes its sections early will proceed to the instructions following the SECTIONS construct. If you do not specify the NOWAIT clause, each thread will wait for all of the other threads in the same team to reach the END SECTIONS directive. However, there is no implied BARRIER at the start of the SECTIONS construct.

You cannot specify a SECTIONS directive within the dynamic extent of a CRITICAL, MASTER, ORDERED, or TASK directive.

You cannot nest SECTIONS, DO or SINGLE directives that bind to the same PARALLEL directive.

BARRIER and MASTER directives are not permitted in the dynamic extent of a SECTIONS directive.

The END SECTIONS directive implies the FLUSH directive.

Examples

Example 1: This example shows a valid use of the SECTIONS construct within a PARALLEL region.

```
 INTEGER :: I, B(500), S, SUM
!
 S = 0
 SUM = 0
 !$OMP PARALLEL SHARED(SUM), FIRSTPRIVATE(S)
 !$OMP SECTIONS REDUCTION(+: SUM), LASTPRIVATE(I)
 !$OMP SECTION
   S = FCT1(B(1:2)) ! Array B is not altered in FCT1.
   SUM = SUM + S
 !
 !$OMP SECTION
   S = FCT2(B(2:2)) ! Array B is not altered in FCT2.
   SUM = SUM + S
 !
 !$OMP SECTION
   DO I = 1, 500 ! The local copy of S is initialized
   S = S + B(I) ! to zero.
   END DO
   SUM = SUM + S
 !
 !$OMP END SECTIONS
 !
 !$OMP DO REDUCTION(-: SUM)
   DO J=I-1, 1, -1 ! The loop starts at 500 -- the last
   ! value from the previous loop.
   SUM = SUM - B(J)
   END DO
```
$OMP MASTER
  SUM = SUM - FCT1(B(1::2)) - FCT2(B(2::2))
$OMP END MASTER
$OMP END PARALLEL
  ! ...  
  ! Upon termination of the PARALLEL
  ! region, the value of SUM remains zero.

Example 2: This example shows a valid use of nested SECTIONS.

$OMP PARALLEL
  $OMP MASTER
    CALL RANDOM_NUMBER(CX)
    CALL RANDOM_NUMBER(CY)
    CALL RANDOM_NUMBER(CZ)
  $OMP END MASTER

  $OMP SECTIONS
  $OMP SECTION
    $OMP PARALLEL
      $OMP SECTIONS PRIVATE(I)
      $OMP SECTION
        DO I=1, 5000
          X(I) = X(I) + CX
        END DO
      $OMP SECTION
        DO I=1, 5000
          Y(I) = Y(I) + CY
        END DO
      $OMP END SECTIONS
    $OMP END PARALLEL
  $OMP END SECTIONS
  $OMP END PARALLEL

  $OMP SECTION
  $OMP PARALLEL SHARED(CZ,Z)
  $OMP DO
    DO I=1, 5000
      Z(I) = Z(I) + CZ
    END DO
  $OMP END DO
  $OMP END PARALLEL
  $OMP END SECTIONS NOWAIT

  ! The following computations do not
  ! depend on the results from the
  ! previous section.

  $OMP DO
    DO I=1, 5000
      T(I) = T(I) * CT
    END DO
  $OMP END DO
  $OMP END PARALLEL

Related reference:

"PARALLEL / END PARALLEL" on page 139
"BARRIER" on page 116
"PARALLEL DO / END PARALLEL DO" on page 142

See INDEPENDENT in the Language Reference
"THREADPRIVATE" on page 185

See -directive in the Compiler Reference
See -qsmp in the Compiler Reference
**SIMD / END SIMD**

**Purpose**

The **SIMD** directive is applied to a loop to indicate that multiple iterations of the loop can be executed concurrently using SIMD instructions.

**Required option**

```
-qsm
```

**Syntax**

```
SIMD
  simd_clause
  do_loop
  END SIMD
```

where `simd_clause` is:

```
aligned_clause
  collapse_clause
  lastprivate_clause
  linear_clause
  private_clause
  reduction_clause
  safelen_clause
  simdlen_clause
```

**aligned_clause**

Declares that the location of list item is byte aligned according to the number of bytes expressed by `alignment`. The syntax is

```
ALIGNED([list[alignment]])
```

`alignment` must be a constant positive integer expression. If `alignment` is not specified, the alignment is defined by the target platforms. A list item cannot appear in more than one aligned clause.

**collapse_clause**

Specifies the number of loops that the **SIMD** directive applies to. The syntax is

```
COLLAPSE(n)
```

The expression that is represented by `n` must be a constant positive integer expression. If no collapse clause is specified, the **SIMD** directive applies to only the loop that immediately follows.

**lastprivate_clause**

Declares the scope of the data variables in `list` to be private to each SIMD lane. The final value of each variable in `list` is as follows:
• If assigned a value, each variable has the value that is assigned to that variable in the sequentially last iteration.
• If not assigned a value, each variable has an indeterminate value.

The syntax is `LASTPRIVATE(list)`. Data variables in `list` are separated by commas.

**linear_clause**

Declares the data variables in `list` to be private to a SIMD lane and to have a linear relationship with the iteration space of a loop. The value of the new list item on each iteration of the associated loops is the result of adding the following values:
• The value of the original list item before entering the construct
• The product of the logical number of the iteration and `linear-step`

The final value of each variable in `list` has the value that is assigned to that variable in the sequentially last iteration. The default value for `linear-step` is 1. The syntax is `LINEAR(list[linear-step])`.

**private_clause**

Declares the scope of the data variables in `list` to be private to each SIMD lane. A new item is created for each list item that is referenced by the target task. The syntax is `PRIVATE(list)`. Data variables in `list` are separated by commas.

**reduction_clause**

Performs a reduction on each data variable in `list` according to `reduction-identifier`.

The clause creates a private copy for each list item in each implicit task or SIMD lane, initializes the private copies with the initializer value of `reduction-identifier`, and updates the original list item after the end of the region with the values of the private copies using the combiner associated with `reduction-identifier`.

The syntax is `REDUCTION(reduction-identifier: list)`.

For more information, refer to the OpenMP Application Program Interface Language Specification, which is available at [http://www.openmp.org](http://www.openmp.org).

**safelen_clause**

Indicates that no two iterations that are executed concurrently by using SIMD instructions can have a distance in the logical iteration space greater than the value expressed by `length`. The syntax is `SAFELEN(length)`. `length` must be a constant positive integer expression.

**simdlen_clause**

Specifies the preferred number of iterations to be executed concurrently. The number of SIMD loop iterations that are executed concurrently is implementation defined. Each concurrent iteration is executed by a different SIMD lane. Lexical forward dependencies in the iterations of the original loop must be preserved within each set of concurrent iterations.

The syntax is `SIMDLEN(length)`. `length` must be a constant positive integer expression.

**Notes:**
1. You can specify this clause only once for each SIMD directive.
2. Iterations in a SIMD loop are logically numbered from 0 to N-1, where N is the number of loop iterations. The logical numbering denotes the sequence in which the iterations would be executed if the associated loop was executed not using SIMD instructions.

3. If you specify both the SIMDLEN and SAFELEN clauses, the value of the SIMDLEN parameter must be less than or equal to the value of the SAFELEN parameter.

Rules

All loops that are associated with the construct must be perfectly nested; that is, you cannot insert any intervening code or OpenMP directive between any two loops.

The associated loops must be structured blocks.

A program that branches into or out of a simd region is nonconforming.

An ordered construct with the simd clause is the only OpenMP construct that can be encountered during the execution of a simd region.

Limitation: The DECLARE SIMD directive is not supported in this release.

Examples

Example 1

The following SIMD construct enables the execution of multiple iterations of the associated loop concurrently by using SIMD instructions.

```fortran
!$OMP SIMD
  DO i=1, N, 1
    a(i) = a(i) + b(i) * c(i)
  END DO
```

Example 2

The loop in the following example contains a lexically forward loop-carried dependency that prohibits concurrent execution of all iterations of the loop. The omp simd safelen(4) clause specifies that the loop iterations which are at a distance of four or less in the logical iteration space can be executed in parallel by using SIMD instructions.

```fortran
!$OMP SIMD SAFELEN(4)
  DO i=1, N-4, 1
    a(i) = a(i+4) + b(i) * c(i)
  END DO
```

Related reference:

See -qsmp in the Compiler Reference

SINGLE / END SINGLE

Purpose

You can use the SINGLE / END SINGLE directive construct to specify that the enclosed code should only be executed by one thread in the team.
Required option

-qsm

Syntax

\[
\text{where } single\_clause \text{ is:}
\]

\[
\text{private}\_\text{clause}
\]

\[
\text{firstprivate}\_\text{clause}
\]

\[
\text{private}\_\text{clause}
\]

See — “PRIVATE” on page 200.

\[
\text{firstprivate}\_\text{clause}
\]

See — “FIRSTPRIVATE” on page 202.

\[
\text{where } end\_single\_clause \text{ is:}
\]

\[
\text{copyprivate}\_\text{clause}
\]

NOWAIT

\[
\text{copyprivate}\_\text{clause}
\]

See — “COPYPRIVATE” on page 212

Rules

It is illegal to branch into or out of a block that is enclosed within the SINGLE construct.

The SINGLE construct must be encountered by all threads in a team or by none of the threads in a team. The first thread to encounter the SINGLE construct will execute it. All work-sharing constructs and BARRIER directives that are encountered must be encountered in the same order by all threads in the team.
If you specify NOWAIT on the END SINGLE directive, the threads that are not executing the SINGLE construct will proceed to the instructions following the SINGLE construct. If you do not specify the NOWAIT clause, each thread will wait at the END SINGLE directive until the thread executing the construct reaches the END SINGLE directive. You may not specify NOWAIT and COPYPRIVATE as part of the same END SINGLE directive.

There is no implied BARRIER at the start of the SINGLE construct. If you do not specify the NOWAIT clause, the BARRIER directive is implied at the END SINGLE directive.

You cannot nest work-sharing constructs inside one another if they bind to the same PARALLEL directive.

SINGLE directives are not permitted within the CRITICAL, MASTER, ORDERED, or TASK regions. BARRIER and MASTER directives are not permitted within the SINGLE regions.

If you have specified a variable as PRIVATE, FIRSTPRIVATE, LASTPRIVATE, or REDUCTION in the PARALLEL construct which encloses your SINGLE construct, you cannot specify the same variable in the PRIVATE or FIRSTPRIVATE clause of the SINGLE construct.

The SINGLE directive binds to the closest enclosing PARALLEL region, if one exists.

**Examples**

**Example 1:** In this example, the BARRIER directive is used to ensure that all threads finish their work before entering the SINGLE construct.

```fortran
REAL :: X(100), Y(50)
!
!$OMP PARALLEL DEFAULT(SHARED)
 CALL WORK(X)
!$OMP BARRIER
!$OMP SINGLE
 CALL OUTPUT(X)
 CALL INPUT(Y)
!$OMP END SINGLE
!
 CALL WORK(Y)
!$OMP END PARALLEL
```

**Example 2:** In this example, the SINGLE construct ensures that only one thread is executing a block of code. In this case, array B is initialized in the DO (work-sharing) construct. After the initialization, a single thread is employed to perform the summation.

```fortran
INTEGER :: I, J
REAL :: B(500,500), SM
!
J = ...
SM = 0.0
!$OMP PARALLEL
!$OMP DO PRIVATE(I)
 DO I=1, 500
 CALL INITARR(B(I,:), I) ! initialize the array B
 ENDDO
```
Example 3: This example shows a valid use of the PRIVATE clause. Array X is PRIVATE to the SINGLE construct. If you were to reference array X immediately following the construct, it would be undefined.

    REAL :: X(2000), A(1000), B(1000)

Example 4: In this example, the LASTPRIVATE variable I is used in allocating TMP, the PRIVATE variable in the SINGLE construct.

    SUBROUTINE ADD(A, UPPERBOUND)
      INTEGER :: A(UPPERBOUND), I, UPPERBOUND
      INTEGER, ALLOCATABLE :: TMP(:)
    ! ... !$OMP PARALLEL !$OMP SINGLE PRIVATE(X) CALL READ_IN_DATA(X) A = X(1:2) B = X(2:2) !$OMP END SINGLE ! $OMP END PARALLEL

Example 5: In this example, a value for the variable I is entered by the user. This value is then copied into the corresponding variable I for all other threads in the team using a COPYPRIVATE clause on an END SINGLE directive.

    INTEGER I
    !$OMP PARALLEL PRIVATE (I)
    ! ... !$OMP SINGLE READ (*, *) I !$OMP END SINGLE COPYPRIVATE (I) ! In all threads in the team, I ! is equal to the value ! that you entered.
    ! ... !$OMP END PARALLEL
Example 6: In this example, variable $J$ with a POINTER attribute is specified in a COPYPRIVATE clause on an END SINGLE directive. The value of $J$, not the value of the object that it points to, is copied into the corresponding variable $J$ for all other threads in the team. The object itself is shared among all the threads in the team.

```fortran
INTEGER, POINTER :: J
!$OMP PARALLEL PRIVATE (J)
! ... !$OMP SINGLE
ALLOCATE (J)
READ (+, *, J)
!$OMP END SINGLE COPYPRIVATE (J)
!$OMP ATOMIC
J = J + OMP_GET_THREAD_NUM()
!$OMP BARRIER
!$OMP SINGLE
WRITE (*, *, 'J = ', J) ! The result is the sum of all values added to ! J. This result shows that the pointer object ! is shared by all threads in the team.
DEALLOCATE (J)
!$OMP END SINGLE
!$OMP END PARALLEL
```

Related reference:

“BARRIER” on page 116
“CRITICAL / END CRITICAL” on page 117
“FLUSH” on page 133
“MASTER / END MASTER” on page 135
“PARALLEL / END PARALLEL” on page 139

TARGET / END TARGET

Purpose

The TARGET directive instructs the compiler to generate a target task, that is, to map variables to a device data environment and to execute the enclosed block of code on that device.

Use the TARGET and END TARGET directives to define a target region, which is a block of computation that operates within a distinct data environment and is intended to be offloaded onto a parallel computation device during execution.

Required options

-q SMP and -q offload
Syntax

where target_clause is:

- defaultmap_clause
- depend_clause
- device_clause
- firstprivate_clause
- if_clause
- is_device_ptr_clause
- map_clause
- nowait_clause
- private_clause

defaultmap_clause
Changes the default implicit mapping rule from FIRSTPRIVATE to TOFROM for scalar variables. The syntax is DEFAULTMAP(TOFROM:SCALAR). For more information about implicit mapping, see the Rules section.

depend_clause
Establishes scheduling dependences between the target task and sibling tasks that share list items. The syntax is DEPEND(dependence-type:list). The dependence-type can be IN, OUT, or INOUT. Data variables in list are separated by commas.

- If dependence-type is IN or INOUT, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the OUT or INOUT dependence type, a scheduling dependence for the target task on the sibling task is created.
- If dependence-type is OUT or INOUT, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the IN, OUT, or INOUT dependence type, a scheduling dependence for the target task on the sibling task is created.

device_clause
Creates the data environment on the device with the designated ID. The syntax is DEVICE(scalar-integer-expression). The scalar-integer-expression must evaluate to a non-negative integer value that is less than the value of the omp_get_num_devices function.

firstprivate_clause
Declares the listed data variables to be private to the target task and shared...
by every thread team that runs the region. A new item is created for each list item that is referenced by the target task as if there was an implied declaration within the statement block. Each new private object is initialized with the value of the original variable.

For more information, see "FIRSTPRIVATE" on page 202.

**if_clause**

When an IF clause is present and the IF clause expression evaluates to false, the target region is executed by the host device in the host data environment. The syntax is `IF([TARGET:]logical-expression).`

**is_device_ptr_clause**

Indicates that the listed data variables are device pointers that exist within the device data environment. Any listed data variable must be a dummy argument. The syntax is `IS_DEVICE_PTR(list).`

**map_clause**

Specifies the listed data variables to be explicitly mapped from the original variables in the host data environment to the corresponding variables in the device data environment of the device specified by the construct. The syntax is `MAP([map-type-modifier[,]]map-type:]list).`

*map-type* can be `TO`, `FROM`, `TOFROM`, or `ALLOC`.

- If a list item does not exist in the device data environment, a new item is created in the device data environment.
  - If *map-type* is `TO` or `TOFROM`, this new item is initialized with the value of the original list item in *list* in the host data environment.
  - If *map-type* is `FROM` or `ALLOC`, the initial value of the list item in the device data environment is undefined.

On exit from the target region, if storage for the list item was created in the device data environment when this construct was first encountered, the list item is deallocated from the device data environment. Furthermore, if *map-type* is `FROM` or `TOFROM`, the original list item is updated with the current value of the corresponding list item in the device data environment before the list item in the device data environment is deallocated.

- If the list item exists in the device data environment when the construct is encountered, the allocation count of the item in the device environment changes as follows:
  - It is incremented by one at the start of the construct
  - It is decremented by one at the end of the construct.

*map-type-modifier* is `ALWAYS`. If this modifier is present, the following rules apply:

- If *map-type* is `TO` or `TOFROM`, the value of the original list item is always copied to the device environment, regardless of whether a new item was created in the device data environment for the list item.
- If *map-type* is `FROM` or `TOFROM`, the value of the list item is always copied from the device environment to the original list item, regardless of whether the device list item will be deallocated at termination of the construct.

You can specify associate names in *map_clause*.

**nowait_clause**

Eliminates the implicit barrier so the parent task can make progress even if
the target task is not yet completed. By default, an implicit barrier exists at
the end of the target construct, which ensures the parent task cannot
continue until the target task is completed. The syntax is NOWAIT.

**private_clause**
Declares the listed data variables to be private to the target and shared by
every thread team that runs the region. A new item is created for each list
task item that is referenced by the target task.

For more information, see **“PRIVATE” on page 200.**

**reduction_clause**
Specifies that for each data variable in list, a private copy is created and
initialized based on the reduction-identifier. At the end of the region, the
original data variable is updated with the values of the private copies
using a combiner based on the reduction-identifier. The syntax is
REDUCTION(reduction-identifier:list).

**Limitations:**

- The reduction clause on the TARGET directive is supported only in the
  form of combined constructs, such as TARGET PARALLEL DO or
  TARGET TEAMS DISTRIBUTE PARALLEL DO.
- Data variables in list cannot be arrays or array sections.
- User-defined reductions are not supported.

For more information, see **“REDUCTION” on page 206.**

**block**
Represents the block of code to be executed in the device data
environment.

**Rules**

Execution of the target region depends on the successful of
loading of the region to
the device environment. If a target region cannot be successfully offloaded to a
device, the target region is executed within the host environment.

Nesting of target regions, either dynamically or statically, is not allowed.

The data environment of a target region is defined by the implicit and explicit
mapping of variables between the host and device:

**Implicit mapping**
The compiler determines which variables must be mapped to, from, or
both to and from the device data environment. Scalar variables that are not
explicitly mapped are implicitly mapped as FIRSTPRIVATE unless
DEFAULTMAP(TOFROM:SCALAR) is specified.

**Explicit mapping**
You can use the MAP clause on the target region to explicitly list variables
to be mapped to, from, or both to and from the device data environment.

A listed data variable cannot appear in both a data-sharing clause and the map
clause on the same target construct.
Examples

INTEGER :: x
x = 1
!$OMP TARGET MAP(TOFROM: x)
  x = x + 1
!$OMP END TARGET
WRITE(*,*) "After target region, x = ", x

The integer x is declared in the host environment, and its initial value is set to 1 on the host. The target region is declared with explicit map type TOFROM of x, so the storage for x is allocated on the device and the device copy of x is initialized to 1. Within the target region, the value of the copy of x on the device is incremented by 1. At the end of the target region, x is mapped back to the host environment according to the map type TOFROM, and the host prints the value of x to be 2.

Related reference:
- See -qsmp in the Compiler Reference
- See -qoffload in the Compiler Reference

TARGET DATA/ END TARGET DATA

Purpose

The TARGET DATA directive maps variables to a device data environment, and defines the lexical scope of the data environment that is created. The TARGET DATA directive can reduce data copies to and from the offloading device when multiple target regions are using the same data.

Required options

-qsm and -qoffload

Syntax

```
TARGET DATA target_data_clause
```

Notes:
1. You must specify at least one map_clause or use_device_ptr_clause.

where target_data_clause is:
if_clause
When an IF clause is present and the IF clause expression evaluates to false, the device is the host. The syntax is IF([TARGET DATA:]logical-expression).

At most one IF clause can appear on the directive.

device_clause
Creates the data environment on the device with the designated ID. The syntax is DEVICE(scalar-integer-expression). The scalar-integer-expression must evaluate to a non-negative integer value that is less than the value of the omp_get_num_devices function.

map_clause
Specify the listed data variables to be explicitly mapped from the original variables in the host data environment to the corresponding variables in the device data environment of the device specified by the construct. The syntax is MAP([[map-type-modifier[[]map-type]]list]).

The map-type can be TO, FROM, TOFROM, or ALLOC.

- If a list item does not exist in the device data environment, a new item is created in the device data environment.
  - If map-type is TO or TOFROM, this new item is initialized with the value of the original list item in list in the host data environment.
  - If map-type is FROM or ALLOC, the initial value of the list item in the device data environment is undefined.

On exit from the target data region, if storage for the list item was created in the device data environment when this construct was first encountered, the list item will be deallocated from the device data environment. Furthermore, if the map-type is FROM or TOFROM, the original list item is updated with the current value of the corresponding list item from the device data environment before deallocating the list item from the device data environment.

- If the list item exists in the device data environment when the construct is encountered, the allocation count of the item in the device environment changes as follows:
  - It is incremented by one at the start of the construct
  - It is decremented by one at the end of the construct.

The map-type-modifier is ALWAYS. If this modifier is present, the following rules apply:

- If map-type is TO or TOFROM, the value of the original list item is always copied to the device environment, regardless of whether a new item was created in the device data environment for the list item.

- If map-type is FROM or TOFROM, the value of the list item is always copied from the device environment to the original list item, regardless of whether the device list item will be deallocated at the termination of the construct.

You can specify associate names in map_clause.
use_device_ptr_clause

Converts the listed data variables into device pointers to the corresponding variables in the device data environment. References to the listed variables throughout the target data region must only be to the address of those variables. You can use only direct access variables; object members and indirectly accessed variables are not supported by use_device_ptr_clause. The syntax is USE_DEVICE_PTR(list).

Rules

The target data construct creates a device data environment, for the duration of the execution of its lexical scope by the encountering thread, during which the storage, and values, of the mapped list items are present on the device.

Examples

```fortran
INTEGER :: p1(5)
INTEGER :: p2(5)=(/ 1,2,3,4,5 /)
INTEGER :: p3(5)=(/ 2,4,6,8,10 /)
!Target data region
!$OMP TARGET DATA MAP(TOFROM: p1)
!The first target region
!$OMP TARGET MAP(TOFROM: p1)
p1=p2
!$OMP END TARGET
!The second target region
!$OMP TARGET MAP(TOFROM: p1)
p1=p3
!$OMP END TARGET
!$OMP END TARGET DATA
```

At first, storage for the array p1 is declared in the host environment, but this storage is not initialized. When the target data region is encountered, corresponding storage for the array is created on the device. The device storage is also not initialized.

When the first target region is encountered, the OpenMP runtime will check whether the storage corresponding to the array already exists on the device. No further action, with respect to the device storage, is taken because the corresponding storage already exists on the device when the target region is encountered. The device storage of the array is then initialized, and the target region completes. Upon completion, the OpenMP runtime will recognize that the storage of the array should remain on the device, so no copy-back from device to host will occur. At this point, the storage of the array on the host remains uninitialized, while the storage of the array on the device is initialized.

The same happens when the second target region is encountered. No copies between host and device will occur because the storage is already present on the device when the target construct is encountered, and because that storage is to remain on the device after completion of the target region. After execution of this target region is completed, the storage of the array on the host remains uninitialized and the storage of the array on the device has been altered.

Finally, the end of the target data lexical scope is encountered. This causes the values of the array storage on the device to be copied back to the host, and the device storage to be deallocated. After the lexical scope of the target data region is executed, only the host storage of the array exists, and it contains the values that were calculated on the device.
In contrast, see the following example that doesn’t contain a target data construct.

```fortran
INTEGER :: p1(5)
INTEGER :: p2(5)=/ 1,2,3,4,5 /
INTEGER :: p3(5)=/ 2,4,6,8,10 /
!The first target region
!$OMP TARGET MAP(TOFROM: p1)
p1=p2
!$OMP END TARGET
!The second target region
!$OMP TARGET MAP(TOFROM: p1)
p1=p3
!$OMP END TARGET
```

When each of the two target regions is encountered, the OpenMP runtime takes the following actions:

1. Allocate storage on the device corresponding to the array.
2. Copy the values of the array from the host to the device.
3. Execute the region on the device.
4. Copy the values of the array from the device to the host.
5. Deallocate the device storage of the array.

Related reference:

- See -qsmp in the Compiler Reference
- See -qoffload in the Compiler Reference

**TARGET ENTER DATA**

**Purpose**

The **TARGET ENTER DATA** directive maps variables to a device data environment. The **TARGET ENTER DATA** directive can reduce data copies to and from the offloading device when multiple target regions are using the same data, and when the lexical scope requirement of the **TARGET DATA** construct is not appropriate for the application.

**Required options**

- `qsmp` and `qoffload`

**Syntax**

```fortran
TARGET ENTER DATA target_enter_data_clause
```

**Notes:**

1. You must specify at least one `map` clause.

where `target_enter_data_clause` is:
if_clause
When an IF clause is present and the IF clause expression evaluates to false, the device is the host. The syntax is IF([TARGET ENTER DATA:]logical-expression).

At most one IF clause can appear on the directive.

depend_clause
Establishes scheduling dependences between the target task and sibling tasks that share list items. The syntax is DEPEND(dependence-type:list). The dependence-type can be IN, OUT, or INOUT. Data variables in list are separated by commas.

- If dependence-type is IN or INOUT, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the OUT or INOUT dependence type, a scheduling dependence for the generated task on the sibling task is created.
- If dependence-type is OUT or INOUT, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the IN, OUT, or INOUT dependence type, a scheduling dependence for the generated task on the sibling task is created.

device_clause
Creates the data environment on the device with the designated ID. The syntax is DEVICE(scalar-integer-expression). The scalar-integer-expression must evaluate to a non-negative integer value that is less than the value of the omp_get_num_devices function.

map_clause
Specifies the listed data variables to be explicitly mapped from the original variables in the host data environment to the corresponding variables in the device data environment of the device specified by the construct. The syntax is MAP([map-type-modifier[]]map-type:]list).

The map-type can be TO or ALLOC.

- If a list item does not exist in the device data environment, a new item is created in the device data environment.
  - If map-type is TO, this new item is initialized with the value of the original list item in list in the host data environment.
  - If map-type is ALLOC, the initial value of the list item in the device data environment is undefined.
- If the list item exists in the device data environment when the construct is encountered, the allocation count of the item in the device environment is incremented by one.

The map-type-modifier is ALWAYS. If this modifier is present, the value of the original list item is always copied to the device environment if map-type is TO, regardless of whether a new item was created in the device data environment for the list item.

You can specify associate names in map_clause.
**nowait_clause**

Enables the target enter data construct to execute asynchronously with respect to the encountering thread. By default, the encountering thread must wait for the completion of the construct. The syntax is `NOWAIT`.

**Rules**

The target enter data construct adds mapped list items to the device data environment.

**Examples**

```fortran
INTEGER :: p1(5)
INTEGER :: p2(5)=(/ 1,2,3,4,5 /)
INTEGER :: p3(5)=(/ 2,4,6,8,10 /)
!$OMP TARGET ENTER DATA MAP(ALLOC: p1)
!$OMP TARGET MAP(TOFROM: p1)
p1=p2
!$OMP END TARGET
!$OMP TARGET MAP(TOFROM: p1)
p1=p3
!$OMP END TARGET
!$OMP TARGET UPDATE FROM(p1)
```

At first, storage for an array `p1` is declared in the host environment, but this storage is not initialized. When the target enter data construct is encountered, corresponding storage for the array is created on the device. This device storage is also not initialized.

When the first target region is encountered, the OpenMP runtime will check whether storage corresponding to the array already exists on the device. No further action, with respect to the device storage, is taken because the corresponding storage already exists on the device when the target region is encountered. The device storage of the array is then initialized, and the target region completes. Upon completion, the OpenMP runtime will recognize that the storage of the array should remain on the device, and so no copy-back from device to host will occur. At this point, the storage of the array on the host remains uninitialized, and the storage of the array on the device is initialized.

The same happens when the second target region is encountered. No copies between host and device will occur because the storage is already present on the device when the target construct is encountered, and because that storage is to remain on the device after completion of the target region. After execution of this target region is completed, the storage of the array on the host remains uninitialized and the storage of the array on the device has been altered.

Finally, the target update construct is encountered. This causes the values of the array storage on the device to be copied back to the host. Now, both host and device have the storage for the array, and both of these copies contain the same values.

**Related reference:**

- See `-qsmp` in the Compiler Reference
- See `-qofload` in the Compiler Reference
**TARGET EXIT DATA**

**Purpose**

The **TARGET EXIT DATA** directive unmaps variables from a device data environment. The **TARGET EXIT DATA** directive can limit the amount of device memory used when you use the **TARGET ENTER DATA** construct to map items to the device data environment.

**Required options**

- `qsmp` and `qoffload`

**Syntax**

```
TARGET EXIT DATA -target_exit_data_clause
```

Notes:

1. You must specify at least one `map` clause.

Where `target_exit_data_clause` is:

```
- depend_clause
- device_clause
- if_clause
- map_clause
- nowait_clause
```

**depend_clause**

Establishes scheduling dependences between the target task and sibling tasks that share list items. The syntax is `DEPEND(dependence-type:list)`. The dependence-type can be **IN**, **OUT**, or **INOUT**. Data variables in list are separated by commas.

- If dependence-type is **IN** or **INOUT**, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the **OUT** or **INOUT** dependence type, a scheduling dependence for the generated task on the sibling task is created.
- If dependence-type is **OUT** or **INOUT**, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the **IN**, **OUT**, or **INOUT** dependence type, a scheduling dependence for the generated task on the sibling task is created.

**device_clause**

Creates the data environment on the device with the designated ID. The syntax is `DEVICE(scalar-integer-expression)`. The `scalar-integer-expression` must evaluate to a non-negative integer value that is less than the value of the `omp_get_num_devices` function.
if_clause
When an IF clause is present and the IF clause expression evaluates to false, the device is the host. The syntax is IF([TARGET EXIT DATA:]logical-expression).

At most one IF clause can appear on the directive.

map_clause
Specifies the listed data variables to be explicitly mapped from the original variables in the host data environment to the corresponding variables in the device data environment of the device specified by the construct. The syntax is MAP([[map-type-modifier[,]][map-type:]list]).

The map-type can be FROM, RELEASE, or DELETE.

- If a list item does not exist in the device data environment, the construct does nothing with respect to that list item.
- If the map-type is FROM, or RELEASE, the allocation count of the item in the device environment is decremented by one.
- If the map-type is DELETE, the allocation count of the item in the device data environment is set to zero.
- If the map-type is DELETE, FROM, or RELEASE, and if the construct reduces the allocation count of an item in the device data environment to zero, the item is deallocated from the device data environment.
- If the map-type is FROM, and the construct deallocates a list item from the device data environment, the values for that list item are copied from the device data environment to the host prior to deallocation of the list item on the device.

The map-type-modifier is ALWAYS. If this modifier is present, the value of the original list item is always assigned the value of the corresponding list item on the device environment if map-type is FROM, regardless of whether the construct reduces the allocation count of the item to zero.

You can specify associate names in map_clause.

nowait_clause
Enables the target exit data construct to execute asynchronously with respect to the encountering thread. By default, the encountering thread must wait for the completion of the construct. The syntax is NOWAIT.

Rules
The target exit data construct decrements the allocation count of mapped list items in the device data environment. When the allocation count of an item reaches zero, it is deallocated from the device data environment and its value might be copied back to the host environment.

Examples
INTEGER :: p1(5)
INTEGER :: p2(5)=(/ 1,2,3,4,5 /)
INTEGER :: p3(5)=(/ 2,4,6,8,10 /)
 !$OMP TARGET ENTER DATA MAP(ALLOC: p1)
 !$OMP TARGET MAP(TOFROM: p1)
p1=p2
 !$OMP END TARGET
 !$OMP TARGET MAP(TOFROM: p1)
p1=p3
 !$OMP END TARGET
 !$OMP TARGET EXIT DATA MAP(FROM:p1)
At first, storage for the array \texttt{p1} is declared in the host environment, but this storage is not initialized. When the target enter data construct is encountered, corresponding storage for the array is created on the device. This device storage is also not initialized.

When the first target region is encountered, the OpenMP runtime will check whether the storage corresponding to the array already exists on the device. No further action, with respect to the device storage, is taken because the corresponding storage already exists on the device when the target region is encountered. The device storage of the array is then initialized, and the target region completes. Upon completion, the OpenMP runtime will recognize that the storage of the array should remain on the device, so no copy-back from device to host will occur. At this point, the array storage on the host remains uninitialized, and the array storage on the device is initialized.

The same happens when the second target region is encountered. No copies between host and device will occur because the storage is already present on the device when the target construct is encountered, and because that storage is to remain on the device after completion of the target region. After execution of this target region is completed, the array storage on the host remains uninitialized and the array storage on the device has been altered.

Finally, the target exit data construct is encountered. The array storage in the device data environment will be deallocated. This causes the values of the array storage on the device to be copied back to the host because the \texttt{map-type} is \texttt{FROM}.

Now, only the host has the storage for this array, and the values of the array are the same as those calculated by the offload device.

\textbf{Related reference:}

- See \texttt{-qsmp} in the Compiler Reference
- See \texttt{-qoffload} in the Compiler Reference

\textbf{TARGET UPDATE}

\textbf{Purpose}

The \texttt{TARGET UPDATE} directive makes the list items in the device data environment consistent with the original list items by copying data between the host and the device.

The direction of data copying is specified by \texttt{motion-type} in \texttt{motion_clause}.

\textbf{Required options}

- \texttt{-qsmp} and \texttt{-qoffload}
Syntax

wheremotion_clauseis:

motion_clause
Synchronizes the values of the list items between the host and device data environment. The syntax is motion-type(list).

The motion-type can be FROM or TO. A list item can only appear in a FROM or TO clause, but not both. The copying occurs to each list item that has storage on the device data environment or each original list item on the host data environment according to the value of motion-type:

- If motion-type is FROM, the value of each list item is copied from the corresponding item on the device to the original list item on the host.
- If motion-type is TO, the value of each list item is copied from the original list item on the host to the corresponding item on the device.

If the corresponding list item is not present in the device data environment, no data movement happens.

You can specify associate names in motion_clause.

depend_clause
Establishes scheduling dependences between sibling tasks that share list items. The syntax is DEPEND(dependence-type:list). The dependence-type can be IN, OUT, or INOUT. Data variables in list are separated by commas.

- If dependence-type is IN or INOUT, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the OUT or INOUT dependence type, a scheduling dependence for the generated task on the sibling task is created.
- If dependence-type is OUT or INOUT, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the IN, OUT, or INOUT dependence type, a scheduling dependence for the generated task on the sibling task is created.

device_clause
Creates the data environment on the device with the designated ID. The syntax is DEVICE(scalar-integer-expression). The scalar-integer-expression must
evaluate to a non-negative integer value that is less than the value of the `omp_get_num_devices` function. You can specify at most one `DEVICE` clause.

**if_clause**

When an **IF** clause is present and the **IF** clause expression evaluates to false, no copying of data occurs. The syntax is **IF([TARGET UPDATE:]logical-expression)**.

**nowait_clause**

Enables the target update construct to execute asynchronously with respect to the encountering thread. By default, the encountering thread must wait for the completion of the construct. The syntax is **NOWAIT**.

**Examples**

```fortran
INTEGER :: x
x = 0
!$OMP TARGET DATA MAP(TOFROM:x)
! See status 1.
x = 10
! See status 2.
!$OMP TARGET UPDATE TO(x)
! See status 3.
!$OMP END TARGET DATA
```

You can find the variable values for each status in the following table. Note that assumption is made that the storage for `x` on the device did not exist before the `TARGET DATA` directive is encountered.

**Table 22. Variable values on the host and device**

<table>
<thead>
<tr>
<th>Status</th>
<th>Value of x on the host</th>
<th>Value of x on the device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status 1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Status 2</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Status 3</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

**Related reference:**

- See `-qsmp` in the Compiler Reference
- See `-qoffload` in the Compiler Reference

**Related information:**

- `ASSOCIATE (Fortran 2003)` in the *XL Fortran Language Reference*

**TASK / END TASK**

**Purpose**

The **TASK** directive instructs the compiler to run a block of code in parallel with the code outside the task region. The **TASK** directive can be useful for parallelizing irregular algorithms such as pointer chasing or recursive algorithms.

**Required option**

- `qsmp`
Syntax

where task_clause is:

- default_clause
- depend_clause
- final_clause
- firstprivate_clause
- if_clause
- mergeable_clause
- private_clause
- shared_clause
- untied_clause

default_clause

If you specify the DEFAULT clause, all variables in the lexical extent of the task construct will have a scope attribute of default_scope_attr. See "DEFAULT" on page 196 for more details.

depend_clause

Establishes scheduling dependences between sibling tasks that share list items. The syntax is DEPEND(dependence-type: list). The dependence-type can be IN, OUT, or INOUT. Data variables in list are separated by commas.

- If dependence-type is IN or INOUT, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the OUT or INOUT dependence type, a scheduling dependence for the generated task on the sibling task is created.
- If dependence-type is OUT or INOUT, for each list item that has the same storage location as a list item in a depend clause of a sibling task with the IN, OUT, or INOUT dependence type, a scheduling dependence for the generated task on the sibling task is created.

final_clause

The FINAL clause is used with the TASK directive. If you specify a FINAL clause and the scalar_logical_expr evaluates to .TRUE., the generated task is a final task. All task constructs encountered inside a final task create final and included tasks. See "FINAL" on page 213 for more details.

firstprivate_clause

If you use the FIRSTPRIVATE clause, each thread has its own initialized
local copy of the variables and common blocks in \texttt{data\_scope\_entity\_list}. See “FIRSTPRIVATE” on page 202 for more details.

\textit{if\_clause}

The runtime environment evaluates whether the \texttt{scalar\_logical\_expression} is true or false, and the behaviour is as follows:

- If \texttt{scalar\_logical\_expression} is true, the block is run in parallel.
- If \texttt{scalar\_logical\_expression} is false, the containing region is suspended and the generated task is immediately run as though it is in a distinct task region.

See “IF” on page 214 for more details.

\textit{mergeable\_clause}

If you specify a \texttt{MERGEABLE} clause and the generated task is an \texttt{undeclared task} or an \texttt{included task} a \texttt{merged task} might be generated. See “MERGEABLE” on page 215 for more details.

\textit{private\_clause}

If you specify the \texttt{PRIVATE} clause, each thread in a team has its own uninitialized local copy of the variables and common blocks in \texttt{data\_scope\_entity\_list}. See “PRIVATE” on page 200 for more details.

\textit{shared\_clause}

All sections use the same copy of the variables and common blocks you specify in \texttt{data\_scope\_entity\_list}. The \texttt{SHARED} clause specifies variables that must be available to all threads. If you specify a variable as \texttt{SHARED}, you are stating that all threads can safely share a single copy of the variable. See “SHARED” on page 198.

\textit{untied\_clause}

When a task region is suspended, untied tasks can be resumed by any thread in a team. See “UNTIED” on page 220 for more details.

\textbf{Rules}

A final task is a task that makes all its child tasks become final and included tasks. A final task is generated when either of the following conditions is true:

- A \texttt{FINAL} clause is specified on a task construct and the \texttt{FINAL} clause expression evaluates to \texttt{.TRUE.}.
- The generated task is a child task of a final task.

An undeferred task is a task whose execution is not deferred with respect to its generating task region. In other words, the generating task region is suspended until the undeferred task has finished running. An undeferred task is generated when an \texttt{IF} clause is specified on a task construct and the \texttt{IF} clause expression evaluates to \texttt{.FALSE.}.

An included task is a task whose execution is sequentially included in the generating task region. In other words, an included task is undeferred and executed immediately by the encountering thread. An included task is generated when the generated task is a child task of a final task.

A merged task is a task that has the same data environment as that of its generating task region. A merged task might be generated when both the following conditions are true:

- A \texttt{MERGEABLE} clause is specified on a task construct.
• The generated task is an undeferred task or an included task.

The following rules are true if no DEFAULT clause is specified with the enclosing TASK construct:
• If the enclosing TASK construct is not lexically enclosed by a parallel region, dummy arguments that do not appear in any PRIVATE, FIRSTPRIVATE, LASTPRIVATE, or SHARED clause of the enclosing TASK construct are firstprivate.
• A variable that is private in the innermost enclosing parallel construct is firstprivate in the TASK construct.
• Local variables of a routine are firstprivate if there is no enclosing parallel construct.
• A variable that is determined to be shared in all of the enclosing constructs, up to and including the innermost enclosing parallel construct, is shared.

The IF clause expression and the FINAL clause expression are evaluated outside of the task construct, and the evaluation order is not specified.

Related reference:
“FINAL” on page 213
“FIRSTPRIVATE” on page 202
“IF” on page 214
“MERGEABLE” on page 215
“DEFAULT” on page 196
“PRIVATE” on page 200
“SHARED” on page 198
“TASKWAIT”
“UNTIED” on page 220

TASKWAIT

Purpose

The TASKWAIT directive specifies a wait for child tasks to be completed that are generated by the current task.

Required option

-qsm

Syntax


Related reference:
“TASK / END TASK” on page 176

TASKYIELD

Purpose

The TASKYIELD directive instructs the compiler that it can suspend the current task in favor of running a different task. The TASKYIELD region includes an
explicit task scheduling point in the current task region.

Required option

-qsmp

Syntax

```
TEAMS / END TEAMS

Purpose

The TEAMS directive creates a collection of thread teams. The master thread of each team executes the teams region.

Required options

-qsmp and -qoffload

Syntax

```

```
TEAMS

where teams_clause is:

```

**default_clause**

Specifies the default data sharing attribute of variables referenced inside the teams region. The syntax is DEFAULT(default-type).

default-type can be NONE, PRIVATE, FIRSTPRIVATE, or SHARED.
Specifying DEFAULT(NONE) requires variables with no implicit data sharing attributes to be specified on firstprivate_clause, private-clause or shared_clause.

firstprivate_clause
Similar to private_clause, except the private copy is initialized with the value of the original variable. Data variables in list are separated by commas. The syntax is FIRSTPRIVATE(list).

num_teams_clause
Specifies an upper limit on the number of teams created. The syntax is NUM_TEAMS(scalar-integer-expression). The scalar-integer-expression must evaluate to a positive integer value.

You can obtain the number of teams by calling the omp_get_num_teams routine.

private_clause
Declares one or more list items to be private to the team. For every list item, a local copy is created for each team. All references to the original list item in the teams region are replaced with references to the private copy. A copy is created per team; hence that copy is shared among the threads in the team. The syntax is PRIVATE(list).

reduction_clause
Specifies a reduction operator and a list of reduction variables. For each reduction variable, a private copy is created and initialized with the value of the reduction-identifier. At the end of the teams region, the master threads of all teams perform a reduction into the value of the original variable. The syntax is REDUCTION(reduction-identifier:list). See for more information.

shared_clause
Declares one or more list items to be shared among the teams. The syntax is SHARED(list).

thread_limit_clause
Specifies an upper limit on the number of threads inside each team. The syntax is THREAD_LIMIT(scalar-integer-expression). The scalar-integer-expression must evaluate to a positive integer value.

Rules
- For a target region without specifying TEAMS, a single team is created and its master thread executes the target region.
- You must strictly nest the TEAMS directive inside the target region, that is, no code exists between the TARGET directive and the TEAMS directive. You must strictly nest the following OpenMP regions inside the teams region:
  - OMP Distribute
  - OMP Distribute simd
  - OMP Distribute Parallel do
  - OMP Distribute Parallel do simd
  - Parallel regions, including any parallel regions arising from combined constructs
- Basically, the compiler creates as many teams as you request. However, if the number you request exceeds either of the following numbers, teams of the smaller number between the two are created:
  - The value specified on the NUM_TEAMS clause
  - 65536, which is the implementation defined limit
• Basically, the compiler creates as many threads per team as you request. However, if the number you request exceeds either of the following numbers, threads of the smaller number between the two are created per team:
  – The value specified on the THREAD_LIMIT clause
  – 992, which is the implementation defined limit
• After the teams are created, the number of teams remains constant for the duration of the teams region.
• When the OMP TEAMS directive is used as part of a combined construct, for example, the OMP TARGET TEAMS directive, the expression used in the NUM_TEAMS or THREAD_LIMIT clause is evaluated on the host.
• Within a teams region, each team has a unique team number. Team numbers are consecutive integers that range from zero to one less than the number of teams. You can obtain the team number of a thread by calling the omp_get_team_num routine.

Example
PROGRAM main
INTEGER :: res, n
INTEGER,EXTERNAL :: foo
res = 0
n = 0
!$OMP TARGET MAP(res, n)
!$OMP TEAMS REDUCTION(+:res) NUM_TEAMS(foo())
res = omp_get_team_num()
IF (omp_get_team_num() == 0) THEN
  n = omp_get_num_teams()
END IF
!$OMP END TEAMS
!$OMP END TARGET
IF (res /= (n*(n-1))/2) THEN !Sum of first n-1 natural numbers
  STOP
END IF
END PROGRAM main

In the preceding example, foo() is evaluated on the host and does not need to be specified using the declare target directive. The example performs a teams reduction on the mapped variable res. Because only the master thread of each team executes the team region, the team-private reduction variable res is safely updated to the team number of the thread. Teams are numbered from zero to the value obtained at run time by calling the omp_get_num_teams routine. Finally, to safely update n with the actual number of teams, only one master thread should perform the write.

Related reference:

- See -qsmp in the Compiler Reference
- See -qoffload in the Compiler Reference

THREADLOCAL
Purpose

You can use the THREADLOCAL directive to declare thread-specific common data. It is a possible method of ensuring that access to data that is contained within COMMON blocks is serialized.
Required innovation command

In order to make use of this directive it is not necessary to specify the -qsmp compiler option, but the invocation command must be xlf_r, xlf90_r, xlf95_r, xlf2003_r, xlf2008_r, or CUDA Fortran xlcuf to link the necessary libraries.

Syntax

```
THREADLOCAL :: /
```

Rules

You can only declare named blocks as THREADLOCAL. All rules and constraints that normally apply to named common blocks apply to common blocks that are declared as THREADLOCAL. See the COMMON statement in the XL Fortran Language Reference for more information on the rules and constraints that apply to named common blocks.

The THREADLOCAL directive must appear in the specification_part of the scoping unit. If a common block appears in a THREADLOCAL directive, it must also be declared within a COMMON statement in the same scoping unit. The THREADLOCAL directive may occur before or after the COMMON statement. See Main program in the XL Fortran Language Reference for more information on the specification_part of the scoping unit.

A common block cannot be given the THREADLOCAL attribute if it is declared within a PURE subprogram.

Members of a THREADLOCAL common block must not appear in NAMELIST statements.

A common block that is use-associated must not be declared as THREADLOCAL in the scoping unit that contains the USE statement.

Any pointers declared in a THREADLOCAL common block are not affected by the -qinit=f90ptr compiler option.

Objects within THREADLOCAL common blocks may be used in parallel loops and parallel sections. However, these objects are implicitly shared across the iterations of the loop, and across code blocks within parallel sections. In other words, within a scoping unit, all accessible common blocks, whether declared as THREADLOCAL or not, have the SHARED attribute within parallel loops and sections in that scoping unit.

If a common block is declared as THREADLOCAL within a scoping unit, any subprogram that declares or references the common block, and that is directly or indirectly referenced by the scoping unit, must be executed by the same thread executing the scoping unit. If two procedures that declare common blocks are executed by different threads, then they would obtain different copies of the
common block, provided that the common block had been declared THREADLOCAL. Threads can be created in one of the following ways:

- Explicitly, via pthreads library calls
- Implicitly by the compiler for parallel loop execution
- Implicitly by the compiler for parallel section execution.

If a common block is declared to be THREADLOCAL in one scoping unit, it must be declared to be THREADLOCAL in every scoping unit that declares the common block.

If a THREADLOCAL common block that does not have the SAVE attribute is declared within a subprogram, the members of the block become undefined at subprogram RETURN or END, unless there is at least one other scoping unit in which the common block is accessible that is making a direct or indirect reference to the subprogram.

You cannot specify the same common_block_name for both a THREADLOCAL directive and a THREADPRIVATE directive.

**Example 1:** The following procedure "FORT_SUB" is invoked by two threads:

```fortran
SUBROUTINE FORT_SUB(IARG)
  INTEGER IARG
  CALL LIBRARY_ROUTINE1()
  CALL LIBRARY_ROUTINE2()
  ...
END SUBROUTINE FORT_SUB

SUBROUTINE LIBRARY_ROUTINE1()
  COMMON /BLOCK/ R
  SAVE /BLOCK/
  !IBM* THREADLOCAL /BLOCK/
  R = 1.0
  ...
END SUBROUTINE LIBRARY_ROUTINE1

SUBROUTINE LIBRARY_ROUTINE2()
  COMMON /BLOCK/ R
  SAVE /BLOCK/
  !IBM* THREADLOCAL /BLOCK/
  ...
  = R
  ...
END SUBROUTINE LIBRARY_ROUTINE2
```

**Example 2:** "FORT_SUB" is invoked by multiple threads. This is an invalid example because "FORT_SUB" and "ANOTHER_SUB" both declare /BLOCK/ to be THREADLOCAL. They intend to share the common block, but they are executed by different threads.

```fortran
SUBROUTINE FORT_SUB()
  COMMON /BLOCK/ J
  INTEGER :: J
  !IBM* THREADLOCAL /BLOCK/
  ! Each thread executing FORT SUB obtains its own copy of /BLOCK/
  INTEGER A(10)
  ...
  !IBM* INDEPENDENT
  DO INDEX = 1,10
    CALL ANOTHER_SUB(A(I))
  END DO
```

---

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END DO
...

END SUBROUTINE FORT_SUB

SUBROUTINE ANOTHER_SUB(AA)
  ! Multiple threads are used to execute ANOTHER_SUB
  INTEGER AA
  COMMON /BLOCK/ J
  INTEGER :: J
  !IBM* THREADLOCAL /BLOCK/
  ...
  AA = J
  ! The value of 'J' is undefined.
END SUBROUTINE ANOTHER_SUB

Related reference:
- See -qdirective in the Compiler Reference
- See -qinit in the Compiler Reference
- See COMMON in the Language Reference
- See Main program in the Language Reference

THREADPRIVATE
Purpose

The THREADPRIVATE directive allows you to specify named common blocks and named variables as private to a thread but global within that thread. Once you declare a common block or variable THREADPRIVATE, each thread in the team maintains a separate copy of that common block or variable. Data written to a THREADPRIVATE common block or variable remains private to that thread and is not visible to other threads in the team.

In the serial and MASTER sections of a program, only the master thread’s copy of the named common block and variable is accessible.

Use the COPYIN clause on the PARALLEL, PARALLEL DO, PARALLEL SECTIONS or PARALLEL WORKSHARE directives to specify that upon entry into a parallel region, data in the master thread's copy of a named common block or named variable is copied to each thread's private copy of that common block or variable.

Required option
-q SMP

Syntax
**common_block_name**  
is the name of a common block to be made private to a thread.

**variable_name**  
is the name of a variable to be made private to a thread.

### Rules

You cannot specify a THREADPRIVATE variable, common block, or the variables that comprise that common block in a PRIVATE, FIRSTPRIVATE, LASTPRIVATE, SHARED, or REDUCTION clause.

A THREADPRIVATE variable must have the SAVE attribute. For variables or common blocks declared in the scope of a module, the SAVE attribute is implied. If you declare the variable outside of the scope of the module, the SAVE attribute must be specified.

In THREADPRIVATE directives, you can only specify named variables and named common blocks.

A variable can only appear in a THREADPRIVATE directive in the scope in which it is declared, and a THREADPRIVATE variable or common block may only appear once in a given scope. The variable must not be an element of a common block, or be declared in an EQUIVALENCE statement.

You cannot specify the same common_block_name for both a THREADPRIVATE directive and a THREADLOCAL directive.

All rules and constraints that apply to named common blocks also apply to common blocks declared as THREADPRIVATE. See the COMMON statement in the XL Fortran Language Reference.

If you declare a common block as THREADPRIVATE in one scoping unit, you must declare it as THREADPRIVATE in all other scoping units in which it is declared.

If you declare a THREADPRIVATE variable or a THREADPRIVATE common block with the BIND attribute, you must specify the corresponding C entities in a THREADPRIVATE directive in the C program. See Example 4 for the detailed usage information.

On entry into any parallel region, a THREADPRIVATE variable, or a variable in a THREADPRIVATE common block specified in a COPYIN clause is subject to the criteria stated in the Rules section for the COPYIN clause.
On entry into the first parallel region of the program, THREADPRIVATE variables or variables within a THREADPRIVATE common block not specified in a COPYIN clause are subject to the following criteria:

- If the variable has the ALLOCATABLE attribute, the initial allocation status of each copy of that variable is not currently allocated.
- If the variable has the POINTER attribute, and that pointer is disassociated through either explicit or default initialization, the association status of each copy of that variable is disassociated. Otherwise, the association status of the pointer is undefined.
- If the variable has neither the ALLOCATABLE nor the POINTER attribute and is defined through either explicit or default initialization, then each copy of that variable is defined. If the variable is undefined, then each copy of that variable is undefined.

On entry into subsequent parallel regions of the program, THREADPRIVATE variables, or variables within a THREADPRIVATE common block not specified in a COPYIN clause, are subject to the following criteria:

- If you are using the OMP_DYNAMIC environment variable, or the omp_set_dynamic subroutine to enable dynamic threads and:
  - If the number of threads is smaller than the number of threads in the previous region, and if a THREADPRIVATE object is referenced in both regions, then threads with the same thread number in their respective regions will reference the same copy of that variable.
  - If the number of threads is larger than the number of threads in the previous region, then the definition and association status of a THREADPRIVATE object is undefined, and the allocation status is undefined.
- If dynamic threads are disabled, the definition, association, or allocation status and definition, if the thread's copy of the variable was defined, is retained.

You cannot access the name of a common block by use association or host association. Thus, a named common block can only appear on a THREADPRIVATE directive if the common block is declared in the scoping unit that contains the THREADPRIVATE directive. However, you can access the variables in the common block by use association or host association. For more information, see Host and Use association in the XL Fortran Language Reference.

The -qinit=f90ptr compiler option does not affect pointers that you have declared in a THREADPRIVATE common block.

The DEFAULT clause does not affect variables in THREADPRIVATE common blocks.

Examples

Example 1: In this example, the PARALLEL DO directive invokes multiple threads that call SUB1. The common block BLK in SUB1 shares the data that is specific to the thread with subroutine SUB2, which is called by SUB1.

```fortran
PROGRAM TT
  INTEGER :: I, B(50)
!
!$OMP PARALLEL DO SCHEDULE(STATIC, 10)
  DO I=1, 50
    CALL SUB1(I, B(I))  ! Multiple threads call SUB1.
  ENDDO
END PROGRAM TT
```

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SUBROUTINE SUB1(J, X)
  INTEGER :: J, X, A(100)
  COMMON /BLK/ A
  !$OMP THREADPRIVATE(/BLK/)
  ! Array a is private to each thread.
  ! ...
  CALL SUB2(J)
  X = A(J) + A(J + 50)
  ! ...
END SUBROUTINE SUB1

SUBROUTINE SUB2(K)
  INTEGER :: C(100)
  COMMON /BLK/ C
  !$OMP THREADPRIVATE(/BLK/)
  ! ...
  C = K
  ! ...
END SUBROUTINE SUB2

Example 2: In this example, each thread has its own copy of the common block ARR in the parallel section. If one thread initializes the common block variable TEMP, the initial value is not visible to other threads.

PROGRAM ABC
  INTEGER :: I, TEMP(100), ARR1(50), ARR2(50)
  COMMON /ARR/ TEMP
  !$OMP THREADPRIVATE(/ARR/)
  INTERFACE
    SUBROUTINE SUBS(X)
      INTEGER :: X(:)
    END SUBROUTINE
  END INTERFACE
  ! ...
  !$OMP PARALLEL SECTIONS
  !$OMP SECTION
    ! The thread has its own copy of the common block ARR.
    TEMP(1:100:2) = -1
    TEMP(2:100:2) = 2
    CALL SUBS(ARR1)
  !$OMP SECTION
    ! The thread has its own copy of the common block ARR.
    TEMP(1:100:2) = 1
    TEMP(2:100:2) = -2
    CALL SUBS(ARR2)
  !$OMP END PARALLEL SECTIONS
  ! ...
  PRINT *, SUM(ARR1), SUM(ARR2)
END PROGRAM ABC

SUBROUTINE SUBS(X)
  INTEGER :: K, X(:), TEMP(100)
  COMMON /ARR/ TEMP
  !$OMP THREADPRIVATE(/ARR/)
  ! ...
  DO K = 1, UBOUND(X, 1)
    X(K) = TEMP(K) + TEMP(K + 1)
      ! The thread is accessing its own copy of the common block.
  ENDDO
  ! ...
END SUBROUTINE SUBS
The expected output for this program is:

50 -50

**Example 3:** In the following example, local variables outside of a common block are declared as `THREADPRIVATE`.

```fortran
MODULE MDL
  INTEGER :: A(2)
  INTEGER, POINTER :: P
  INTEGER, TARGET :: T
!$OMP THREADPRIVATE(A, P)
END MODULE MDL

PROGRAM MVAR
  USE OMP_LIB
  USE MDL

  INTEGER :: I

  CALL OMP_SET_NUM_THREADS(2)
  A = (/1, 2/)
  T = 4
  P => T

!$OMP PARALLEL PRIVATE(I)
  I = OMP_GET_THREAD_NUM()
  IF (I .EQ. 0) THEN
    A(1) = 100
    T = 5
  ELSE IF (I .EQ. 1) THEN
    A(2) = 200
  END IF
!$OMP END PARALLEL

!$OMP PARALLEL PRIVATE(I)
  I = OMP_GET_THREAD_NUM()
  IF (I .EQ. 0) THEN
    PRINT *, 'A(2) = ', A(2)
    T = 5
  ELSE IF (I .EQ. 1) THEN
    PRINT *, 'A(1) = ', A(1)
  PRINT *, 'P => ', P
  END IF
!$OMP END PARALLEL

END PROGRAM MVAR
```

If dynamic threads mechanism is disabled, the expected output is:

- A(2) = 2
- A(1) = 1
- P => 5

or

- A(1) = 1
- P => 5
- A(2) = 2

**Example 4:** In this example, the C interoperable variable `NUMVAR` is declared as `THREADPRIVATE`. Changes made by thread 1 to the private copy of `NUMVAR` does not affect the copy of the master thread.

**Fortran source file**

```fortran
MODULE M
  USE, INTRINSIC :: ISO_C_BINDING
  INTEGER(C_INT), BIND(C) :: NUMVAR(10)
END MODULE M
```

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!$OMP THREADPRIVATE(NUMVAR)
END MODULE M

PROGRAM P
USE M
USE OMP_LIB
INTERFACE
  SUBROUTINE INIT_NUM() BIND(C)
  END SUBROUTINE INIT_NUM
END INTERFACE
  SUBROUTINE PRINT_NUM() BIND(C)
  END SUBROUTINE PRINT_NUM
END INTERFACE
INTEGER TNUM
CALL INIT_NUM()
CALL OMP_SET_NUM_THREADS(2)

!$OMP PARALLEL COPYIN(NUMVAR)
  TNUM = OMP_GET_THREAD_NUM()
  IF (TNUM .EQ. 0) THEN
    ! PROCESS NUMVAR
  ELSE IF (TNUM .EQ. 1) THEN
    NUMVAR = NUMVAR * 4
    CALL PRINT_NUM()
    ! PROCESS NUMVAR
  END IF
!$OMP END PARALLEL
CALL PRINT_NUM()
END PROGRAM P

Related reference:

- See COMMON in the Language Reference
- “OMP_DYNAMIC” on page 94
- “omp_set_dynamic(enable_expr)” on page 241
- “PARALLEL / END PARALLEL” on page 139
- “PARALLEL DO / END PARALLEL DO” on page 142
- “PARALLEL SECTIONS / END PARALLEL SECTIONS” on page 146

WORKSHARE / END WORKSHARE

Purpose

The WORKSHARE directive allows you to parallelize the execution of array operations. A WORKSHARE directive divides the tasks associated with an enclosed block of code into units of work. When a team of threads encounters a WORKSHARE directive, the threads in the team share the tasks, so that each unit of work executes exactly once.

Required option

-qsmp
Syntax

...WORKSHARE...

...block...

...END WORKSHARE...

block is a structured block of statements that allows work sharing within the lexical extent of the WORKSHARE construct. The execution of statements are synchronized so that statements whose result is a dependent on another statement are evaluated before that result is required. The block can contain any of the following:

* Array assignment statements
* ATOMIC directives
* CRITICAL constructs
* FORALL constructs
* FORALL statements
* PARALLEL constructs
* PARALLEL DO constructs
* PARALLEL SECTION constructs
* PARALLEL WORKSHARE constructs
* Scalar assignment statements
* WHERE constructs
* WHERE statements

The transformational intrinsic functions you can use as part of an array operation are:

- ALL
- ANY
- COUNT
- CSHIFT
- DOT_PRODUCT
- ESHIFT
- MATMUL
- MAXLOC
- MAXVAL
- MINLOC
- MINVAL
- PACK
- PRODUCT
- RESHAPE
- SPREAD
- SUM
- TRANSPOSE
- UNPACK

The block can also contain statements bound to lexically enclosed PARALLEL constructs. These statements are not restricted.

Any user–defined function calls within the block must be elemental.

Statements enclosed in a WORKSHARE directive are divided into units of work. The definition of a unit of work varies according to the statement evaluated. A unit of work is defined as follows:

* Array expressions: Evaluation of each element of an array expression is a unit of work. Any of the transformational intrinsic functions listed above may be divided into any number of units of work.
• **Assignment statements:** In an array assignment statement, the assignment of each element in the array is a *unit of work*. For scalar assignment statements, the assignment operation is a *unit of work*.

• **Constructs:** Evaluation of each **CRITICAL** construct is a *unit of work*. Each **PARALLEL** construct contained within a **WORKSHARE** construct is a single *unit of work*. New teams of threads execute the statements contained within the lexical extent of the enclosed **PARALLEL** constructs. In **FORALL** constructs or statements, the evaluation of the mask expression, expressions occurring in the specification of the iteration space, and the masked assignments are *units of work*. In **WHERE** constructs or statements, the evaluation of the mask expression and the masked assignments are *units of work*.

• **Directives:** The update of each scalar variable for an **ATOMIC** directive and its assignments is a *unit of work*.

• **ELEMENTAL functions:** If the argument to an **ELEMENTAL** function is an array, then the application of the function to each element of an array is a *unit of work*.

If none of the above definitions apply to a statement within the *block*, then that statement is a *unit of work*.

**Rules**

In order to ensure that the statements within a **WORKSHARE** construct execute in parallel, the construct must be enclosed within a parallel region. Threads encountering a **WORKSHARE** construct outside the dynamic extent of a parallel region will evaluate the statements within the construct serially.

A **WORKSHARE** directive binds to the closest enclosing **PARALLEL** region if one exists.

You must not nest work-sharing regions that bind to the same **PARALLEL** region.

You must not specify a **WORKSHARE** directive within the **CRITICAL**, **MASTER**, or **ORDERED** regions.

You must not specify **BARRIER**, **MASTER**, or **ORDERED** directives within a **WORKSHARE** region.

If an array assignment, scalar assignment, a masked array assignment or a **FORALL** assignment assigns to a private variable in the *block*, the result is undefined.

If an array expression in the *block* references the value, association status or allocation status of private variables, the value of the expression is undefined unless each thread computes the same value.

If you do not specify a **NO WAIT** clause at the end of a **WORKSHARE** construct, a **BARRIER** directive is implied.

A **WORKSHARE** construct must be encountered by all threads in the team or by none at all.
Examples

Example 1: In the following example, the WORKSHARE directive evaluates the masked expressions in parallel.

```fortran
!$OMP WORKSHARE
   FORALL (I = 1 : N, AA(1, I) == 0) AA(1, I) = I
   BB = TRANSPOSE(AA)
   CC = MATMUL(AA, BB)
!$OMP ATOMIC
   S = S + SUM(CC)
!$OMP END WORKSHARE
```

Example 2: The following example includes a user defined ELEMENTAL as part of a WORKSHARE construct.

```fortran
!$OMP WORKSHARE
   WHERE (AA(1, :) /= 0.0) AA(1, :) = 1 / AA(1, :)
   DD = TRANS(AA(1, :))
!$OMP END WORKSHARE

ELEMENTAL REAL FUNCTION TRANS(ELM) RESULT(RES)
   REAL, INTENT(IN) :: ELM
   RES = ELM * ELM + 4
END FUNCTION
```

Related reference:
- “ATOMIC” on page 111
- “BARRIER” on page 116
- “CRITICAL / END CRITICAL” on page 117
- “PARALLEL WORKSHARE / END PARALLEL WORKSHARE” on page 148

See -qsmp in the Compiler Reference

Data sharing attribute rules

The rules of data sharing attributes determine the attributes of variables that are referenced in TARGET, PARALLEL, TASK and SIMD directives, and work-sharing 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 three categories

- Predetermined data sharing attributes
- Explicitly determined data sharing attributes
- Implicitly determined data sharing attributes

Predetermined data sharing attributes

Specifying a variable in a FIRSTPRIVATE, LASTPRIVATE, LINEAR, REDUCTION, or COPYPRIVATE clause of an enclosed construct initiates an implicit reference to the variable in the enclosing construct. Specifying a variable on a MAP clause of an enclosed construct might initiate 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 and common blocks specified in the THREADPRIVATE directive are threadprivate.
• The loop iteration variables in the associated DO loops of a DO or PARALLEL DO construct are private.
• Loop iteration variables for a sequential loop in a PARALLEL or TASK construct are private in the innermost such construct that encloses the loop.
• Implied-DO indices and FORALL indices are private.
• Integer pointees inherit the data sharing attributes of the storage with which their integer pointers are associated.
• Assumed-size arrays are shared.
• Any associate name preserves the association with the selector. The association is established by the ASSOCIATE statement.

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 DO loops of a DO or PARALLEL DO construct can be specified in a PRIVATE or LASTPRIVATE clause.
• Variables used as loop iteration variables in sequential loops within a PARALLEL or TASK construct can be specified in data sharing clauses on the construct itself, and on enclosed constructs, subject to other restrictions.
• Assumed-size arrays can be specified in a SHARED clause.

Explicitly determined data sharing attributes

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.

Implicitly determined data sharing attributes

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.

Rules for variables that have implicitly determined data sharing attributes are as follows:
• In a PARALLEL, TEAMS, 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 or TARGET, if no DEFAULT clause is present, the variables inherit their data sharing attributes from the enclosing context.
• In a TARGET construct, variables that are not mapped after applying data mapping attribute rules described in “TARGET / END TARGET” on page 162 are firstprivate.
• In a TASK construct, if no DEFAULT clause is present, a variable that is determined to be shared in the enclosing context by all implicit tasks bound to the current team is shared.

• In an orphaned TASK construct, if no DEFAULT clause is present, dummy arguments are firstprivate.

• 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

These rules determine the data sharing attributes of variables that are referenced in a region, but not in a construct.

• For local variables declared in called routines in the region, if the variables have the save attribute or are data initialized, then they are shared unless they are specified in a THREADPRIVATE directive.

• Variables that belong to common blocks, or declared in modules, and referenced in called procedures in the region are shared unless they are specified in a THREADPRIVATE directive.

• Dummy arguments of called procedures in the region that are passed by reference inherit the data sharing attributes of the associated actual argument.

• Integer pointees inherit the data sharing attribute of the storage with which their integer pointers are associated.

• Implied-DO indices, FORALL indices, and other local variables declared in procedures in the region are private.

Directive clauses

You can use directive clauses to specify additional information to directives.

Global rules for directive clauses

You must not specify a variable or common block name more than once in a clause.

A variable, common block name, or variable name that is a member of a common block must not appear in more than one clause on the same directive, with the following exceptions:

• You can define a named common block or named variable as FIRSTPRIVATE and LASTPRIVATE for the same directive.

• A variable appearing in a NUM_THREADS clause can appear in another clause for the same directive.

• A variable appearing in an IF clause can appear in another clause for the same directive.

If you do not specify a clause that changes the scope of a variable, the default scope for variables affected by a directive is SHARED.

A local variable with the SAVE or STATIC attribute declared in a procedure referenced a parallel region has an implicit SHARED attribute. A local variable without the SAVE or STATIC attribute declared in a procedure referenced a parallel region has an implicit PRIVATE attribute.
Members of common blocks and variables of modules declared in a procedure referenced within the dynamic extent of a parallel region have an implicit \texttt{SHARED} attribute, unless they are \texttt{THREADLOCAL} or \texttt{THREADPRIVATE} common blocks and module variables.

While a parallel or work-sharing construct is running, a variable or variable subobject used in a \texttt{PRIVATE, FIRSTPRIVATE, LASTPRIVATE} or \texttt{REDUCTION} clause of the directive must not be referenced, become defined, become undefined, have its association status or allocation status changed, or appear as an actual argument:

- In a scoping unit other than the one in which the directive construct appears
- In a variable format expression

You can declare a variable as \texttt{PRIVATE, FIRSTPRIVATE, LASTPRIVATE}, or \texttt{REDUCTION}, even if that variable is already storage associated with other variables. Storage association may exist for variables declared in \texttt{EQUIVALENCE} statements or in \texttt{COMMON} blocks. If a variable is storage associated with a \texttt{PRIVATE, FIRSTPRIVATE, LASTPRIVATE}, or \texttt{REDUCTION} variable, then:

- The contents, allocation status and association status of the variable that is storage associated with the \texttt{PRIVATE, FIRSTPRIVATE, LASTPRIVATE} or \texttt{REDUCTION} variable are undefined on entry to the parallel construct.
- The allocation status, association status and the contents of the associated variable become undefined if you define the \texttt{PRIVATE, FIRSTPRIVATE, LASTPRIVATE} or \texttt{REDUCTION} variable or if you define that variable's allocation or association status.
- The allocation status, association status and the contents of the \texttt{PRIVATE, FIRSTPRIVATE, LASTPRIVATE} or \texttt{REDUCTION} variable become undefined if you define the associated variable or if you define the associated variable's allocation or association status.

\section*{Pointers and OpenMP API}

OpenMP API allows a variable or variable subobject of a \texttt{PRIVATE} clause to have the \texttt{POINTER} or \texttt{ALLOCATABLE} attribute. The association status of the pointer is undefined at thread creation and when the thread is destroyed.

See the following topics for more information about the selected directive clauses. Note that this is not a complete list of all the supported directive clauses. You can find relevant information in the directive descriptions.

\begin{verbatim}
COLLAPSE     FIRSTPRIVATE     PRIVATE
COPYIN       LASTPRIVATE     REDUCTION
COPYPRIVATE   NUM_THREADS    SCHEDULE
DEFAULT      ORDERED        SHARED
IF
\end{verbatim}

\section*{Data sharing attribute clauses}

Data sharing attribute clauses refer to these clauses.

\textbf{Related information:}

- “Data sharing attribute rules” on page 193

\begin{verbatim}
DEFAULT:
\end{verbatim}
Purpose

If you specify the DEFAULT clause, all variables in the lexical extent of the parallel construct will have a scope attribute of default_scope_attr.

If you specify DEFAULT(NONE), there is no default scope attribute. Therefore, you must explicitly list each variable you use in the lexical extent of the parallel construct in a data scope attribute clause on the parallel construct, unless the variable is:

• THREADPRIVATE
• A member of a THREADPRIVATE common block.
• A pointee
• A loop iteration variable used only as a loop iteration variable for:
  – Sequential loops in the lexical extent of the parallel region, or,
  – Parallel do loops that bind to the parallel region
• A variable that is only used in work-sharing constructs that bind to the parallel region, and is specified in a data scope attribute clause for each of the work-sharing constructs.

The DEFAULT clause specifies that all variables in the parallel construct share the same default scope attribute of either FIRSTPRIVATE, PRIVATE, SHARED, or no default scope attribute.

Syntax

```
DEFAULT(--default_scope_attr--)
```

default_scope_attr

is one of FIRSTPRIVATE, PRIVATE, SHARED, or NONE

Rules

If you specify DEFAULT(NONE) on a directive you must specify all named variables and all the leftmost names of referenced array sections, array elements, structure components, or substrings in the lexical extent of the directive construct in a FIRSTPRIVATE, LASTPRIVATE, PRIVATE, REDUCTION, or SHARED clause.

If you specify DEFAULT(FIRSTPRIVATE) on a directive, all named variables and all leftmost names of referenced array sections, array elements, structure components, or substrings in the lexical extent of the directive construct, including common block and use associated variables, but excluding POINTEEs and THREADLOCAL common blocks, have a FIRSTPRIVATE attribute to a thread as if they were listed explicitly in a FIRSTPRIVATE clause.

If you specify DEFAULT(PRIVATE) on a directive, all named variables and all leftmost names of referenced array sections, array elements, structure components, or substrings in the lexical extent of the directive construct, including common block and use associated variables, but excluding POINTEEs and THREADLOCAL common blocks, have a PRIVATE attribute to a thread as if they were listed explicitly in a PRIVATE clause.
If you specify **DEFAULT(SHARED)** on a directive, all named variables and all leftmost names of referenced array sections, array elements, structure components, or substrings in the lexical extent of the directive construct, excluding **POINTER**s have a **SHARED** attribute to a thread as if they were listed explicitly in a **SHARED** clause.

The default behavior will be **DEFAULT(SHARED)** if you do not explicitly indicate a **DEFAULT** clause on a directive.

**Example for OpenMP**

The following example demonstrates the use of **DEFAULT(NONE)** for OpenMP, and some of the rules for specifying the data scope attributes of variables in the parallel region.

```fortran
PROGRAM MAIN
    COMMON /COMBLK/ abc(10), def
    ! The loop iteration variable, i, is not required to be
    ! in data scope attribute clause.
    !$OMP PARALLEL DEFAULT(NONE) SHARED(ABC)
    ! def is specified on the work-sharing DO, and is not required to be
    ! specified in a data scope attribute clause on the parallel region.
    !$OMP DO FIRSTPRIVATE(def)
        DO i = 1,10
            ABC(i) = def
        END DO
    !$OMP END PARALLEL
END PROGRAM
```

**Related reference:**

- **PARALLEL / END PARALLEL**
- **PARALLEL DO / END PARALLEL DO**
- **PARALLEL SECTIONS / END PARALLEL SECTIONS**
- **PARALLEL WORKSHARE / END PARALLEL WORKSHARE**
- **"TASK / END TASK"** on page 176

**SHARED:**

**Purpose**

All sections use the same copy of the variables and common blocks you specify in `data_scope_entity_list`.

The **SHARED** clause specifies variables that must be available to all threads. If you specify a variable as **SHARED**, you are stating that all threads can safely share a single copy of the variable.

**Syntax**

```fortran
    data_scope_entity
```

```
    data_scope_entity
```
named_variable
is a named variable that is accessible in the directive construct

common_block_name
is a common block name that is accessible in the directive construct

Rules

A variable in the SHARED clause must not be either:

- A pointee
- A runtime size array, which can be an assumed-shape array, an allocatable array, an array pointer, or an explicitly array with runtime bounds
- A THREADLOCAL common block.
- A THREADPRIVATE common block or its members.
- A THREADPRIVATE variable.

If a SHARED variable, a subobject of a SHARED variable, or an object associated with a SHARED variable or subobject of a SHARED variable appears as an actual argument in a reference to a non-intrinsic procedure and:

- The actual argument is an array section with a vector subscript; or
- The actual argument is
  - An array section,
  - An assumed-shape array, or,
  - A pointer array

  and the associated dummy argument is an explicit-shape or assumed-size array;

then any references to or definitions of the shared storage that is associated with the dummy argument by any other thread must be synchronized with the procedure reference. In other words, you must structure your code in such a way that if a thread encounters a procedure reference, then the procedure call by that thread and any reference to or definition of the shared storage by any other thread will always occur in the same sequence. You can do this, for example, by placing the procedure reference after a BARRIER.

Example for OpenMP

In the following example, the procedure reference with an array section actual argument is required to be synchronized with references to the dummy argument by placing the procedure reference in a critical section, because the associated dummy argument is an explicit-shape array.

```
INTEGER :: abc(10)

i = 2
j = 5

!$OMP PARALLEL DEFAULT(NONE), SHARED(abc, i, j)
```
!$OMP CRITICAL
! Actual argument is an array section.
! The procedure reference must be in a critical section.
CALL sub1(abc(i: j))
!$OMP END CRITICAL
!$OMP END PARALLEL

CONTAINS
SUBROUTINE sub1(arr)
   INTEGER:: arr(1: 4)
   DO i = 1, 4
      arr(i) = i
   END DO
END SUBROUTINE
END

Related reference:
PARALLEL / END PARALLEL
PARALLEL DO / END PARALLEL DO
PARALLEL SECTIONS / END PARALLEL SECTIONS
PARALLEL WORKSHARE / END PARALLEL WORKSHARE
"TASK / END TASK" on page 176

PRIVATE:
Purpose

If you specify the PRIVATE clause on one of the directives listed below, each thread in a team has its own uninitialized local copy of the variables and common blocks in data_scope_entity_list.

You should specify a variable in the PRIVATE clause if its value is calculated by a single thread and that value is not dependent on any other thread, if it is defined before it is used in the construct, and if its value is not used after the construct ends. Copies of the PRIVATE variable exist, locally, on each thread. Each thread receives its own uninitialized copy of the PRIVATE variable. All thread variables within the lexical extent of the directive construct have the PRIVATE attribute by default.

Syntax

PRIVATE—(data_scope_entity_list)—

Rules

A variable in the PRIVATE clause must not be any of the following elements:

- A pointee
- An assumed-size array
- A runtime size array, which can be an assumed-shape array, an allocatable array, an array pointer, or an explicitly array with runtime bounds
- A THREADLOCAL common block
- A THREADPRIVATE common block or its members
- A THREADPRIVATE variable or the variable equivalenced with a THREADPRIVATE variable
You cannot specify a variable in a PRIVATE clause of a parallel construct if:

- the variable appears in a namelist statement, variable format expression or in an expression for a statement function definition, and,
- you reference the statement function, the variable format expression through formatted I/O, or the namelist through namelist I/O, within the parallel construct.

If one of the entities involved in an asynchronous I/O operation is a PRIVATE variable, a subobject of a PRIVATE variable, or a pointer that is associated with a PRIVATE variable, the matching implied wait or WAIT statement must be executed before the end of the thread.

When individual members of a common block are privatized, the storage of the specified variable is no longer associated with the storage of the common block.

A variable that appears in the REDUCTION clause of a parallel construct can also appear in a PRIVATE clause on a work-sharing construct.

If a directive construct contains a PRIVATE argument to a Message Passing Interface (MPI) routine performing non-blocking communication, the MPI communication must complete before the end of that construct.

A variable name in the data_scope_entity_list of the PRIVATE clause can be an allocatable array. If the allocatable array is allocated on entry to a parallel region, the private copies of the array has an allocation status of allocated and has the same rank and bounds as the PRIVATE variable. If the allocatable array is deallocated on entry to a parallel region, the private copies of the array has an allocation status of deallocated.

Local variables without the SAVE or STATIC attributes in referenced subprograms in the dynamic extent of a directive construct have an implicit PRIVATE attribute.

Examples for OpenMP

Example 1: The following example demonstrates the proper use of a PRIVATE variable that is used to define a statement function. A commented line shows the invalid use. Since $J$ appears in a statement function, the statement function cannot be referenced within the parallel construct for which $J$ is PRIVATE.

```
INTEGER :: arr(10), j = 17
ISTFNC() = j

!$OMP PARALLEL DO PRIVATE(j)
DO i = 1, 10
   j = i
   ! arr(i) = ISTFNC() **ERROR** A reference to ISTFNC would
   ! make the PRIVATE(j) clause invalid.
   arr(i) = j
END DO
PRINT *, arr
```

Example 2: The following example demonstrates the use of allocatable arrays on a PRIVATE clause:

```
USE OMP_LIB
REAL, ALLOCATABLE :: temp(:,:)
REAL :: arr(4, 20, 20)
INTEGER :: thd
```
ALLOCATE(temp(20, 20))
!$OMP PARALLEL PRIVATE(thd, temp) NUM_THREADS(4)

! Private copies of "temp" are allocated with the same
! bounds and shape of the original "temp".
thd = OMP_GET_THREAD_NUM()
IF(MOD(thd, 2).EQ. 0) THEN
  temp = RESHAPE((/(i, i=1, 400)/), (/20, 20/))
ELSE
  temp = RESHAPE((/(i, i=1, 800, 2)/), (/20, 20/))
ENDIF
arr(thd + 1, :, :) = temp

! Private copies of "temp" are deallocated.
!$OMP END PARALLEL
DEALLOCATE(temp)
END

Note: If the machine has less than 4 CPUs, you must set OMP_THREAD_LIMIT=4.

Example 3: The following example demonstrates the persistence of the original
value of the PRIVATE variables after exit from a parallel region:

PROGRAM MAIN
  INTEGER :: i, j
  i = 1
  j = 2
  !$OMP PARALLEL PRIVATE(i, j)
  i = 3
  j = j + 2
  !$OMP END PARALLEL
  PRINT *, i, j ! Output: 1 2
END PROGRAM

Related reference:
DO / END DO
PARALLEL / END PARALLEL
PARALLEL DO / END PARALLEL DO
PARALLEL SECTIONS / END PARALLEL SECTIONS
PARALLEL WORKSHARE / END PARALLEL WORKSHARE
SECTIONS / END SECTIONS
SINGLE / END SINGLE
"TASK / END TASK" on page 176

FIRSTPRIVATE:
Purpose

If you use the FIRSTPRIVATE clause, each thread has its own initialized local
copy of the variables and common blocks in data_scope_entity_list.

The FIRSTPRIVATE clause can be specified for the same variables as the PRIVATE
clause, and functions in a manner similar to the PRIVATE clause. The exception is
the status of the variable upon entry into the directive construct; the
FIRSTPRIVATE variable exists and is initialized for each thread entering the
directive construct.
Syntax

```fortran
FIRSTPRIVATE(data_scope_entity_list)
```

Rules

A variable in a `FIRSTPRIVATE` clause must not be any of the following elements:

- A pointee
- An assumed-size array
- A runtime size array, which can be an assumed-shape array, an allocatable array, an array pointer, or an explicitly array with runtime bounds
- A `THREADLOCAL` common block
- A `THREADPRIVATE` common block or its members
- A `THREADPRIVATE` variable

You cannot specify a variable in a `FIRSTPRIVATE` clause of a parallel construct if both the following conditions are true:

- The variable appears in a namelist statement, variable format expression or in an expression for a statement function definition.
- You reference the statement function, the variable format expression through formatted I/O, or the namelist through namelist I/O, within the parallel construct.

For a variable specified in the `FIRSTPRIVATE` clause, the status of the private copies is determined as follows:

- If the variable has the `POINTER` attribute, the private copies of the `FIRSTPRIVATE` variable receive the same association status as the original copy as if by pointer assignment.
- If the variable does not have the `POINTER` attribute, the initialization of the private copies occurs as if by intrinsic assignment. However, if the original variable is not currently allocated, the private copies have the same allocation status as the original copy.

If an allocatable array appears on a `FIRSTPRIVATE` clause, it must have an allocation status of allocated upon entrance into the parallel construct that contains the `FIRSTPRIVATE` clause.

When individual members of a common block are privatized, the storage of the specified variable is no longer associated with the storage of the common block.

Any variable that is storage associated with a `FIRSTPRIVATE` variable is undefined on entrance into the parallel construct.

If one of the entities involved in an asynchronous I/O operation is a `FIRSTPRIVATE` variable, a subobject of a `FIRSTPRIVATE` variable, or a pointer that is associated with a `FIRSTPRIVATE` variable, the matching implied wait or `WAIT` statement must be executed before the end of the thread.

If a directive construct contains a `FIRSTPRIVATE` argument to a Message Passing Interface (MPI) routine performing non-blocking communication, the MPI communication must complete before the end of the construct.
**Related reference:**

```fortran
DO / END DO
PARALLEL / END PARALLEL
PARALLEL DO / END PARALLEL DO
PARALLEL SECTIONS / END PARALLEL SECTIONS
PARALLEL WORKSHARE / END PARALLEL WORKSHARE
SECTIONS / END SECTIONS
SINGLE / END SINGLE
"TASK / END TASK" on page 176
```

**LASTPRIVATE:**

**Purpose**

If you use the `LASTPRIVATE` clause, each variable and common block in `data_scope_entity_list` is `PRIVATE`, and the last value of each variable in `data_scope_entity_list` can be referred to outside of the construct of the directive. If you use the `LASTPRIVATE` clause with `DO` or `PARALLEL DO`, the last value is the value of the variable after the last sequential iteration of the loop. If you use the `LASTPRIVATE` clause with `SECTIONS` or `PARALLEL SECTIONS`, the last value is the value of the variable after the last `SECTION` of the construct. If the last iteration of the loop or last section of the construct does not define a `LASTPRIVATE` variable, the variable is undefined after the loop or construct.

The `LASTPRIVATE` clause functions in a manner similar to the `PRIVATE` clause and you should specify it for variables that match the same criteria. The exception is in the status of the variable on exit from the directive construct. The compiler determines the last value of the variable, and takes a copy of that value which it saves in the named variable for use after the construct. A `LASTPRIVATE` variable is undefined on entry to the construct if it is not a `FIRSTPRIVATE` variable.

**Syntax**

```fortran
LASTPRIVATE—(—data_scope_entity_list—)◄◄
```

**Rules**

A variable in a `LASTPRIVATE` clause must not be any of the following elements:

- A pointee
- An assumed-size array
- A runtime size array, which can be an assumed-shape array, an allocatable array, an array pointer, or an explicitly array with runtime bounds
- A `THREADLOCAL` common block
- A `THREADPRIVATE` common block or its members
- A `THREADPRIVATE` variable

You cannot specify a variable in a `LASTPRIVATE` clause of a parallel construct if both the following conditions are true:

- The variable appears in a namelist statement, variable format expression or in an expression for a statement function definition.
• You reference the statement function, the variable format expression through formatted I/O, or the namelist through namelist I/O, within the parallel construct.

A **LASTPRIVATE** variable must be definable.

For a variable specified in a **LASTPRIVATE** clause,

• If the variable has the **POINTER** attribute, the original variable is updated as if by pointer assignment.
• If the variable does not have the **POINTER** attribute, the original variable is updated as if by intrinsic assignment.

If an allocatable array appears on a **LASTPRIVATE** clause, its allocation status must be allocated when it enters into the parallel construct that contains the **LASTPRIVATE** clause. The private copies of the **LASTPRIVATE** variable in the sequentially last iteration or lexically last section must have an allocation status of allocated. They must have the same bounds and rank as the corresponding **LASTPRIVATE** variable when they exit from that iteration or section.

When individual members of a common block are privatized, the storage of the specified variable is no longer associated with the storage of the common block.

Any variable that is storage associated with a **LASTPRIVATE** variable is undefined on entrance into the parallel construct.

If you specify a variable as **LASTPRIVATE** on a work-sharing directive, and you have specified a **NOWAIT** clause on that directive, you cannot use that variable between the end of the work-sharing construct and a **BARRIER** directive.

Variables that you specify as **LASTPRIVATE** to a parallel construct become defined at the end of the construct. If you have concurrent definitions or uses of **LASTPRIVATE** variables on multiple threads, you must ensure that the threads are synchronized at the end of the construct when the variables become defined. For example, if multiple threads encounter a **PARALLEL** construct with a **LASTPRIVATE** variable, you must synchronize the threads when they reach the **END PARALLEL** directive, because the **LASTPRIVATE** variable becomes defined at **END PARALLEL**. Therefore the whole **PARALLEL** construct must be enclosed within a synchronization construct.

If one of the entities involved in an asynchronous I/O operation is a **LASTPRIVATE**, a subobject of a **LASTPRIVATE** variable, or a pointer that is associated with a **LASTPRIVATE** variable, the matching implied wait or **WAIT** statement must be executed before the end of the thread.

If a directive construct contains a **LASTPRIVATE** argument to a Message Passing Interface (MPI) routine performing non-blocking communication, the MPI communication must complete before the end of that construct.

**Example for OpenMP**

The following example shows the proper use of a **LASTPRIVATE** variable after a **NOWAIT** clause.

```fortran
!$OMP PARALLEL
!$OMP DO LASTPRIVATE(k)
DO i = 1,10
  k = i + 1
```

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END DO

!$OMP END DO NOWAIT
k = ... **ERROR**! The reference to k must occur after a barrier.

!$OMP BARRIER
k = ...! this reference to k is valid.

!$OMP END PARALLEL
END

Related reference:

DO / END DO
PARALLEL DO / END PARALLEL DO
PARALLEL SECTIONS / END PARALLEL SECTIONS
SECTIONS / END SECTIONS

REDUCTION:

Purpose

The REDUCTION clause updates named variables declared on the clause within the directive construct. Intermediate values of REDUCTION variables are not used within the parallel construct other than in the updates themselves.

Syntax

```
REDUCTION(reduction-identifier: variable_name_list)
```

reduction-identifier

is a reduction_op or a reduction_function that appears in all REDUCTION statements involving this variable. You must not specify more than one REDUCTION operator or function for a variable in the directive construct. To maintain OpenMP API compliance, you must specify reduction-identifier for the REDUCTION clause.

A REDUCTION statement can have one of the following forms:

```
reduction_var_ref = expr reduction_op reduction_var_ref
```

```
reduction_var_ref = reduction_var_ref reduction_op expr
```

```
reduction_var_ref = reduction_function(expr, reduction_var_ref)
```

```
reduction_var_ref = reduction_function(reduction_var_ref, expr)
```

where:

reduction_var_ref

is a variable or subobject of a variable that appears in a REDUCTION clause.
reduction_op

is one of the intrinsic operators: +, -, *, .AND., .OR., .EQV., .NEQV., or .XOR.

when reduction_op is an intrinsic operator, it should be the last operation performed on the right side.

reduction_function

is one of the intrinsic procedures: MAX, MIN, IAND, IOR, or IEB.

expr should not contain references to reduction_var_ref

The canonical initialization value of each of the operators and intrinsics is shown in the following table. The actual initialization value will be consistent with the data type of your corresponding REDUCTION variable.

<table>
<thead>
<tr>
<th>Intrinsic Operator</th>
<th>Initialization</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>*</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>.AND.</td>
<td>.TRUE.</td>
</tr>
<tr>
<td>.OR.</td>
<td>.FALSE.</td>
</tr>
<tr>
<td>.EQV.</td>
<td>.TRUE.</td>
</tr>
<tr>
<td>.NEQV.</td>
<td>.FALSE.</td>
</tr>
<tr>
<td>.XOR.</td>
<td>.FALSE.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intrinsic Procedure</th>
<th>Initialization</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>Smallest representable number</td>
</tr>
<tr>
<td>MIN</td>
<td>Largest representable number</td>
</tr>
<tr>
<td>IAND</td>
<td>All bits on</td>
</tr>
<tr>
<td>IOR</td>
<td>0</td>
</tr>
<tr>
<td>IEB</td>
<td>0</td>
</tr>
</tbody>
</table>

Rules

The following rules apply to REDUCTION statements:

- A variable in the REDUCTION clause must only occur in a REDUCTION statement within the directive construct on which the REDUCTION clause appears.

- The two reduction_var_refs that appear in a REDUCTION statement must be lexically identical.

- You cannot use the following form of the REDUCTION statement:

  reduction_var_ref = expr operator reduction_var_ref, where operator is any operator other than reduction_op.

When you specify individual members of a common block in a REDUCTION clause, the storage of the specified variable is no longer associated with the storage of the common block.

Any variable you specify in a REDUCTION clause of a work-sharing construct must be shared in the enclosing PARALLEL construct.
A variable that appears in the REDUCTION clause of a parallel construct can also appear in a PRIVATE clause on a work-sharing construct.

If you use a REDUCTION clause on a construct that has a NOWAIT clause, the REDUCTION variable remains undefined until a barrier synchronization has been performed to ensure that all threads have completed the REDUCTION clause.

A REDUCTION variable must not appear in a FIRSTPRIVATE, PRIVATE, or LASTPRIVATE clause of another construct within the dynamic extent of the construct in which it appeared as a REDUCTION variable.

If you specify reduction-identifier for the REDUCTION clause, each variable in the variable_name_list must be of intrinsic type. The variable can only appear in a REDUCTION statement within the lexical extent of the directive construct. You must specify reduction-identifier if the directive uses the trigger_constant $OMP.

The REDUCTION clause specifies named variables that appear in reduction operations. The compiler will maintain local copies of such variables, but will combine them upon exit from the construct. The intermediate values of the REDUCTION variables are combined in random order, dependent on which threads finish their calculations first. Therefore, there is no guarantee that bit-identical results will be obtained from one parallel run to another. This is true even if the parallel runs use the same number of threads, scheduling type, and chunk size.

Variables that you specify as REDUCTION or LASTPRIVATE to a parallel construct become defined at the end of the construct. If you have concurrent definitions or uses of REDUCTION or LASTPRIVATE variables on multiple threads, you must ensure that the threads are synchronized at the end of the construct when the variables become defined. For example, if multiple threads encounter a PARALLEL construct with a REDUCTION variable, you must synchronize the threads when they reach the END PARALLEL directive, because the REDUCTION variable becomes defined at END PARALLEL. Therefore the whole PARALLEL construct must be enclosed within a synchronization construct.

If an allocatable array appears on a REDUCTION clause, it must have an allocation status of allocated upon entrance into the construct that contains the REDUCTION clause. Additionally, the private copies of the REDUCTION variable must not be deallocated or allocated within the region.

A variable in the REDUCTION clause must be of intrinsic type. A variable in the REDUCTION clause, or any element thereof, must not be any of the following:

- A pointee
- An assumed-size array
- A runtime size array, which can be an assumed-shape array, an allocatable array, an array pointer, or an explicitly array with runtime bounds
- A THREADLOCAL common block
- A THREADPRIVATE common block or its members
- A THREADPRIVATE variable
- An allocatable scalar object
- A Fortran 90 pointer

These rules describe the use of REDUCTION on OpenMP directives. If you are using the REDUCTION clause on the INDEPENDENT directive, see the
INDEPENDENT directive in the XL Fortran Language Reference directive.

Related reference:

DO / END DO
PARALLEL / END PARALLEL
PARALLEL DO / END PARALLEL DO
PARALLEL SECTIONS / END PARALLEL SECTIONS
PARALLEL WORKSHARE / END PARALLEL WORKSHARE
SECTIONS / END SECTIONS

COLLAPSE

Purpose

Specifying the COLLAPSE clause allows you to parallelize multiple loops in a nest without introducing nested parallelism.

Syntax

\[
\text{COLLAPSE} (\langle n \rangle)
\]

\(n\) is a positive constant integer expression

Rules

- Only one collapse clause is allowed on a worksharing DO or PARALLEL DO directive.
- The specified number of loops must be present lexically. That is, none of the loops can be in a called subroutine.
- The loops must form a rectangular iteration space and the bounds and stride of each loop must be invariant over all the loops.
- If the loop indices are of different size, the index with the largest size will be used for the collapsed loop.
- The loops must be perfectly nested; that is, there is no intervening code nor any OpenMP directive between the loops which are collapsed.
- The associated do-loops must be structured blocks. Their execution must not be terminated by an EXIT statement.
- If multiple loops are associated with the loop construct, only an iteration of the innermost associated loop may be curtailed by a CYCLE statement. If multiple loops are associated with the loop construct, there must be no branches to any of the loop termination statements except for the innermost associated loop.

Ordered construct

During execution of an iteration of a loop or a loop nested within a loop region, the executing thread must not execute more than one ordered region which binds to the same loop region. As a consequence, if multiple loops are associated with the loop construct by a collapse clause, the ordered construct has to be located inside all associated loops.

LASTPRIVATE clause

When a LASTPRIVATE clause appears on the directive that identifies a work-sharing construct, the value of each new list item from the sequentially last iteration of the associated loops is assigned to the original list item even if a collapse clause is associated with the loop.
Other SMP and performance directives

The STREAM_UNROLL, UNROLL, UNROLL_AND_FUSE, and NOUNROLL_AND_FUSE directives cannot be used for any of the loops associated with the COLLAPSE clause loop nest. The INDEPENDENT directive can be used for any of the loops associated with the COLLAPSE clause.

Examples

In Example 1 and Example 2 the loops over k and j are collapsed and their iteration space is executed by all threads of the current team.

Example 1

```fortran
!$omp do collapse(2) private(i,j,k)
  do k = kl, ku, ks
    do j = jl, ju, js
      do i = il, iu, is
        call bar(a,i,j,k)
      enddo
    enddo
  enddo
!$omp end do
```

Example 2

```fortran
program test
 !$omp parallel
 !$omp do private(j,k) collapse(2) lastprivate(jlast, klast)
  do k = 1,2
    do j = 1,3
      jlast=j
      klast=k
    enddo
  enddo
 !$omp end do
 !$omp single
   print *, klast, jlast
 !$omp end single
 !$omp end parallel
end program test
```

Output:

2 3

Example 3

As both loops are collapsed into one, the ordered construct has to be inside all loops associated with the for construct. As an iteration may not execute more than one ordered region, this program would be incorrect without the collapse(2) clause.

```fortran
program test
 !$omp parallel num_threads(2)
 !$omp do collapse(2) ordered private(j,k) schedule(static,3)
  do k = 1,3
    do j = 1,2
     !$omp ordered
      print *, k, j
     !$omp end ordered
  enddo
```
enddo
!$omp end do
!$omp end parallel
end program test

Output:
1 1
1 2
2 1
2 2
3 1
3 2

Related reference:
ORDERED / END ORDERED
DO / END DO
PARALLEL DO / END PARALLEL DO

COPYIN
Purpose

If you specify the COPYIN clause, the master thread’s copy of each variable, or common block declared in the copyin_entity_list is duplicated at the beginning of a parallel region. Each thread in the team that will execute within that parallel region receives a private copy of all entities in the copyin_entity_list. All variables declared in the copyin_entity_list must be THREADPRIVATE or members of a common block that appears in a THREADPRIVATE directive.

Syntax

```
COPYIN—(—copyin_entity_list—)
```

copyin_entity

```
variable_name
/—common_block_name—/
```

variable is a THREADPRIVATE variable, or THREADPRIVATE variable in a common block.

common_block_name is a THREADPRIVATE common block name.

Rules

If you specify a COPYIN clause, you cannot:

- specify the same entity name more than once in a copyin_entity_list.
• specify the same entity name in separate COPYIN clauses on the same directive.
• specify both a common block name and any variable within that same named common block in a copyin_entity_list.
• specify both a common block name and any variable within that same named common block in different COPYIN clauses on the same directive.

When the master thread of a team of threads reaches a directive containing the COPYIN clause, each thread’s private copy of a variable or common block specified in the COPYIN clause will have the same value as the master thread’s copy.

On entry into any parallel region, a THREADPRIVATE variable, or a variable in a THREADPRIVATE common block is subject to the following criteria when declared in a COPYIN clause:
• If the variable has the POINTER attribute and the master thread’s copy of the variable is associated with a target, then each copy of that variable is associated with the same target. If the master thread’s pointer is disassociated, then each copy of that variable is disassociated. If the master thread’s copy of the variable has an undefined association status, then each copy of that variable has an undefined association status.
• Each copy of a variable without the POINTER attribute becomes defined with the value of the master thread’s copy as if by intrinsic assignment.

If an allocatable array is specified in a COPYIN clause and it is allocated on entry into a parallel region, each thread copy of that array must be allocated with the same bounds and rank.

Related reference:
PARALLEL / END PARALLEL
PARALLEL DO / END PARALLEL DO
PARALLEL SECTIONS / END PARALLEL SECTIONS
PARALLEL WORKSHARE / END PARALLEL WORKSHARE

COPYPRIVATE

Purpose
If you specify the COPYPRIVATE clause, the value of a private variable or pointer to a shared object from one thread in a team is copied into the corresponding variables of all other threads in that team. If the variable in copyprivate_entity_list is not a pointer, then the corresponding variables of all threads within that team are defined with the value of that variable. If the variable is a pointer, then the corresponding variables of all threads within that team are defined with the association status of the pointer. Integer pointers and assumed-size arrays must not appear in copyprivate_entity_list.

Syntax

```
COPYPRIVATE(copyprivate_entity_list)
```

copyprivate_entity
variable is a private variable within the enclosing parallel region

common_block_name is a THREADPRIVATE common block name

Rules

If a common block is part of the copyprivate_entity_list, then it must appear in a THREADPRIVATE directive. Furthermore, the COPYPRIVATE clause treats a common block as if all variables within its object_list were specified in the copyprivate_entity_list.

A COPYPRIVATE clause must occur on an END SINGLE directive at the end of a SINGLE construct. The compiler evaluates a COPYPRIVATE clause before any threads have passed the implied BARRIER directive at the end of that construct. The variables you specify in copyprivate_entity_list must not appear in a PRIVATE or FIRSTPRIVATE clause for the SINGLE construct. If the END SINGLE directive occurs within the dynamic extent of a parallel region, the variables you specify in copyprivate_entity_list must be private within that parallel region.

A COPYPRIVATE clause must not appear on the same END SINGLE directive as a NOWAIT clause.

A THREADLOCAL common block, or members of that common block, are not permitted as part of a COPYPRIVATE clause.

If an allocatable array appears on a COPYPRIVATE clause, it must have an allocation status of allocated with the same bounds and rank in all threads that are affected by the COPYPRIVATE clause.

Related reference:
SINGLE / END SINGLE

FINAL

Purpose

The FINAL clause is used with the TASK directive. If you specify a FINAL clause and the scalar_logical_expr evaluates to .TRUE., the generated task is a final task. All task constructs encountered inside a final task create final and included tasks.

Syntax

FINAL—(scalar_logical_expr)
Rules

You can specify only one FINAL clause on the TASK directive.

Related reference

"TASK / END TASK" on page 176

IF

Purpose

When the IF clause is used in the PARALLEL, PARALLEL DO, PARALLEL SECTIONS, PARALLEL WORKSHARE, and TASK directives, the runtime environment evaluates whether the scalar_logical_expression is true or false, and the behaviour is as follows:

• If scalar_logical_expression is true, the block is run in parallel.
• If scalar_logical_expression is false, the containing region is suspended and the generated task is immediately run as though it is in a distinct task region.

Note that for the TASK directive, if the IF clause is evaluated to true, the block is not required to run in parallel.

When the IF clause is used in other directives, see the description of the directives for its specific purpose.

Syntax

\[
\text{IF} \((\text{scalar_logical_expression})\) \text{directive-name-modifier}\]

where directive-name-modifier is the name of the directive that scalar_logical_expression applies to. Specifying directive-name-modifier is useful for composite and combined constructs.

Rules

The IF clause may appear at most once in any directive.

By default, a nested parallel loop is serialized, regardless of the setting of the IF clause. You can change this default by using the -qsm=nest ed_par compiler option.

An IF expression is evaluated outside of the context of the parallel construct. Any function reference in the IF expression must not have side effects.

Related reference:

"PARALLEL / END PARALLEL" on page 139
"PARALLEL DO / END PARALLEL DO" on page 142
"PARALLEL SECTIONS / END PARALLEL SECTIONS" on page 146
"PARALLEL WORKSHARE / END PARALLEL WORKSHARE" on page 148
"TASK / END TASK" on page 176
MERGEABLE

Purpose

The MERGEABLE clause is used with the TASK directive. If you specify a MERGEABLE clause and the generated task is an undefined task or an included task, a merged task might be generated.

Syntax

```
->MERGEABLE<-  
```

Related reference

“TASK / END TASK” on page 176

NUM_THREADS

Purpose

The NUM_THREADS clause allows you to specify the number of threads used in a parallel region. Subsequent parallel regions are not affected. The NUM_THREADS clause takes precedence over the number of threads specified using the omp_set_num_threads library routine or the environment variable OMP_NUM_THREADS.

Syntax

```
->NUM_THREADS—(<scalar_integer_expression>)<-  
```

Rules

The value of scalar_integer_expression must be a positive integer. Evaluation of the expression occurs outside the context of the parallel region. Any function calls that appear in the expression and change the value of a variable referenced in the expression will have unspecified results.

If you are using the environment variable OMP_DYNAMIC to enable dynamic threads, scalar_integer_expression defines the maximum number of threads available in the parallel region.

You must specify the omp_set_nested library routine or set the OMP_NESTED environment variable when including the NUM_THREADS clause as part of a nested parallel regions; otherwise, the execution of that parallel region is serialized.

Related reference:

PARALLEL / END PARALLEL
PARALLEL DO / END PARALLEL DO
PARALLEL SECTIONS / END PARALLEL SECTIONS
PARALLEL WORKSHARE / END PARALLEL WORKSHARE
**ORDERED**

**Purpose**

Specifying the **ORDERED** clause on a work-sharing construct allows you to specify the **ORDERED** directive within the dynamic extent of a parallel loop.

**Syntax**

\[ \text{ORDERED} (n) \]

\( n \) A constant positive integer representing the number of the loops that are associated with the loop construct. \( n \) does not affect how the logical iteration space is divided. If \( n \) is specified for the loop construct, the associated loops form a doacross loop nest, which is a loop nest that has cross-iteration dependence.

**Rules**

The **ORDERED** clause applies to the following directives:

- "DO / END DO" on page 127
- "PARALLEL DO / END PARALLEL DO" on page 142

**Related reference**

- "DO / END DO" on page 127
- "PARALLEL DO / END PARALLEL DO" on page 142

**PROC_BIND**

**Purpose**

The **PROC_BIND** clause specifies a policy for binding and distributing threads to places within the current place partition.

**Syntax**

\[ \text{PROC_BIND} ( ) \]

- **MASTER**
  
  Instructs the execution environment to assign every thread in the team to the same place as the master thread.

- **CLOSE**
  
  Instructs the execution environment to assign the threads to places that are close to the place of the parent’s thread. The master thread executes on the parent’s place. The remaining threads in the team execute on places from the place list consecutive from the parent’s position in the list with wrap around.
SPREAD
Instructs the compiler to spread a set of \( T \) threads as evenly as possible among the \( P \) places of the parent's place partition at run time.

Rules
- At most one \texttt{PROC_BIND} clause can appear on the \texttt{PARALLEL} directive.
- If the \texttt{OMP_PROC_BIND} environment variable is not set to \texttt{FALSE}, the \texttt{PROC_BIND} clause overrides the first element in the \texttt{OMP_PROC_BIND} environment variable.
- If the \texttt{OMP_PROC_BIND} environment variable is set to \texttt{FALSE}, the \texttt{PROC_BIND} clause has no effect.

Related reference:
\begin{itemize}
  \item \texttt{PARALLEL / END PARALLEL}
  \item \texttt{PARALLEL SECTIONS / END PARALLEL SECTIONS}
  \item \texttt{omp_get_proc_bind}
\end{itemize}

Related information:
\begin{itemize}
  \item \texttt{OMP_PROC_BIND}
\end{itemize}

SCHEDULE
Purpose
You can use the \texttt{SCHEDULE} clause to specify the chunking method for parallelization. Work is assigned to threads in different manners depending on the scheduling type or chunk size used.

Syntax
\begin{verbatim}
  SCHEDULE(\texttt{sched_type}[,\texttt{n}])
\end{verbatim}

\texttt{sched_type} is one of \texttt{AFFINITY}, \texttt{AUTO}, \texttt{DYNAMIC}, \texttt{GUIDED}, \texttt{RUNTIME}, or \texttt{STATIC}.

\texttt{n} must be a positive scalar integer expression; do not specify \texttt{n} for the \texttt{AUTO} and \texttt{RUNTIME} schedule type. If you are using the \texttt{trigger_constant OMP_SCHEDULE}, do not specify the scheduling type \texttt{AFFINITY}.

AFFINITY
The iterations of a loop are initially divided into \texttt{number_of_threads} partitions, containing \texttt{CEILING}(\texttt{number_of_iterations} / \texttt{number_of_threads}) iterations. Each partition is initially assigned to a thread, and is then further subdivided into chunks containing \texttt{n} iterations, if \texttt{n} has been specified. If \texttt{n} has not been specified, then the chunks consist of \texttt{CEILING}(\texttt{number_of_iterations_remaining_in_partition} / 2) loop iterations.

When a thread becomes free, it takes the next chunk from its initially assigned partition. If there are no more chunks in that partition, then the thread takes the next available chunk from a partition that is initially assigned to another thread.

Threads that are active will complete the work in a partition that is initially assigned to a sleeping thread.
Note: This scheduling type has been deprecated and might be removed in a future release. You can use the GUIDED scheduling type for a similar functionality.

AUTO

The compiler and runtime system choose the most appropriate mapping of iteration to threads for each loop.

DYNAMIC

If \( n \) has been specified, the iterations of a loop are divided into chunks containing \( n \) contiguous iterations each except for the last chunk. If \( n \) is not specified, the default chunk size is 1 iteration.

Chunks are assigned to threads on a "first-come, first-do" basis as threads become available. Chunks of the remaining work are assigned to available threads until all work has been assigned.

GUIDED

If you specify a value for \( n \), the iterations of a loop are divided into chunks such that the size of each successive chunk is exponentially decreasing. \( n \) specifies the size of the smallest chunk, except possibly the last. If you do not specify a value for \( n \), the default value is 1.

The size of the initial chunk is proportional to 
\[
\text{CEILING}\left(\frac{\text{number_of_iterations}}{\text{number_of_threads}}\right)
\]
iterations. Subsequent chunks are proportional to 
\[
\text{CEILING}\left(\frac{\text{number_of_iterations_remaining}}{\text{number_of_threads}}\right)
\]
iterations. If \( n \) is greater than 1, each chunk must contain at least \( n \) consecutive iterations (except for the last chunk to be assigned, which can have fewer than \( n \) iterations. As each thread finishes a chunk, it dynamically obtains the next available chunk.

You can use guided scheduling in a situation in which multiple threads in a team might arrive at a DO work-sharing construct at varying times, and each iteration requires roughly the same amount of work. For example, if you have a DO loop preceded by one or more work-sharing SECTIONS or DO constructs with NOWAIT clauses, you can guarantee that no thread waits at the barrier longer than it takes another thread to execute its final iteration, or final \( k \) iterations if a chunk size of \( k \) is specified. The GUIDED schedule requires the fewest synchronizations of all the scheduling methods.

An \( n \) expression is evaluated outside of the context of the DO construct. Any function reference in the \( n \) expression must not have side effects.

The value of the \( n \) parameter on the SCHEDULE clause must be the same for all of the threads in the team.

RUNTIME

Determine the scheduling type at run time.

At run time, the scheduling type can be specified using the environment variable OMP_SCHEDULE. If no scheduling type is specified using that variable, the default scheduling type used is AUTO.

STATIC

If \( n \) has been specified, the iterations of a loop are divided into chunks that contain \( n \) iterations. Each thread is assigned chunks in a "round robin" fashion. This is known as block cyclic scheduling. If the value of \( n \) is 1, then the scheduling type is specifically referred to as cyclic scheduling.
If \( n \) has not been specified, the chunks will contain \( \text{FLOOR} \left( \frac{\text{number_of_iterations}}{\text{number_of_threads}} \right) \) contiguous iterations. The first \( \text{REMAINDER} \left( \frac{\text{number_of_iterations}}{\text{number_of_threads}} \right) \) chunks have one more iteration. Each thread is assigned a separate chunk. This is known as block cyclic scheduling.

If a thread is asleep and it has been assigned work, it will be awakened so that it may complete its work.

The \texttt{STATIC} schedule ensures that the same logical iteration numbers are assigned to threads in two work-sharing loop regions if the following conditions are satisfied:

- Both loop regions have the same number of loop iterations
- Both loop regions either have the same value of \( n \) specified, or have no \( n \) specified
- Both loop regions bind to the same parallel region

A data dependence between the same logical iterations in two such loops is guaranteed to be satisfied to allow the safe use of the \texttt{NOWAIT} clause. In addition, you must make sure that all three conditions mentioned above are satisfied to get the correct result.

Consecutive loop constructs with \texttt{STATIC} schedule with \texttt{NOWAIT} clause now guarantee the same iterations are being assigned to the same thread in the constructs.

For an example of the loop constructs that satisfy all three conditions, see “Example for OpenMP.”

\section*{Rules}

You must not specify the \texttt{SCHEDULE} clause more than once for a particular \texttt{DO} directive.

\section*{Example for OpenMP}

The following example illustrates loop constructs that satisfy all three conditions listed in the \texttt{STATIC} section.

```
!$OMP PARALLEL
!$OMP DO SCHEDULE(STATIC)
   DO i = 1, n
      c(i) = (a(i) + b(i)) / 2.0;
   ENDDO
!$OMP END DO NOWAIT
!$OMP DO SCHEDULE(STATIC)
   DO i = 1, n
      z(i) = sqrt(c(i))
   ENDDO
!$OMP END DO
!$OMP END PARALLEL
```

\section*{Related reference:}

“\texttt{DO / END DO}” on page 127

“\texttt{PARALLEL DO / END PARALLEL DO}” on page 142
UNTIED
Purpose

The UNTIED clause is used with the TASK directive. When a task region is suspended, untied tasks can be resumed by any thread in a team.

Syntax

```
UNTIED
```

Rules

The UNTIED clause is ignored if either of the following conditions is true:

- A FINAL clause is specified on the same task construct and the FINAL clause expression evaluates to .TRUE..
- The task is an included task

Related reference:

“TASK / END TASK” on page 176

Routines for OpenMP

The OpenMP specification provides a number of routines that you can use to control and query the parallel execution environment, timing, and lock.

Parallel threads created by the runtime environment through the OpenMP interface are considered independent of the threads you create and control using calls to the Fortran Pthreads library module. References within the following descriptions to “serial portions of the program” refer to portions of the program that are executed by only one of the threads that have been created by the runtime environment. For example, you can create multiple threads by using f_pthread_create. However, if you then call omp_get_num_threads from outside of an OpenMP parallel block, or from within a serialized nested parallel region, the function will return 1, regardless of the number of threads that are currently executing.

OpenMP runtime library calls must not appear in PURE and ELEMENTAL procedures.
Included in the OpenMP runtime library are two routines that support a portable wall-clock timer.

**Table 24. OpenMP timing routines**

<table>
<thead>
<tr>
<th>Routine</th>
</tr>
</thead>
<tbody>
<tr>
<td>omp_get_wtick</td>
</tr>
<tr>
<td>omp_get_wtime</td>
</tr>
</tbody>
</table>

The OpenMP runtime library also supports a set of simple and nestable lock routines. You must only lock variables through these routines. Simple locks may not be locked if they are already in a locked state. Simple lock variables are associated with simple locks and may only be passed to simple lock routines. Nestable locks may be locked multiple times by the same thread. Nestable lock variables are associated with nestable locks and may only be passed to nestable lock routines. Note that locks are now associated with task regions, and no longer with threads as such, in accordance with changes in the OMP standard.

For all the routines listed below, the lock variable is an integer whose KIND type parameter is denoted either by the symbolic constant omp_lock_kind, or by omp_nest_lock_kind.

This variable is sized to 8.

**Table 25. OpenMP simple lock routines**

<table>
<thead>
<tr>
<th>Routine</th>
</tr>
</thead>
<tbody>
<tr>
<td>omp_destroy_lock</td>
</tr>
<tr>
<td>omp_init_lock</td>
</tr>
<tr>
<td>omp_set_lock</td>
</tr>
<tr>
<td>omp_test_lock</td>
</tr>
<tr>
<td>omp_unset_lock</td>
</tr>
</tbody>
</table>
Table 26. OpenMP nestable lock routines

<table>
<thead>
<tr>
<th>Routine</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>omp_destroy_nest_lock</code></td>
<td>Puts a given lock variable to the free list.</td>
</tr>
<tr>
<td><code>omp_init_nest_lock</code></td>
<td>Initializes a given lock variable.</td>
</tr>
<tr>
<td><code>omp_set_nest_lock</code></td>
<td>Sets a given lock variable in a spin lock.</td>
</tr>
<tr>
<td><code>omp_test_nest_lock</code></td>
<td>Returns true if a given lock variable is spin lock.</td>
</tr>
<tr>
<td><code>omp_unset_nest_lock</code></td>
<td>Removes a given lock variable from the free list.</td>
</tr>
</tbody>
</table>

**Note:** You can define and implement your own versions of the OpenMP routines. However, by default, the compiler will substitute the XL Fortran versions of the OpenMP routines regardless of the existence of other implementations, unless you specify the `-qnomadomp` compiler option. For more information, see *XL Fortran Compiler Reference.*

**omp_destroy_lock(svar)**

**Purpose**

The `omp_destroy_lock` subroutine disassociates a given lock variable from all locks. You must use `omp_init_lock` to reinitialize a lock variable that was destroyed with a call to `omp_destroy_lock` before using it again as a lock variable.

If you call `omp_destroy_lock` with an uninitialized lock variable, the result of the call is undefined.

**Class**

Subroutine.

**Argument Type and Attributes**

`svar`

Type integer with kind `omp_lock_kind`.

**Result Type and Attributes**

None.

**Result Value**

None.

**Examples**

In the following example, threads and their associated tasks are generated by the parallel region, and one at a time, each task gains ownership of the lock associated with the lock variable LCK, prints the thread ID, and releases ownership of the lock.

```fortran
USE omp_lib
INTEGER(kind=omp_lock_kind) LCK
INTEGER ID
CALL omp_init_lock(LCK)
!$OMP PARALLEL SHARED(LCK), PRIVATE(ID)
  ID = omp_get_thread_num()
  CALL omp_set_lock(LCK)
  PRINT *, 'MY THREAD ID IS ', ID
  CALL omp_unset_lock(LCK)
!$OMP END PARALLEL
CALL omp_destroy_lock(LCK)
END
```
omp_destroy_nest_lock(nvar)

Purpose

The `omp_destroy_nest_lock` subroutine initializes a nestable lock variable, causing the lock variable to become undefined. The variable `nvar` must be an unlocked and initialized nestable lock variable.

If you call `omp_destroy_nest_lock` using an uninitialized variable, the result is undefined.

Class

Subroutine.

Argument Type and Attributes

`nvar`

Type integer with kind `omp_nest_lock_kind`.

Result Type and Attributes

None.

Result Value

None.

omp_get_active_level()

Purpose

The `omp_get_active_level` function returns the number of nested, active parallel regions.

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Default integer.

Result Value

An integer that indicates the number of nested, active parallel regions.

omp_get_ancestor_thread_num(level)

Purpose

The `omp_get_ancestor_thread_num` function returns the thread number of the ancestor at a given nested level of the current thread.
Class Function.

**Argument Type and Attributes**

*level*

Default integer.

**Result Type and Attributes**

Default integer.

**Result Value**

The thread number of the ancestor at a given nested level (*level*) of the current thread. If *level* is outside the range of 0 and the nested level of the current thread, as returned by the `omp_get_level` routine, the function returns -1.

**omp_get_default_device()**

**Purpose**

Returns the default target device.

Class Function.

**Result Type and Attributes**

Default integer.

**Result Value**

The routine returns the value of the `default-device-var` ICV of the current task.

When the routine is called from within a target region on a target device, the effect is unspecified.

**omp_get_dynamic()**

**Purpose**

The `omp_get_dynamic` function returns `.TRUE.` if dynamic thread adjustment by the runtime environment is enabled. Otherwise, the `omp_get_dynamic` function returns `.FALSE.`

Class Function.

**Argument Type and Attributes**

None.
Result Type and Attributes

Default logical.

Result Value

.TRUE. if dynamic thread adjustment by the runtime environment is enabled; .FALSE. otherwise.

omp_get_initial_device()

Purpose

Returns the device number of the host device.

Class

Function.

Result Type and Attributes

Default integer.

Result Value

The value of the device number is implementation defined. If the value is in the range of zero and one less than omp_get_num_devices(), the device number can be used with all device constructs and routines; if the value is outside that range, the device number cannot be used in the DEVICE clause.

> GPU When the routine is called from within a target region on a target device, the effect is unspecified. < GPU

omp_get_level()

Purpose

Theomp_get_level function returns the number of nested parallel regions (both active and inactive).

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Default integer.

Result Value

The number of nested parallel regions (both active and inactive) in which the generating task is executing, not including the implicit parallel region. Returns 0 if
it is called from the sequential part of the program. Otherwise, returns a non-negative integer.

**omp_get_max_active_levels()**

**Purpose**

The `omp_get_max_active_levels` function returns the maximum number of nested, active parallel regions.

**Class**

Function.

**Argument Type and Attributes**

None.

**Result Type and Attributes**

Default integer.

**Result Value**

The maximum number of nested, active parallel regions that is allowed.

**omp_get_max_threads()**

**Purpose**

The `omp_get_max_threads` routine returns the first value of `num_list` for the OMP_NUM_THREADS environment variable. This value is the maximum number of threads that can be used to form a new team if a parallel region without a `num_threads` clause is encountered.

If you use `omp_set_num_threads` to change the number of threads, subsequent calls to `omp_get_max_threads` will return the new value.

The routine has global scope, which means that the maximum value it returns applies to all routines, subroutines, and compilation units in the program. It returns the same value whether executing from a serial or parallel region.

You can use `omp_get_max_threads` to allocate maximum-sized data structures for each thread when you have enabled dynamic thread adjustment by passing `omp_set_dynamic` an argument which evaluates to .TRUE.

**Class**

Function.

**Argument Type and Attributes**

None.

**Result Type and Attributes**

Default integer.
**Result Value**

The maximum number of threads that can execute concurrently in a single parallel region.

**omp_get_nested()**

**Purpose**

The `omp_get_nested` function returns `.TRUE.` if nested parallelism is enabled and `.FALSE.` if nested parallelism is disabled.

**Class**

Function

**Argument Type and Attributes**

None.

**Result Type and Attributes**

Default logical.

**Result Value**

`.TRUE.` if nested parallelism is enabled. `.FALSE.` otherwise.

**omp_get_num_devices()**

**Purpose**

Returns the number of target devices.

**Class**

Function.

**Result Type and Attributes**

Default integer.

**Result Value**

The routine returns the number of available target devices.

- **GPU** When the routine is called from within a target region on a target device, the effect is unspecified.

**omp_get_num_places()**

**Purpose**

The `omp_get_num_places` function returns the number of places that are available to the execution environment in the place list.
Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Default integer.

Result Value

The number of places in the \textit{place-partition-var} internal control variable (ICV) in the execution environment of the initial task.

\verb+omp_get_num_procs+()

Purpose

The \verb+omp_get_num_procs+ function returns the number of online processors on the machine.

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Default integer.

Result Value

The number of online processors on the machine.

\verb+omp_get_num_teams+()

Purpose

Returns the number of teams in the current teams region.

Class

Function.

Result Type and Attributes

Default integer.
Result Value

The routine returns the number of teams in the current teams region. When it is called from outside of a teams region, it returns 1.

**omp_get_num_threads()**

**Purpose**

The `omp_get_num_threads` function returns the number of threads in the team currently executing the parallel region from which it is called. The function binds to the closest enclosing `PARALLEL` directive.

The `omp_set_num_threads` subroutine and the `OMP_NUM_THREADS` environment variable control the number of threads in a team. If you do not explicitly set the number of threads, the runtime environment will use the number of online processors on the machine by default. The number of online processors is less than or equal to the number of physical processors actually installed in a machine.

If you call `omp_get_num_threads` from a serial portion of your program or from a nested parallel region that is serialized, the function returns 1.

**Class**

Function.

**Argument Type and Attributes**

None.

**Result Type and Attributes**

Default integer.

**Result Value**

The number of threads in the team currently executing the parallel region from which the function is called.

**Examples**

```
USE omp_lib
INTEGER N1, N2

N1 = omp_get_num_threads()
PRINT *, N1
!$OMP PARALLEL PRIVATE(N2)
N2 = omp_get_num_threads()
PRINT *, N2
!$OMP END PARALLEL
END
```

The `omp_get_num_threads` call returns 1 in the serial section of the code, so `N1` is assigned the value 1. `N2` is assigned the number of threads in the team executing the parallel region, so the output of the second print statement will be an arbitrary number less than or equal to the value returned by `omp_get_max_threads`. 
omp_get_partition_num_places()

Purpose

The `omp_get_partition_num_places` function returns the number of places in the place partition of the innermost implicit task.

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Default integer.

Result Value

The number of places in the `place-partition-var` internal control variable (ICV).

omp_get_partition_place_nums(place_nums)

Purpose

The `omp_get_partition_place_nums` subroutine returns the list of place numbers corresponding to the places in the `place-partition-var` internal control variable (ICV) of the innermost implicit task. The `place-partition-var` ICV controls the place partition that is available to the execution environment for encountered parallel regions. Each implicit task has one copy of the `place-partition-var` ICV.

Class

Subroutine.

Argument Type and Attributes

place_nums

An assumed-size array of integer type.

Result Type and Attributes

None.

Result Value

None.

Usage

The size of the array `place_nums` that contains place numbers must be equal to or larger than the return value of `omp_get_partition_num_places();` otherwise, the behavior is undefined.
omp_get_place_num()

Purpose

The `omp_get_place_num` function returns the place number of the place to which the encountering thread is bound.

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Default integer.

Result Value

The place number of the place to which the encountering thread is bound.

Usage

When the encountering thread is bound to a place, the routine returns the place number that is associated with the thread. The returned value is between -1 and the return value of `omp_get_num_places()` exclusive. When the encountering thread is not bound to a place, the routine returns -1.

omp_get_place_num_procs(place_num)

Purpose

The `omp_get_place_num_procs` function returns the number of processors that are available to the execution environment in the specified place.

Class

Function.

Argument Type and Attributes

`place_num`

Default integer.

Result Type and Attributes

Default integer.

Result Value

The routine returns the number of processors that are associated with the place that is numbered `place_num`. The routine returns zero when `place_num` is negative or is equal to or larger than the result value of `omp_get_num_places()`.
omp_get_place_proc_ids(place_num, ids)

Purpose

The `omp_get_place_proc_ids` subroutine returns the numerical identifiers of the processors that are available to the execution environment in the specified place.

Class

Subroutine.

Argument Type and Attributes

- `place_num`  
  Default integer.

- `ids`  
  An assumed-size array of integer type.

Result Type and Attributes

None.

Result Value

None.

Usage

The routine returns the non-negative numerical identifiers of each processor that is associated with the place that is numbered `place_num`. The numerical identifiers are returned in the array `ids` whose size must be equal to or larger than the return value of `omp_get_place_num_procs(place_num)`; otherwise, the behavior is undefined. The routine has no effect when `place_num` is a negative value or is equal to or larger than the return value of `omp_get_num_places()`.

omp_get_proc_bind()

Purpose

Returns the thread affinity policy to be applied for the subsequent nested parallel regions that do not specify a `proc_bind` clause.

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Default integer of kind `omp_proc_bind_kind` as defined in the `omp_lib` module.
**Result Value**

The result value is one of the following constant parameters that are defined in the `omp_lib` module:

- `omp_proc_bind_false`
- `omp_proc_bind_true`
- `omp_proc_bind_master`
- `omp_proc_bind_close`
- `omp_proc_bind_spread`

Related information:

“OMP_PROC_BIND” on page 99

### `omp_get_schedule(kind, modifier)`

**Purpose**

The `omp_get_schedule` subroutine returns the scheduling type that is applied when using the runtime schedule. The argument `kind` returns the type of schedule that is used. `modifier` represents the chunk size that is set for applicable schedule types.

**Class**

Subroutine.

**Argument Type and Attributes**

**kind**

Integer of kind `omp_sched_kind`. The value returned for `kind` is one of the following constants that are defined in `omp_lib` module:

- `omp_sched_static`
- `omp_sched_dynamic`
- `omp_schedguided`
- `omp_sched_auto`
- `ibm_sched_affinity`

where `ibm_sched_affinity` is not part of the OpenMP specification.

**Note:** `ibm_sched_affinity` has been deprecated and might be removed in a future release. You can use `omp_sched_guided` for a similar functionality.

**modifier**

Default integer. For the schedule type `dynamic`, `guided`, or `static`, `modifier` is the chunk size that is set. For the schedule type `auto`, `modifier` has no meaning.

**Result Type and Attributes**

None.

**Result Value**

None.
omp_get_team_num()

Purpose

The omp_get_team_num function returns the team number of the calling thread.

Class

Function.

Result Type and Attributes

Default integer.

Result Value

The routine returns the team number of the calling thread. The team number is an integer in the range of 0 and one less than the number of teams in the current teams region, inclusive. When the routine is called outside of a teams region, it returns zero.

Related reference:

“omp_get_num_teams()” on page 228

omp_get_team_size(level)

Purpose

The omp_get_team_size function returns the size of the thread team that the ancestor belongs to.

Class

Function.

Argument Type and Attributes

level

Default integer. level is the nested level of the current thread.

Result Type and Attributes

Default integer.

Result Value

The size of the thread team that the ancestor belongs to. If level is outside of the range of 0 and the nested level of the current thread, as returned by the omp_get_level function, the function returns -1.

omp_get_thread_limit()

Purpose

The omp_get_thread_limit function returns the maximum number of OpenMP threads that are available to the program.
Class
Function.

Argument Type and Attributes
None.

Result Type and Attributes
Default integer.

Result Value
The maximum number of OpenMP threads that are available to the program.

`omp_get_thread_num()`

Purpose

The `omp_get_thread_num` function returns the number of the currently executing thread within the team. The number returned will always be between 0 and `NUM_PARTHDS` - 1. `NUM_PARTHDS` is the number of currently executing threads within the team. The master thread of the team returns a value of 0.

If you call `omp_get_thread_num` from within a serial region, from within a serialized nested parallel region, or from outside the dynamic extent of any parallel region, this function will return a value of 0.

This function binds to the closest parallel region.

Class
Function.

Argument Type and Attributes
None.

Result Type and Attributes
Default integer.

Result Value
The value of the currently executing thread within the team between 0 and `NUM_PARTHDS` - 1. `NUM_PARTHDS` is the number of currently executing threads within the team. A call to `omp_get_thread_num` from a serialized nested parallel region, or from outside the dynamic extent of any parallel region returns 0.

Examples

The following example illustrates the return value of the `omp_get_thread_num` routine in a PARALLEL region and a MASTER construct.

```fortran
USE omp_lib
INTEGER NP
call omp_set_num_threads(4) ! 4 threads are used in the
```
! parallel region

!$OMP PARALLEL PRIVATE(NP)
   NP = omp_get_thread_num()
   CALL WORK('in parallel', NP)
!$OMP MASTER
   NP = omp_get_thread_num()
   CALL WORK('in master', NP)
!$OMP END MASTER
!$OMP END PARALLEL
END SUBROUTINE WORK(msg, THD_NUM)

INTEGER THD_NUM
character(*) msg
PRINT *, msg, THD_NUM
END

Output:
in parallel 1
in parallel 3
in parallel 2
in parallel 0
in master 0
(The order may be different.)

omp_get_wtick()

Purpose

The omp_get_wtick function returns a double precision value equal to the number of seconds between consecutive clock ticks.

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Double precision real.

Result Value

The number of seconds between consecutive ticks of the operating system real-time clock.

Examples

USE omp_lib
DOUBLE PRECISION WTICKS
WTICKS = omp_get_wtick()
PRINT *, 'The clock ticks ', 10 / WTICKS, &
' times in 10 seconds.'
END
omp_get_wtime()

Purpose

The omp_get_wtime function returns a double precision value equal to the number of seconds since the initial value of the operating system real-time clock. The initial value is guaranteed not to change during execution of the program.

The value returned by the omp_get_wtime function is not consistent across all threads in the team.

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Double precision real.

Result Value

The number of seconds since the initial value of the operating system real-time clock.

Examples

USE omp_lib
DOUBLE PRECISION START, END
START = omp_get_wtime()
! Work to be timed
END = omp_get_wtime()
PRINT *, 'Stuff took ', END - START, ' seconds.'
END

omp_in_final()

Purpose

The omp_in_final routine returns .TRUE. if the routine is called in a final task region. Otherwise, the routine returns .FALSE..

Class

Function.

Argument Type and Attributes

None.

Result Type and Attributes

Default logical.
Result Value

If the routine is called in a final task region, the result value is .TRUE.; otherwise, the result value is .FALSE..

**omp_in_parallel()**

**Purpose**

The **omp_in_parallel** function returns .TRUE. if you call it from the dynamic extent of a region executing in parallel and returns .FALSE. otherwise. If you call **omp_in_parallel** from a region that is serialized but nested within the dynamic extent of a region executing in parallel, the function will still return .TRUE. (Nested parallel regions are serialized by default. See "omp_set_nested(enable_expr)" on page 243 and the OMP_NESTED environment variable for more information.)

**Class**

Function.

**Argument Type and Attributes**

None.

**Result Type and Attributes**

Default logical.

**Result Value**

.TRUE. if called from the dynamic extent of a region executing in parallel. .FALSE. otherwise.

**Examples**

In the following example, the first call to **omp_in_parallel** returns .FALSE. because the call is outside the dynamic extent of any parallel region. The second call returns .TRUE., even if the nested PARALLEL DO loop is serialized, because the call is still inside the dynamic extent of the outer PARALLEL DO loop.

```fortran
USE omp_lib
INTEGER N, M
N = 4
M = 3
PRINT*, omp_in_parallel() !$OMP PARALLEL DO
DO I = 1, N
  !$OMP PARALLEL DO
  DO J=1, M
    PRINT *, omp_in_parallel()
  END DO
END DO
!$OMP END PARALLEL DO
END DO
!$OMP END PARALLEL DO
END
```
omp_init_lock(svar)

Purpose

The `omp_init_lock` subroutine initializes a lock and associates it with the lock variable passed in as a parameter. After the call to `omp_init_lock`, the initial state of the lock variable is unlocked.

If you call this routine with a lock variable that you have already initialized, the result of the call is undefined.

Class

Subroutine.

Argument Type and Attributes

`svar`

Integer of kind `omp_lock_kind`.

Result Type and Attributes

None.

Result Value

None.

Examples

In the following example, threads and their associated tasks are generated by the parallel region, and one at a time, each task gains ownership of the lock associated with the lock variable LCK, prints the thread ID, and releases ownership of the lock.

```fortran
USE omp_lib
INTEGER(kind=omp_lock_kind) LCK
INTEGER ID
CALL omp_init_lock(LCK)
!$OMP PARALLEL SHARED(LCK), PRIVATE(ID)
  ID = omp_get_thread_num()
  CALL omp_set_lock(LCK)
  PRINT *, 'MY THREAD ID IS', ID
  CALL omp_unset_lock(LCK)
!$OMP END PARALLEL
CALL omp_destroy_lock(LCK)
END
```

omp_init_nest_lock(nvar)

Purpose

The `omp_init_nest_lock` subroutine allows you to initialize a nestable lock and associate it with the lock variable you specify. The initial state of the lock variable is unlocked, and the initial nesting count is zero. The `nvar` must be an unitialized nestable lock variable.

If you call `omp_init_nest_lock` using a variable that is already initialized, the result is undefined.
Class
Subroutine.

Argument Type and Attributes

\( nvar \)
Integer of kind omp_nest_lock_kind.

Result Type and Attributes
None.

Result Value
None.

Examples
The following example illustrates the use of a nestable lock for updating variable \( P \) in the PARALLEL SECTIONS construct.

USE omp_lib
INTEGER \( P \)
INTEGER \( A \)
INTEGER \( B \)
INTEGER ( kind=omp_nest_lock_kind ) LCK
CALL omp_init_nest_lock ( LCK ) ! initialize the nestable lock

!$OMP PARALLEL SECTIONS
!$OMP SECTION
CALL omp_set_nest_lock ( LCK )
P = \( P + A \)
CALL omp_set_nest_lock ( LCK )
P = \( P + B \)
CALL omp_unset_nest_lock ( LCK )
CALL omp_unset_nest_lock ( LCK )
!$OMP SECTION
CALL omp_set_nest_lock ( LCK )
P = \( P + B \)
CALL omp_unset_nest_lock ( LCK )
!$OMP END PARALLEL SECTIONS

CALL omp_destroy_nest_lock ( LCK )
END

omp_is_initial_device()

Purpose
Tests whether the current task is executing on the host device.

Class
Function.

Result Type and Attributes
Default logical.
Result Value

If the current task is executing on the host device, the routine returns .TRUE.. Otherwise, it returns .FALSE..

**omp_set_default_device(device_num)**

**Purpose**

Controls the default target device by setting the **default-device-var** internal control variable (ICV).

**Class**

Subroutine.

**Argument Type and Attributes**

device_num

An integer that is the device number of the host device or is non-negative and less than the number of target devices.

**Result Value**

The routine sets the value of the **default-device-var** ICV of the current task to the value specified by device_num.

> GPU When the routine is called from within a target region on a target device, the effect of it is unspecified.

Related reference:

"omp_get_initial_device()" on page 225
"omp_get_num_devices()" on page 227

**omp_set_dynamic(enable_expr)**

**Purpose**

The **omp_set_dynamic** subroutine enables or disables dynamic adjustment, by the runtime environment, of the number of threads available to execute parallel regions.

If enable_expr is evaluated to .TRUE., the runtime environment can automatically adjust the number of threads that are used to execute subsequent parallel regions to obtain the best use of system resources. The number of threads you specify using **omp_set_num_threads** becomes the maximum, not exact, thread count.

If enable_expr is evaluated to .FALSE., dynamic adjustment of the number of threads is disabled. The runtime environment cannot automatically adjust the number of threads used to execute subsequent parallel regions. The value you pass to **omp_set_num_threads** becomes the exact thread count.

By default, dynamic thread adjustment is disabled. If your code depends on a specific number of threads for correct execution, you should explicitly disable dynamic threads.

If the routine is called from a portion of the program where the **omp_in_parallel** routine returns .TRUE., the routine has no effect.
This subroutine has precedence over the **OMP_DYNAMIC** environment variable.

**Class**

Subroutine.

**Argument Type and Attributes**

(enable_expr)

*Logical.*

**Result Type and Attributes**

None.

**Result Value**

None.

```fortran
omp_set_lock(svar)
```

**Purpose**

The **omp_set_lock** subroutine forces the calling task region to wait until the specified lock is available before executing subsequent instructions. The calling task region is given ownership of the lock when it becomes available.

If you call this routine with an uninitialized lock variable, the result of the call is undefined. If a task region that owns a lock tries to lock it again by issuing a call to **omp_set_lock**, the call produces a deadlock.

**Class**

Subroutine.

**Argument Type and Attributes**

*svar*

*Integer of kind omp_lock_kind.*

**Result Type and Attributes**

None.

**Result Value**

None.

**Examples**

In the following example, the lock variable LCK_X is used to avoid race conditions when updating the shared variable X. By setting the lock before each update to X and unsettimg it after the update, you ensure that only one task region updates X at a given time.

```fortran
USE omp_lib
INTEGER A(100), X
INTEGER(kind=omp_lock_kind) LCK_X
X=1
```
CALL omp_init_lock (LCK_X)
!$OMP PARALLEL PRIVATE (I), SHARED (A, X)
!$OMP DO
  DO I = 3, 100
    A(I) = I * 10
    CALL omp_set_lock (LCK_X)
    X = X + A(I)
    CALL omp_unset_lock (LCK_X)
  END DO
$OMP END DO
$OMP END PARALLEL
CALL omp_destroy_lock (LCK_X)
END

omp_set_max_active_levels(max_levels)

Purpose

The `omp_set_max_active_levels` subroutine limits the number of nested, active parallel regions. Use `omp_set_max_active_levels` only in serial regions of a program. This routine has no effect in parallel regions of a program.

Class

Subroutine.

Argument Type and Attributes

`max_levels`

Default integer.

Result Type and Attributes

None.

Result Value

None.

omp_set_nested(enable_expr)

Purpose

The `omp_set_nested` subroutine enables or disables nested parallelism.

If `enable_expr` is evaluated to `.FALSE.`, nested parallelism is disabled. Nested parallel regions are serialized, and they are executed by the current thread. This is the default setting.

If `enable_expr` is evaluated to `.TRUE.`, nested parallelism is enabled. Parallel regions that are nested can deploy additional threads to the team. It is up to the runtime environment to determine whether additional threads should be deployed. Therefore, the number of threads used to execute parallel regions may vary from one nested region to the next.

If the routine is called from a portion of the program where the `omp_in_parallel` routine returns true, the routine has no effect.

The setting of the `omp_set_nested` subroutine overrides the setting of the `OMP_NESTED` environment variable.
Note: If the number of threads from all regions exceeds the number of available processors, your program might suffer performance degradation.

Class
Subroutine.

Argument Type and Attributes

enable_expr
Logical.

Result Type and Attributes
Default logical.

Result Value
None.

omp_set_nest_lock(nvar)

Purpose
The omp_set_nest_lock subroutine allows you to set a nestable lock. The task region executing the subroutine will wait until the lock becomes available and then set that lock, incrementing the nesting count. A nestable lock is available if it is owned by the task region executing the subroutine, or is unlocked.

Class
Subroutine.

Argument Type and Attributes

nvar
Integer of kind omp_nest_lock_kind.

Result Type and Attributes
None.

Result Value
None.

Examples
USE omp_lib
INTEGER P
INTEGER A
INTEGER B
INTEGER (kind=omp_nest_lock_kind) LCK

CALL omp_init_nest_lock ( LCK )

!$OMP PARALLEL SECTIONS
!$OMP SECTION
CALL omp_set_nest_lock ( LCK )
P = P + A
**omp_set_num_threads(number_of_threads_expr)**  

**Purpose**

The `omp_set_num_threads` routine specifies the number of threads to use for the next parallel region by setting the first value of `num_list` for the `OMP_NUM_THREADS` environment variable.

The `number_of_threads_expr` argument is evaluated, and its value is used as the number of threads. If you have enabled dynamic adjustment of the number of threads (see “omp_set_dynamic(enable_expr)” on page 241), `omp_set_num_threads` sets the maximum number of threads to use for the next parallel region. The runtime environment then determines the exact number of threads to use. However, when dynamic adjustment of the number of threads is disabled, `omp_set_num_threads` sets the exact number of threads to use in the next parallel region. If the number of threads you request exceeds the number your execution environment can support, your application will terminate.

This subroutine takes precedence over the `OMP_NUM_THREADS` environment variable.

If you call this subroutine from the dynamic extent of a region executing in parallel, the behavior of the subroutine is undefined.

**Class**

Subroutine.

**Argument Type and Attributes**

`number_of_threads_expr`  
Integer.

**Result Type and Attributes**

None.

**Result Value**

None.
omp_set_schedule(kind, modifier)

Purpose

The omp_set_schedule routine affects the schedule that is applied when runtime is used as schedule kind. Use omp_set_schedule if you want to set the schedule type separately from the OMP_SCHEDULE environment variable.

Note: You can use the omp_get_schedule to return scheduling type. For details, see omp_get_schedule.

Class

Subroutine.

Argument Type and Attributes

**kind**
Type integer with kind omp_sched_kind. Must be one of the schedule types as represented by the following constants:

- omp_sched_static
- omp_sched_dynamic
- omp_sched_guided
- omp_sched_auto
- ibm_sched_affinity

where ibm_sched_affinity is not part of the OpenMP.

Note: ibm_sched_affinity has been deprecated and might be removed in a future release. You can use omp_sched_guided for a similar functionality.

**modifier**
Default integer. For the schedule type dynamic, guided, or static, modifier is the chunk size that you want to set. Typically, it is a positive integer. If the value is less than one, the default is used. For the schedule type auto, modifier has no meaning. For the default setting of each schedule type, see -qsmp in the XL Fortran Compiler Reference.

Result Type and Attributes

None.

Result Value

None.

omp_test_lock(svar)

Purpose

The omp_test_lock function attempts to set the lock associated with the specified lock variable. It returns .TRUE. if it was able to set the lock and .FALSE. otherwise. In either case, the calling task region will continue to execute subsequent instructions in the program.

If you call omp_test_lock with an uninitialized lock variable, the result of the call is undefined.
Class
Function.

Argument Type and Attributes

\( svar \)
Integer of kind \texttt{omp\_lock\_kind}.

Result Type and Attributes
Default logical.

Result Value

\( \text{.TRUE.} \) if the function was able to set the lock. \( \text{.FALSE.} \) otherwise.

Examples

In the following example, a task region repeatedly executes \texttt{WORK\_A} until it can set the lock variable, \texttt{LCK}. When the lock is set, the task region executes \texttt{WORK\_B}.

\begin{verbatim}
USE omp_lib
INTEGER LCK
INTEGER ID
CALL omp_init_lock (LCK)
 !$OMP PARALLEL SHARED(LCK), PRIVATE(ID)
   ID = omp_get_thread_num()
   DO WHILE (.NOT. omp_test_lock(LCK))
      CALL WORK_A (ID)
   END DO
   CALL WORK_B (ID)
   CALL omp_unset_lock (LCK)
 !$OMP END PARALLEL
 END
\end{verbatim}

\texttt{omp\_test\_nest\_lock(nvar)}

Purpose

The \texttt{omp\_test\_nest\_lock} subroutine allows you to attempt to set a lock using the same method as \texttt{omp\_set\_nest\_lock}, but the executing task region does not wait for confirmation that the lock is available. If the lock is successfully set, the function will increment the nesting count and return the new nesting count. If the lock is unavailable the function returns a value of zero. Also, a child task sees a value of zero if the parent task has already set the same lock. The result value is always a default integer.

Class
Function.

Argument Type and Attributes

\( nvar \)
Integer of kind \texttt{omp\_nest\_lock\_kind}. 

Result Type and Attributes

Default integer.

Result Value

The new nesting count if the lock is successfully set; otherwise, it returns zero.

\texttt{omp_unset_lock(svar)}

\textbf{Purpose}

The \texttt{omp_unset_lock} subroutine causes the executing task region to release ownership of the specified lock. The lock can then be set by another task region as required. The behavior of the \texttt{omp_unset_lock} subroutine is undefined if either of the following conditions occur:

- The calling task region does not own the lock specified.
- The routine is called with an uninitialized lock variable.

Class

Subroutine.

\textbf{Argument Type and Attributes}

\texttt{svar}

Integer of kind \texttt{omp_lock_kind}.

\textbf{Result Type and Attributes}

None.

\textbf{Result Value}

None.

\textbf{Examples}

\begin{verbatim}
USE omp_lib
INTEGER A(100)
INTEGER(kind=omp_lock_kind) LCK_X
CALL omp_init_lock(LCK_X)
!$OMP PARALLEL PRIVATE (I), SHARED (A, X)
!$OMP DO DO I = 3, 100
    A(I) = I * 10
    CALL omp_set_lock(LCK_X)
    X = X + A(I)
    CALL omp_unset_lock(LCK_X)
END DO
!$OMP END DO
!$OMP END PARALLEL
CALL omp_destroy_lock(LCK_X)
END
\end{verbatim}

In this example, the lock variable LCK_X is used to avoid race conditions when updating the shared variable X. By setting the lock before each update to X and unsetting it after the update, you ensure that only one task region is updating X at a given time.
omp_unset_nest_lock(nvar)

Purpose

The `omp_unset_nest_lock` subroutine allows you to release ownership of a nestable lock. The subroutine decrements the nesting count and releases the associated task region from ownership of the nestable lock.

Class

Subroutine.

Argument Type and Attributes

`nvar`

Integer of kind `omp_lock_kind`.

Result Type and Attributes

None.

Result Value

None.

Examples

USE omp_lib
INTEGER P
INTEGER A
INTEGER B
INTEGER ( kind=omp_nest_lock_kind ) LCK

CALL omp_init_nest_lock ( LCK )

!$OMP PARALLEL SECTIONS
!$OMP SECTION
CALL omp_set_nest_lock ( LCK )
P = P + A
CALL omp_set_nest_lock ( LCK )
P = P + B
CALL omp_unset_nest_lock ( LCK )
CALL omp_unset_nest_lock ( LCK )
!$OMP SECTION
CALL omp_set_nest_lock ( LCK )
P = P + B
CALL omp_unset_nest_lock ( LCK )
!$OMP END PARALLEL SECTIONS

CALL omp_destroy_nest_lock ( LCK )
END

Pthreads Library Module

The Pthreads Library Module (`f_pthread`) is a Fortran 90 module that defines data types and routines to make it easier to interface with the Linux pthreads library. The Linux pthreads library is used to parallelize and to make your code thread-safe.

The `f_pthread` library module naming convention is the use of the prefix `f_` before the corresponding Linux pthreads library routine name or type definition name.
In general, there is a one-to-one corresponding relationship between the procedures in the Fortran 90 module `f_pthread` and the library routines contained in the Linux pthreads library. However, some of the pthread routines have no corresponding procedures in this module because they are not supported on Linux. One example of these routines is the thread stack address option. There are also some non-pthread interfacing routines contained in the `f_pthread` library module. The `f_make_time` routine is one example and is included to return an absolute time in a `f_timespec` derived type variable.

Most of the routines return an integer value. A return value of 0 will always indicate that the routine call did not result in any error. Any non-zero return value indicates an error. Each error code has a corresponding definition of a system error code in Fortran. These error codes are available as Fortran integer constants. The naming of these error codes in Fortran is consistent with the corresponding Linux error code names. For example, `EINVAL` is the Fortran constant name of the error code `EINVAL` on the system. For a complete list of these error codes, refer to the file `/usr/include/errno.h`.

**Note:** The pthread module in XL Fortran is an extension to the standard Fortran language.

**Pthreads data structures, functions, and subroutines**

**Pthreads data types**

- `f_thread_attr_t`
- `f_thread_cond_t`
- `f_thread_condattr_t`
- `f_thread_key_t`
- `f_thread_mutex_t`
- `f_thread_mutexattr_t`
- `f_thread_once_t`
- `f_thread_rwlock_t`
- `f_thread_rwlockattr_t`
- `f_thread_t`
- `f_sched_param`
- `f_timespec`

**Functions that perform operations on thread attribute objects**

- `f_thread_attr_destroy(attr)`
- `f_thread_attr_getdetachstate(attr, detach)`
- `f_thread_attr_getguaranteedsize(attr, guaranteed)`
- `f_thread_attr_getinheritsched(attr, inherit)`
- `f_thread_attr_getschedparam(attr, param)`
- `f_thread_attr_getschedpolicy(attr, policy)`
- `f_thread_attr_getscope(attr, scope)`
- `f_thread_attr_getstack(attr, stackaddr, ssize)`
- `f_thread_attr_init(attr)`
- `f_thread_attr_setdetachstate(attr, detach)`
- `f_thread_attr_setguaranteedsize(attr, guaranteed)`
- `f_thread_attr_setinheritsched(attr, inherit)`
Functions and subroutines that perform operations on threads

• `f_pthread_attr_setschedparam(attr, param)`
• `f_pthread_attr_setschedpolicy(attr, policy)`
• `f_pthread_attr_setscope(attr, scope)`
• `f_pthread_attr_setstack(attr, stackaddr, ssize)`

• `f_pthread_cancel(thread)`
• `f_pthread_cleanup_pop(exec)`
• `f_pthread_cleanup_push(cleanup, flag, arg)`
• `f_pthread_create(thread, attr, flag, ent, arg)`
• `f_pthread_detach(thread)`
• `f_pthread_equal(thread1, thread2)`
• `f_pthread_exit(ret)`
• `f_pthread_getconcurrency()`
• `f_pthread_getschedparam(thread, policy, param)`
• `f_pthread_join(thread, ret)`
• `f_pthread_kill(thread, sig)`
• `f_pthread_self()`
• `f_pthread_setconcurrency(new_level)`
• `f_pthread_setschedparam(thread, policy, param)`

Functions that perform operations on mutex attribute objects

• `f_pthread_mutexattr_destroy(mattr)`
• `f_pthread_mutexattr_getpshared(mattr, pshared)`
• `f_pthread_mutexattr_gettype(mattr, type)`
• `f_pthread_mutexattr_init(mattr)`
• `f_pthread_mutexattr_setpshared(mattr, pshared)`
• `f_pthread_mutexattr_settype(mattr, type)`

Functions that perform operations on mutex objects

• `f_pthread_mutex_destroy(mutex)`
• `f_pthread_mutex_init(mutex, mattr)`
• `f_pthread_mutex_lock(mutex)`
• `f_pthread_mutex_trylock(mutex)`
• `f_pthread_mutex_unlock(mutex)`

Functions that perform operations on attribute objects of condition variables

• `f_pthread_condattr_destroy(cattr)`
• `f_pthread_condattr_getpshared(cattr, pshared)`
• `f_pthread_condattr_init(cattr)`
• `f_pthread_condattr_setpshared(cattr, pshared)`

Functions that perform operations on condition variable objects

• `f_maketime(delay)`
• `f_pthread_cond_broadcast(cond)`
• `f_pthread_cond_destroy(cond)`
Functions that perform operations on thread-specific data

- `f_pthread_getspecific(key, arg)`
- `f_pthread_key_create(key, dtr)`
- `f_pthread_key_delete(key)`
- `f_pthread_setspecific(key, arg)`

Functions and subroutines that perform operations to control thread cancelability

- `f_pthread_setcancelstate(state, oldstate)`
- `f_pthread_setcanceltype(type, oldtype)`
- `f_pthread_testcancel()`

Functions that perform operations on read-write lock attribute objects

- `f_pthread_rwlockattr_destroy(rwattr)`
- `f_pthread_rwlockattr_getpshared(rwattr, pshared)`
- `f_pthread_rwlockattr_init(rwattr)`
- `f_pthread_rwlockattr_setpshared(rwattr, pshared)`

Functions that perform operations on read-write lock objects

- `f_pthread_rwlock_destroy(rwlock)`
- `f_pthread_rwlock_init(rwlock, rwattr)`
- `f_pthread_rwlock_rdlock(rwlock)`
- `f_pthread_rwlock_tryrdlock(rwlock)`
- `f_pthread_rwlock_trywrlock(rwlock)`
- `f_pthread_rwlock_unlock(rwlock)`
- `f_pthread_rwlock_wrlock(rwlock)`

Functions that perform operations for one-time initialization

- `f_pthread_once(once, initr)`

```
f_maketime(delay)
```

**Purpose**

This function accepts an integer value specifying a delay in seconds and returns an `f_timespec` type object containing the absolute time, which is `delay` seconds from the calling moment.

**Class**

Function

**Argument Type and Attributes**

- `delay`  INTEGER(4), INTENT(IN)
Result Type and Attributes

TYPE (f_timespec)

Result Value

The absolute time, which is delay seconds from the calling moment, is returned.

f_pthread_attr_destroy(attr)

Purpose

This function must be called to destroy any previously initialized thread attribute objects when they will no longer be used. Threads that were created with this attribute object will not be affected in any way by this action. Memory that was allocated when it was initialized will be recollected by the system.

Class

Function

Argument Type and Attributes

attr TYPE(f_pthread_attr_t), INTENT(IN)

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINVAL

The argument attr is invalid.

f_pthread_attr_getdetachstate(attr, detach)

Purpose

This function can be used to query the setting of the detach state attribute in the thread attribute object attr. The current setting will be returned through argument detach.

Class

Function

Argument Type and Attributes

attr TYPE(f_pthread_attr_t), INTENT(IN)
detach INTEGER(4), INTENT(OUT)

Contains one of the following values:
PTHREAD_CREATE_DETACHED:
when a thread attribute object of this attribute setting is used to
create a new thread, the newly created thread will be in detached
state.

PTHREAD_CREATE_JOINABLE:
when a thread attribute object of this attribute setting is used to
create a new thread, the newly created thread will be in
undetached state.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns
the following error:

EINVAL
    The argument attr is invalid.

f_pthread_attr_getguardsize(attr, guardsize)

Purpose

This function is used to get the guardsize attribute in the thread attribute object attr.
The current setting of the attribute will be returned through the argument
guardsize.

Class

Function

Argument Type and Attributes

attr    TYPE(f_pthread_attr_t), INTENT(IN)
guardsize    INTEGER(KIND=register_size), INTENT(IN)
    where register_size is 8.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns
the following error:

EINVAL
    The argument attr is invalid.
f_pthread_attr_getinheritsched(attr, inherit)

Purpose

This function can be used to query the inheritance scheduling attribute in the thread attribute object attr. The current setting will be returned through the argument inherit.

Class

Function

Argument Type and Attributes

attr TYPE(f_pthread_attr_t), INTENT(INOUT)
inherit INTEGER(4)

On return from the function, inherit contains one of the following values:

PTHREAD_INHERIT_SCHED: indicating that newly created threads will inherit the scheduling property of the parent thread and ignore the scheduling property of the thread attribute object used to create them.

PTHREAD_EXPLICIT_SCHED: the scheduling property in the thread attribute object will be assigned to the newly created threads when it is used to create them.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise this function returns the following error.

EINVAL
The argument attr is invalid.

f_pthread_attr_getschedparam(attr, param)

Purpose

This function can be used to query the scheduling property setting in the thread attribute object attr. The current setting will be returned in the argument param.

Class

Function

Argument Type and Attributes

attr TYPE(f_pthread_attr_t), INTENT(IN)
param TYPE(f_sched_param), INTENT(OUT)
Result Type and Attributes
INTEGER(4)

Result Value
On successful completion, this function returns 0. Otherwise, this function returns the following error.
EINVAL
The argument attr is invalid.

f_pthread_attr_getschedpolicy(attr, policy)
Purpose
This function can be used to query the scheduling policy attribute setting in the attribute object attr. The current setting of the scheduling policy will be returned in the argument policy.

Class
Function

Argument Type and Attributes
attr TYPE(f_pthread_attr_t), INTENT(IN)
policy INTEGER(4), INTENT(OUT)

Result Type and Attributes
INTEGER(4)

Result Value
On successful completion, this function returns 0. Otherwise, this function returns the following error.
EINVAL
The argument attr is invalid.

f_pthread_attr_getscope(attr, scope)
Purpose
This function can be used to query the current setting of the scheduling scope attribute in the thread attribute object attr. The current setting will be returned through the argument scope.

Class
Function

Argument Type and Attributes
attr TYPE(f_pthread_attr_t), INTENT(IN)
scope INTEGER(4), INTENT(OUT)
On return from the function, `scope` will contain one of the following values:

**PTHREAD_SCOPE_SYSTEM:**
the thread will compete for system resources on a system wide scope.

**PTHREAD_SCOPE_PROCESS:**
the thread will compete for system resources locally within the owning process.

`scope` contains the following value:

**PTHREAD_SCOPE_SYSTEM:**
the thread will compete for system resources on a system wide scope.

---

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns the following error.

**EINVAL**

The argument `attr` is invalid.

---

```fortran
f_pthread_attr_getstack(attr, stackaddr, ssize)
```

**Purpose**

Retrieves the values of the `stackaddr` and `stacksize` arguments from the thread attribute object `attr`.

**Class**

Function

**Argument Type and Attributes**

<table>
<thead>
<tr>
<th>Argument</th>
<th>Type and Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>attr</code></td>
<td>TYPE(f_thread_attr_t), INTENT(IN)</td>
</tr>
<tr>
<td><code>stackaddr</code></td>
<td>[Integer pointer] INTENT(OUT)</td>
</tr>
<tr>
<td><code>ssize</code></td>
<td>INTEGER(KIND=register_size), INTENT(OUT)</td>
</tr>
</tbody>
</table>

where `register_size` is 8.

---

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns the following error.
One or more of the supplied arguments is invalid.

### f pthread_attr_init(attr)

#### Purpose
This function must be called to create and initialize the pthread attribute object attr before it can be used in any way. It will be filled with system default thread attribute values. After it is initialized, certain pthread attributes can be changed and/or set through attribute access procedures. Once initialized, this attribute object can be used to create a thread with the intended attributes.

#### Class
Function

#### Argument Type and Attributes
- **attr**
  
  TYPE(f pthread_attr_t), INTENT(OUT)

#### Result Type and Attributes
 INTEGER(4)

#### Result Value
On successful completion, this function returns 0. Otherwise, this function returns the following error.

**EINVAL**

The argument attr is invalid.

### f pthread_attr_setdetachstate(attr, detach)

#### Purpose
This function can be used to set the detach state attribute in the thread attribute object attr.

#### Class
Function

#### Argument Type and Attributes
- **attr**
  
  TYPE(f pthread_attr_t), INTENT(OUT)
- **detach**
  
  INTEGER(4), INTENT(IN)

  Must contain one of the following values:

  **PTHREAD_CREATE_DETACHED**

  when a thread attribute object of this attribute setting is used to create a new thread, the newly created thread will be in detached state. This is the system default setting.
PTHREAD_CREATE_JOINABLE:
when a thread attribute object of this attribute setting is used to
create a new thread, the newly created thread will be in
undetached state.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns
the following error.

EINV
The argument detach is invalid.

f_pthread_attr_setguardsize(attr, guardsize)
Purpose

This function is used to set the guardsize attribute in the thread attributes object
attr. The new value of this attribute is obtained from the argument guardsize. If
guardsize is zero, a guard area will not be provided for threads created with attr.
If guardsize is greater than zero, a guard area of at least size guardsize bytes is
provided for each thread created with attr.

Class

Function

Argument Type and Attributes

attr      TYPE(f_pthread_attr_t), INTENT(INOUT)
guardsize INTEGER(KIND=register_size), INTENT(IN)
          where register_size is 8.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns
the following error.

EINV
The argument attr or the argument guardsize is invalid.

f_pthread_attr_setinheritsched(attr, inherit)
Purpose

This function can be used to set the inheritance attribute of the thread scheduling
property in the thread attribute object attr.
Class

Function

Argument Type and Attributes

attr TYPE(f_thread_attr_t), INTENT(OUT)

inherit INTEGER(4), INTENT(IN)

Must contain one of the following values:

PThread_INHERIT_SCHED:
indicating that newly created threads will inherit the scheduling property of the parent thread and ignore the scheduling property of the thread attribute object used to create them.

PThread_EXPLICIT_SCHED:
the scheduling property in the thread attribute object will be assigned to the newly created threads when it is used to create them.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINVAL
The argument inherit is invalid.

f_thread_attr_setschedparam(attr, param)

Purpose

This function can be used to set the scheduling property attribute in the thread attribute object attr. Threads created with this new attribute object will assume the scheduling property of argument param if they are not inherited from the creating thread. The sched_priority field in argument param indicates the thread’s scheduling priority. The priority field must assume a value in the range of 1-127, where 127 is the most favored scheduling priority while 1 is the least.

Class

Function

Argument Type and Attributes

attr TYPE(f_thread_attr_t), INTENT(INOUT)

param TYPE(f_sched_param), INTENT(IN)

Result Type and Attributes

INTEGER(4)
Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINVAL

The argument param is invalid.

f_pthread_attr_setschedpolicy(attr, policy)

Purpose

After the attribute object is set by this function, threads created with this attribute object will assume the set scheduling policy if the scheduling property is not inherited from the creating thread.

Class

Function

Argument Type and Attributes

attr TYPE(f_pthread_attr_t), INTENT(INOUT)
policy INTEGER(4), INTENT(IN)

Must contain one of the following values:

SCHED_FIFO:
    indicating a first-in first-out thread scheduling policy.

SCHED_RR:
    indicating a round-robin scheduling policy.

SCHED_OTHER:
    the default scheduling policy.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns one of the following error.

EINVAL

The argument policy is invalid.

f_pthread_attr_setscope(attr, scope)

Purpose

This function can be used to set the contention scope attribute in the thread attribute object attr.

Class

Function
**Argument Type and Attributes**

*attr*  
TYPE(f_pthread_attr_t), INTENT(INOUT)

*scope*  
INTEGER(4), INTENT(IN)

Must contain one of the following values:

**PTHREAD_SCOPE_SYSTEM:**  
the thread will compete for system resources on a system wide scope.

**PTHREAD_SCOPE_PROCESS:**  
the thread will compete for system resources locally within the owning process.

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns the following error.

**EINVAL**  
The argument *scope* is invalid.

**f_pthread_attr_setstack(attr, stackaddr, ssize)**

**Purpose**

Use this function to set the stack address and stack size attributes in the pthread attribute object *attr*. The *stackaddr* argument represents the stack address as an Integer pointer. The *ssize* argument is an integer that represents the size of the stack in bytes. When creating a thread using the attribute object *attr*, the system allocates a minimum stack size of *ssize* bytes.

**Class**

Function

**Argument Type and Attributes**

*attr*  
TYPE(f_pthread_attr_t), INTENT(INOUT)

*stackaddr*  
Integer pointer, INTENT(IN)

*ssize*  
INTEGER(KIND=register_size)

where *register_size* is 8.

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.
EINV
The value of one or both of the supplied arguments is invalid.

EACCES
The stack pages specified are not readable by the thread.

**f_pthread_attr_t**

**Purpose**
A derived data type whose components are all private. Any object of this type should be manipulated only through the appropriate interfaces provided in this module.

This data type corresponds to the POSIX `pthread_attr_t`, which is the type of thread attribute object.

**Class**
Data Type.

**f_pthread_cancel(thread)**

**Purpose**
This function can be used to cancel a target thread. How this cancelation request will be processed depends on the state of the cancelability of the target thread. The target thread is identified by argument `thread`. If the target thread is in deferred-cancel state, this cancelation request will be put on hold until the target thread reaches its next cancelation point. If the target thread disables its cancelability, this request will be put on hold until it is enabled again. If the target thread is in async-cancel state, this request will be acted upon immediately.

**Class**
Function

**Argument Type and Attributes**

<table>
<thead>
<tr>
<th>Argument</th>
<th>Type</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>thread</td>
<td>TYPE(f_pthread_t), INTENT(INOUT)</td>
<td></td>
</tr>
</tbody>
</table>

**Result Type and Attributes**

<table>
<thead>
<tr>
<th>Result Type</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTEGER(4)</td>
<td></td>
</tr>
</tbody>
</table>

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns the following error.

**ESRCH**
The argument `thread` is invalid.

**f_pthread_cleanup_pop(exec)**

**Purpose**
This subroutine should be paired with `f_pthread_cleanup_push` in using the cleanup stack for thread safety. If the supplied argument `exec` contains a non-zero
value, the last pushed cleanup function will be popped from the cleanup stack and executed, with the argument arg (from the last _f_pthread_cleanup_push_) passed to the cleanup function.

If exec contains a zero value, the last pushed cleanup function will be popped from the cleanup stack, but will not be executed.

**Class**

Subroutine

**Argument Type and Attributes**

exec  INTEGER(4), INTENT(IN)

**Result Type and Attributes**

None.

**Result Value**

None.

```fortran
_f_pthread_cleanup_push(cleanup, flag, arg)
```

**Purpose**

This function can be used to register a cleanup subroutine for the calling thread. In case of an unexpected termination of the calling thread, the system will automatically execute the cleanup subroutine in order for the calling thread to terminate safely. The argument cleanup must be a subroutine expecting exactly one argument. If it is executed, the argument arg will be passed to it as the actual argument.

The argument arg is a generic argument that can be of any type and any rank. The actual argument arg must be a variable, and consequently eligible as a left-value in an assignment statement. If you pass an array section with vector subscripts to the argument arg, the result is unpredictable.

If the actual argument arg is an array section, the corresponding dummy argument in subroutine cleanup must be an assumed-shape array. Otherwise, the result is unpredictable.

If the actual argument arg has the pointer attribute that points to an array or array section, the corresponding dummy argument in subroutine cleanup must have a pointer attribute or be an assumed-shape array. Otherwise, the result is unpredictable.

For a normal execution path, this function must be paired with a call to _f_pthread_cleanup_pop_.

The argument flag must be used to convey the property of argument arg exactly to the system.

**Class**

Function
**Argument Type and Attributes**

**cleanup**
A subroutine that has one dummy argument.

**flag**
Flag is an INTEGER(4), INTENT(IN) argument that can contain one of, or a combination of, the following constants:

- **FLAG_CHARACTER:**
  if the entry subroutine `cleanup` expects an argument of type `CHARACTER` in any way or any form, this flag value must be included to indicate this fact. However, if the subroutine expects a Fortran 90 pointer pointing to an argument of type `CHARACTER`, the `FLAG_DEFAULT` value should be included instead.

- **FLAG_ASSUMED_SHAPE:**
  if the entry subroutine `cleanup` has a dummy argument that is an assumed-shape array of any rank, this flag value must be included to indicate this fact.

- **FLAG_DEFAULT:**
  otherwise, this flag value is needed.

**arg**
A generic argument that can be of any type, kind, and rank.

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

- **ENOMEM**
  The system cannot allocate memory to push this routine.

- **EAGAIN**
  The system cannot allocate resources to push this routine.

- **EINVAL**
  The argument `flag` is invalid.

**f_pthread_cond_broadcast(cond)**

**Purpose**

This function will unblock all threads waiting on the condition variable `cond`. If there is no thread waiting on this condition variable, the function will still succeed, but the next caller to `f_pthread_cond_wait` will be blocked, and will wait on the condition variable `cond`.

**Class**

Function

**Argument Type and Attributes**

**cond**
TYPE(f_pthread_cond_t), INTENT(INOUT)
Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns following error.

EINVAL
  The argument cond is invalid.

f_pthread_cond_destroy(cond)

Purpose

This function can be used to destroy those condition variables that are no longer required. The target condition variable is identified by the argument cond. System resources allocated during initialization will be recollected by the system.

Class

Function

Argument Type and Attributes

cond  TYPE(f_pthread_cond_t), INTENT(INOUT)

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EBUSY
  The condition variable cond is being used by another thread.

f_ppthread_cond_init(cond, cattr)

Purpose

This function can be used to dynamically initialize a condition variable cond. Its attributes will be set according to the attribute object cattr, if it is provided; otherwise, its attributes will be set to the system default. After the condition variable is initialized successfully, it can be used to synchronize threads.

Another method of initializing a condition variable is to initialize it statically using the Fortran constant PTHREAD_COND_INITIALIZER.

Class

Function

Argument Type and Attributes

cond  TYPE(f_pthread_cond_t), INTENT(INOUT)
cattr  TYPE(f_pthread_condattr_t), INTENT(IN), OPTIONAL

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

EBUSY  The condition variable is already in use. It is initialized and not destroyed.

EINV  The argument cond or cattr is invalid.

f_pthread_cond_signal(cond)

Purpose

This function will unblock at least one thread waiting on the condition variable cond. If there is no thread waiting on this condition variable, the function will still succeed, but the next caller to f_pthread_cond_wait will be blocked, and will wait on the condition variable cond.

Class

Function

Argument Type and Attributes

cond  TYPE(f_pthread_cond_t), INTENT(INOUT)

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINV  The argument cond is invalid.

f_pthread_cond_t

Purpose

A derived data type whose components are all private. Any object of this type should be manipulated through the appropriate interfaces provided in this module. In addition, objects of this type can be initialized at compile time using the Fortran constant PTHREAD_COND_INITIALIZER.

This data type corresponds to the POSIX pthread_cond_t, which is the type of condition variable object.
Class

Data Type.

\textbf{f\_pthread\_cond\_timedwait(cond, mutex, timeout)}

\textbf{Purpose}

This function can be used to wait for a certain condition to occur. The argument \texttt{mutex} must be locked before calling this function. The mutex is unlocked atomically and the calling thread waits for the condition to occur. The argument \texttt{timeout} specifies a deadline before which the condition must occur. If the deadline is reached before the condition occurs, the function will return an error code. This function provides a cancelation point in that the calling thread can be canceled if it is in the enabled state.

The argument \texttt{timeout} will specify an absolute date of the form: Oct. 31 10:00:53, 1998. For related information, see \texttt{f\_maketime} and \texttt{f\_timespec}.

Class

Function

\textbf{Argument Type and Attributes}

\begin{itemize}
  \item \texttt{cond} \quad \text{TYPE}(\text{f\_pthread\_cond\_t}), \text{INTENT}(\text{INOUT})
  \item \texttt{mutex} \quad \text{TYPE}(\text{f\_pthread\_mutex\_t}), \text{INTENT}(\text{INOUT})
  \item \texttt{timeout} \quad \text{TYPE}(\text{f\_timespec}), \text{INTENT}(\text{IN})
\end{itemize}

\textbf{Result Type and Attributes}

\text{INTEGER}(4)

\textbf{Result Value}

On successful completion, this function returns 0. Otherwise this function returns one of the following errors:

\begin{itemize}
  \item \texttt{EINVAL}
    \quad The argument \texttt{cond}, \texttt{mutex}, or \texttt{timeout} is invalid.
  \item \texttt{ETIMEOUT}
    \quad The waiting deadline was reached before the condition occurred.
\end{itemize}

\textbf{f\_pthread\_cond\_wait(cond, mutex)}

\textbf{Purpose}

This function can be used to wait for a certain condition to occur. The argument \texttt{mutex} must be locked before calling this function. The mutex is unlocked atomically, and the calling thread waits for the condition to occur. If the condition does not occur, the function will wait until the calling thread is terminated in another way. This function provides a cancelation point in that the calling thread can be canceled if it is in the enabled state.
Class

Function

**Argument Type and Attributes**

- **cond**  TYPE(f_pthread_cond_t), INTENT(INOUT)
- **mutex**  TYPE(f_pthread_mutex_t), INTENT(INOUT)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

This function returns 0.

f_pthread_condattr_destroy(cattr)

**Purpose**

This function can be called to destroy the condition variable attribute objects that are no longer required. The target object is identified by the argument cattr. The system resources allocated when it is initialized will be recollected.

Class

Function

**Argument Type and Attributes**

- **cattr**  TYPE(f_pthread_condattr_t), INTENT(INOUT)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

- **EINVAL**
  
  The argument cattr is invalid.

- **EBUSY**

  Returns EBUSY if threads are waiting on the for the condition to occur.

f_pthread_condattr_getpshared(cattr, pshared)

**Purpose**

This function can be used to query the process-shared attribute of the condition variable attributes object identified by the argument cattr. The current setting of this attribute will be returned in the argument pshared.
Class

Function

**Argument Type and Attributes**

- **cattr**: TYPE(f_thread_condattr_t), INTENT(IN)
- **pshared**: INTEGER(4), INTENT(OUT)

On successful completion, **pshared** contains one of the following values:

- **PTHREAD_PROCESS_SHARED**: The condition variable can be used by any thread that has access to the memory where it is allocated, even if these threads belong to different processes.
- **PTHREAD_PROCESS_PRIVATE**: The condition variable shall only be used by threads within the same process as the thread that created it.

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns the following error.

**EINVAL**: The argument **cattr** is invalid.

**f_thread_condattr_init(cattr)**

**Purpose**

Use this function to initialize a condition variable attributes object **cattr** with the default value for all of the attributes defined by the implementation. Attempting to initialize an already initialized condition variable attributes object results in undefined behavior. After a condition variable attributes object has been used to initialize one or more condition variables, any function affecting the attributes object (including destruction) does not affect any previously initialized condition variables.

Class

Function

**Argument Type and Attributes**

- **cattr**: TYPE(f_thread_condattr_t), INTENT(OUT)

**Result Type and Attributes**

INTEGER(4)
Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

ENOOMEM

There is insufficient memory to initialize the condition variable attributes object.

\texttt{f_pthread_condattr_setpshared(cattr, pshared)}

Purpose

This function is used to set the process-shared attribute of the condition variable attributes object identified by the argument \texttt{cattr}. Its process-shared attribute will be set according to the argument \texttt{pshared}.

Class

Function

Argument Type and Attributes

\texttt{cattr}  
\texttt{TYPE(f_pthread_condattr_t), INTENT(INOUT)}

\texttt{pshared}  
is an \texttt{INTEGER(4), INTENT(IN)} argument that must contain one of the following values:

\texttt{PTHREAD_PROCESS_SHARED}  
Specifies that the condition variable can be used by any thread that has access to the memory where it is allocated, even if these threads belong to different processes.

\texttt{PTHREAD_PROCESS_PRIVATE}  
Specifies that the condition variable shall only be used by threads within the same process as the thread that created it. This is the default setting of the attribute.

Result Type and Attributes

\texttt{INTEGER(4)}

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINVVAL

The value specified by the argument \texttt{cattr} or \texttt{pshared} is invalid.

\texttt{f_pthread_condattr_t}

Purpose

A derived data type whose components are all private. Any object of this type should be manipulated only through the appropriate interfaces provided in this module.
This data type corresponds to the POSIX pthread_condattr_t, which is the type of condition variable attribute object.

Class

Data Type

f_pthread_create(thread, attr, flag, ent, arg)

Purpose

This function is used to create a new thread in the current process. The newly created thread will assume the attributes defined in the thread attribute object attr, if it is provided. Otherwise, the new thread will have system default attributes. The new thread will begin execution at the subroutine ent, which is required to have one dummy argument. The system will pass the argument arg to the thread entry subroutine ent as its actual argument. The argument flag is used to inform the system of the property of the argument arg. When the execution returns from the entry subroutine ent, the new thread will terminate automatically.

If subroutine ent was declared such that an explicit interface would be required if it was called directly, then an explicit interface is also required when it is passed as an argument to this function.

The argument arg is a generic argument that can be of any type and any rank. The actual argument arg must be a variable, and consequently eligible as a left-value in an assignment statement. If you pass an array section with vector subscripts to the argument arg, the result is unpredictable.

If the actual argument arg is an array section, the corresponding dummy argument in subroutine ent must be an assumed-shape array. Otherwise, the result is unpredictable.

If the actual argument arg has the pointer attribute that points to an array or array section, the corresponding dummy argument in subroutine ent must have a pointer attribute or be an assumed-shape array. Otherwise, the result is unpredictable.

Class

Function

Argument Type and Attributes

thread TYPE(f_pthread_t), INTENT(OUT)

On successful completion of the function, f_pthread_create stores the ID of the created thread in the thread.

attr TYPE(f_pthread_attr_t), INTENT(IN)

flag INTEGER(4), INTENT(IN)

The argument flag must convey the property of the argument arg exactly to the system. The argument flag can be one of, or a combination of, the following constants:

FLAG_CHARACTER:
if the entry subroutine ent expects an argument of type
CHARACTER in any way or any form, this flag value must be included to indicate this fact. However, if the subroutine expects a Fortran 90 pointer pointing to an argument of type CHARACTER, the FLAG_DEFAULT value should be included instead.

**FLAG_ASSUMED_SHAPE:**
- if the entry subroutine ent has a dummy argument which is an assumed-shape array of any rank, this flag value must be included to indicate this fact.

**FLAG_DEFAULT:**
- otherwise, this flag value is needed.

ent  A subroutine that has one dummy argument of any type, kind and rank.

arg  A generic argument of any type, kind, and rank. It is passed to ent as the only actual argument.

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

**EAGAIN**
- The system does not have enough resources to create a new thread.

**EINVAL**
- The argument thread, attr, or flag is invalid.

**ENOMEM**
- The system does not have sufficient memory to create a new thread.

**f_pthread_detach(thread)**

**Purpose**

This function is used to indicate to the pthreads library implementation that storage for the thread whose thread ID is specified by the argument thread can be claimed when this thread terminates. If the thread has not yet terminated, f_pthread_detach shall not cause it to terminate. Multiple f_pthread_detach calls on the same target thread cause an error.

**Class**

Function

**Argument Type and Attributes**

thread  TYPE(f_pthread_t), INTENT(IN)

**Result Type and Attributes**

INTEGER(4)
Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

ESRCH
The argument thread is invalid.

f_pthread_equal(thread1, thread2)

Purpose

This function can be used to compare whether two thread ID's identify the same thread or not.

Class

Function

Argument Type and Attributes

thread1
TYPE(f_pthread_t), INTENT(IN)

thread2
TYPE(f_pthread_t), INTENT(IN)

Result Type and Attributes

LOGICAL(4)

Result Value

TRUE  The two thread ID's identify the same thread.
FALSE  The two thread ID's do not identify the same thread.

f_pthread_exit(ret)

Purpose

This subroutine can be called explicitly to terminate the calling thread before it returns from the entry subroutine. The actions taken depend on the state of the calling thread. If it is in non-detached state, the calling thread will wait to be joined. If the thread is in detached state, or when it is joined by another thread, the calling thread will terminate safely. First, the cleanup stack will be popped and executed, and then any thread-specific data will be destructed by the destructors. Finally, the thread resources are freed and the argument ret will be returned to the joining threads. The argument ret of this subroutine is optional. Currently, argument ret is limited to be an Integer pointer. If it is not an Integer pointer, the behavior is undefined. Calling f_pthread_exit will not automatically free all of the memory allocated to a thread. To avoid memory leaks, finalization must be handled separately from f_pthread_exit.

This subroutine never returns. If argument ret is not provided, NULL will be provided as this thread's exit status.
**f_pthread_getconcurrency()**

**Purpose**

This function returns the value of the concurrency level set by a previous call to the `f_pthread_setconcurrency` function. If the `f_pthread_setconcurrency` function was not previously called, this function returns zero to indicate that the system is maintaining the concurrency level.

**f_pthread_getschedparam(thread, policy, param)**

**Purpose**

This function can be used to query the current setting of the scheduling property of the target thread. The target thread is identified by argument `thread`. Its scheduling policy will be returned through argument `policy` and its scheduling property through argument `param`. The sched_priority field in `param` defines the scheduling priority. The priority field will assume a value in the range of 1-127, where 127 is the most favored scheduling priority while 1 is the least.
Argument Type and Attributes

thread  TYPE(f_thread_t), INTENT(IN)
policy  INTEGER(4), INTENT(OUT)
param   TYPE(f_sched_param), INTENT(OUT)

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

ESRCH    The target thread is invalid or has already terminated.
EFAULT   The policy or param points are outside the process memory space

f_pthread_getspecific(key, arg)

Purpose

This function can be used to retrieve the thread-specific data associated with key. Note that the argument arg is not optional in this function as it will return the thread-specific data. After execution of the procedure, the argument arg holds a pointer to the data, or NULL if there is no data to retrieve. The argument arg must be an Integer pointer, or the result is undefined.

The actual argument arg must be a variable, and consequently eligible as a left-value in an assignment statement. If you pass an array section with vector subscripts to the argument arg, the result is unpredictable.

Class

Function

Argument Type and Attributes

key     TYPE(f_thread_key_t), INTENT(IN)
arg     [Integer pointer] INTENT(OUT)

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINV     The argument key is invalid.
**f_pthread_join(thread, ret)**

**Purpose**

This function can be called to join a particular thread designated by the argument `thread`. If the target thread is in non-detached state and is already terminated, this call will return immediately with the target thread’s status returned in argument `ret` if it is provided. The argument `ret` is optional. Currently, `ret` must be an Integer pointer if it is provided.

If the target thread is in detached state, it is an error to join it.

**Class**

Function

**Argument Type and Attributes**

<table>
<thead>
<tr>
<th>Argument</th>
<th>Type and Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>thread</td>
<td>TYPE(f_pthread_t), INTENT(IN)</td>
</tr>
<tr>
<td>ret</td>
<td>Integer pointer, INTENT(OUT), OPTIONAL</td>
</tr>
</tbody>
</table>

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

- **EDEADLK**
  - This call will cause a deadlock, or the calling thread is trying to join itself.

- **EINVAL**
  - The argument `thread` is invalid.

- **ESRCH**
  - The argument `thread` designates a thread which does not exist or is in detached state.

**f_pthread_key_create(key, dtr)**

**Purpose**

This function can be used to acquire a thread-specific data key. The key will be returned in the argument `key`. The argument `dtr` is a subroutine that will be used to destruct the thread-specific data associated with this key when any thread terminates after this calling point. The destructor will receive the thread-specific data as its argument. The destructor itself is optional. If it is not provided, the system will not invoke any destructor on the thread-specific data associated with this key. Note that the number of thread-specific data keys is limited in each process. It is the user’s responsibility to manage the usage of the keys. The per-process limit can be checked by the Fortran constant `PTHREAD_DATAKEYS_MAX`.

**Class**

Function
**Argument Type and Attributes**

key 

TYPE(f_thread_key_t), INTENT(OUT)

dtr

External, optional subroutine

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

**EAGAIN**

The maximum number of keys has been exceeded.

**EINVAL**

The argument key is invalid.

**ENOMEM**

There is insufficient memory to create this key.

**f_pthread_key_delete(key)**

**Purpose**

This function will destroy the thread-specific data key identified by the argument key. It is the user's responsibility to ensure that there is no thread-specific data associated with this key. This function does not call any destructor on the thread's behalf. After the key is destroyed, it can be reused by the system for f_pthread_key_create requests.

**Class**

Function

**Argument Type and Attributes**

key 

TYPE(f_thread_key_t), INTENT(INOUT)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

**EINVAL**

The argument key is invalid.

**EBUSY**

There is still data associated with this key.
**f_pthread_key_t**

**Purpose**

A derived data type whose components are all private. Any object of this type should be manipulated only through the appropriate interfaces provided in this module.

This data type corresponds to the POSIX `pthread_key_t`, which is the type of key object for accessing thread-specific data.

**Class**

Data Type

**f_pthread_kill(thread, sig)**

**Purpose**

This function can be used to send a signal to a target thread. The target thread is identified by argument `thread`. The signal which will be sent to the target thread is identified in argument `sig`. If `sig` contains value zero, error checking will be done by the system but no signal will be sent.

**Class**

Function

**Argument Type and Attributes**

- `thread` TYPE(f_pthread_t), INTENT(INOUT)
- `sig` INTEGER(4), INTENT(IN)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

- **EINVAL**
  
  The argument `thread` or `sig` is invalid.

- **ESRCH**
  
  The target thread does not exist.

**f_pthread_mutex_destroy(mutex)**

**Purpose**

This function should be called to destroy those mutex objects that are no longer required. In this way, the system can recollect the memory resources. The target mutex object is identified by the argument `mutex`. 
Class

Function

Argument Type and Attributes
mutex  TYPE(f_thread_mutex_t), INTENT(INOUT)

Result Type and Attributes
INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

EBUSY
The target mutex is locked or referenced by another thread.

EINVAL
The argument mutex is invalid.

f_pthread_mutex_init(mutex, mattr)

Purpose

This function can be used to initialize the mutex object identified by argument mutex. The initialized mutex will assume attributes set in the mutex attribute object mattr, if it is provided. If mattr is not provided, the system will initialize the mutex to have default attributes. After it is initialized, the mutex object can be used to synchronize accesses to critical data or code. It can also be used to build more complicated thread synchronization objects.

Another method to initialize mutex objects is to statically initialize them through the Fortran constant PTHREAD_MUTEX_INITIALIZER. If this method of initialization is used it is not necessary to call the function before using the mutex objects.

Class

Function

Argument Type and Attributes
mutex  TYPE(f_thread_mutex_t), INTENT(OUT)
mattr  TYPE(f_thread_mutexattr_t), INTENT(IN), OPTIONAL

Result Type and Attributes
INTEGER(4)

Result Value

This function always returns 0.
**f_pthread_mutex_lock(mutex)**

**Purpose**

This function can be used to acquire ownership of the mutex object. (In other words, the function will lock the mutex.) If the mutex has already been locked by another thread, the caller will wait until the mutex is unlocked. If the mutex is already locked by the caller itself, an error will be returned to prevent recursive locking.

**Class**

Function

**Argument Type and Attributes**

`mutex`  TYPE(f_pthread_mutex_t), INTENT(INOUT)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

- **EDEADLK**
  The mutex is locked by the calling thread already.

- **EINVAL**
  The argument `mutex` is invalid.

**f_pthread_mutex_t**

**Purpose**

A derived data type whose components are all private. Any object of this type should be manipulated through the appropriate interfaces provided in this module. In addition, objects of this type can be initialized statically through the Fortran constant `PTHREAD_MUTEX_INITIALIZER`.

This data type corresponds to the POSIX `pthread_mutex_t`, which is the type of mutex object.

**Class**

Data Type

**f_pthread_mutex_trylock(mutex)**

**Purpose**

This function can be used to acquire ownership of the mutex object. (In other words, the function will lock the mutex.) If the mutex has already been locked by another thread, the function returns the error code `EBUSY`. The calling thread can check the return code to take further actions. If the mutex is already locked by the caller itself, an error will be returned to prevent recursive locking.
**f_pthread_mutex_unlock(mutex)**

**Purpose**

This function releases the mutex object’s ownership in order to allow other threads to lock the mutex.

**f_pthread_mutexattr_destroy(mattr)**

**Purpose**

This function can be used to destroy a mutex attribute object that has been initialized previously. Allocated memory will then be recollected. A mutex created with this attribute will not be affected by this action.
Class

Function

**Argument Type and Attributes**

matr TYPE(f_pthread_mutexattr_t), INTENT(INOUT)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

This function always returns 0.

*f_pthread_mutexattr_getpshared(matr, pshared)*

**Purpose**

This function is used to query the process-shared attribute in the mutex attributes object identified by the argument matr. The current setting of the attribute will be returned through the argument pshared.

Class

Function

**Argument Type and Attributes**

matr TYPE(f_pthread_mutexattr_t), INTENT(IN)

pshared INTEGER(4), INTENT(IN)

On return from this function, pshared contains one of the following values:

**PTHREAD_PROCESS_SHARED**

The mutex can be operated upon by any thread that has access to the memory where the mutex is allocated, even if the mutex is allocated in memory that is shared by multiple processes.

**PTHREAD_PROCESS_PRIVATE**

The mutex will only be operated upon by threads created within the same process as the thread that initialized the mutex.

**Result Type and Attributes**

INTEGER(4)

**Result Value**

If this function completes successfully, value 0 is returned and the value of the process-shared attribute is returned through the argument pshared. Otherwise, the following error will be returned:

**EINVAL**

The argument matr is invalid.
f_pthread_mutexattr_gettype(mattr, type)

Purpose

This function is used to query the mutex type attribute in the mutex attributes object identified by the argument mattr.

If this function completes successfully, value 0 is returned and the type attribute will be returned through the argument type.

Class

Function

Argument Type and Attributes

mattr  TYPE(f_pthread_mutexattr_t), INTENT(IN)

type  INTEGER(4), INTENT(OUT)

On return from this function, type contains one of the following values:

PTHREAD_MUTEX_NORMAL
This type of mutex does not detect deadlock. A thread attempting to relock this mutex without first unlocking it will deadlock. Attempting to unlock a mutex locked by a different thread results in undefined behavior.

PTHREAD_MUTEX_ERRORCHECK
This type of mutex provides error checking. A thread attempting to relock this mutex without first unlocking it will return with an error. A thread attempting to unlock a mutex which another thread has locked will return an error. A thread attempting to unlock an unlocked mutex will return with an error.

PTHREAD_MUTEX_RECURSIVE
A thread attempting to relock this mutex without first unlocking it will succeed in locking the mutex. The relocking deadlock that can occur with mutexes of type PTHREAD_MUTEX_NORMAL cannot occur with this type of mutex. Multiple locks of this mutex require the same number of unlocks to release the mutex before another thread can acquire the mutex.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINVAL
The argument is invalid.
f_pthread_mutexattr_init(mat)

Purpose

This function can be used to initialize a mutex attribute object before it can be used in any other way. The mutex attribute object will be returned through argument mat.

Class

Function

Argument Type and Attributes

mat TYPE(f_pthread_mutexattr_t), INTENT(OUT)

Result Type and Attributes

INTEGER(4)

Result Value

This function returns 0.

f_pthread_mutexattr_setpshared(mat, pshared)

Purpose

This function is used to set the process-shared attribute of the mutex attribute object identified by the argument mat.

Class

Function

Argument Type and Attributes

mat TYPE(f_pthread_mutexattr_t), INTENT(INOUT)

pshared INTEGER(4), INTENT(IN)

Must contain one of the following values:

PTHREAD_PROCESS_SHARED

Specifies the mutex can be operated upon by any thread that has access to the memory where the mutex is allocated, even if the mutex is allocated in memory that is shared by multiple processes.

PTHREAD_PROCESS_PRIVATE

Specifies the mutex will only be operated upon by threads created within the same process as the thread that initialized the mutex. This is the default setting of the attribute.

Result Type and Attributes

INTEGER(4)
Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINVAL
The argument is invalid.

f_pthread_mutexattr_settype(mattr, type)

Purpose

This function is used to set the mutex type attribute in the mutex attributes object identified by the argument mattr. The argument type identifies the mutex type attribute to be set.

Class

Function

Argument Type and Attributes

mattr TYPE(f_pthread_mutexattr_t), INTENT(INOUT)
type INTEGER(4), INTENT(IN)

Must contain one of the following values:

PTHREAD_MUTEX_NORMAL
This type of mutex does not detect deadlock. A thread attempting to relock this mutex without first unlocking it will deadlock. Attempting to unlock a mutex locked by a different thread results in undefined behavior.

PTHREAD_MUTEX_ERRORCHECK
This type of mutex provides error checking. A thread attempting to relock this mutex without first unlocking it will return with an error. A thread attempting to unlock a mutex which another thread has locked will return an error. A thread attempting to unlock an unlocked mutex will return with an error.

PTHREAD_MUTEX_RECURSIVE
A thread attempting to relock this mutex without first unlocking it will succeed in locking the mutex. The relocking deadlock that can occur with mutexes of type PTHREAD_MUTEX_NORMAL cannot occur with this type of mutex. Multiple locks of this mutex require the same number of unlocks to release the mutex before another thread can acquire the mutex.

PTHREAD_MUTEX_DEFAULT
The same as PTHREAD_MUTEX_NORMAL.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.
f_pthread_mutexattr_t

**Purpose**

A derived data type whose components are all private. Any object of this type should be manipulated only through the appropriate interfaces provided in this module.

This data type corresponds to the POSIX `pthread_mutexattr_t`, which is the type of mutex attribute object.

**Class**

Data Type

f_pthread_once(once, initr)

**Purpose**

This function can be used to initialize those data required to be initialized only once. The first thread calling this function will call `initr` to do the initialization. Other threads calling this function afterwards will have no effect. Argument `initr` must be a subroutine without dummy arguments.

**Class**

Function

**Argument Type and Attributes**

- `once`  TYPE(f_pthread_once_t), INTENT(INOUT)
- `initr` A subroutine that has no dummy arguments.

**Result Type and Attributes**

- INTEGER(4)

**Result Value**

This function returns 0.

f_pthread_once_t

**Purpose**

A derived data type whose components are all private. Any object of this type should be manipulated through the appropriate interfaces provided in this module. However, objects of this type can only be initialized through the Fortran constant `PTHREAD_ONCE_INIT`.

**Class**

Data Type
f_pthread_rwlock_destroy(rwlock)

Purpose

This function destroys the read-write lock object specified by the argument `rwlock` and releases any resources used by the lock.

Class

Function

Argument Type and Attributes

- `rwlock`  
  └TYPE(f_pthread_rwlock_t), INTENT(INOUT)

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

EBUSY  
The target read-write object is locked.

f_pthread_rwlock_init(rwlock, rwattr)

Purpose

This function initializes the read-write lock object specified by `rwlock` with the attribute specified by the argument `rwattr`. If the optional argument `rwattr` is not provided, the system will initialize the read-write lock object with the default attributes. After it is initialized, the lock can be used to synchronize access to critical data. With a read-write lock, many threads can have simultaneous read-only access to data, while only one thread can have write access at any given time and no other readers or writers are allowed.

Another method to initialize read-write lock objects is to statically initialize them through the Fortran constant `PTHREAD_RWLOCK_INITIALIZER`. If this method of initialization is used, it is not necessary to call this function before using the read-write lock objects.

Class

Function

Argument Type and Attributes

- `rwlock`  
  └TYPE(f_pthread_rwlock_t), INTENT(OUT)
- `rwattr`  
  └TYPE(f_pthread_rwlockattr_t), INTENT(IN), OPTIONAL

Result Type and Attributes

INTEGER(4)
Result Value

This function returns 0.

\[ \text{f_pthread_rwlock_rdlock(rwlock)} \]

**Purpose**

This function applies a read lock to the read-write lock specified by the argument `rwlock`. The calling thread acquires the read lock if a writer does not hold the lock and there are no writes blocked on the lock. Otherwise, the calling thread will not acquire the read lock. If the read lock is not acquired, the calling thread blocks (that is, it does not return from the `f_pthread_rwlock_rdlock` call) until it can acquire the lock. Results are undefined if the calling thread holds a write lock on `rwlock` at the time the call is made. A thread may hold multiple concurrent read locks on `rwlock` (that is, successfully call the `f_pthread_rwlock_rdlock` function \( n \) times). If so, the thread must perform matching unlocks (that is, it must call the `f_pthread_rwlock_unlock` function \( n \) times).

**Class**

Function

**Argument Type and Attributes**

`rwlock`

\[ \text{TYPE(f_pthread_rwlock_t), INTENT(INOUT)} \]

**Result Type and Attributes**

\[ \text{INTEGER(4)} \]

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.

**EAGAIN**

The read-write lock could not be acquired because the maximum number of read locks for `rwlock` has been exceeded.

**EINVAL**

The argument `rwlock` does not refer to an initialized read-write lock object.

\[ \text{f_pthread_rwlock_t} \]

**Purpose**

A derived data type whose components are all private. Any object of this type should be manipulated only through the appropriate interfaces provided in this module. In addition, objects of this type can be initialized statically through the Fortran constant `PTHREAD_RWLOCK_INITIALIZER`.

**Class**

Data Type
f_pthread_rwlock_tryrdlock(rwlock)

Purpose

This function applies a read lock like the f_pthread_rwlock_rdlock function with the exception that the function fails if any thread holds a write lock on rwlock or there are writers blocked on rwlock. In that case, the function returns EBUSY. The calling thread can check the return code to take further actions.

Class

Function

Argument Type and Attributes

rwlock
TYPE(f_pthread_rwlock_t), INTENT(INOUT)

Result Type and Attributes

INTEGER(4)

Result Value

This function returns zero if the lock for reading on the read-write lock object specified by rwlock is acquired. Otherwise, the following error will be returned:

EBUSY
The read-write lock could not be acquired for reading because a writer holds the lock or was blocked on it.

f_pthread_rwlock_trywrlock(rwlock)

Purpose

This function applies a write lock like the f_pthread_rwlock_wrlock function with the exception that the function fails if any thread currently holds rwlock (for reading or writing). In that case, the function returns EBUSY. The calling thread can check the return code to take further actions.

Class

Function

Argument Type and Attributes

rwlock
TYPE(f_pthread_rwlock_t), INTENT(INOUT)

Result Type and Attributes

INTEGER(4)

Result Value

This function returns zero if the lock for writing on the read-write lock object specified by rwlock is acquired. Otherwise, the following error will be returned:
EBUSY
The read-write lock could not be acquired for writing because it is already locked for reading or writing.

f_pthread_rwlock_unlock(rwlock)

Purpose
This function is used to release a lock held on the read-write lock object specified by the argument rwlock. If this function is called to release a read lock from the read-write lock object and there are other read locks currently held on this read-write lock object, the read-write lock object remains in the read locked state. If this function releases the calling thread’s last read lock on this read-write lock object, then the calling thread is no longer one of the owners of the object. If this function releases the last read lock for this read-write lock object, the read-write lock object will be put in the unlocked state with no owners.

Class
Function

Argument Type and Attributes
rwlock
TYPE(f_pthread_rwlock_t), INTENT(INOUT)

Result Type and Attributes
INTEGER(4)

Result Value
On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.
EPERM
The current thread does not own the read-write lock.

f_pthread_rwlock_wrlock(rwlock)

Purpose
This function applies a write lock to the read-write lock specified by the argument rwlock. The calling thread acquires the write lock if no other thread (reader or writer) holds the read-write lock rwlock. Otherwise, the thread blocks (that is, does not return from the f_pthread_rwlock_wrlock call) until it acquires the lock. Results are undefined if the calling thread holds the read-write lock (whether a read or write lock) at the time the call is made.

Class
Function

Argument Type and Attributes
rwlock
TYPE(f_pthread_rwlock_t), INTENT(INOUT)
Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINVAL

The argument rwlock does not refer to an initialized read-write lock object.

f_pthread_rwlockattr_destroy(rwattr)

Purpose

This function destroys a read-write lock attributes object specified by the argument rwattr which has been initialized previously. A read-write lock created with this attribute will not be affected by the action.

Class

Function

Argument Type and Attributes

rwattr  TYPE(f_pthread_rwlockattr_t), INTENT(INOUT)

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINVAL

The argument rwattr is invalid.

f_pthread_rwlockattr_getpshared(rwattr, pshared)

Purpose

This function is used to obtain the value of the process-shared attribute from the initialized read-write lock attributes object specified by the argument rwattr. The current setting of this attribute will be returned in the argument pshared.

Class

Function

Argument Type and Attributes

rwattr  TYPE(f_pthread_rwlockattr_t), INTENT(IN)
pshared  INTEGER(4), INTENT(OUT)
On return from this function, the value of `pshared` will be one of the following values:

**PTHREAD_PROCESS_SHARED**

The read-write lock can be operated upon by any thread that has access to the memory where it is allocated, even if these threads belong to different processes.

**PTHREAD_PROCESS_PRIVATE**

The read-write lock shall only be used by threads within the same process as the thread that created it.

**Result Type and Attributes**

INTEGER(4)

**Result Value**

If this function completes successfully, value 0 is returned and the value of the process-shared attribute of `rwattr` is stored into the object specified by the argument `pshared`. Otherwise, the following error will be returned:

**EINVAL**

The argument `rwattr` is invalid.

**f_pthread_rwlockattr_init(rwattr)**

**Purpose**

This function initializes a read-write lock attributes object specified by `rwattr` with the default value for all of the attributes.

**Class**

Function

**Argument Type and Attributes**

`rwattr`  TYPE(f_pthread_rwlockattr_t), INTENT(OUT)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns the following error:

**ENOMEM**

There is insufficient memory to initialize the read-write lock attributes object.
f_pthread_rwlockattr_setpshared(rwattr, pshared)

Purpose

This function is used to set the process-shared attribute in an initialized read-write lock attributes object specified by the argument rwattr, based on the value provided by the argument pshared.

Class

Function

Argument Type and Attributes

<table>
<thead>
<tr>
<th>Argument</th>
<th>Type</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>rwattr</td>
<td>TYPE(f_thread_rwlockattr_t), INTENT(INOUT)</td>
<td></td>
</tr>
<tr>
<td>pshared</td>
<td>INTEGER(4), INTENT(IN)</td>
<td></td>
</tr>
</tbody>
</table>

Must be one of the following values:

- **PTHREAD_PROCESS_SHARED**
  Specifies the read-write lock can be operated upon by any thread that has access to the memory where it is allocated, even if these threads belong to different processes.

- **PTHREAD_PROCESS_PRIVATE**
  Specifies the read-write lock shall only be used by threads within the same process as the thread that created it. This is the default setting of the attribute.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors:

- **EINV**
  The argument rwattr is invalid.

- **ENOSYS**
  The value of pshared is equal to pthread_process_shared.

f_pthread_rwlockattr_t

Purpose

This is a derived data type whose components are all private. Any object of this type should be manipulated only through the appropriate interfaces provided in this module.

Class

Data Type
**f_pthread_self()**

**Purpose**

This function can be used to return the thread ID of the calling thread.

**Class**

Function

**Argument Type and Attributes**

None

**Result Type and Attributes**

TYPE(f_pthread_t)

**Result Value**

The calling thread’s ID is returned.

---

**f_pthread_setcancelstate(state, oldstate)**

**Purpose**

This function can be used to set the thread’s cancelability state. The new state will be set according to the argument `state`. The old state will be returned in the argument `oldstate`.

**Class**

Function

**Argument Type and Attributes**

- `state` INTEGER(4), INTENT(IN)
  
  Must contain one of the following values:
  
  **PTHREAD_CANCEL_DISABLE:**
  
  The thread’s cancelability is disabled.
  
  **PTHREAD_CANCEL_ENABLE:**
  
  The thread’s cancelability is enabled.

- `oldstate` INTEGER(4), INTENT(OUT)
  
  On return from this function, `oldstate` will contain one of the following values:
  
  **PTHREAD_CANCEL_DISABLE:**
  
  The thread’s cancelability is disabled.
  
  **PTHREAD_CANCEL_ENABLE:**
  
  The thread’s cancelability is enabled.

**Result Type and Attributes**

INTEGER(4)
Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINV
   The argument state is invalid.

f pthread_setcanceltype(type, oldtype)

Purpose

This function can be used to set the thread's cancelability type. The new type will be set according to the argument type. The old type will be returned in argument oldtype.

Class

Function

Argument Type and Attributes

type      INTEGER(4), INTENT(IN)
   Must contain one of the following values:

     PTHREAD_CANCEL_DEFERRED:
        Cancelation request will be delayed until a cancelation point.

     PTHREAD_CANCEL_ASYNCHRONOUS:
        Cancelation request will be acted upon immediately. This may cause unexpected results.

oldtype   INTEGER(4), INTENT(OUT)
   On return from this procedure, oldtype will contain one of the following values:

     PTHREAD_CANCEL_DEFERRED:
        Cancelation request will be delayed until a cancelation point.

     PTHREAD_CANCEL_ASYNCHRONOUS:
        Cancelation request will be acted upon immediately. This may cause unexpected results.

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns the following error.

EINV
   The argument type is invalid.
**f_pthread_setconcurrency(new_level)**

**Purpose**

This function is used to inform the pthreads library implementation of the desired concurrency level as specified by the argument `new_level`. The actual level of concurrency provided by the implementation as a result of this function call is unspecified.

**Class**

Function

**Argument Type and Attributes**

new_level

INTEGER(4), INTENT(IN)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

This function returns 0.

**f_pthread_setschedparam(thread, policy, param)**

**Purpose**

This function can be used to dynamically set the scheduling policy and the scheduling property of a thread. The target thread is identified by argument `thread`. The new scheduling policy for the target thread is provided through argument `policy`. The new scheduling property of the target thread will be set to the value provided by argument `param`. The sched_priority field in `param` defines the scheduling priority. Its range is 1-127.

**Class**

Function

**Argument Type and Attributes**

thread

TYPE(f_pthread_t), INTENT(INOUT)

policy

INTEGER(4), INTENT(IN)

param

TYPE(f_sched_param), INTENT(IN)

**Result Type and Attributes**

INTEGER(4)

**Result Value**

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors.
ENOSYS
The POSIX priority scheduling option is not implemented on Linux.

ENOTSUP
The value of argument policy or param is not supported.

EPERM
The target thread is not permitted to perform the operation or is in a mutex protocol already.

ESRCH
The target thread does not exist or is invalid.

f_pthread_setspecific(key, arg)

Purpose

This function can be used to set the calling thread’s specific data associated with the key identified by argument key. The argument arg, which is optional, identifies the thread-specific data to be set. If arg is not provided, the thread-specific data will be set to NULL, which is the initial value for each thread. Only an Integer pointer can be passed as the arg argument. If arg is not an Integer pointer, the result is undefined.

The actual argument arg must be a variable, and consequently eligible as a left-value in an assignment statement. If you pass an array section with vector subscripts to the argument arg, the result is unpredictable.

Class

Function

Argument Type and Attributes

key TYPE(f_pthread_key_t), INTENT(IN)
arg Integer pointer INTENT(IN), OPTIONAL

Result Type and Attributes

INTEGER(4)

Result Value

On successful completion, this function returns 0. Otherwise, this function returns one of the following errors

EINVAL
The argument key is invalid.

ENOMEM
There is insufficient memory to associate the data with the key.

f_pthread_t

Purpose

A derived data type whose components are all private. Any object of this type should be manipulated only through the appropriate interfaces provided in this module.
This data type corresponds to the POSIX `pthread_t`, which is the type of thread object.

**Class**

Data Type

**f_pthread_testcancel()**

**Purpose**

This subroutine provides a cancelation point in a thread. When this subroutine is called, any pending cancelation request will be acted upon immediately if the cancelability state of the thread is in the enabled state.

**Class**

Subroutine

**Argument Type and Attributes**

None

**Result Type and Attributes**

None

**f_sched_param**

**Purpose**

This data type corresponds to the Linux system data structure `sched_param`, which is a system data type.

This is a public data structure defined as:

```fortran
type f_sched_param
  sequence
    integer sched_priority
end type f_sched_param
```

**Class**

Data Type

**f_sched_yield()**

**Purpose**

This function is used to force the calling thread to relinquish the processor until it again becomes the head of its thread list.

**Class**

Function

**Argument Type and Attributes**

None.
Result Type and Attributes

INTEGER(4)

Result Value

If this function completes successfully, value 0 is returned. Otherwise, a value of -1 will be returned.

f_timespec

Purpose

This is a Fortran definition of the Linux system data structure timespec. Within the Fortran Pthreads module, objects of this type are used to specify an absolute date and time. This deadline absolute date is used when waiting on a POSIX condition variable.

f_timespec is defined as:

```
TYPE F_Timespec
  SEQUENCE
  INTEGER(4) tv_sec
  INTEGER(4) pad
  INTEGER(KIND=REGISTER_SIZE) tv_nsec
END TYPE F_Timespec
```

Class

Data Type
Chapter 10. Offloading computations to the NVIDIA GPUs

The combination of the IBM POWER processors and the NVIDIA GPUs provides a platform for heterogeneous high-performance computing that can run several technical computing workloads efficiently. The computational capability is built on top of massively parallel and multithreaded cores within the NVIDIA GPUs and the IBM POWER processors. You can offload parallel operations within applications, such as data analysis or high-performance computing workloads, to GPUs.

System prerequisites for offloading to the NVIDIA GPUs

To compile and link programs that contain code to be offloaded to the NVIDIA GPUs with IBM XL Fortran for Linux, you must ensure these operating system, hardware, and software requirements are met.

- Use any IBM Power Systems™ server that has one or more NVIDIA GPUs installed and is supported by your Linux operating system distribution and the NVIDIA CUDA Toolkit.
- Use the supported little endian operating system.
- Install NVIDIA CUDA Toolkit 9.0 or 9.1.

For more information, see topic System prerequisites to offload computations to the NVIDIA GPUs in the XL Fortran Installation Guide.

Programming with OpenMP device constructs

IBM XL Fortran for Linux, V15.1.6 partially supports the OpenMP Application Program Interface Version 4.5 specification. You can offload compute-intensive parts of an application and associated data to the NVIDIA GPUs by using these supported device constructs.

Supported device constructs

- TARGET DATA
- TARGET ENTER DATA
- TARGET EXIT DATA
- TARGET
- TARGET UPDATE
- DECLARE TARGET
- TEAMS
- DISTRIBUTE
- DISTRIBUTE PARALLEL DO
- DISTRIBUTE PARALLEL DO SIMD
- DISTRIBUTE SIMD

For example, you can use the TARGET directive to define a target region, which is a block of computation that operates within a distinct data environment and is intended to be offloaded onto a parallel computation device during execution. For more information about the OpenMP directives, see “Parallelization directives” on page 107.
You can also use other OpenMP constructs with these OpenMP device constructs to exert finer control on parallelization, such as the combined constructs that are listed in “OpenMP combined constructs” on page 109.

**GPU-related compiler options**

You must specify the `-qoffload` option to enable the support for offloading OpenMP target regions to NVIDIA GPUs. For `-qoffload` to take effect, you must also specify the `-qsmp` option to enable support for OpenMP target regions. For more information, see `-qoffload` in the *XL Fortran Compiler Reference*.

You can also use the `-qtgtarch` option to specify real or virtual GPU architectures where the code may run. For more information, see `-qtgtarch` in the *XL Fortran Compiler Reference*.

**GPU-related environment variables**

You can control the computations offloaded to target devices by using the following environment variables:

- `XLSMPOPTS=target={mandatory | default | disabled}` controls which device to execute target regions on.
- `XLSMPOPTS=cudamemcheckfriendly={off | on}` controls whether to disable the check for pinned memory in the runtime and allow the program to be executed under the cuda-memcheck tool from the NVIDIA CUDA Toolkit.

For more information, see “XLSMPOPTS” on page 86.

**GPU-related runtime routines**

You can use the following runtime routines to query the target environment.

- `omp_get_default_device`
- `omp_get_initial_device`
- `omp_get_num_devices`
- `omp_get_num_teams`
- `omp_get_team_num`
- `omp_is_initial_device`

For more information about OpenMP runtime functions, see “Routines for OpenMP” on page 220.

**Extensions from OpenMP Technical Reports**

IBM XL Fortran for Linux, V15.1.6 also partially supports the OpenMP Technical Reports augmenting the OpenMP Application Program Interface Version 4.5 specification.

**Support for implicit declare target**

If a function or subroutine is called and defined in the same translation unit, you do not need to explicitly declare it with the `DECLARE TARGET` directive. Such functions or subroutines are treated as if they were explicitly declared. This extension simplifies the use of functions or subroutines defined in the same module or defined as internal procedures, when they are used within a target region.
See the following code snippets for example.

```fortran
MODULE mymodule
  IMPLICIT NONE
  CONTAINS
    SUBROUTINE sub0()
      INTEGER :: rc = 0
      !$OMP TARGET MAP(rc)
      CALL sub2(2, rc)
      !$OMP END TARGET
      PRINT *, rc
    END SUBROUTINE sub0
    SUBROUTINE sub1(i, r)
      INTEGER :: i
      INTEGER :: r
      r = i
    END SUBROUTINE sub1
    SUBROUTINE sub2(i, r)
      INTEGER :: i
      INTEGER :: r
      CALL sub1(i, r)
    END SUBROUTINE sub2
  END MODULE mymodule

PROGRAM main
  USE mymodule
  IMPLICIT NONE
  CALL sub0()
END PROGRAM main
```

In this example, the sub2 subroutine is used within a target region and defined in
the same translation unit as module procedure; the compiler implicitly treats the
subroutine as declared with the DECLARE TARGET directive. Furthermore, as
subroutine sub1 is called by sub2, therefore sub1 is also treated as if it was declared
using the DECLARE TARGET directive.

**Pointer component mapping**

Mapping of a pointer is extended to support mapping a pointer component of a
derived type and the storage that the pointer points to.

```fortran
MODULE m
  TYPE dt
    INTEGER, POINTER :: p(:)
    REAL :: a
  END TYPE
  CONTAINS
    SUBROUTINE foo(ydt)
      !$OMP DECLARE TARGET
      TYPE(dt) :: ydt
      ydt%p = 41
    END SUBROUTINE foo
  END MODULE

USE m
  TYPE(dt) xdt
  ALLOCATE(xdt%p(5))
  xdt%p(3) = 3
  !$OMP TARGET ENTER DATA MAP(TO:xdt)
  !$OMP TARGET MAP(xdt%p)
    CALL foo(xdt)
  !$OMP END TARGET
  PRINT *, xdt%p ! 41 41 41 41 41
END
```
In this example, the derived type xdt including the pointer p is mapped to the device in the target enter data construct. On entering the target region, by having mapped the storage that p points to, the MAP(xdt%p) clause establishes the attachment between xdt%p on the device and the storage being mapped to the device. As a result, in the target region, xdt%p points to the corresponding device storage.

**Allocatable variables mapping**

You can follow the semantic of mapping Fortran allocatable variables with XL Fortran as clarified in the OpenMP Technical Report.

- If an unallocated allocatable variable is mapped, the allocation status of the variable inside the target region is unallocated.
- If an allocated allocatable variable is mapped, the allocation status of the variable inside the target region is allocated with the same shape and size as the original variable.

The following example shows using allocatable arrays in target constructs.

```fortran
REAL, ALLOCATABLE :: a(:), b(:)
LOGICAL :: status
ALLOCATE(a(100))
a = [ (i,i=1,100) ]
!$OMP TARGET MAP(a)
a = a + 1
!$OMP END TARGET
PRINT *, a ! 2, 3, ..., 101

!$OMP TARGET MAP(b) MAP(status)
status = ALLOCATED(b)
!$OMP END TARGET
PRINT *, status ! F
```

**Programming with supported CUDA Fortran features**

IBM XL Fortran for Linux supports the CUDA Fortran programming model to exploit the NVIDIA GPUs. You can use the commonly used subset of CUDA Fortran that is provided by IBM XL Fortran for Linux to offload computations to the NVIDIA GPUs.

You must specify the `-qcuda` option to enable the compiler support for CUDA Fortran. For more information, see `-qcuda` in the *XL Fortran Compiler Reference*.

You can specify the `-qtgtarch` option to specify real or virtual GPU architectures where the code may run. For more information, see `-qtgtarch` in the *XL Fortran Compiler Reference*.

For more information about CUDA Fortran programming using IBM XL Fortran for Linux, including useful compiler options and a list of supported CUDA Fortran features, see the *Getting Started with CUDA Fortran programming using XL Fortran*.

**Limitations**

Note these limitations when you offload computations to the NVIDIA GPUs with IBM XL Fortran for Linux, V15.1.6.

**Workaround to get debugging support on GPUs**

To debug an OpenMP application, you need to compile it with `-g -qsmp=noopt`.
The reason is that due to a limitation in NVVM, IBM XL Fortran for Linux, V15.1.6 cannot generate debug information when GPU runtime inlining is enabled. To cope with this case, you can turn off GPU runtime inlining by specifying `-qsm=noopt`. GPU runtime inlining is enabled at all other optimization levels.

**Limitation related to compute mode**

If the compute mode of a target device is not set to default, a CUDA context created by your code might cause the OpenMP runtime to fail. The reason is that the target device cannot create a second context, which might be required depending on which OpenMP thread tries to initialize the device. You can check the compute mode to verify whether such case happens when you suspect a segment fault or deadlock.

**Performance of nested parallelism on Volta**

On Volta, nested level-1 parallel region and nested SIMD region run sequentially when only a subset of threads in a warp are active at the point of reaching the nested region. This is to cope with the independent thread scheduling of Volta to ensure forward progress in the presence of thread divergence.

**Limitation caused by warp divergence and thread dependency**

When the control path among two or more CUDA threads in the same warp diverges, these CUDA threads are serialized. IBM XL Fortran for Linux generates one CUDA thread for each OpenMP thread. As a result, suppose thread A and B are two OpenMP threads, the program might hang if the progress of thread A depends on thread B performing some action, and if thread A executes first while thread B stalls because of warp divergence.

Warp divergence occurs when two threads of the same warp diverge in their execution due to a branch instruction, where one thread branches and the other does not. This leads to serialization of the two threads by the CUDA hardware until their execution path converges again.

The following two examples demonstrate the problem:

**Example 1**

```fortran
USE OMP_LIB
INTEGER :: i = 0
INTEGER :: local_i
local_i = i
$OMP TARGET
$OMP PARALLEL FIRSTPRIVATE(local_i)
IF (omp_get_thread_num() .EQ. 0) THEN ! thread 0 takes this path
  $OMP ATOMIC
  i=i+1
  $OMP END ATOMIC
ELSE ! the other threads take this path
  DO WHILE (local_i .EQ. 0)
    $OMP ATOMIC READ
    local_i=i
    $OMP END ATOMIC
  END DO
END IF
$OMP END PARALLEL
$OMP END TARGET
END
```

Chapter 10. Offloading computations to the NVIDIA GPUs
Example 2

INTEGER :: i = 0
INTEGER :: local_i
local_i = i
!
!$OMP TARGET
!$OMP PARALLEL FIRSTPRIVATE(local_i)
!$OMP SECTIONS
!$OMP SECTION ! thread 0 executes this section
!$OMP ATOMIC
i = i + 1
!$OMP SECTION ! thread 1 executes this section
DO WHILE (local_i .EQ. 0)
!$OMP ATOMIC READ
local_i = i
!$OMP END ATOMIC
END DO
!$OMP END SECTIONS
!$OMP END PARALLEL
!$OMP END TARGET
END
Chapter 11. Interlanguage calls

Your Fortran application can perform interlanguage calls to routines written in a language other than Fortran.

The guidelines assume that you are familiar with the syntax of all applicable languages.

Conventions for XL Fortran external names

To assist you in writing mixed-language programs, XL Fortran follows a consistent set of rules when translating the name of a global entity into an external name that the linker can resolve.

The rules are:

• Both the underscore (_) and the dollar sign ($) are valid characters anywhere in names.

Because names that begin with an underscore are reserved for the names of library routines, do not use an underscore as the first character of a Fortran external name.

To avoid conflicts between Fortran and non-Fortran function names, you can compile the Fortran program with the -qextname option. This option adds an underscore to the end of the Fortran names. Then use an underscore as the last character of any non-Fortran procedures that you want to call from Fortran.

• Names can be up to 250 characters long.

• Program and symbolic names are interpreted as all lowercase by default. If you are writing new non-Fortran code, use all-lowercase procedure names to simplify calling the procedures from Fortran.

You can use the -U option or the @PROCESS MIXED directive if you want the names to use both uppercase and lowercase:

@process mixed
    external C_Func ! With MIXED, we can call C_Func, not just c_func.
    integer aBc, ABC ! With MIXED, these are different variables.
    common /xYz/ aBc ! The same applies to the common block names.
    common /XYZ/ ABC ! xYz and XYZ are external names that are visible during linking.
end

• Names for module procedures are formed by concatenating __ (two underscores), the module name, _IMOD_ (for intrinsic modules) or _NMOD_ (for non-intrinsic modules), and the name of the module procedure. For example, module procedure MYPROC in module MYMOD has the external name __mymod_NMOD_myproc.

Note: Symbolic debuggers and other tools should account for this naming scheme when debugging XL Fortran programs that contain module procedures. For example, some debuggers default to lowercase for program and symbolic names. This behavior should be changed to use mixed case when debugging XL Fortran programs with module procedures.

• The XL compilers generate code that uses main as an external entry point name. You can only use main as an external name in these contexts:
A Fortran program or local-variable name. (This restriction means that you cannot use \texttt{main} as a binding label, or for the name of an external function, external subroutine, block data program unit, or common block. References to such an object use the compiler-generated \texttt{main} instead of your own.)

The name of the top-level main function in a C program.

- Some other potential naming conflicts may occur when linking a program. For instructions on avoiding them, see \texttt{Avoiding naming conflicts during linking} in the XL Fortran Compiler Reference.

If you are porting your application from another system and your application does encounter naming conflicts like these, you may need to use the \texttt{-qextname} option.

### Mixed-language input and output

To improve performance, the XL Fortran runtime library has its own buffers and its own handling of these buffers. This means that mixed-language programs cannot freely mix I/O operations on the same file from the different languages.

Mixing code compiled by multiple Fortran compilers, for example \texttt{xlf} and \texttt{gfortran}, could face similar problems. The safest approach is to treat the code compiled by another Fortran compiler as non-Fortran code. To maintain data integrity in such cases:

- If the file position is not important, open and explicitly close the file within the Fortran part of the program before performing any I/O operations on that file from subprograms written in another language.

- To open a file in Fortran and manipulate the open file from another language, call the \texttt{flush} procedure to save any buffer for that file, and then use the \texttt{getfd} procedure to find the corresponding file descriptor and pass it to the non-Fortran subprogram.

As an alternative to calling the \texttt{flush} procedure, you can use the \texttt{buffering} runtime option to disable the buffering for I/O operations. When you specify \texttt{buffering=disable_preconn}, XL Fortran disables the buffering for preconnected units. When you specify \texttt{buffering=disable_all}, XL Fortran disables the buffering for all logical units.

**Note:** After you call \texttt{flush} to flush the buffer for a file, do not do anything to the file from the Fortran part of the program except to close it when the non-Fortran processing is finished.

- If any XL Fortran subprograms containing \texttt{WRITE} statements are called from a non-Fortran main program, explicitly \texttt{CLOSE} the data file, or use the \texttt{flush} subroutine in the XL Fortran subprograms to ensure that the buffers are flushed. Alternatively, you can use the \texttt{buffering} runtime option to disable buffering for I/O operations.

For more information on the \texttt{flush} and \texttt{getfd} procedures, see the Service and utility \texttt{procedures} topic in the XL Fortran Language Reference. For more information on the \texttt{buffering} runtime option, see Setting runtime options in the XL Fortran Compiler Reference.

### Mixing Fortran and C++

When mixing Fortran and C++ in the same program, you need to invoke the C++ compiler to correctly link the final program.
Most of the information in this section applies to Fortran and languages with similar data types and naming schemes. However, to mix Fortran and C++ in the same program, you must add an extra level of indirection and pass the interlanguage calls through C++ wrapper functions.

Because the C++ compiler mangles the names of some C++ objects, you must use your C++ compiler's invocation command, like xlC or g++, to link the final program and include -L and -l options for the XL Fortran library directories and libraries.

```fortran
program main
  integer idim, idim1
  idim = 35
  idim1 = 45
  write(6,*) 'Inside Fortran calling first C function'
  call cfun(idim)
  write(6,*) 'Inside Fortran calling second C function'
  call cfun1(idim1)
  write(6,*) 'Exiting the Fortran program'
end
```

Figure 4. Main Fortran program that calls C++ (main1.f)

```c
#include <stdio.h>
#include "cplus.h"

extern "C" void cfun(int *idim) {
    printf("%sInside C function before creating C++ Object\n");
    int i = *idim;
    junk<int> *jj = new junk<int>(10, 30);
    jj->store(idim);
    jj->print();
    printf("%sInside C function after creating C++ Object\n");
    delete jj;
    return;
}

extern "C" void cfun1(int *idim) {
    printf("%sInside C function cfun1 before creating C++ Object\n");
    int i = *idim;
    temp<double> *tmp = new temp<double>(40, 50.54);
    tmp->print();
    printf("%sInside C function after creating C++ temp object\n");
    delete tmp;
    return;
}

Figure 5. C++ wrapper functions for calling C++ (cfun.C)
Compiling this program, linking it with the XLIC command, and running it produces the following output:

```
Inside Fortran calling first C function
%Inside C function before creating C++ Object
***Inside C++ constructor
10 30 35
%Inside C function after creating C++ Object
***Inside C++ Destructor
Inside Fortran calling second C function
%Inside C function cfun1 before creating C++ Object
***Inside C++ temp Constructor
40 50.54
%Inside C function after creating C++ temp object
***Inside C++ temp destructor
Exiting the Fortran program
```

Making calls to C functions work

When you pass an argument to a subprogram call, the usual Fortran convention is to pass the address of the argument. Many C functions expect arguments to be passed as values, however, not as addresses.

For these arguments, specify them as `%VAL(argument)` in the call to C, or make use of the standards-compliant `VALUE` attribute. For example:

```c++
#include <iostream.h>

template<class T> class junk {
  private:
    int inter;
    T templ_mem;
    T stor_val;
  public:
    junk(int i, T j): inter(i), templ_mem(j)
    {cout <<***Inside C++ constructor" << endl;}
    ~junk() {cout <<***Inside C++ Destructor" << endl;}
    void store(T *val){ stor_val = *val;}
    void print(void) {cout << inter << "\t" << templ_mem;
                   cout <<"\t" << stor_val << endl;}

  template<class T> class temp {
  private:
    int internal;
    T temp_var;
  public:
    temp(int i, T j): internal(i), temp_var(j)
    {cout <<***Inside C++ temp Constructor" << endl;
     cout <<"\t" << temp_var << endl;}
    ~temp() {cout <<***Inside C++ temp destructor" << endl;
     cout <<"\t" << temp_var << endl;}};
```

Figure 6. C++ code called from Fortran (cplus.h)
MEMBLK = MALLOC(1024) ! Wrong, passes the address of the constant
MEMBLK = MALLOC(N) ! Wrong, passes the address of the variable

MEMBLK = MALLOC(%VAL(1024)) ! Right, passes the value 1024
MEMBLK = MALLOC(%VAL(N)) ! Right, passes the value of the variable

See “Passing arguments by reference or by value” on page 315 and %VAL and %REF in the XL Fortran Language Reference for more details.

Passing data from one language to another

You need to account for corresponding data types in Fortran and C when passing data from one language to another.

The Corresponding data types in Fortran and C table shows the data types available in the XL Fortran and C languages. Further topics detail how Fortran arguments can be passed by reference to C programs. To use the Fortran Standard interoperability features, see the BIND attribute and ISO_C_BINDING module in the XL Fortran Language Reference.

Passing arguments between languages

When calling Fortran procedures, the C routines must pass arguments as pointers to the types listed in the following table.

Table 27. Corresponding data types in Fortran and C

<table>
<thead>
<tr>
<th>XL Fortran Data Types</th>
<th>XL/C++ Data Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTEGER(1), BYTE</td>
<td>signed char</td>
</tr>
<tr>
<td>INTEGER(2)</td>
<td>signed short</td>
</tr>
<tr>
<td>INTEGER(4)</td>
<td>signed int</td>
</tr>
<tr>
<td>INTEGER(8)</td>
<td>signed long long</td>
</tr>
<tr>
<td>REAL, REAL(4)</td>
<td>float</td>
</tr>
<tr>
<td>REAL(8), DOUBLE PRECISION</td>
<td>double</td>
</tr>
<tr>
<td>REAL(16)</td>
<td>long double</td>
</tr>
<tr>
<td>COMPLEX, COMPLEX(4)</td>
<td>float _Complex</td>
</tr>
<tr>
<td>COMPLEX(8), DOUBLE COMPLEX</td>
<td>double _Complex</td>
</tr>
<tr>
<td>COMPLEX(16)</td>
<td>long double _Complex</td>
</tr>
<tr>
<td>LOGICAL(1)</td>
<td>unsigned char</td>
</tr>
<tr>
<td>LOGICAL(2)</td>
<td>unsigned short</td>
</tr>
<tr>
<td>LOGICAL(4)</td>
<td>unsigned int</td>
</tr>
<tr>
<td>LOGICAL(8)</td>
<td>unsigned long long</td>
</tr>
<tr>
<td>CHARACTER</td>
<td>char</td>
</tr>
<tr>
<td>CHARACTER(n)</td>
<td>char[n]</td>
</tr>
<tr>
<td>Integer POINTER</td>
<td>void *</td>
</tr>
<tr>
<td>Array</td>
<td>array</td>
</tr>
<tr>
<td>Sequence-derived type</td>
<td>structure (with C/C++ -qalign=packed option)</td>
</tr>
</tbody>
</table>

Notes:
1. In interlanguage communication, it is often necessary to use the \%VAL built-in function, or the standards-compliant VALUE attribute, and the \%REF built-in function that are defined in "Passing arguments by reference or by value" on page 315.

2. C programs automatically convert float values to double and short integer values to integer when calling an unprototyped C function. Because XL Fortran does not perform a conversion on REAL(4) quantities passed by value, you should not pass REAL(4) and INTEGER(2) by value to a C function that you have not declared with an explicit interface.

3. The Fortran-derived type and the C structure must match in the number, data type, and length of subobjects to be compatible data types.

One or more sample programs under the directory /opt/ibm/xlf/15.1.0/samples illustrate how to call from Fortran to C.

To use the Fortran Standard interoperability features provided by XL Fortran, see the Language interoperability features section in the XL Fortran Language Reference.

### Passing global variables between languages

To access a C data structure from within a Fortran program or to access a common block from within a C program, follow these steps:

1. Create a named common block that provides a one-to-one mapping of the C structure members. If you have an unnamed common block, change it to a named one. Name the common block with the name of the C structure.

2. Declare the C structure as a global variable by putting its declaration outside any function or inside a function with the extern qualifier.

3. Compile the C source file to get packed structures.

   ```fortran
   program cstruct
     struct mystuff {
       double a;
       int b,c;
       double d;
     };
     common /mystuff/ a,b,c,d
     main() {
     end
   }
   ```

If you do not have a specific need for a named common block, you can create a sequence-derived type with the same one-to-one mapping as a C structure and pass it as an argument to a C function. You must compile the C source file to get packed structures or put #pragmas into the struct.

Common blocks that are declared THREADLOCAL are thread-specific data areas that are dynamically allocated by compiler-generated code. A static block is still reserved for a THREADLOCAL common block, but the compiler and the compiler's runtime environment use it for control information. If you need to share THREADLOCAL common blocks between Fortran and C procedures, your C source must be aware of the implementation of the THREADLOCAL common block. For more information, see the Directives section in the XL Fortran Language Reference, and Chapter 15, “Sample Fortran programs,” on page 365.

Common blocks that are declared THREADPRIVATE can be accessed using a C global variable that is declared as THREADPRIVATE.
Passing character types between languages

One difficult aspect of interlanguage calls is passing character strings between languages. The difficulty is due to the following underlying differences in the way that different languages represent such entities:

- The only character type in Fortran is `CHARACTER`, which is stored as a set of contiguous bytes, one character per byte. The length is not stored as part of the entity. Instead, it is passed by value as an extra argument at the end of the declared argument list when the entity is passed as an argument. The size of the argument is 8 bytes.
- Character strings in C are stored as arrays of the type `char`. A null character indicates the end of the string.

**Note:** To have the compiler automatically add the null character to certain character arguments, you can use the `-qnullterm` option (described in the XL Fortran Compiler Reference).

If you are writing both parts of the mixed-language program, you can make the C routines deal with the extra Fortran length argument, or you can suppress this extra argument by passing the string using the `%REF` function. If you use `%REF`, which you typically would for pre-existing C routines, you need to indicate where the string ends by concatenating a null character to the end of each character string that is passed to a C routine:

```fortran
! Initialize a character string to pass to C.
character*6 message1 /'Hello\0'/
! Initialize a character string as usual, and append the null later.
character*5 message2 /'world'/

! Pass both strings to a C function that takes 2 (char *) arguments.
call cfunc(%ref(message1), %ref(message2 // '\0'))
end
```

For compatibility with C language usage, you can encode the following escape sequences in XL Fortran character strings:

**Table 28. Escape sequences for character strings**

<table>
<thead>
<tr>
<th>Escape</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>\b</td>
<td>Backspace</td>
</tr>
<tr>
<td>\f</td>
<td>Form feed</td>
</tr>
<tr>
<td>\n</td>
<td>New-line</td>
</tr>
<tr>
<td>\r</td>
<td>Carriage return</td>
</tr>
<tr>
<td>\t</td>
<td>Tab</td>
</tr>
<tr>
<td>\0</td>
<td>Null</td>
</tr>
<tr>
<td>'</td>
<td>Apostrophe (does not terminate a string)</td>
</tr>
<tr>
<td>&quot;</td>
<td>Double quotation mark (does not terminate a string)</td>
</tr>
<tr>
<td>\ \</td>
<td>Backslash</td>
</tr>
<tr>
<td>\x</td>
<td>x, where x is any other character (the backslash is ignored)</td>
</tr>
</tbody>
</table>

If you do not want the backslash interpreted as an escape character within strings, you can compile with the `-qnoescape` option.
Passing arrays between languages

Fortran stores array elements in ascending storage units in column-major order. C stores array elements in row-major order. Fortran array indexes start at 1, while C array indexes start at 0.

The following example shows how a two-dimensional array that is declared by A(3,2) is stored in Fortran and C.

Table 29. Corresponding array layouts for Fortran and C. The Fortran array reference A(X,Y,Z) can be expressed in C as a[Z-1][Y-1][X-1]. Keep in mind that although C passes individual scalar array elements by value, it passes arrays by reference.

<table>
<thead>
<tr>
<th>Lowest storage unit</th>
<th>A(1,1)</th>
<th>A[0][0]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A(2,1)</td>
<td>A[0][1]</td>
</tr>
<tr>
<td></td>
<td>A(3,1)</td>
<td>A[1][0]</td>
</tr>
<tr>
<td></td>
<td>A(1,2)</td>
<td>A[1][1]</td>
</tr>
<tr>
<td></td>
<td>A(2,2)</td>
<td>A[2][0]</td>
</tr>
<tr>
<td>Highest storage unit</td>
<td>A(3,2)</td>
<td>A[2][1]</td>
</tr>
</tbody>
</table>

To pass all or part of a Fortran array to another language, you can use Fortran 90/Fortran 95 array notation:

REAL, DIMENSION(4,8) :: A, B(10)

! Pass an entire 4 x 8 array.
CALL CFUNC( A )

! Pass only the upper-left quadrant of the array.
CALL CFUNC( A(1:2,1:4) )

! Pass an array consisting of every third element of A.
CALL CFUNC( A(1:4:3,1:8) )

! Pass a 1-dimensional array consisting of elements 1, 2, and 4 of B.
CALL CFUNC( B( (/1,2,4/) ) )

Where necessary, the Fortran program constructs a temporary array and copies all the elements into contiguous storage. In all cases, the C routine needs to account for the column-major layout of the array.

Any array section or noncontiguous array is passed as the address of a contiguous temporary unless an explicit interface exists where the corresponding dummy argument is declared as an assumed-shape array or a pointer. To avoid the creation of array descriptors (which are not supported for interlanguage calls) when calling non-Fortran procedures with array arguments, either do not give the non-Fortran procedures any explicit interface, or do not declare the corresponding dummy arguments as assumed-shape or pointers in the interface:

! This explicit interface must be changed before the C function
! can be called.

INTERFACE
FUNCTION CFUNC (ARRAY, PTR1, PTR2)
    INTEGER, DIMENSION (:): :: ARRAY   ! Change this : to *.
    INTEGER, POINTER, DIMENSION (:): :: PTR1  ! Change this : to *
    ! and remove the POINTER attribute.
    REAL, POINTER :: PTR2               ! Remove this POINTER attribute or change to TARGET.
END FUNCTION
END INTERFACE
Passing pointers between languages

Integer POINTERs always represent the address of the pointee object and must be passed by value:

```
CALL CFUNC(%VAL(INTPTR))
```

Fortran 90 POINTERs can also be passed back and forth between languages but only if there is no explicit interface for the called procedure or if the argument in the explicit interface does not have a POINTER attribute or assumed-shape declarator. You can remove any POINTER attribute or change it to TARGET and can change any deferred-shape array declarator to be explicit-shape or assumed-size.

Because of XL Fortran’s call-by-reference conventions, you must pass even scalar values from another language as the address of the value, rather than the value itself. For example, a C function passing an integer value x to Fortran must pass &x. Also, a C function passing a pointer value p to Fortran so that Fortran can use it as an integer POINTER must declare it as void **p. A C array is an exception: you can pass it to Fortran without the & operator.

Passing arguments by reference or by value

To call subprograms written in languages other than Fortran (for example, user-written C programs, or operating system routines), the actual arguments may need to be passed by a method different from the default method used by Fortran. C routines, including those in system libraries, such as libc.so, require you to pass arguments by value instead of by reference. (Although C passes individual scalar array elements by value, it passes arrays by reference.)

You can change the default passing method by using the %VAL built-in function or VALUE attribute and the %REF built-in function in the argument list of a CALL statement or function reference. You cannot use them in the argument lists of Fortran procedure references or with alternate return specifiers.

%REF Passes an argument by reference (that is, the called subprogram receives the address of the argument). It is the same as the default calling method for Fortran except that it also suppresses the extra length argument for character strings.

%VAL Passes an argument by value (that is, the called subprogram receives an argument that has the same value as the actual argument, but any change to this argument does not affect the actual argument).

You can use this built-in function with actual arguments that are CHARACTER(1), BYTE, logical, integer, real, or complex expressions or that are sequence-derived type. Objects of derived type cannot contain pointers, arrays, or character structure components whose lengths are greater than one byte.

You cannot use %VAL with actual arguments that are array entities, procedure names, or character expressions of length greater than one byte.

%VAL causes XL Fortran to pass the actual argument as 32-bit or 64-bit intermediate values.

32-bit intermediate values

If the actual argument is one of the following:

- An integer or a logical that is shorter than 32 bits, it is sign-extended to a 32-bit value.
• An integer or a logical that is longer than 32 bits, it is passed as two 32-bit intermediate values.
• Of type real or complex, it is passed as multiple 32-bit intermediate values.
• Of sequence-derived type, it is passed as multiple 32-bit intermediate values.

Byte-named constants and variables are passed as if they were INTEGER(1). If the actual argument is a CHARACTER(1), the compiler pads it on the left with zeros to a 32-bit value, regardless of whether you specified the -qctyplss compiler option.

64-bit intermediate values

If the actual argument is one of the following:
• An integer or a logical that is shorter than 64 bits, it is sign-extended to a 64-bit value.
• Of type real or complex, it is passed as multiple 64-bit intermediate values.
• Of sequence-derived type, it is passed as multiple 64-bit intermediate values.

Byte-named constants and variables are passed as if they were INTEGER(1). If the actual argument is a CHARACTER(1), the compiler pads it on the left with zeros to a 64-bit value, regardless of whether you specified the -qctyplss compiler option.

VALUE attribute

Specifies an argument association between a dummy and an actual argument that allows you to pass the dummy argument with the value of the actual argument. Changes to the value or definition status of the dummy argument do not affect the actual argument.

You must specify the VALUE attribute for dummy arguments only.

You must not use the %VAL or %REF built-in functions to reference a dummy argument with the VALUE attribute, or the associated actual argument.

A referenced procedure that has a dummy argument with the VALUE attribute must have an explicit interface.

You must not specify the VALUE attribute with the following:
• Arrays
• Derived types with ALLOCATABLE components
• Dummy procedures

EXTERNAL FUNC
COMPLEX XVAR
IVAR8=6

CALL RIGHT2(%REF(FUNC)) ! procedure name passed by reference
CALL RIGHT3(%VAL(XVAR)) ! complex argument passed by value
CALL TPROG(%VAL(IVARB)) ! integer argument passed by value
END

Explicit interface for %VAL and %REF

You can specify an explicit interface for non-Fortran procedures to avoid coding calls to %VAL and %REF in each argument list, as follows:
INTERFACE
  FUNCTION C_FUNC(%VAL(A),%VAL(B)) ! Now you can code "c_func(a,b)"
    INTEGER A,B
  ! instead of
  END FUNCTION C_FUNC ! "c_func(%val(a),%val(b))".
END INTERFACE

Example with VALUE attribute

Program validexm1
  integer :: x = 10, y = 20
  print *, 'before calling: ', x, y
  call intersub(x, y)
  print *, 'after calling: ', x, y
contains
  subroutine intersub(x,y)
    integer, value :: x
    integer y
    x = x + y
    y = x*y
    print *, 'in subroutine after changing: ', x, y
  end subroutine
end program validexm1

Expected output:
before calling: 10 20
in subroutine after changing: 30 600
after calling: 10 600

Passing COMPLEX values to/from gcc

Passing COMPLEX values between Fortran and GCC depends on what is specified for the -qfloat=[no]complexgcc suboption. If -qfloat=complexgcc is specified, the compiler uses Linux conventions when passing or returning complex numbers. -qfloat=nocomplexgcc is the default.

For -qfloat=complexgcc, COMPLEX*8 values are passed in 1 GPR, and COMPLEX*16 in 2 GPRs. For -qfloat=nocomplexgcc, COMPLEX*8 and COMPLEX*16 values are passed in 2 floating-point registers (FPRs). COMPLEX*32 values are always passed in 4 FPRs for both -qfloat=complexgcc and -qfloat=nocomplexgcc (since gcc does not support COMPLEX*32).

For -qfloat=complexgcc, COMPLEX*8 values are returned in GPR3, and COMPLEX*16 in GPR 3-GPR4. For -qfloat=nocomplexgcc, COMPLEX*8 and COMPLEX*16 values are returned in FPR1-FPR2. For both -qfloat=complexgcc and -qfloat=nocomplexgcc, COMPLEX*32 is always returned in FPR1-FPR4.

Returning values from Fortran functions

XL Fortran does not support calling certain types of Fortran functions from non-Fortran procedures. If a Fortran function returns a pointer, array, or character of nonconstant length, do not call it from outside Fortran.

You can call such a function indirectly:

```
SUBROUTINE MAT2(A,B,C) ! You can call this subroutine from C, and the
  ! result is stored in C.
  INTEGER, DIMENSION(10,10) :: A,B,C
  C = ARRAY_FUNC(A,B)
END
```

But you could not call ARRAY_FUNC directly.
Arguments with the OPTIONAL attribute

When you pass an optional argument by reference, the address in the argument list is zero if the argument is not present.

When you pass an optional argument by value, the value is zero if the argument is not present. The compiler uses an extra register argument to differentiate that value from a regular zero value. If the register has the value 1, the optional argument is present; if it has the value 0, the optional argument is not present.

Related information:
“Order of arguments in argument list” on page 324

Assembler-level subroutine linkage conventions

The subroutine linkage convention specifies the machine state at subroutine entry and exit, allowing routines that are compiled separately in the same or different languages to be linked.

The information on subroutine linkage and system calls in the System V Application Binary Interface: PowerPC Processor Supplement and 64-bit PowerPC ELF Application Binary Interface Supplement are the base references on this topic. You should consult these for full details. This section summarizes the information needed to write mixed-language Fortran and assembler programs or to debug at the assembler level, where you need to be concerned with these kinds of low-level details.

The system linkage convention passes arguments in registers, taking full advantage of the large number of floating-point registers (FPRs), general-purpose registers (GPRs), vector registers (VRs and VSRs) and minimizing the saving and restoring of registers on subroutine entry and exit. The linkage convention allows for argument passing and return values to be in registers (FPRs, GPRs, VRs or multiple register types), memory, or both.

The following table lists floating-point registers and their functions. The floating-point registers are double precision (64 bits).

Table 30. Floating-point register usage across calls

<table>
<thead>
<tr>
<th>Register</th>
<th>Preserved Across Calls</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>no</td>
<td>FP parameter 1, function return 1.</td>
</tr>
<tr>
<td>1</td>
<td>no</td>
<td>FP parameter 2, function return 2.</td>
</tr>
<tr>
<td>2</td>
<td>no</td>
<td>FP parameter 3, function return 3,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>function return complex *32.</td>
</tr>
<tr>
<td>4</td>
<td>no</td>
<td>FP parameter 4, function return 4,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>function return complex *32.</td>
</tr>
<tr>
<td>5</td>
<td>no</td>
<td>FP parameter 5, function return 5.</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>8</td>
<td>no</td>
<td>FP parameter 8, function return 8.</td>
</tr>
<tr>
<td>9</td>
<td>no</td>
<td>FP parameter 9</td>
</tr>
<tr>
<td>10</td>
<td>no</td>
<td>FP parameter 10</td>
</tr>
<tr>
<td>11</td>
<td>no</td>
<td>FP parameter 11</td>
</tr>
</tbody>
</table>
### Table 30. Floating-point register usage across calls (continued)

<table>
<thead>
<tr>
<th>Register</th>
<th>Preserved Across Calls</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>no</td>
<td>FP parameter 12</td>
</tr>
<tr>
<td>13</td>
<td>no</td>
<td>FP parameter 13</td>
</tr>
<tr>
<td>14-31</td>
<td>yes</td>
<td>local variables</td>
</tr>
</tbody>
</table>

The following table lists general-purpose registers and their functions.

### Table 31. General-purpose register usage across calls

<table>
<thead>
<tr>
<th>Register</th>
<th>Preserved Across Calls</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>yes</td>
<td>Stack pointer.</td>
</tr>
<tr>
<td>2</td>
<td>yes</td>
<td>System-reserved TOC/GOT pointer.</td>
</tr>
<tr>
<td>3</td>
<td>no</td>
<td>1st word of arg list; return value 1.</td>
</tr>
<tr>
<td>4</td>
<td>no</td>
<td>2nd word of arg list; return value 2.</td>
</tr>
<tr>
<td>5</td>
<td>no</td>
<td>3rd word of arg list</td>
</tr>
<tr>
<td>..</td>
<td>..</td>
<td>..</td>
</tr>
<tr>
<td>10</td>
<td>no</td>
<td>8th word of arg list</td>
</tr>
<tr>
<td>11-12</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>yes</td>
<td>SDA (thread local storage) pointer.</td>
</tr>
<tr>
<td>14-30</td>
<td>no</td>
<td>Local variables.</td>
</tr>
<tr>
<td>31</td>
<td>yes</td>
<td>Local variables or “environment pointers”.</td>
</tr>
</tbody>
</table>

If a register is not designated as preserved, its contents may be changed during the call, and the caller is responsible for saving any registers whose values are needed later. Conversely, if a register is supposed to be preserved, the callee is responsible for preserving its contents across the call, and the caller does not need any special action.

The following table lists vector register conventions.

### Table 32. VMX Vector register usage across calls

<table>
<thead>
<tr>
<th>Register</th>
<th>Preserved Across Calls</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>no</td>
<td>Local variables</td>
</tr>
<tr>
<td>1</td>
<td>no</td>
<td>Local variables</td>
</tr>
<tr>
<td>2</td>
<td>no</td>
<td>Vector parameter 1, vector result 1</td>
</tr>
<tr>
<td>3</td>
<td>no</td>
<td>Vector parameter 2, vector result 2</td>
</tr>
<tr>
<td>4</td>
<td>no</td>
<td>Vector parameter 3, vector result 3</td>
</tr>
<tr>
<td>5</td>
<td>no</td>
<td>Vector parameter 4, vector result 4</td>
</tr>
<tr>
<td>6</td>
<td>no</td>
<td>Vector parameter 5, vector result 5</td>
</tr>
<tr>
<td>7</td>
<td>no</td>
<td>Vector parameter 6, vector result 6</td>
</tr>
</tbody>
</table>
Table 32. VMX Vector register usage across calls (continued)

<table>
<thead>
<tr>
<th>Register</th>
<th>Preserved Across Calls</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>no</td>
<td>Vector parameter 7, vector result 7</td>
</tr>
<tr>
<td>9</td>
<td>no</td>
<td>Vector parameter 8, vector result 8</td>
</tr>
<tr>
<td>10</td>
<td>no</td>
<td>Vector parameter 9</td>
</tr>
<tr>
<td>11</td>
<td>no</td>
<td>Vector parameter 10</td>
</tr>
<tr>
<td>12</td>
<td>no</td>
<td>Vector parameter 11</td>
</tr>
<tr>
<td>13</td>
<td>no</td>
<td>Vector parameter 12</td>
</tr>
<tr>
<td>14-19</td>
<td>no</td>
<td>Local variables</td>
</tr>
<tr>
<td>20-31</td>
<td>yes</td>
<td>Local variables</td>
</tr>
</tbody>
</table>

VMX vector registers VR0-31 correspond to VSX registers 32-63. FPR floating-point registers FP0-31 correspond to the upper halves of VSX registers 0-31.

The following table lists special-purpose register conventions.

Table 33. Special-purpose register usage across calls

<table>
<thead>
<tr>
<th>Register</th>
<th>Preserved Across Calls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition register</td>
<td></td>
</tr>
<tr>
<td>Bits 0-7 (CR0,CR1)</td>
<td>no</td>
</tr>
<tr>
<td>Bits 8-22 (CR2,CR3,CR4)</td>
<td>yes</td>
</tr>
<tr>
<td>Bits 23-31 (CR5,CR6,CR7)</td>
<td>no</td>
</tr>
<tr>
<td>Link register</td>
<td>no</td>
</tr>
<tr>
<td>Count register</td>
<td>no</td>
</tr>
<tr>
<td>XER register</td>
<td>no</td>
</tr>
<tr>
<td>FPSCR register</td>
<td>The control flags are preserved except for calls to functions whose purposes are to change them. The status flags are not preserved.</td>
</tr>
</tbody>
</table>

The stack

The stack is a portion of storage that is used to hold local storage, register save areas, parameter lists, and call-chain data. The stack grows from higher addresses to lower addresses. A stack pointer register (register 1) is used to mark the current “top” of the stack.

A stack frame is the portion of the stack that is used by a single procedure. In either case, the stack frame size is best defined as the difference between the caller’s stack pointer and the callee’s.

The following diagram shows the storage maps of typical stack frames.

In this diagram, the current routine has acquired a stack frame that allows it to call other functions. If the routine does not make any calls and there are no local variables or temporaries, and it does not need to save any nonvolatile registers, the function need not allocate a stack frame. It can use the register save area at the top of the stack that would have been, if needed.
The stack frame is quadword aligned.

The following diagram shows the storage map of a typical stack frame.

**Figure 7. Runtime Stack**

**The Linkage Area and Minimum Stack Frame**

The linkage area consists of four doublewords at offset zero from the caller’s stack pointer on entry to a procedure. The first doubleword contains the caller’s back chain (stack pointer). The first half of the second doubleword is the location where the callee saves the Condition Register (CR) if it is needed. The third doubleword is the location where the callee’s prolog code saves the Link Register if it is needed.
The last doubleword (doubleword 4) is where the caller’s TOC pointer is saved when the routine is called via its Global Entry Point (for example, when it is in a shared library, or called via a pointer). The minimum stack frame size is 32 bytes.

**The input parameter area**

The input parameter area is a contiguous piece of storage reserved by the calling program under specific conditions (when an overflow area is needed, or when the callee is declared as a varargs function) to represent the register image of the input parameters of the callee. The input parameter area is quadword aligned and is located on the stack directly following the caller's link area. If it is allocated, this area is at least 8 doublewords in size. If more than 8 doublewords of parameters are passed, they are stored as register images that start at positive offset 96 from the caller's stack pointer.

The first 8 doublewords only appear in registers at the call point, never in the stack. Remaining words are always in the stack.

**The register save area**

Register save area is doubleword aligned for GPRs and FPRs and quadword aligned for VRs. It provides the space that is needed to save all nonvolatile FPRs, GPRs and VRs used by the callee program. The FPRs are saved next to the link area. The FPRs are saved at the highest addresses of the stack frame. The GPRs are saved just below (in lower addresses than) the FPRs. The VRs are saved just below (in lower addresses than) the GPRs. The called function may save the registers here even if it does not need to allocate a new stack frame. The system-defined stack floor includes the maximum possible save area:

$$18 \times 8 \text{ for FPRs} + 18 \times 8 \text{ for GPRs} + 12 \times 16 \text{ for VRs}$$

For each register type, a callee needs only to save the nonvolatile registers starting with the lowest that it actually uses, up to the highest register number; for example, using r27 and r31 means that r27 to r31 must be saved.

**The local stack area**

The local stack area is the space that is allocated by the callee procedure for local variables and temporaries.

**The output parameter area**

The output parameter area (P1...Pn) is optional. It must be allocated when calling a varargs function or when more than 8 doublewords of parameters are being passed. If more than 8 doublewords are being passed, an extension list is constructed, which begins at offset 96 from the current stack pointer.

The first 8 doublewords only appear in registers at the call point, never in the stack. Remaining doublewords are always in the stack, and they can also be in registers.

**Linkage convention for argument passing**

The system linkage convention takes advantage of the large number of registers available.

The linkage convention passes arguments in GPRs, FPRs and VRs. Three fixed lists, R3-R10, FP1-FP13 and VR2-VR13, specify the GPRs, FPRs and VRs available.
When there are more argument words than available argument GPRs, FPRs and VRs, the remaining words are passed in storage on the stack. The values in storage are the same values as if they were in registers but are in memory format while values in registers might be in a different format. Here are some examples. A single precision floating-point is in double precision format when in an FPR but in single precision format when in memory or passed in a GPR. A small struct may be right justified when in a GPR but left justified in memory. A vector may have its element order reversed when in a VR.

When it must be allocated, the size of the parameter area is sufficient to contain all the arguments passed on any call statement from the procedure that is associated with the stack frame. Although not all the arguments for a particular call actually appear in storage, it is convenient to consider them as forming a list in this area, each one occupying one or more doublewords.

For call by reference (as is the default for Fortran), the address of the argument is passed in a register. The following information refers to call by value, as in C or as in Fortran when %VAL is used. For purposes of their appearance in the list, arguments are classified as floating-point values including homogeneous floating-point aggregates of up to 8 single precision REAL(4)s, 4 single precision COMPLEX(8)s, 4 double precision REAL(8)s and 2 double precision COMPLEX(16)s, vector values including homogeneous vector aggregates of up to 8 vectors and other types that are passed in vector registers, or general values.

- All general values require one doubleword that is doubleword aligned.
- Each single-precision (REAL(4)) value and each double-precision (REAL(8)) value occupies one doubleword in the list. Each extended-precision (REAL(16)) value occupies two successive doublewords in the list.
- A COMPLEX value occupies twice as many doublewords as a REAL value with the same kind type parameter.
- A VECTOR value occupies four words (16 bytes) in a vector register
- In Fortran and C, structure values appear in successive words as they would anywhere in storage, satisfying all appropriate alignment requirements. Structures are aligned to a doubleword and occupy (sizeof(struct X)+7)/8 doublewords, with any padding at the end. A structure that is smaller than a doubleword is right-justified within its doubleword or register. Larger structures can occupy multiple registers and may be passed partly in storage and partly in registers.
- Other aggregate values are passed “val-by-ref”. That is, the compiler actually passes their address and arranges for a copy to be made in the invoked program.
- A procedure or function pointer is passed as the address of its Global Entry Point, or in some cases as the address of its Procedure Linkage Table (PLT) stub, which is automatically generated by the linker, or a dynamic library loader or trampoline code for a nested routine. See “Pointers to functions” on page 325 for more information.

**Argument passing rules (by value)**

From the following illustration, we state these rules:

- If the called procedure treats the parameter list as a contiguous piece of storage (for example, if the address of a parameter is taken in C), the parameter registers are stored in the space reserved for them in the stack.
- A register image is stored on the stack, except as described in section “Linkage convention for argument passing” on page 322.
• If it exists, the argument area ($P_1...P_n$) must be large enough to hold the largest parameter list. Unless the overflow parameter area is needed or the called function is declared varargs, the argument area will not be allocated, and the callee must allocate its own area or individual variables.

Here is an example of a call to a function:

\[ f(\%val(11), \%val(12), \%val(13), \%val(14), \%val(15), \%val(16), \%val(17), \%val(d1), \%val(f1), \%val(c1), \%val(d2), \%val(s1), \%val(cx2)) \]

where:
- \(l\) denotes integer(4) (fullword integer)
- \(d\) denotes real(8) (double precision)
- \(f\) denotes real(4) (real)
- \(s\) denotes integer(2) (halfword integer)
- \(c\) denotes character (one character)
- \(cx\) denotes complex(8) (double complex)

**Order of arguments in argument list**

The argument list is constructed in the following order. Items in the same bullet appear in the same order as in the procedure declaration, whether or not argument keywords are used in the call.

1. There may be other items in this list during Fortran-Fortran calls. However, they will not be visible to non-Fortran procedures that follow the calling rules in this section.
• All addresses or values (or both) of actual arguments ¹
• “Present” indicators for optional arguments
• Length arguments for strings ¹

Linkage convention for function calls

Function calls to a routine make use of its entry point symbols.

A routine has two symbols associated with it: a Global Entry Point (name) and a Local Entry Point (name plus a small offset provided in its symbol table entry). Calls that might need a new TOC pointer loaded use the GEP, and examples are calls crossing shared library boundaries and calls via a pointer. Calls that share the same TOC use the LEP, and examples are calls to a nested routine or to a statically linked routine. When a call is made to a routine, the program branches to the entry point directly. Excluding the loading of parameters (if any) in the proper registers, compilers expand calls to functions to one or in general both of the following two-instruction sequence. The special NOP is needed only if the called routine might need a new TOC pointer loaded.

BL .foo  # Branch to foo
ORI R0,R0,0x0000  # Special NOP

The linker does one of two things when it encounters a BL instruction:
1. If foo is imported (not in the same object module), the linker changes the BL to .foo to a BL to the Procedure Linkage Table (PLT) stub for foo and inserts the PLT stub into the object module. Also, if a NOP instruction (ORI R0,R0,0x0000) immediately follows the BL instruction, the linker replaces the NOP instruction with the LOAD instruction L R2, 24(R1).
2. If foo is bound in the same object module as its caller and a LOAD instruction above, or ORI R0,R0,0 immediately follows the BL instruction, the linker replaces the LOAD instruction with a NOP (ORI R0,R0,0).

Calls to nested routines are more complicated. Nested routines can only be accessed from outside their parent via a pointer, which will contain the address of a trampoline routine to provide an environment pointer for them to access their parent’s data, automatically generated by the compiler. Because trampolines require an executable stack, pointers to nested routines should generally not be used in programs with root security access.

Pointers to functions

A function pointer is a data type whose values range over procedure names. Variables of this type appear in several programming languages, such as C and Fortran. In Fortran, a dummy argument that appears in an EXTERNAL statement is a function pointer. Fortran provides support for the use of function pointers in contexts such as the target of a call statement or an actual argument of such a statement.

A function pointer is a doubleword quantity that is the address of the Global Entry Point for a function, or of a Procedure Linkage Table stub for a function, or of a trampoline for a nested function.

Function pointers are 8 bytes long and contain a 64-bit address. For pointers to local functions, the address contained is the Global Entry Point address of the function in the text section. For imported functions, the address is that of the
function's PLT stub. Every unique and imported function will have a PLT stub in the executable or shared library's non-lazy symbol pointer section.

**Function values**

Functions return their values according to type:

- **INTEGER** and **LOGICAL** of kind 1, 2, and 4 are returned (sign/zero extended) in R3.
- **INTEGER** and **LOGICAL** of kind 8 are returned in R3.
- **REAL(4)** or **REAL(8)** are returned in FP1. **REAL(16)** are returned in FP1 and FP2.
- **COMPLEX(4)** or **COMPLEX(8)** are returned in FP1 and FP2. **COMPLEX(16)** are returned in FP1-FP4.
- Individual vector results and other types that are processed in vector registers are returned in VR2. Homogeneous vector aggregates are returned in up to 8 vector registers VR2 to VR9.
- Character strings are returned in a buffer allocated by the caller. The address and the length of this buffer are passed in R3 and R4 as hidden parameters. The first explicit parameter doubleword is in R5, and all subsequent parameters are moved to the next doubleword.
- Homogeneous floating-point structures are returned in up to 8 FPRs FPR1 to FPR8. Homogeneous vector structures are returned in up to 8 VRs VR2 to VR9. Other structures up to 2 doublewords are returned in up to 2 GPRs R3 to R4. Other structures are returned in a buffer that is allocated by the caller. The address is passed in R3; there is no length. The first explicit parameter is in R4.

**The stack floor**

Stack floor is a system-defined address below which the stack cannot grow. All programs in the system must avoid accessing locations in the stack segment that are below the stack floor.

All programs must maintain other system invariants that are related to the stack:

- The stack pointer must always be quadword (16 byte) aligned.
- No data is saved or accessed from an address lower than the stack floor, except that locations within a small distance below the stack frame may be accessed before the stack is allocated or after it is deallocated, or without it ever being allocated.
- The stack pointer is always valid. You must take care to ensure that the stack pointer is changed in a single instruction. When allocating a new stack frame, the old stack pointer must be saved at the beginning of the new stack frame by that same instruction. When an allocation is of more than 32,767 bytes, an index register must be used instead of an immediate operand. This step ensures that there is no timing window where a signal handler would either overlay the stack data or erroneously appear to overflow the stack segment.

**Stack overflow**

The linkage convention requires no explicit inline check for overflow. The operating system uses a storage protection mechanism to detect stores past the end of the stack segment.
Prolog and epilog

You need to consider a number of steps when entering a procedure and when exiting a procedure.

On entry to a procedure, you might have to do some or all of the following steps:
1. Save the link register.
2. If the procedure uses any of the CR bits 8-23 (CR2, CR3, CR4), save the CR.
3. Save all nonvolatile FPRs that are used by this procedure in the FPR save area.
4. Save all nonvolatile VRs that are used by this procedure in the VR save area.
5. Save all nonvolatile GPRs that are used by this procedure in the GPR save area.
6. Atomically store the back chain and decrease the stack pointer by the size of the stack frame. Note that if a stack overflow occurs, it will be known immediately when the store of the back chain is done.

On exit from a procedure, you might have to perform some or all of the following steps:
1. Restore all GPRs saved that have been modified.
2. Restore all FPRs saved that have been modified.
3. Restore all VRs saved that have been modified.
4. Restore bits 8-23 of the CR (CR2, CR3, CR4) if they were used, if necessary.
5. Atomically restore the stack pointer to the value it had on entry.
6. Return to caller.

Traceback

XL Fortran supports the traceback mechanism, which symbolic debuggers need to unravel the call or return stack. Each object module has a traceback table in the text segment at the end of its code. This table contains information about the object module, including the type of object module, as well as stack frame and register information.

Note: You can make the traceback table smaller or remove it entirely with the `-qtbtable` option
Chapter 12. Implementation details of XL Fortran Input/Output (I/O)

This topic describes XL Fortran support (through extensions and platform-specific details) for the Linux file system.

See “Mixed-language input and output” on page 308 for further considerations related to input and output operations.

Implementation details of file formats

The manner in which XL Fortran implements files is based on their file format.

**Sequential-access unformatted files:**
An integer that contains the length of the record precedes and follows each record. The length of the integer is 4 bytes if you set the **uwidth** runtime option to 32 (the default), and 8 bytes if you set the **uwidth** runtime option to 64.

**Sequential-access formatted files:**
XL Fortran programs break these files into records while reading, by using each newline character (X'0A') as a record separator.

On output, the input/output system writes a newline character at the end of each record. Programs can also write newline characters for themselves. This practice is not recommended because the effect is that the single record that appears to be written is treated as more than one record when being read or backspaced over.

**Direct access files:**
XL Fortran simulates direct-access files with operating system files whose length is a multiple of the record length of the XL Fortran file. You must specify, in an **OPEN** statement, the record length (**RECL**) of the direct-access file. XL Fortran uses this record length to distinguish records from each other.

For example, the third record of a direct-access file of record length 100 bytes would start at the 201st byte of the single record of a Linux file and end at the 300th byte.

If the length of the record of a direct-access file is greater than the total amount of data you want to write to the record, XL Fortran pads the record on the right with blanks (X'20').

**Stream-access unformatted files:**
Unformatted stream files are viewed as a collection of file storage units. In XL Fortran, a file storage unit is one byte.

A file connected for unformatted stream access has the following properties:
- The first file storage unit has position 1. Each subsequent file storage unit has a position that is one greater than that of the preceding one.
- For a file that can be positioned, file storage units need not be read or written in the order of their position. Any file storage unit may be read from the file while it is connected to a unit, provided that the file
storage unit has been written since the file was created, and if a READ statement for the connection is permitted.

Stream-access formatted files:
A record file connected for formatted stream access has the following properties:
- Some file storage units may represent record markers. The record marker is the newline character (X'0A').
- The file will have a record structure in addition to the stream structure.
- The record structure is inferred from the record markers that are stored in the file.
- Records can have any length up to the internal limit allowed by XL Fortran (See XL Fortran Internal limits in the XL Fortran Compiler Reference.)
- There may or may not be a record marker at the end of the file. If there is no record marker at the end of the file, the final record is incomplete, but not empty.

A file connected for formatted stream access has the following properties:
- The first file storage unit has position 1. Each subsequent file storage unit has a position that is greater than that of the preceding one. Unlike unformatted stream access, the positions of successive file storage units are not always consecutive.
- The position of a file connected for formatted stream access can be determined by the POS= specifier in an INQUIRE statement.
- For a file that can be positioned, the file position can be set to a value that was previously identified by the POS= specifier in INQUIRE.

Related information
- The XLFRTDEOPTS environment variable

File names
There are a number of considerations to be aware of when working with file names.

You can specify file names as either relative (such as file, dir/file, or ../file) or absolute (such as /file or /dir/file). The maximum length of a file name (the full path name) is 4095 characters, even if you only specify a relative path name in the I/O statement. The maximum length of a file name with no path is 255 characters.

You must specify a valid file name in such places as the following:
- The FILE= specifier of the OPEN and INQUIRE statements
- INCLUDE lines

Note: To specify a file whose location depends on an environment variable, you can use the GET_ENVIRONMENT_VARIABLE intrinsic procedure to retrieve the value of the environment variable:

```fortran
character(100) home, name

call get_environment_variable('HOME', value=home)
! Now home = $HOME + blank padding.
! Construct the complete path name and open the file.
name=trim(home) // '/remainder/of/path'
open (unit=10, file=name)
...```

end
Preconnected and implicitly connected files

Whether files are preconnected or implicitly connected is dependent on their units and specific statements.

Units 0, 5, and 6 are preconnected to standard error, standard input, and standard output, respectively, before the program runs.

All other units can be implicitly connected when an ENDFILE, PRINT, READ, REWIND, or WRITE statement is performed on a unit that has not been opened. Unit \( n \) is implicitly connected to a file that is named \( \text{fort.} n \). These files need not exist, and XL Fortran does not create them unless you use the corresponding units implicitly.

**Note:** Because unit 0 is preconnected for standard error, you cannot use it for the CLOSE, ENDFILE, BACKSPACE, or REWIND statements with sequential input/output. You cannot use unit 0 for direct or stream input/output. You can use unit 0 in an OPEN statement only to change the values of the BLANK=, DELIM=, DECIMAL= or PAD= specifiers.

You can also implicitly connect units 5 and 6 (and *) by using I/O statements that follow a CLOSE of these units:

```
WRITE (6,10) "This message goes to stdout."
CLOSE (6)
WRITE (6,10) "This message goes in the file \text{fort.}6."
PRINT *, "Output to * now also goes in \text{fort.}6."
10 FORMAT (A)
END
```

The FORM= specifier of implicitly connected files has the value FORMATTED before any READ, WRITE, or PRINT statement is performed on the unit. The first such statement on such a file determines the FORM= specifier from that point on: FORMATTED if the formatting of the statement is format-directed, list-directed, or namelist; and UNFORMATTED if the statement is unformatted.

Preconnected files also have FORM='FORMATTED', STATUS='OLD', and ACTION='READWRITE' as default specifier values.

The other properties of a preconnected or implicitly connected file are the default specifier values for the OPEN statement. These files always use sequential access.

If you want XL Fortran to use your own file instead of the \text{fort.}n file, you can either specify your file for that unit through an OPEN statement or create a symbolic link before running the application. In the following example, there is a symbolic link between \text{myfile} and \text{fort.10}:

```
ln -s myfile fort.10
```

When you run an application that uses the implicitly connected file \text{fort.10} for input/output, XL Fortran uses the file \text{myfile} instead. The file \text{fort.10} exists, but only as a symbolic link. The following command will remove the symbolic link, but will not affect the existence of \text{myfile}:

```
rm fort.10
```
File positioning

The position of a file pointer when a file is opened with no POSITION= specifier is summarized in the following table.

Table 34. Position of the file pointer when a file is opened with no POSITION= specifier

<table>
<thead>
<tr>
<th>-qposition suboptions</th>
<th>Implicit OPEN</th>
<th>Explicit OPEN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STATUS = 'NEW'</td>
<td>STATUS = 'OLD'</td>
</tr>
<tr>
<td></td>
<td>File exists</td>
<td>File does not exist</td>
</tr>
<tr>
<td>option not specified</td>
<td>Start</td>
<td>Start</td>
</tr>
<tr>
<td>appendold</td>
<td>Start</td>
<td>Start</td>
</tr>
<tr>
<td>appendunknown</td>
<td>Start</td>
<td>Start</td>
</tr>
<tr>
<td>appendold and appendunknown</td>
<td>Start</td>
<td>Start</td>
</tr>
</tbody>
</table>

I/O redirection

You can use the redirection operator on the command line to redirect input to and output from your XL Fortran program.

How you specify and use this operator depends on which shell you are running. Here is a bash example:

```
$ cat redirect.f
write (6,*) 'This goes to standard output'
write (0,*) 'This goes to standard error'
read (5,*) i
print *,i
end

$ xlf95 redirect.f
** main     *** End of Compilation 1 ***
1501-510 Compilation successful for file redirect.f.
$ # No redirection. Input comes from the terminal. Output goes to
$ # the screen.
$ a.out
This goes to standard output
This goes to standard error
4
4
$ # Create an input file.
$ echo >stdin 2
$ # Redirect each standard I/O stream.
$ a.out >stdout 2>stderr <stdin
$ cat stdout
This goes to standard output
2
$ cat stderr
This goes to standard error
```

Refer to your man pages for more information on redirection.
How XL Fortran I/O interacts with pipes, special files, and links

You can access regular operating system files and blocked special files by using sequential-access, direct-access, or stream-access methods.

You can only access pseudo-devices, pipes, and character special files by using sequential-access methods, or stream-access without using the POS= specifier.

When you use symbolic link to link files together, you can use their names interchangeably, as shown in the following example:

```
OPEN (4, FILE="file1")
OPEN (4, FILE="link_to_file1", PAD="NO") ! Modify connection
```

Do not specify the POSITION= specifier as REWIND or APPEND for pipes.

Do not specify ACTION='READWRITE' for a pipe.

Do not use the BACKSPACE statement on files that are pseudo-devices or character special files.

Do not use the REWIND statement on files that are pseudo-devices or pipes.

Default record lengths

The default record lengths for files is dependent on the file format and on the RECL= qualifier.

If a pseudo-device, pipe, or character special file is connected for formatted or unformatted sequential access with no RECL= qualifier, or for formatted stream access, the default record length is 32 768 rather than 2 147 483 647, which is the default for sequential-access files connected to random-access devices. (See the [default_rec] runtime option in the XL Fortran Compiler Reference.)

In certain cases, the default maximum record length for formatted files is larger, to accommodate programs that write long records to standard output. If a unit is connected to a terminal for formatted sequential access and there is no explicit RECL= qualifier in the OPEN statement, the program uses a maximum record length of 2 147 483 646 (2^31-2) bytes, rather than the usual default of 32 768 bytes. When the maximum record length is larger, formatted I/O has one restriction: WRITE statements that use the T or TL edit descriptors must not write more than 32 768 bytes. This is because the unit's internal buffer is flushed each 32 768 bytes, and the T or TL edit descriptors will not be able to move back past this boundary.

File permissions

A file must have the appropriate permissions (read, write, or both) for the corresponding operation being performed on it.

When a file is created, the default permissions (if the umask setting is 000) are both read and write for user, group, and other. You can turn off individual permission bits by changing the umask setting before you run the program.
Selecting error messages and recovery actions

There are various ways to control a program’s behavior when errors are encountered.

By default, an XL Fortran-compiled program continues after encountering many kinds of errors, even if the statements have no \texttt{ERR=} or \texttt{IOSTAT=} specifiers. The program performs some action that might allow it to recover successfully from the bad data or other problem.

To control the behavior of a program that encounters errors, set the \texttt{XLFRTEOPTS} environment variable, which is described in \textit{Setting runtime options} in the \textit{XL Fortran Compiler Reference}, before running the program:

- To make the program stop when it encounters an error instead of performing a recovery action, include \texttt{err\_recovery=no} in the \texttt{XLFRTEOPTS} setting.
- To make the program stop issuing messages each time it encounters an error, include \texttt{xf\_messages=no}.
- To disallow XL Fortran extensions to Fortran 90 at run time, include \texttt{langlvl=90std}. To disallow XL Fortran extensions to Fortran 95 at run time, include \texttt{langlvl=95std}. To disallow XL Fortran extensions to Fortran 2003 behavior at run time, include \texttt{langlvl=2003std}. To disallow XL Fortran extensions to Fortran 2008 behavior at run time, include \texttt{langlvl=2008std}. These settings, in conjunction with the \texttt{-qlanglvl} compiler option, can help you locate extensions when preparing to port a program to another platform.

For example:

```fortran
# Switch defaults for some runtime settings.
XLFRTEOPTS="err_recovery=no:noconverr=no"
export XLFRTEOPTS
```

If you want a program always to work the same way, regardless of environment-variable settings, or want to change the behavior in different parts of the program, you can call the \texttt{SETRTEOPTS} procedure:

```fortran
PROGRAM RTEOPTS
USE XLUTILITY
CALL SETRTEOPTS("err_recovery=no") ! Change setting.
... some I/O statements ...
CALL SETRTEOPTS("err_recovery=yes") ! Change it back.
... some more I/O statements ...
END
```

Because a user can change these settings through the \texttt{XLFRTEOPTS} environment variable, be sure to use \texttt{SETRTEOPTS} to set all the runtime options that might affect the wanted operation of the program.

Flushing I/O buffers

To protect data from being lost if a program ends unexpectedly, you can use the \texttt{FLUSH} statement or the \texttt{flush\_subroutine} to write any buffered data to a file.

The \texttt{FLUSH} statement is recommended for better portability and is used in the following example:

```fortran
INTEGER, PARAMETER :: UNIT = 10
DO I = 1, 1000000
   WRITE((UNIT, *), I
   CALL MIGHT_CRASH
! If the program ends in the middle of the loop, some data
```
! may be lost.
END DO
DO I = 1, 1000000
  WRITE(UNIT, *) I
  FLUSH(UNIT)
  CALL MIGHT_CRASH
  ! If the program ends in the middle of the loop, all data written
  ! up to that point will be safely in the file.
END DO
END

Related information:
“Mixed-language input and output” on page 308
See FLUSH in the Compiler Reference

Choosing locations and names for Input/Output files

If you need to override the default locations and names for input/output files, you can use the following methods without making any changes to the source code.

Naming files that are connected with no explicit name

To give a specific name to a file that would usually have a name of the form fort.\text{unit}, you must set the runtime option \texttt{unit\_vars} and then set an environment variable with a name of the form XLFUNIT\_\text{unit} for each scratch file. The association is between a unit number in the Fortran program and a path name in the file system.

For example, suppose that the Fortran program contains the following statements:

```fortran
OPEN (UNIT=1, FORM='FORMATTED', ACCESS='SEQUENTIAL', RECL=1024)
...
OPEN (UNIT=12, FORM='UNFORMATTED', ACCESS='DIRECT', RECL=131072)
...
OPEN (UNIT=123, FORM='UNFORMATTED', ACCESS='SEQUENTIAL', RECL=997)
```

XLFREOPTS="unit\_vars=yes" # Allow overriding default names.
XLFUNIT\_1="/\texttt{tmp}/molecules.dat" # Use this named file.
XLFUNIT\_12="../\texttt{data}/scratch" # Relative to current directory.
XLFUNIT\_123="/\texttt{home}/\texttt{user}/\texttt{data}/\texttt{Users}/\texttt{username}/\texttt{data}" # Somewhere besides /tmp.
export XLFREOPTS XLFUNIT\_1 XLFUNIT\_12 XLFUNIT\_123

Notes:

1. The XLFUNIT\_\text{number} variable name must be in uppercase, and \text{number} must not have any leading zeros.

2. \texttt{unit\_vars=yes} might be only part of the value for the XLFREOPTS variable, depending on what other runtime options you have set. See Setting runtime options in the XL Fortran Compiler Reference for other options that might be part of the XLFREOPTS value.

3. If the \texttt{unit\_vars} runtime option is set to no or is undefined or if the applicable XLFUNIT\_\text{number} variable is not set when the program is run, the program uses a default name (fort.\text{unit}) for the file and puts it in the current directory.

Naming scratch files

To place all scratch files in a particular directory, set the TMPDIR environment variable to the name of the directory. The program then opens the scratch files in this directory. You might need to do this if your /tmp directory is too small to hold the scratch files.
To give a specific name to a scratch file, you must do the following:
1. Set the runtime option `scratch_vars`.
2. Set an environment variable with a name of the form `XLFSCRATCH_unit` for each scratch file.

The association is between a unit number in the Fortran program and a path name in the file system. In this case, the `TMPDIR` variable does not affect the location of the scratch file.

For example, suppose that the Fortran program contains the following statements:

```fortran
OPEN (UNIT=1, STATUS='SCRATCH', &
     FORM='FORMATTED', ACCESS='SEQUENTIAL', RECL=1024)
...
OPEN (UNIT=12, STATUS='SCRATCH', &
     FORM='UNFORMATTED', ACCESS='DIRECT', RECL=131072)
...
OPEN (UNIT=123, STATUS='SCRATCH', &
     FORM='UNFORMATTED', ACCESS='SEQUENTIAL', RECL=997)
XLFRTEOPTS="scratch_vars=yes"       # Turn on scratch file naming.
XLFSCRATCH_1="/tmp/molecules.dat"    # Use this named file.
XLFSCRATCH_12="../data/scratch"      # Relative to current directory.
XLFSCRATCH_123="/home/user/data/Users/username/data" # Somewhere besides /tmp.
export XLFRTEOPTS XLFSCRATCH_1 XLFSCRATCH_12 XLFSCRATCH_123
```

Notes:
1. The `XLFSCRATCH_number` variable name must be in uppercase, and `number` must not have any leading zeros.
2. `scratch_vars=yes` might be only part of the value for the `XLFRTEOPTS` variable depending on what other runtime options you have set. See `Setting [runtime options]` in the XL Fortran Compiler Reference for other options that might be part of the `XLFRTEOPTS` value.
3. If the `scratch_vars` runtime option is set to no or is undefined or if the applicable `XLFSCRATCH_number` variable is not set when the program is run, the program chooses a unique file name for the scratch file and puts it in the directory named by the `TMPDIR` variable or in the `/tmp` directory if the `TMPDIR` variable is not set.

Asynchronous I/O

You may need to use asynchronous I/O for speed and efficiency in scientific programs that perform I/O for large amounts of data. Synchronous I/O blocks the execution of an application until the I/O operation completes. Asynchronous I/O allows an application to continue processing while the I/O operation is performed in the background.

You can modify applications to take advantage of the ability to overlap processing and I/O operations. Multiple asynchronous I/O operations can also be performed simultaneously. For a complete description of the syntax and language elements that you require to use this feature, see the following topics in the XL Fortran Language Reference:

- `INQUIRE` Statement
- `OPEN` Statement
- `READ` Statement
- `WAIT` Statement
- `WRITE` Statement
Execution of an asynchronous data transfer operation

The effect of executing an asynchronous data transfer operation will be as if the following steps were performed in the order specified, with steps (6)-(9) possibly occurring asynchronously:

1. Determine the direction of the data transfer.
2. Identify the unit.
3. Establish the format if one is present.
4. Determine whether an error condition, end-of-file condition, or end-of-record condition has occurred.
5. Cause the variable that you specified in the IOSTAT= specifier in the data transfer statement to become defined.
6. Position the file before you transfer data.
7. Transfer data between the file and the entities that you specified by the input/output list (if any).
8. Determine whether an error condition, end-of-file condition, or end-of-record condition has occurred.
9. Position the file after you transfer data.
10. Cause any variables that you specified in the IOSTAT= and SIZE= specifiers in the WAIT statement to become defined.

Usage

You can use Fortran asynchronous READ and WRITE statements to initiate asynchronous data transfers in Fortran. Execution continues after the asynchronous I/O statement, regardless of whether the actual data transfer has completed.

A program may synchronize itself with a previously initiated asynchronous I/O statement by using a WAIT statement. There are two forms of the WAIT statement:

1. In a WAIT statement without the DONE= specifier, the WAIT statement halts execution until the corresponding asynchronous I/O statement has completed:
   ```fortran
   integer idvar
   integer, dimension(1000):: a
   ....
   READ(unit_number,ID=idvar) a
   ....
   WAIT(ID=idvar)
   ....
   ```

2. In a WAIT statement with the DONE= specifier, the WAIT statement returns the completion status of an asynchronous I/O statement:
   ```fortran
   integer idvar
   logical done
   integer, dimension(1000):: a
   ....
   READ(unit_number,ID=idvar) a
   ....
   WAIT(ID=idvar, DONE=done)
   ....
   ```

   The variable you specified in the DONE= specifier is set to "true" if the corresponding asynchronous I/O statement completes. Otherwise, it is set to "false".

The actual data transfer can take place in the following cases:

- During the asynchronous READ or WRITE statement
• At any time before the execution of the corresponding WAIT statement
• During the corresponding WAIT statement

Because of the nature of asynchronous I/O, the actual completion time of the request cannot be predicted.

You can specify asynchronous READ and WRITE statements by using the ID= specifier. The value set for the ID= specifier by an asynchronous READ or WRITE statement must be the same value specified in the ID= specifier in the corresponding WAIT statement. You must preserve this value until the associated asynchronous I/O statement has completed.

The following program shows a valid asynchronous WRITE statement:

```fortran
program sample0
integer, dimension(1000) :: a
integer idvar
a = *((i,i=1,1000)/)
WRITE(10,ID=idvar) a
WAIT(ID=idvar)
end
```

The following program is not valid, because the value of the asynchronous I/O identifier in variable idvar is destroyed before the associated WAIT statement:

```fortran
program sample1
integer, dimension(1000) :: a
integer idvar
a = *((i,i=1,1000)/)
WRITE(10,ID=idvar) a
idvar = 999 ! Valid id is destroyed.
WAIT(ID=idvar)
end
```

An application that uses asynchronous I/O typically improves performance by overlapping processing with I/O operations. The following is a simple example:

```fortran
program sample2
integer (kind=4), parameter :: isize=1000000, icol=5
integer (kind=4) :: i, j, k
integer (kind=4), dimension(icol) :: handle
integer (kind=4), dimension(isize,icol), static :: a, a1
!
! Opens the file for both synchronous and asynchronous I/O.
!
open(20,form="unformatted",access="direct", &
     status="scratch", recl=isize4,asynch="yes")
!
! This loop overlaps the initialization of a(:,j) with
! asynchronous write statements.
!
! NOTE: The array is written out one column at a time.
! Since the arrays in Fortran are arranged in column
! major order, each WRITE statement writes out a
! contiguous block of the array.
!
do 200 j = 1, icol
   a(:,j) = *((i*j,i=1,isize)/)
   WRITE(20, id=handle(j), rec=j) a(:,j)
200   end do
!
! Wait for all writes to complete before reading.
!
```

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do 300 j = 1, icol
    wait(id=handle(j))
300 end do
!
! Reads in the first record.
! read(20, id=handle(1), rec=1) a1(:,1)
!
!
do 400 j = 2, icol
    k = j - 1
!
! Waits for a previously initiated read to complete.
! wait(id=handle(k))
!
! Initiates the next read immediately.
! read(20, id=handle(j), rec=j) a1(:,j)
!
! While the next read is going on, we do some processing here.
!
    do 350 i = 1, isize
        if (a(i,k) .ne. a1(i,k)) then
            print *, "(" , i , "," , k , ") & expected " , a(i,k) , " got ", a1(i,k)
        end if
350 end do
!
!
400 end do
!
! Finish the last record.
!
wait(id=handle(icol))

    do 450 i = 1, isize
        if (a(i,icol) .ne. a1(i,icol)) then
            print *, "(" , i , "," , icol , ") & expected " , a(i,icol) , " got ", a1(i,icol)
        end if
450 end do

close(20)
end

Performance
To maximize the benefits of asynchronous I/O, you should only use it for large contiguous data items.

It is possible to perform asynchronous I/O on a large number of small items, but the overall performance will suffer. This is because extra processing overhead is required to maintain each item for asynchronous I/O. Performing asynchronous I/O on a larger number of small items is strongly discouraged. The following are two examples:
1. WRITE(unit_number, ID=idvar) a1(1:100000000:2)
2. WRITE(unit_number, ID=idvar) (a2(i,j),j=1,100000000)

Performing asynchronous I/O on unformatted sequential files is less efficient. This is because each record might have a different length, and these lengths are stored with the records themselves. You should use unformatted direct access or unformatted stream access, if possible, to maximize the benefits of asynchronous I/O.
Compiler-generated temporary I/O items

There are situations when the compiler must generate a temporary variable to hold the result of an I/O item expression. In such cases, synchronous I/O is performed on the temporary variable, regardless of the mode of transfer that you specified in the I/O statement. The following are examples of such cases:

1. For READ, when an array with vector subscripts appears as an input item:
   a.   integer a(5), b(3)
       b = (/1,3,5/)
       read(99, id=i) a(b)
   b.   real a(10)
       read(99, id=i) a(/1,3,5/)

2. For WRITE, when an output item is an expression that is a constant or a constant of certain derived types:
   a.   write(99, id=i) 1000
   b.   integer a
       parameter(a=1000)
       write(99, id=i) a
   c.   type mytype
       integer a
       integer b
       end type mytype
       write(99, id=i) mytype(4,5)

3. For WRITE, when an output item is a temporary variable:
   a.   write(99, id=i) 99+100
   b.   write(99, id=i) a+b
   c.   external ff
       real(8) ff
       write(99, id=i) ff()

4. For WRITE, when an output item is an expression that is an array constructor:
   write(99, id=i) (/1,2,3,4,5/)

5. For WRITE, when an output item is an expression that is a scalarized array:
   integer a(5), b(5)
   write(99, id=i) a+b

Error handling

For an asynchronous data transfer, errors or end-of-file conditions might occur either during execution of the data transfer statement or during subsequent data transfer. If these conditions do not result in the termination of the program, you can detect these conditions via ERR=, END= and IOSTAT= specifiers in the data transfer or in the matching WAIT statement.
Execution of the program terminates if an error condition occurs during execution or during subsequent data transfer of an input/output statement that contains neither an IOSTAT= nor an ERR= specifier. In the case of a recoverable error, if the IOSTAT= and ERR= specifiers are not present, the program terminates if you set the err_recovery runtime option to no. If you set the err_recovery runtime option to yes, recovery action occurs, and the program continues.

If an asynchronous data transfer statement causes either of the following events, a matching WAIT statement cannot run, because the ID= value is not defined:

- A branch to the label that you specified by ERR= or END=
- The IOSTAT= specifier to be set to a non-zero value

**XL Fortran thread-safe I/O library**

The XL Fortran runtime library `libxlf90_r.so` provides support for parallel execution of Fortran I/O statements.

**Synchronization of I/O operations**

During parallel execution, multiple threads might perform I/O operations on the same file at the same time. If they are not synchronized, the results of these I/O operations could be shuffled or merged or both, and the application might produce incorrect results or even terminate. The XL Fortran runtime library synchronizes I/O operations for parallel applications. It performs the synchronization within the I/O library, and it is transparent to application programs. The purpose of the synchronization is to ensure the integrity and correctness of each individual I/O operation. However, the run time does not have control over the order in which threads execute I/O statements. Therefore, the order of records read in or written out is not predictable under parallel I/O operations. Refer to “Parallel I/O issues” for details.

**External files**

For external files, the synchronization is performed on a per-unit basis. The XL Fortran runtime ensures that only one thread can access a particular logical unit to prevent several threads from interfering with each other. When a thread is performing an I/O operation on a unit, other threads attempting to perform I/O operations on the same unit must wait until the first thread finishes its operation. Therefore, the execution of I/O statements by multiple threads on the same unit is serialized. However, the runtime environment does not prevent threads from operating on different logical units in parallel. In other words, parallel access to different logical units is not necessarily serialized.

**Functionality of I/O under synchronization**

The XL Fortran runtime sets its internal locks to synchronize access to logical units. This should not have any functional impact on the I/O operations performed by a Fortran program. Also, it will not impose any additional restrictions to the operability of Fortran I/O statements except for the use of I/O statements in a signal handler that is invoked asynchronously. Refer to “Use of I/O statements in signal handlers” on page 343 for details.

**Parallel I/O issues**

The order in which parallel threads perform I/O operations is not predictable. The XL Fortran run time does not have control over the ordering. It will allow whichever thread that executes an I/O statement on a particular logical unit and obtains the lock on it first to proceed with the operation. Therefore, only use parallel I/O in cases where at least one of the following is true:
• Each thread performs I/O on a predetermined record in direct-access files.
• Each thread performs I/O on a different part of a stream-access file. Different I/O statements cannot use the same, or overlapping, areas of a file.
• The result of an application does not depend on the order in which records are written out or read in.
• Each thread performs I/O on a different file.

In these cases, results of the I/O operations are independent of the order in which threads execute. However, you might not get the performance improvements that you expect, since the I/O library serializes parallel access to the same logical unit from multiple threads. Examples of these cases are as follows:

• Each thread performs I/O on a pre-determined record in a direct-access file:

```fortran
  do i = 1, 10
    write(4, '(i4)', rec = i) a(i)
  enddo
```

• Each thread performs I/O on a different part of a stream-access file. Different I/O statements cannot use the same, or overlapping, areas of a file.

```fortran
  do i = 1, 9
    write(4, '(i4)', pos = 1 + 5 * (i - 1)) a(i)
    ! We use 5 above because i4 takes 4 file storage units + 1 file storage unit for the record marker.
  enddo
```

• In the case that each thread operates on a different file, since threads share the status of the logical units connected to the files, the thread still needs to obtain the lock on the logical unit for either retrieving or updating the status of the logical unit. However, the runtime allows threads to perform the data transfer between the logical unit and the I/O list item in parallel. If an application contains a large number of small I/O requests in a parallel region, you might not get the expected performance because of the lock contention. Consider the following example:

```fortran
program example
  use omp_lib

  integer, parameter :: num_of_threads = 4, max = 5000000
  character*10 file_name
  integer i, file_unit, thread_id
  integer, dimension(max, 2 * num_of_threads) :: aa
  call omp_set_num_threads(num_of_threads)

  !$omp parallel private(file_name, thread_id, file_unit, i) shared(aa)

  thread_id = omp_get_thread_num()
  file_name = 'file_'
  file_name(6:6) = char(ichar('0') + thread_id)
  file_unit = 10 + thread_id
  open(file_unit, file = file_name, status = 'old', action = 'read')
  do i = 1, max
    read(file_unit, *) aa(i, thread_id * 2 + 1), aa(i, thread_id * 2 + 2)
  end do
  close(file_unit)

  !$omp end parallel
end
```

---

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The XL Fortran runtime synchronizes retrieving and updating the status of the logical units while performing data transfer in parallel. In order to increase performance, it is recommended to increase the size of data transfer per I/O request. The do loop, therefore, should be rewritten as follows:

```fortran
read(file_unit, *) a(:, thread_id * 2 + 1 : thread_id * 2 + 2)

do i = 1, max
    ! Do something for each element of array 'aa'.
end do
```

- The result does not depend on the order in which records are written out or read in:

  ```fortran
  real a(100)
do i = 1, 10
    read(4) a(i)
endo
call qsort_(a)
```

- Each thread performs I/O on a different logical unit of direct access, sequential access, or stream access:

  ```fortran
  do i = 11, 20
    write(i, '(i4)') a(i - 10)
  enddo
  ```

For multiple threads to write to or read from the same sequential-access file, or to write to or read from the same stream-access file without using the `POS=` specifier, the order of records written out or read in depends on the order in which the threads execute the I/O statement on them. This order, as stated previously, is not predictable. Therefore, the result of an application could be incorrect if it assumes records are sequentially related and cannot be arbitrarily written out or read in. For example, if the following loop is parallelized, the numbers printed out will no longer be in the sequential order from 1 to 500 as the result of a serial execution:

```fortran
do i = 1, 500
    print *, i
enddo
```

Applications that depend on numbers being strictly in the specified order will not work correctly.

The XL Fortran runtime option `multconn=yes` allows connection of the same file to more than one logical unit simultaneously. Since such connections can only be made for reading (`ACCESS='READ'`), access from multiple threads to logical units that are connected to the same file will produce predictable results.

### Use of I/O statements in signal handlers

There are basically two kinds of signals in the POSIX signal model: *synchronously* and *asynchronously* generated signals. Signals caused by the execution of some code of a thread, such as a reference to an unmapped, protected, or bad memory (SIGSEGV or SIGBUS), floating-point exception (SIGFPE), execution of a trap instruction (SIGTRAP), or execution of illegal instructions (SIGILL) are said to be synchronously generated. Signals may also be generated by events outside the process: for example, SIGINT, SIGHUP, SIGQUIT, SIGIO, and so on. Such events are referred to as interrupts. Signals that are generated by interrupts are said to be asynchronously generated.

The XL Fortran runtime is asynchronous signal unsafe. This means that an XL Fortran I/O statement cannot be used in a signal handler that is entered because of an asynchronously generated signal. The behavior of the system is undefined when...
an XL Fortran I/O statement is called from a signal handler that interrupts an I/O statement. However, it is safe to use I/O statements in signal handlers for synchronous signals.

Sometimes an application can guarantee that a signal handler is not entered asynchronously. For example, an application might mask signals except when it runs certain known sections of code. In such situations, the signal will not interrupt any I/O statements and other asynchronous signal unsafe functions. Therefore, you can still use Fortran I/O statements in an asynchronous signal handler.

A much easier and safer way to handle asynchronous signals is to block signals in all threads and to explicitly wait (using `sigwait()`) for them in one or more separate threads. The advantage of this approach is that the handler thread can use Fortran I/O statements as well as other asynchronous signal unsafe routines.

### Asynchronous thread cancellation

When a thread enables asynchronous thread cancellability, any cancellation request is acted upon immediately.

The XL Fortran runtime environment is not asynchronous thread cancellation safe. The behavior of the system is undefined if a thread is cancelled asynchronously while it is in the XL Fortran runtime environment.
Chapter 13. Implementation details of XL Fortran floating-point processing

This topic answers some common questions about floating-point processing.

- How can I get predictable, consistent results?
- How can I get the fastest or the most accurate results?
- How can I detect, and possibly recover from, exception conditions?
- Which compiler options can I use for floating-point calculations?

The topics describing floating-point precision make frequent reference to the compiler options that are grouped together in [Floating-point and integer control] in the XL Fortran Compiler Reference, especially the **-qfloat** option. The XL Fortran compiler also provides three intrinsic modules for exception handling and IEEE arithmetic support to help you write IEEE module-compliant code that can be more portable. See [IEEE Modules and Support] in the XL Fortran Language Reference for details.

The use of the compiler options for floating-point calculations affects the accuracy, performance, and possibly the correctness of floating-point calculations. Although the default values for the options were chosen to provide efficient and correct execution of most programs, you may need to specify nondefault options for your applications to work the way you want. We strongly advise you to read this section before using these options.

**Note:** The discussions of single-precision, double-precision, and extended-precision calculations in this section all refer to the default situation, with `-qqrealsize=4` and no `-qautodbl` specified. If you change these settings, keep in mind that the size of a Fortran REAL, DOUBLE PRECISION, and so on may change, but single precision, double precision, and extended precision (in lowercase) still refer to 4-, 8-, and 16-byte entities respectively.

### IEEE floating-point overview

The ANSI/IEEE Standard for Binary Floating-Point Arithmetic, ANSI/IEEE Std 754-1985 and IEEE Std 754-2008 and the details of how it applies to XL Fortran on specific hardware platforms, are summarized in the following topics.

For information on the Fortran 2003 IEEE Module and arithmetic support, see the XL Fortran Language Reference.

### Compiling for strict IEEE conformance

By default, XL Fortran follows most, but not all of the rules in the IEEE standard. To compile for strict compliance with the standard:

- Use the compiler option `-qfloat=nomaf`.
- If the program changes the rounding mode at run time, include `rrm` among the `-qfloat` suboptions.
- If the data or program code contains signaling NaN values (NAN), include `nans` among the `-qfloat` suboptions. (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` or `-qinitalloc` compiler option.)
• If you are compiling with -O3 or a higher base optimization level, include the -qstrict option after it. You can also use the -qstrict suboptions to refine the level of control for the transformations performed by the optimizers.

Related reference:

See -qstrict in the Compiler Reference

IEEE single-precision and double-precision values

XL Fortran encodes single-precision and double-precision values in IEEE format. For the range and representation, see Real in the XL Fortran Language Reference.

IEEE extended-precision values

The IEEE standard suggests, but does not mandate, a format for extended-precision values. XL Fortran does not use this format. “Extended-precision values” on page 349 describes the format that XL Fortran uses.

Infinities and NaNs

For single-precision real values:
• Positive infinity is represented by the bit pattern X'7F80 0000'.
• Negative infinity is represented by the bit pattern X'FF80 0000'.
• A signaling NaN is represented by any bit pattern between X'7F80 0001' and X'7FFB FFFF' or between X'FF80 0001' and X'FFBF FFFF'.
• A quiet NaN is represented by any bit pattern between X'7FC0 0000' and X'7FFF FFFF' or between X'FFC0 0000' and X'FFFF FFFF'.

For double-precision real values:
• Positive infinity is represented by the bit pattern X'7FF00000 00000000'.
• Negative infinity is represented by the bit pattern X'7FF00000 00000000'.
• A signaling NaN is represented by any bit pattern between X'7FF00000 00000001' and X'7FF7FFFF FFFFFFFF' or between X'7FF00000 00000001' and X'7FF7FFFF FFFFFFFF'.
• A quiet NaN is represented by any bit pattern between X'7FF80000 00000000' and X'7FFFFFF FFFFFFFF' or between X'7FF80000 00000000' and X'7FFFFFF FFFFFFFF'.

These values do not correspond to any Fortran real constants. You can generate all of these by encoding the bit pattern directly, or by using the ieee_value function provided in the ieee_arithmetic intrinsic module. Using the ieee_value function is the preferred programming technique, as it is allowed by the Fortran 2003 standard and the results are portable. Encoding the bit pattern directly could cause portability problems on machines using different bit patterns for the different values. All except signaling NaN values can occur as the result of arithmetic operations:
## Exception-handling model

The IEEE standard defines several exception conditions that can occur:

**OVERFLOW**

The exponent of a value is too large to be represented.

**UNDERFLOW**

A nonzero value is so small that it cannot be represented without an extraordinary loss of accuracy. The value can be represented only as zero or a subnormal number (denorm).

**ZERODIVIDE**

A finite nonzero value is divided by zero.

**INVALID**

Operations are performed on values for which the results are not defined. These include:

- Operations on signaling NaN values
- infinity - same infinity, or infinity + opposite infinity
- 0.0 * infinity
- 0.0 / 0.0
- mod(x,y) or ieee_rem(x,y) (or other remainder functions) when x is infinite or y is zero
- The square root of a negative number except -0.0
- Conversion of a floating-point number to an integer when the converted value cannot be represented faithfully
Comparisons involving NaN values

**INEXACT**

A computed value cannot be represented exactly, so a rounding error is introduced. (This exception is very common.)

XL Fortran always detects these exceptions when they occur, but by default does not take any special action. Calculation continues, usually with a NaN or infinity value as the result. If you want to be automatically informed when an exception occurs, you can turn on exception trapping through compiler options or calls to intrinsic subprograms. However, different results, intended to be manipulated by exception handlers, are produced:

| Table 35. Results of IEEE exceptions, with and without trapping enabled |
|--------------------------|-------------------|----------------|-----------|--------------------------|
|                         | Overflow          | Underflow       | Zerodivide  | Invalid      | Inexact                 |
| Exceptions not enabled (default) | INF               | Subnormal number or zero | INF          | NaN          | Rounded result          |
| Exceptions enabled      | Unnormalized number with biased exponent | Unnormalized number with biased exponent | No result    | No result    | Rounded result          |

**Note:** Because different results are possible, it is very important to make sure that any exceptions that are generated are handled correctly. See “Detecting and trapping floating-point exceptions” on page 354 for instructions on doing so.

**Hardware-specific floating-point overview**

Single-precision and double-precision values and extended-precision values for hardware-specific floating-point processing are described in the following topics.

**Single-precision and double-precision values**

The PowerPC floating-point hardware performs calculations in either IEEE single-precision (equivalent to REAL(4) in Fortran programs) or IEEE double-precision (equivalent to REAL(8) in Fortran programs).

Keep the following considerations in mind:

- Double precision provides greater range (approximately 10**(-308) to 10**308) and precision (about 15 decimal digits) than single precision (approximate range 10**(-38) to 10**38, with about 7 decimal digits of precision).
- Computations that mix single and double operands are performed in double precision, which requires conversion of the single-precision operands to double-precision. These conversions do not affect performance.
- Double-precision values that are converted to single-precision (such as when you specify the SNGL intrinsic or when a double-precision computation result is stored into a single-precision variable) require rounding operations. A rounding operation produces the correct single-precision value, which is based on the IEEE rounding mode in effect. The value may be less precise than the original double-precision value, as a result of rounding error. Conversions from double-precision values to single-precision values may reduce the performance of your code.
- Programs that manipulate large amounts of floating-point data may run faster if they use REAL(4) rather than REAL(8) variables. (You need to ensure that REAL(4) variables provide you with acceptable range and precision.)
programs may run faster because the smaller data size reduces memory traffic, which can be a performance bottleneck for some applications.

The floating-point hardware also provides a special set of double-precision operations that multiply two numbers and add a third number to the product. These combined multiply-add (MAF) operations are performed at the same speed at which either an individual multiply or add is performed. The MAF functions provide an extension to the IEEE 754-1985 standard (but are in the 754-2008 standard) because they perform the multiply and add with one (rather than two) rounding errors. The MAF functions are faster and more accurate than the equivalent separate operations.

Extended-precision values

XL Fortran extended precision is not in the binary128 format suggested by the IEEE standard. The IEEE standard suggests extended formats use more bits in the exponent for greater range and the fraction for greater precision.

XL Fortran extended precision, equivalent to REAL(16) in Fortran programs, is implemented in software. Extended precision provides the same range as double precision (about 10**(-308) to 10**308) but more precision (a variable amount, about 31 decimal digits or more). The software support is restricted to round-to-nearest mode. Programs that use extended precision must ensure that this rounding mode is in effect when extended-precision calculations are performed. For the different ways you can control the rounding mode, see “Selecting the rounding mode” on page 350.

Programs that specify extended-precision values as hexadecimal, octal, binary, or Hollerith constants must follow these conventions:

- Extended-precision numbers are composed of two double-precision numbers with different magnitudes that do not overlap (except when the number is zero or close to zero). That is, the binary exponents differ by at least the number of fraction bits in a REAL(8). The high-order double-precision value (the one that comes first in storage) must have the larger magnitude. The value of the extended-precision number is the sum of the two double-precision values.
- For a value of NaN or infinity, you must encode one of these values within the high-order double-precision value. The low-order value is not significant except that it cannot be set to NaN when the high-order value is infinity.

Because an XL Fortran extended-precision value can be the sum of two values with greatly different exponents, leaving a number of assumed zeros in the fraction, the format actually has a variable precision with a minimum of about 31 decimal digits. You get more precision in cases where the exponents of the two double values differ in magnitude by more than the number of digits in a double-precision value. This encoding allows an efficient implementation intended for applications requiring more precision but no more range than double precision.

Note:

1. In the discussions of rounding errors because of compile-time folding of expressions, keep in mind that this folding produces different results for extended-precision values more often than for other precisions.
2. Special numbers, such as NaN, infinity, and negative zero, are not fully supported by the extended-precision values. Arithmetic operations do not necessarily propagate these numbers in extended precision.
3. XL Fortran does not always detect floating-point exception conditions (see "Detecting and trapping floating-point exceptions" on page 354) for extended-precision values. If you turn on floating-point exception trapping in programs that use extended precision, XL Fortran may also generate signals in cases where an exception condition does not really occur.

4. The exact representation is sometimes different between AIX® and Linux.

5. Not all math library functions are available for extended precision.

How XL Fortran rounds floating-point calculations

Understanding rounding operations in XL Fortran can help you get predictable, consistent results. It can also help you make informed decisions when you have to make tradeoffs between speed and accuracy.

In general, floating-point results from XL Fortran programs are more accurate than those from other implementations because of MAF operations and the higher precision used for intermediate results. If identical results are more important to you than the extra precision and performance of the XL Fortran defaults, read "Duplicating the floating-point results of other systems" on page 353.

Selecting the rounding mode

To change the rounding mode in a program, you can call the fpsets and fpgets routines, which use an array of logicals named fpstat, defined in the include files /opt/ibm/xlf/15.1.0/include/fpdt.h and /opt/ibm/xlf/15.1.0/include/fpdc.h. The fpstat array elements correspond to the bits in the floating-point status and control register. They correspond to the lower half of the FPCSR bits.

For floating-point rounding control, the array elements fpstat(fprn1) and fpstat(fprn2) are set as specified in the following table:

<table>
<thead>
<tr>
<th>fpstat(fprn1)</th>
<th>fpstat(fprn2)</th>
<th>Rounding Mode Enabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>.true.</td>
<td>.true.</td>
<td>Round towards -infinity.</td>
</tr>
<tr>
<td>.true.</td>
<td>.false.</td>
<td>Round towards +infinity.</td>
</tr>
<tr>
<td>.false.</td>
<td>.true.</td>
<td>Round towards zero.</td>
</tr>
<tr>
<td>.false.</td>
<td>.false.</td>
<td>Round to nearest.</td>
</tr>
</tbody>
</table>

For example:

```fortran
program fptest
  include 'fpdc.h'

  call fpgets( fpstat )  ! Get current register values.
  if ( (fpstat(fprn1) .eqv. .false.) .and. +
       (fpstat(fprn2) .eqv. .false.)) then
    print *, 'Before test: Rounding mode is towards nearest'
    print *, '  2.0 / 3.0 = ', 2.0 / 3.0
    print *, ' -2.0 / 3.0 = ', -2.0 / 3.0
  end if

  call fpsets( fpstat )  ! Get current register values.
  fpstat(fprn1) = .TRUE. ! These 2 lines mean round towards
  fpstat(fprn2) = .FALSE. ! +infinity.

  call fpsets( fpstat )
  r = 2.0 / 3.0
  print *, 'Round towards +infinity: 2.0 / 3.0 = ', r
```

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call fpgets( fpstat ) ! Get current register values.
fpstat(fprn1) = .TRUE. ! These 2 lines mean round towards
fpstat(fprn2) = .TRUE. ! -infinity.
call fpsets( fpstat )
  r = -2.0 / 3.0
  print *, 'Round towards -infinity: -2.0 / 3.0= ', r
end ! This block data program unit initializes the fpstat array, and so on.
block data
  include 'fpdc.h'
  include 'fpdt.h'
end

XL Fortran also provides several procedures that allow you to control the floating-point status and control register of the processor directly. These procedures are more efficient than the fpsets and fpgets subroutines because they are mapped into inlined machine instructions that manipulate the floating-point status and control register (fpscr) directly.

XL Fortran supplies the get_round_mode() and set_round_mode() procedures in the xlf_fp_util module. These procedures return and set the current binary floating-point rounding mode, respectively.

For example:

program fptest
  use, intrinsic :: xlf_fp_util
  integer(fpscr_kind) old_fpscr
  if ( get_round_mode() == fp_rnd rn ) then
    print *, 'Before test: Rounding mode is towards nearest'
    print *, '  2.0 / 3.0 = ', 2.0 / 3.0
    print *, '  -2.0 / 3.0 = ', -2.0 / 3.0
  end if

  old_fpscr = set_round_mode( fp_rnd rp )
  r = 2.0 / 3.0
  print *, 'Round towards +infinity: 2.0 / 3.0= ', r

  old_fpscr = set_round_mode( fp_rnd rm )
  r = -2.0 / 3.0
  print *, 'Round towards -infinity: -2.0 / 3.0= ', r
end

XL Fortran supplies the ieee_get_rounding_mode() and ieee_set_rounding_mode() procedures in the ieee_arithmetic module. These portable procedures retrieve and set the current floating-point rounding mode, respectively.

For example:

program fptest
  use, intrinsic :: ieee_arithmetic
  type(ieee_round_type) current_mode
  call ieee_get_rounding_mode( current_mode )
  if ( current_mode == ieee_nearest ) then
    print *, 'Before test: Rounding mode is towards nearest'
    print *, '  2.0 / 3.0 = ', 2.0 / 3.0
    print *, '  -2.0 / 3.0 = ', -2.0 / 3.0
  end if

  call ieee_set_rounding_mode( ieee_up )
  r = 2.0 / 3.0
  print *, 'Round towards +infinity: 2.0 / 3.0= ', r
call ieee_set_rounding_mode( ieee_down )
  r = -2.0 / 3.0
  print *, 'Round towards -infinity: -2.0 / 3.0 = ', r
end

Notes:
1. Extended-precision floating-point values must only be used in round-to-nearest mode.
2. For thread-safety and reentrancy, the include file /opt/ibm/xlf/15.1.0/include/fpdc.h contains a THREADLOCAL directive that is protected by the trigger constant IBMT. The invocation commands xlf_r, xlf90_r, xlf95_r, xlf2003_r, xlf2008_r, and CUDA Fortran turn on the -qthreaded compiler option by default, which in turn implies the trigger constant IBMT. If you are including the file /opt/ibm/xlf/15.1.0/include/fpdc.h in code that is not intended to be threadsafe, do not specify IBMT as a trigger constant.
3. Compile a program that changes the rounding mode with -qfloat=rrm.

Minimizing rounding errors
There are several strategies for handling rounding errors and other unexpected, slight differences in calculated results. You may want to consider one or more of the following strategies:
• Minimizing the amount of overall rounding
• Delaying as much rounding as possible to run time
• Ensuring that if some rounding is performed in a mode other than round-to-nearest, all rounding is performed in the same mode

Minimizing overall rounding
Rounding operations, especially in loops, reduce code performance and may have a negative effect on the precision of computations. Consider using double-precision variables instead of single-precision variables when you store the temporary results of single-precision calculations, and delay rounding operations until the final result is computed.

Delaying rounding until run time
The compiler evaluates floating-point expressions during compilation when it can, so that the resulting program does not run more slowly due to unnecessary runtime calculations. However, the results of the compiler's evaluation might not match exactly the results of the runtime calculation. To delay these calculations until run time, specify the nofold suboption of the -qfloat option.

The results may still not be identical; for example, calculations in DATA and PARAMETER statements are still performed at compile time.

The differences in results due to fold or nofold are greatest for programs that perform extended-precision calculations or are compiled with the -O option or both.

Ensuring that the rounding mode is consistent
You can change the rounding mode from its default setting of round-to-nearest. (See for examples.) If you do so, you must be careful that all rounding operations for the program use the same mode:
• Specify the equivalent setting on the -qieee option, so that any compile-time calculations use the same rounding mode.
• Specify the `rrm` suboption of the `-qfloat` option, so that the compiler does not perform any optimizations that require round-to-nearest rounding mode to work correctly.

For example, you might compile a program like the one in “Selecting the rounding mode” on page 350 with this command if the program consistently uses round-to-plus-infinity mode:

`xlf95 -qieee=plus -qfloat=rrm changes_rounding_mode.f`

---

**Duplicating the floating-point results of other systems**

To duplicate the double-precision results of programs on systems with different floating-point architectures (without multiply-add instructions), specify the `nomaf` suboption of the `-qfloat` option. This suboption prevents the compiler from generating any multiply-add or multiply-subtract instructions except the following cases:

• Instructions used in the COMPLEX operations
• Instructions required for multiply-add or multiply-subtract built in functions or the `fma` function

This results in decreased accuracy and performance but provides strict conformance to the IEEE standard for double-precision arithmetic.

To duplicate the results of programs where the default size of `REAL` items is different from that on systems running XL Fortran, use the `-qrealsize` option to change the default `REAL` size when compiling with XL Fortran.

If the system whose results you want to duplicate preserves full double precision for default real constants that are assigned to `DOUBLE PRECISION` variables, use the `-qdpc` or `-qrealsize` option.

If results consistent with other systems are important to you, include `norsqrt` and `nofold` in the settings for the `-qfloat` option.

If you specify the option `-O3`, `-O4`, or `-O5`, include `-qstrict` and any necessary suboptions too.

**Related information:**

- See `-qarch` in the Compiler Reference
- See `-qfloat` in the Compiler Reference
- See `-qrealsize` in the Compiler Reference
- See `-qstrict` in the Compiler Reference

---

**Maximizing floating-point performance**

If performance is your primary concern and you want your program to be relatively safe but do not mind if results are slightly different (generally more precise) from what they would be otherwise, optimize the program with the `-O` option, and specify `-qfloat=rsqrt:hssngl`.

The following topics describe the functions of these suboptions:
- The **rsqrt** suboption replaces division by a square root with multiplication by the reciprocal of the root, a faster operation that may not produce precisely the same result.

- The **hssngl** suboption improves the performance of single-precision (REAL(4)) floating-point calculations by suppressing rounding operations that are required by the Fortran language but are not necessary for correct program execution. The results of floating-point expressions are kept in double precision where the original program would round them to single-precision. These results are then used in some later expressions instead of the rounded results.

To detect single-precision floating-point overflows and underflows, rounding operations are still inserted when double-precision results are stored into single-precision memory locations. However, if optimization removes such a store operation, **hssngl** also removes the corresponding rounding operation, possibly preventing the exception. (Depending on the characteristics of your program, you may or may not care whether the exception happens.)

The **hssngl** suboption is safe for all types of programs because it always only increases the precision of floating-point calculations. Program results may differ because of the increased precision and because of avoidance of some exceptions.

### Detecting and trapping floating-point exceptions

The IEEE standard for floating-point arithmetic defines a number of exception (or error) conditions that might require special care to avoid or recover from. The following topics are intended to help you make your programs work safely in the presence of such exception conditions while sacrificing the minimum amount of performance.

The floating-point hardware always detects a number of floating-point exception conditions (which the IEEE standard rigorously defines): overflow, underflow, zerodivide, invalid, and inexact.

By default, the only action that occurs is that a status flag is set. The program continues without a problem (although the results from that point on may not be what you expect). If you want to know when an exception occurs, you can arrange for one or more of these exception conditions to generate a signal.

The signal causes a branch to a handler routine. The handler receives information about the type of signal and the state of the program when the signal occurred. It can produce a core dump, display a listing showing where the exception occurred, modify the results of the calculation, or carry out some other processing that you specify.

The XL Fortran compiler uses the operating system facilities for working with floating-point exception conditions. These facilities indicate the presence of floating-point exceptions by generating **SIGFPE** signals.

### Compiler features for trapping floating-point exceptions

To turn on XL Fortran exception trapping, compile the program with the **-qflttrap** option and some combination of suboptions that includes **enable**. This option uses trap operations to detect floating-point exceptions and generates **SIGFPE** signals when exceptions occur, provided that a signal handler for **SIGFPE** is installed.

**-qflttrap** also has suboptions that correspond to the names of the exception conditions. For example, if you are only concerned with handling overflow and underflow exceptions, you can specify a command similar to the following one:
You only need `enable` when you are compiling the main program. However, it is very important then and does not cause any problems if you specify it for other files, so always include it when you use `-qflttrap`.

An advantage of this approach is that performance impact is relatively low. However, this approach only traps exceptions that occur in code that you compiled with `-qflttrap`, which does not include system library routines.

**Notes:**

1. If your program depends on floating-point exceptions occurring for particular operations, also specify `-qfloat` suboptions that include `nofold`. Otherwise, the compiler might replace an exception-producing calculation with a constant NaN or infinity value, or it might eliminate an overflow in a single-precision operation.

2. The suboptions of the `-qflttrap` option replace an earlier technique that required you to modify your code with calls to the `fpsets` and `fpgets` procedures. You no longer require these calls for exception handling if you use the appropriate `-qflttrap` settings.

**Attention:** If your code contains `fpsets` calls that enable checking for floating-point exceptions and you do not use the `-qflttrap` option when compiling the whole program, the program will produce unexpected results if exceptions occur, as explained in Table 35 on page 348.

**Installing an exception handler**

When a program that uses the XL Fortran or Linux exception-detection facilities encounters an exception condition, it receives a signal from the operating system. This causes a branch to whatever handler is specified by the program.

By default, programs on Linux do not trap on floating-point exceptions unless a signal handler is installed. To produce a core file, you can use the `xl__trcedump` signal handler described below. If you want to install a `SIGTRAP` or `SIGFPE` signal handler, use the `-qsigtrap` option. It allows you to specify an XL Fortran handler that produces a traceback or to specify a handler you have written:

```
xlf95 -qflttrap=overflow:underflow:enable compute_pi.f
```

You can also install an alternative exception handler, either one supplied by XL Fortran or one you have written yourself, by calling the `SIGNAL` subroutine (defined in `/opt/ibm/xlf/15.1.0/include/fexcp.h`):

```
INCLUDE 'fexcp.h'
CALL SIGNAL(SIGTRAP, handler_name)
CALL SIGNAL(SIGFPE, handler_name)
```

The XL Fortran exception handlers and related routines are:

**xl__ieee**

Produces a traceback and an explanation of the signal and continues execution by supplying the default IEEE result for the failed computation. This handler allows the program to produce the same results as if exception detection was not turned on.

**xl__trce**

Produces a traceback and stops the program.
xl__trcedump
Produces a traceback and a core file and stops the program.

xl__sigdump
Provides a traceback that starts from the point at which it is called and provides information about the signal. You can only call it from inside a user-written signal handler. It does not stop the program. To successfully continue, the signal handler must perform some cleanup after calling this subprogram.

xl__trbk
Provides a traceback that starts from the point at which it is called. You call it as a subroutine from your code, rather than specifying it with the -qsigtrap option. It requires no parameters. It does not stop the program.

All of these handler names contain double underscores to avoid duplicating names that you declared in your program. All of these routines work for both SIGTRAP and SIGFPE signals.

You can use the -g compiler option to get line numbers in the traceback listings. The file /opt/ibm/xlf/15.1.0/include/fsignal.h defines a Fortran derived type similar to the ucontext_t structure in /usr/include/sys/ucontext.h system header. You can write a Fortran signal handler that accesses this derived type.

“Sample programs for exception handling” on page 359 lists some sample programs that illustrate how to use these signal handlers or write your own. Also see the SIGNAL procedure in the XL Fortran Language Reference for more information.

Producing a core file
To produce a core file, specify the xl__trcedump handler.

Controlling the floating-point status and control register
Before the introduction of -qflttrap suboptions or the -qsigtrap options, most of the processing for floating-point exceptions required you to change your source files to turn on exception trapping or install a signal handler. Although you can still do so, for any new applications, we recommend that you use the options instead.

To control exception handling at run time, compile without the enable suboption of the -qflttrap option:

```
xlf95 -qflttrap compute_pi.f # Check all exceptions, but do not trap.
xlf95 -qflttrap=ov compute_pi.f # Check one type, but do not trap.
```

Then, inside your program, manipulate the fpstats array (defined in the include file /opt/ibm/xlf/15.1.0/include/fpdc.h) and call the fpsets subroutine to specify which exceptions should generate traps.

See the sample program that uses fpsets and fpgets in “Selecting the rounding mode” on page 350.

Another method is to use the set_fpscr_flags() subroutine in the xlf_fp_util module. This subroutine allows you to set the floating-point status and control register flags you specify in the MASK argument. Flags that you do not specify in MASK remain unaffected. MASK must be of type INTEGER(FPSCR_KIND). For example:
USE, INTRINSIC :: xlf_fp_util
INTEGER(FPSCR_KIND) SAVED_FPSCR
INTEGER(FP_MODE_KIND) FP_MODE

SAVED_FPSCR = get_fpscr()  ! Saves the current value of
       ! the fpscr register.

CALL set_fpscr_flags(TRP_DIV_BY_ZERO) ! Enables trapping of
       ! divide-by-zero.
SAVED_FPSCR = set_fpscr(SAVED_FPSCR)  ! Restores fpscr register.

Another method is to use the ieee_set_halting_mode subroutine in the
ieee_exceptions module. This portable subroutine allows you to set the halting
(trapping) status for any FPSCR exception flags. For example:
USE, INTRINSIC :: ieee_exceptions
TYPE(IEEE_STATUS_TYPE) SAVED_FPSCR
CALL ieee_get_status(SAVED_FPSCR)  ! Saves the current value of the
       ! fpscr register

CALL ieee_set_halting_mode(IEEE_DIVIDE_BY_ZERO, .TRUE.) ! Enabled trapping
       ! of divide-by-zero.
CALL IEEE_SET_STATUS(SAVED_FPSCR)  ! Restore fpscr register

xlf_fp_util procedures

The xlf_fp_util procedures allow you to query and control the floating-point status
and control register (fpscr) of the processor directly. These procedures are more
efficient than the fpsets and fpgets subroutines because they are mapped into
inlined machine instructions that manipulate the floating-point status and control
register directly.

The intrinsic module, xlf_fp_util, contains the interfaces and data type definitions
for these procedures and the definitions for the named constants that are needed
by the procedures. This module enables type checking of these procedures at
compile time rather than link time. The following files are supplied for the
xlf_fp_util module:

<table>
<thead>
<tr>
<th>File names</th>
<th>File type</th>
<th>Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>xlf_fp_util.mod</td>
<td>module symbol file</td>
<td>/opt/ibm/xlf/15.1.0/include</td>
</tr>
</tbody>
</table>

To use the procedures, you must add a USE XLF_FP_UTIL statement to your
source file. For more information, see the USE statement in the XL Fortran
Language Reference.

When compiling with the -U option, you must code the names of these procedures
in all lowercase.

For a list of the xlf_fp_util procedures, see the Service and utility procedures
section in the XL Fortran Language Reference.

fpgets and fpsets subroutines

The fpsets and fpgets subroutines provide a way to manipulate or query the
floating-point status and control register. Instead of calling the operating system
routines directly, you pass information back and forth in fpstat, an array of
logicals. The following table shows the most commonly used array elements that
deal with exceptions:
Table 37. Exception bits to use with \texttt{fpsets} and \texttt{fpgets}

<table>
<thead>
<tr>
<th>Array Element to Set to Enable</th>
<th>Array Element to Check if Exception Occurred</th>
<th>Exception Indicated When \texttt{.TRUE.}</th>
</tr>
</thead>
<tbody>
<tr>
<td>n/a</td>
<td>\texttt{fpstat(fpfx)}</td>
<td>Floating-point exception summary</td>
</tr>
<tr>
<td>n/a</td>
<td>\texttt{fpstat(fpfex)}</td>
<td>Floating-point enabled exception summary</td>
</tr>
<tr>
<td>\texttt{fpstat(fpve)}</td>
<td>\texttt{fpstat(fpvx)}</td>
<td>Floating-point invalid operation exception summary</td>
</tr>
<tr>
<td>\texttt{fpstat(fpoe)}</td>
<td>\texttt{fpstat(fpox)}</td>
<td>Floating-point overflow exception</td>
</tr>
<tr>
<td>\texttt{fpstat(fpuex)}</td>
<td>\texttt{fpstat(fpux)}</td>
<td>Floating-point underflow exception</td>
</tr>
<tr>
<td>\texttt{fpstat(fpze)}</td>
<td>\texttt{fpstat(fpzx)}</td>
<td>Zero-divide exception</td>
</tr>
<tr>
<td>\texttt{fpstat(fpze)}</td>
<td>\texttt{fpstat(fpzx)}</td>
<td>Inexact exception</td>
</tr>
<tr>
<td>\texttt{fpstat(fpze)}</td>
<td>\texttt{fpstat(fpzxsnan)}</td>
<td>Floating-point invalid operation exception (signaling NaN)</td>
</tr>
<tr>
<td>\texttt{fpstat(fpze)}</td>
<td>\texttt{fpstat(fpvxisi)}</td>
<td>Floating-point invalid operation exception (INF-INF)</td>
</tr>
<tr>
<td>\texttt{fpstat(fpze)}</td>
<td>\texttt{fpstat(fpvxit)}</td>
<td>Floating-point invalid operation exception (INF/INF)</td>
</tr>
<tr>
<td>\texttt{fpstat(fpze)}</td>
<td>\texttt{fpstat(fpvxdz)}</td>
<td>Floating-point invalid operation exception (0/0)</td>
</tr>
<tr>
<td>\texttt{fpstat(fpze)}</td>
<td>\texttt{fpstat(fpvxdmz)}</td>
<td>Floating-point invalid operation exception (INF*0)</td>
</tr>
<tr>
<td>\texttt{fpstat(fpze)}</td>
<td>\texttt{fpstat(fpvxcv)}</td>
<td>Floating-point invalid operation exception (invalid compare)</td>
</tr>
<tr>
<td>n/a</td>
<td>\texttt{fpstat(fpvxssoft)}</td>
<td>Floating-point invalid operation exception (software request), PowerPC only</td>
</tr>
<tr>
<td>n/a</td>
<td>\texttt{fpstat(fpvxsqrt)}</td>
<td>Floating-point invalid operation exception (invalid square root), PowerPC only</td>
</tr>
<tr>
<td>n/a</td>
<td>\texttt{fpstat(fpvxcvi)}</td>
<td>Floating-point invalid operation exception (invalid integer convert), PowerPC only</td>
</tr>
</tbody>
</table>

To explicitly check for specific exceptions at particular points in a program, use \texttt{fpgets} and then test whether the elements in \texttt{fpstat} have changed. Once an exception has occurred, the corresponding exception bit (second column in the preceding table) is set until it is explicitly reset, except for \texttt{fpstat(fpfx)}, \texttt{fpstat(fpvx)}, and \texttt{fpstat(fpfex)}, which are reset only when the specific exception bits are reset.

An advantage of using the \texttt{fpgets} and \texttt{fpsets} subroutines (as opposed to controlling everything with suboptions of the \texttt{-qflttrap} option) includes control over granularity of exception checking. For example, you might only want to test if an exception occurred anywhere in the program when the program ends.

The disadvantages of this approach include the following:

- You have to change your source code.
- These routines differ from what you may be accustomed to on other platforms.
For example, to trap floating-point overflow exceptions but only in a certain section of the program, you would set `fpstat(fpoe)` to `.TRUE.` and call `fpsets`. After the exception occurs, the corresponding exception bit, `fpstat(fpox)`, is `.TRUE.` until the program runs:

```
call fpgets(fpstat)
fstat(fpox) = .FALSE.
call fpsets(fpstat) ! resetting fpstat(fpox) to .FALSE.
```

### Sample programs for exception handling

Sample programs contained in `/opt/ibm/xlf/15.1.0/samples/floating_point` illustrate different aspects of exception handling:

- **flttrap_handler.c and flttrap_test.f**
  - A sample exception handler that is written in C and a Fortran program that uses it.

- **xl_ieee.F and xl_ieee.c**
  - Exception handlers that are written in Fortran and C that show how to substitute particular values for operations that produce exceptions. Even when you use support code such as this, the implementation of XL Fortran exception handling does not fully support the exception-handling environment that is suggested by the IEEE floating-point standard.

- **check_fpscr.f and postmortem.f**
  - Show how to work with the `fpsets` and `fpgets` procedures and the `fpstats` array.

- **fhandler.F**
  - Shows a sample Fortran signal handler and demonstrates the `xl__sigdump` procedure.

- **xl__trbk_test.f**
  - Shows how to use the `xl__trbk` procedure to generate a traceback listing without stopping the program.

The sample programs are strictly for illustrative purposes only.

### Causing exceptions for particular variables

To mark a REAL variable as “do not use”, you can encode a special value called a signaling NaN in it. This causes an invalid exception condition any time that variable is used in a calculation.

If you use this technique, use the `nans` suboption of the `-qfloat` option and the `-qstrict` or `-qstrict=nans` option, so that the program properly detects all cases where a signaling NaN is used, and one of the methods already described to generate corresponding SIGFPE signals.

### Minimizing the performance impact of floating-point exception trapping

If you need to deal with floating-point exception conditions but are concerned that doing so will make your program too slow, here are some techniques that can help minimize the performance impact:

- Consider using only a subset of the `overflow`, `underflow`, `zerodivide`, `invalid`, and `inexact` suboptions with the `-qflttrap` option if you can identify some conditions that will never happen or you do not care about. In particular, because an `inexact` exception occurs for each rounding error, you probably should not check for it if performance is important.
Chapter 14. Vector element order toggling

To consistently use the instructions generated by vector intrinsic procedures, users need to make all existing Vector Multimedia Extension (VMX) and Vector Scalar Extension (VSX) load and store intrinsic procedures operate on the vectors in registers in the same vector element order, either little endian or big endian element order.

Vector element order

The -qaltivec option affects the vector element order only in registers when the vectors are operated by a specific set of functions. In registers, the vector layout differs when the computer loads the vector in either big endian element order or little endian element order.

Big endian element order

Vectors are laid out in vector registers from left to right, so that element 0 is the leftmost element in the register.

Little endian element order

Vectors are laid out in vector registers from right to left, so that element 0 is the rightmost element in the register.

For more information, see "Example: Vector layout in the memory and register" on page 362.

Rules for vector element order toggling

The vector element order is toggled in registers by following these rules:

- The -qaltivec option does not affect the vector element order in memory, where the vector elements are always stored in big endian element order.
  
  For example, in memory, the -qaltivec option does not affect the vector initialization. The vectors initialized by the EQUIVALENCE statement with the non-vectors (such as arrays) are always in big endian element order in memory. When the initialized vector is loaded to registers, the vector element order is always reversed to little endian element order in registers even when -qaltivec=be. However, if the vector loading is realized by using the vector intrinsic procedure, the vector element order is arranged with respect to the -qaltivec option.

- When -qaltivec=le is in effect, the behaviours of procedures are as follows:
  
  - The VMX and VSX load intrinsic procedures load vectors to registers in little endian element order.
  - The VMX and VSX store intrinsic procedures assume that the vectors to be stored are in little endian element order in registers.
  - The nonload and nonstore intrinsic procedures assume that vectors are loaded in registers in little endian element order.

- When -qaltivec=be is in effect, these procedures operate on the vectors in an opposite way of -qaltivec=le. The vectors in registers are in big endian element order.
• Regardless of the -qaltivec option, the **VEC_XL_BE** procedure loads vectors to registers always in big endian element order and the **VEC_XST_BE** procedure assumes that vectors to be stored are always in big endian element order in registers.

For more information, see ["Example: The vector intrinsic procedure affected by the -qaltivec option"] on page 363 and ["Example: The vector initialization by using the EQUIVALENCE statement with arrays"] on page 363.

**Example: Vector layout in the memory and register**

The following example gets the first element of vector `va` by calling the **VEC_EXTRACT** procedure. The procedure returning value is different based on the -qaltivec option that determines whether **VEC_EXTRACT** arranges the vector elements in big endian or little endian element order.

```fortran
INTEGER(4) FUNCTION get_first_element(va)
   VECTOR(INTEGER(4)) va
   !vec_extract is affected by the -qaltivec option
   get_first_element = VEC_EXTRACT(va, 0)
END FUNCTION
```

The following tables show the vector layout in the memory and the register.

**Table 38. Vector layout in the memory.**

<table>
<thead>
<tr>
<th>Vector element value</th>
<th>E0</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
</tr>
</thead>
</table>

* When -qaltivec=be, the vector elements are loaded to registers in big endian element order and vector layout looks as follows.

**Table 39. Vector layout in big endian element order.**

<table>
<thead>
<tr>
<th>Vector element number</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector element value</td>
<td>E0</td>
<td>E1</td>
<td>E2</td>
<td>E3</td>
</tr>
</tbody>
</table>

The elements of vector `va` are ordered from the first to last, and stored from the left of registers. The **get_first_element** procedure gets the first element E0 from the left of registers.

* When -qaltivec=le, the vector elements are loaded to registers in little endian element order and vector layout looks as follows.

**Table 40. Vector layout in little endian element order.**

<table>
<thead>
<tr>
<th>Vector element number</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector element value</td>
<td>E3</td>
<td>E2</td>
<td>E1</td>
<td>E0</td>
</tr>
</tbody>
</table>

The elements of vector `va` are ordered from the last to first, and also stored from the left of registers. The **get_first_element** procedure gets the first element E0 from the right of registers.
Example: The vector intrinsic procedure affected by the -qaltivec option

The following program example vec_xlw4.f shows that the VEC_XLW4 procedure loads the vector elements in registers in the order specified by the -qaltivec option. The VEC_EXTRACT procedure recognizes the element order because it is affected by the -qaltivec option as well. Therefore, the same output is obtained with -qaltivec=be and -qaltivec=le.

PROGRAM main

IMPLICIT NONE

VECTOR(INTEGER(4)) a4
INTEGER(4) c4(4)
INTEGER i
c4 = [0, 1, 2, 3]

!VEC_XLW4 is affected by the -qaltivec option
a4 = VEC_XLW4(0, c4)

!VEC_EXTRACT is affected by the -qaltivec option
PRINT *, (VEC_EXTRACT(a4, i), i=0, 3)

END

• Compile the program with -qaltivec=le by running the following command:
  xlf95 vec_xlw4.f -qaltivec=le
  Output:
  0 1 2 3

• Compile the program with -qaltivec=be by running the following command:
  xlf95 vec_xlw4.f -qaltivec=be
  The compilation result is the same as that of output generated by using -qaltivec=le.

Example: The vector initialization by using the EQUIVALENCE statement with arrays

The following program example vec_equiv.f contains the vectors initialization by using the EQUIVALENCE statement with arrays. The vector loading is not affected by the -qaltivec option and the vector is loaded to registers in little endian element order. The VEC_EXTRACT procedure is affected by the -qaltivec=be option. Therefore, the program compilation output is difference between -qaltivec=be and -qaltivec=le.

PROGRAM main

IMPLICIT NONE

VECTOR(INTEGER(4)) a4
INTEGER(4) c4(4)
INTEGER i

EQUIVALENCE(a4, c4)
!In the memory, the vector initialization (by using equivalence)
!is not affected by the -qaltivec option and
!the vector is store in big endian element order.
!The initialized vector is loaded in registers by
!being reversed to the little endian element order.
c4 = [0, 1, 2, 3]
!vec_extract is affected by the -qaltivec option
PRINT *, (VEC_EXTRACT(a4, i), i=0, 3)
END

• Compile the codes with -qaltivec=le by running the following command:
  xlf95 vec_equiv.f -qaltivec=le
  Output:
  0 1 2 3

• Compile the program with -qaltivec=be by running the following command:
  xlf95 vec_equiv.f -qaltivec=be
  Output:
  3 2 1 0
  The compilation result is different from that of compilation with -qaltivec=le.

Related information:

- -qaltivec
- EQUIVALENCE
- Migrating program containing vector intrinsic procedures from big endian systems
Chapter 15. Sample Fortran programs

The programs in the topics referenced here are provided as coding examples for XL Fortran.

A number of these samples illustrate various aspects of SMP programming that may be new to many users. If you are new to SMP programming, you should examine these samples to gain a better understanding of the SMP coding style.

You can compile and execute the first program to verify that the compiler is installed correctly and your user ID is set up to execute Fortran programs.

Example 1 - XL Fortran source file

This is an example of an XL Fortran source file

```fortran
PROGRAM CALCULATE
!
! Program to calculate the sum of up to n values of x**3
! where negative values are ignored.
!
IMPLICIT NONE
INTEGER I,N
REAL SUM,X,Y
READ(*,*),N
WRITE(*,*),N
SUM=0
DO I=1,N
   READ(*,*),X
   WRITE(*,*),X
   IF (X.GE.0.0) THEN
      Y=X**3
      SUM=SUM+Y
   END IF
END DO
WRITE(*,*),'This is the sum of the positive cubes: ',SUM
END
```

Execution results

Running the program yields the following results:

```
$ a.out
5
37
22
-4
19
6
This is the sum of the positive cubes: 68376.00000
```

Example 2 - valid C routine source file

This is an example of a valid C routine source file used to execute Fortran test subroutines.

```c
/*
 * ********************************************************************
 * This is a main function that creates threads to execute the Fortran
 * test subroutines.
 */
```

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*/
#include <pthread.h>
#include <stdio.h>
#include <errno.h>

extern char *optarg;
extern int optind;

static char *prog_name;
#define MAX_NUM_THREADS 100

void *f_mt_exec(void *);
void f_pre_mt_exec(void);
void f_post_mt_exec(int *);

void usage(void)
{
    fprintf(stderr, "Usage: %s -t number_of_threads.\n", prog_name);
    exit(-1);
}

int main(int argc, char *argv[])
{
    int i, c, rc;
    int num_of_threads, n[MAX_NUM_THREADS];
    char *num_of_threads_p;
    pthread_attr_t attr;
    pthread_t tid[MAX_NUM_THREADS];

    prog_name = argv[0];
    while ((c = getopt(argc, argv, "t")) != EOF)
    {
        switch (c)
        {
        case 't':
            break;

        default:
            usage();
            break;
        }
    }
    argc -= optind;
    argv += optind;
    if (argc < 1)
    {
        usage();
    }

    num_of_threads_p = argv[0];
    if (((num_of_threads = atoi(num_of_threads_p)) == 0)
    {
        fprintf(stderr, "%s: Invalid number of threads to be created <\n", prog_name, num_of_threads_p);
        exit(1);
    }
    else if (num_of_threads > MAX_NUM_THREADS)
    {
        fprintf(stderr, "%s: Cannot create more than 100 threads.\n", prog_name);
        exit(1);
    }

}
pthread_attr_init(&attr);
pthread_attr_setdetachstate(&attr, PTHREAD_CREATE_JOINABLE);

/* ****************************************************************** 
 * Execute the Fortran subroutine that prepares for multithreaded 
 * execution. 
 * ****************************************************************** */
f_pre_mt_exec();

for (i = 0; i < num_of_threads; i++)
{
    n[i] = i;
    rc = pthread_create(&tid[i], &attr, f_mt_exec, (void *)&n[i]);
    if (rc != 0)
    {
        fprintf(stderr, "Failed to create thread %d.\n", i);
        exit(1);
    }
}

/* The attribute is no longer needed after threads are created. */
pthread_attr_destroy(&attr);

for (i = 0; i < num_of_threads; i++)
{
    rc = pthread_join(tid[i], NULL);
    if (rc != 0)
    {
        fprintf(stderr, "Failed to join thread %d. \n", i);
    }
}

/* Execute the Fortran subroutine that does the check after 
 * multithreaded execution. 
 */
f_post_mt_exec(&num_of_threads);
exit(0);

************************************************************************** 
This test case tests the writing list-directed to a single external 
file by many threads. 
**************************************************************************

subroutine f_pre_mt_exec()
  integer array(1000)
  common /x/ array

  do i = 1, 1000
    array(i) = i
  end do

  open(10, file="fun10.out", form="formatted", status="replace")
end

subroutine f_post_mt_exec(number_of_threads)
  integer array(1000), array1(1000)
  common /x/ array

  close(10)
  open(10, file="fun10.out", form="formatted")
  do j = 1, number_of_threads
    read(10, *) array1
    do i = 1, 1000

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if (array1(i) /= array(i)) then
    print *, "Result is wrong."
    stop
endif
end do
close(10, status="delete")
print *, 'Normal ending.'
end subroutine f_mt_exec(thread_number)
integer thread_number
integer array(1000)
common /x/ array
write(10, *), array
end

Example 3 - valid Fortran SMP source file

This is an example of a valid Fortran SMP source file used to calculate the value of pi.

program compute_pi
    integer n, i
    real*8 w, x, pi, f, a
    f(a) = 4.d0/(1.d0 + a*a)  ! function to integrate
    pi = 0.0d0
    !$OMP PARALLEL private(x, w, n), shared(pi)
    n = 10000               ! number of intervals
    w = 1.0d0/n             ! calculate the interval size
    !$OMP DO reduction(+: pi)
    do i = 1, n
        x = w * (i - 0.5d0)
        pi = pi + f(x)
    enddo
    !$OMP END DO
    !$OMP END PARALLEL
    print *, 'Computed pi = ', pi
end

Example 4 - invalid Fortran SMP source file

This is an example of an invalid Fortran SMP source file.

/* in this example, fort_sub is invoked by multiple threads. */
/* in this example, fort_sub is invoked by multiple threads. */
/* this example is not valid because */
/* fort_sub and another_sub both declare /block/ to be */
/* THREADPRIVATE. They intend to share the common block, but */
/* they are executed via different threads. */
/* */
/* to "fix" this problem, one of the following approaches can */
/* be taken: */
/* (1) the code for another_sub should be brought into the loop. */
/* (2) "j" should be passed as an argument to another_sub, and */
/* the declaration for /block/ should be removed from */
/* another_sub. */
/* (3) the loop should be marked as "do not parallelize" by */
/* using the directive "!$OMP PARALLEL DO IF(.FALSE.)". */
subroutine fort_sub()

common /block/ j
integer :: j
!$OMP THREADPRIVATE(/block/)
!
Each thread executing fort_sub
obtains its own copy of /block/.

integer a(10)
...
!$OMP PARALLEL DO
do index = 1,10
  call another_sub(a(i))
enddo
...
end subroutine fort_sub

subroutine another_sub(aa)
!
Multiple threads are used to
execute another_sub.
integer aa
common /block/ j
integer :: j
!$OMP THREADPRIVATE(/block/)

aa = j ! The value of "j" is undefined.
end subroutine another_sub

Programming examples using the Pthreads Library Module

These examples demonstrate the use of the Pthreads library module.

use, intrinsic::f_pthread
integer(4) ret_val

type(f_pthread_attr_t) attr

type(f_pthread_t) thr

ret_val = f_pthread_attr_init(attr)
ret_val = f_pthread_attr_setschedpolicy(attr, SCHED_RR)
ret_val = f_pthread_attr_setinheritsched(attr, PTHREAD_EXPLICIT_SCHED)
ret_val = f_pthread_create(thr, attr, FLAG_DEFAULT, ent, integer_arg)
ret_val = f_pthread_attr_destroy(attr)
......

Before you can manipulate a pthread attribute object, you need to create and initialize it. The appropriate interfaces must be called to manipulate the attribute objects. A call to f_pthread_attr_setschedpolicy sets the scheduling policy attribute to Round_Robin. Note that this does not affect newly created threads that inherit the scheduling property from the creating thread. For these threads, we explicitly call f_pthread_attr_setinheritsched to override the default inheritance attribute.

The rest of the code is self-explanatory.

* Example 6 : Thread safety *
* In this example, we show that thread safety can be achieved *
* by using the push-pop cleanup stack for each thread. We *
* assume that the thread is in deferred cancellability-enabled *
* state. This means that any thread-cancel requests will be *
* put on hold until a cancellation point is encountered. *
* Note that f_pthread_cond_wait provides a *
* cancellation point.
use, intrinsic::f_pthread

integer(4) ret_val

type(f_pthread_mutex_t) mutex
type(f_pthread_cond_t) cond

pointer(p, byte)

! Initialize mutex and condition variables before using them.
! For global variables this should be done in a module, so that they
! can be used by all threads. If they are local, other threads
! will not see them. Furthermore, they must be managed carefully
! (for example, destroy them before returning, to avoid dangling and
! undefined objects).
mutex = PTHREAD_MUTEX_INITIALIZER
cond = PTHREAD_COND_INITIALIZER

......
! Doing something

......

! This thread needs to allocate some memory area used to
! synchronize with other threads. However, when it waits on a
! condition variable, this thread may be canceled by another
! thread. The allocated memory may be lost if no measures are
! taken in advance. This will cause memory leakage.
ret_val = f_pthread_mutex_lock(mutex)
p = malloc(%val(4096))

! Check condition. If it is not true, wait for it.
! This should be a loop.

! Since memory has been allocated, cleanup must be registered
! for safety during condition waiting.
ret_val = f_pthread_cleanup_push(mycleanup, FLAG_DEFAULT, p)
ret_val = f_pthread_cond_wait(cond, mutex)

! If this thread returns from condition waiting, the cleanup
! should be de-registered.
call f_pthread_cleanup_pop(0) ! not execute
ret_val = f_pthread_mutex_unlock(mutex)

! This thread will take care of p for the rest of its life.
......

! mycleanup looks like:

subroutine mycleanup(passed_in)
    pointer(passed_in, byte)
    external free
    call free(%val(passed_in))
end subroutine mycleanup
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