Intel® Math Kernel Library for Windows* OS

User's Guide

Intel® MKL - Windows OS*

Document Number: 315930-025US

Legal Information

Contents

Legal Information

Introducing the Intel® Math Kernel Library

Intel® Math Kernel Library (Intel® MKL) is a computing math library of highly optimized, extensively threaded routines for applications that require maximum performance. Intel MKL provides comprehensive functionality support in these major areas of computation:

- BLAS (level 1, 2, and 3) and LAPACK linear algebra routines, offering vector, vector-matrix, and matrix-matrix operations.
- The PARDISO* direct sparse solver, an iterative sparse solver, and supporting sparse BLAS (level 1, 2, and 3) routines for solving sparse systems of equations.
- ScaLAPACK distributed processing linear algebra routines for Linux* and Windows* operating systems, as well as the Basic Linear Algebra Communications Subprograms (BLACS) and the Parallel Basic Linear Algebra Subprograms (PBLAS).
- Fast Fourier transform (FFT) functions in one, two, or three dimensions with support for mixed radices (not limited to sizes that are powers of 2), as well as distributed versions of these functions provided for use on clusters of the Linux* and Windows* operating systems.
- Vector Math Library (VML) routines for optimized mathematical operations on vectors.
- Vector Statistical Library (VSL) routines, which offer high-performance vectorized random number generators (RNG) for several probability distributions, convolution and correlation routines, and summary statistics functions.
- Data Fitting Library, which provides capabilities for spline-based approximation of functions, derivatives and integrals of functions, and search.

For details see the *Intel® MKL Reference Manual*.

Intel MKL is optimized for the latest Intel processors, including processors with multiple cores (see the *Intel® MKL Release Notes* for the full list of supported processors). Intel MKL also performs well on non-Intel processors.

Optimization Notice
Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice. Notice revision #20110804

Getting Help and Support

Intel provides a support web site that contains a rich repository of self help information, including getting started tips, known product issues, product errata, license information, user forums, and more. Visit the Intel MKL support website at http://www.intel.com/software/products/support/.

The Intel MKL documentation integrates into the Microsoft Visual Studio* integrated development environment (IDE). See Getting Assistance for Programming in the Microsoft Visual Studio* IDE.

Notational Conventions

The following term is used in reference to the operating system.

Windows* OS	This term refers to information that is valid on all supported Windows* operating systems.

The following notations are used to refer to Intel MKL directories.

`<Composer XE directory>`	The installation directory for the Intel® C++ Composer XE or Intel® Visual Fortran Composer XE .
`<mkl directory>`	The main directory where Intel MKL is installed: *`<mkl directory>`*`=`*`<Composer XE directory>`*`\mkl`. Replace this placeholder with the specific pathname in the configuring, linking, and building instructions.

The following font conventions are used in this document.

Italic	Italic is used for emphasis and also indicates document names in body text, for example: see *Intel MKL Reference Manual*.

`Monospace lowercase mixed with uppercase`	Indicates:
	• Commands and command-line options, for example,
	`ifort myprog.f mkl_blas95.lib mkl_c.lib libiomp5md.lib`
	• Filenames, directory names, and pathnames, for example,
	`C:\Program Files\Java\jdk1.5.0_09`
	• C/C++ code fragments, for example,
	`a = new double [SIZE*SIZE];`

`UPPERCASE MONOSPACE`	Indicates system variables, for example, `$MKLPATH`.
`Monospace italic`	Indicates a parameter in discussions, for example, *`lda`*. When enclosed in angle brackets, indicates a placeholder for an identifier, an expression, a string, a symbol, or a value, for example, *`<mkl directory>`*. Substitute one of these items for the placeholder.
`[ items ]`	Square brackets indicate that the items enclosed in brackets are optional.
`{ item | item }`	Braces indicate that only one of the items listed between braces should be selected. A vertical bar (|) separates the items.

Overview 1

Document Overview

The Intel® Math Kernel Library (Intel® MKL) User's Guide provides *usage information* for the library. The usage information covers the organization, configuration, performance, and accuracy of Intel MKL, specifics of routine calls in mixed-language programming, linking, and more.

This guide describes OS-specific usage of Intel MKL, along with OS-independent features. The document contains usage information for all Intel MKL function domains.

This User's Guide provides the following information:

- Describes post-installation steps to help you start using the library
- Shows you how to configure the library with your development environment
- Acquaints you with the library structure
- Explains how to link your application with the library and provides simple usage scenarios
- Describes how to code, compile, and run your application with Intel MKL

This guide is intended for Windows OS programmers with beginner to advanced experience in software development.

See Also

Language Interfaces Support, by Function Domain

What's New

This User's Guide documents Intel® Math Kernel Library (Intel® MKL) 11.0.

The following new functionality and features of Intel MKL 11.0 have been described in the document:

- The Conditional Numerical Reproducibility (CNR) mode of Intel MKL has been introduced to ensure bitwise reproducibility of results from run to run under certain conditions. It is documented in the Obtaining Numerically Reproducible Results section.
- The GNU Multiple Precision (GMP) arithmetic functions have been removed from the library.
- The `mkl_set_num_threads_local` function, which sets the number of threads on the current execution thread, has been added. See Using Additional Threading Control.

Additionally, minor updates have been made to correct errors in the document.

Related Information

To reference how to use the library in your application, use this guide in conjunction with the following documents:

- The *Intel® Math Kernel Library Reference Manual*, which provides *reference* information on routine functionalities, parameter descriptions, interfaces, calling syntaxes, and return values.
- The *Intel® Math Kernel Library for Windows* OS Release Notes*.

Getting Started

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Checking Your Installation

After installing the Intel® Math Kernel Library (Intel® MKL), verify that the library is properly installed and configured:

1. Intel MKL installs in `<Composer XE directory>`.

   Check that the subdirectory of `<Composer XE directory>` referred to as `<mkl directory>` was created.

   Check that subdirectories for Intel MKL redistributable DLLs `redist\ia32\mkl` and `redist\intel64\mkl` were created in the `<Composer XE directory>` directory (See `redist.txt` in the Intel MKL documentation directory for a list of files that can be redistributed.)
2. If you want to keep multiple versions of Intel MKL installed on your system, update your build scripts to point to the correct Intel MKL version.
3. Check that the following files appear in the `<mkl directory>\bin` directory and its subdirectories:

   `mklvars.bat`

   `ia32\mklvars_ia32.bat`

   `intel64\mklvars_intel64.bat`

   Use these files to assign Intel MKL-specific values to several environment variables, as explained in Setting Environment Variables
4. To understand how the Intel MKL directories are structured, see Intel® Math Kernel Library Structure.
5. To make sure that Intel MKL runs on your system, do one of the following:

   - Launch an Intel MKL example, as explained in Using Code Examples
   - In the Visual Studio* IDE, create and run a simple project that uses Intel MKL, as explained in Running an Intel MKL Example in the Visual Studio IDE

See Also

Notational Conventions

Setting Environment Variables

When the installation of Intel MKL for Windows* OS is complete, set the `PATH`, `LIB`, and `INCLUDE` environment variables in the command shell using one of the script files in the `bin` subdirectory of the Intel MKL installation directory:

`ia32\mklvars_ia32.bat`	for the IA-32 architecture,

`intel64\mklvars_intel64.bat`	for the Intel® 64 architecture,
`mklvars.bat`	for the IA-32 and Intel® 64 architectures.

Running the Scripts

The parameters of the scripts specify the following:

- Architecture.
- Use of Intel MKL Fortran modules precompiled with the Intel® Visual Fortran compiler. Supply this parameter only if you are using this compiler.
- Programming interface (LP64 or ILP64).

Usage and values of these parameters depend on the script. The following table lists values of the script parameters.

Script	Architecture (required, when applicable)	Use of Fortran Modules (optional)	Interface (optional)
`mklvars_ia32`	n/a†	`mod`	n/a
`mklvars_intel64`	n/a	`mod`	`lp64`, default `ilp64`
`mklvars`	`ia32` `intel64`	`mod`	`lp64`, default `ilp64`

† Not applicable.

For example:

- The command
  `mklvars ia32`
  sets the environment for Intel MKL to use the IA-32 architecture.
- The command
  `mklvars intel64 mod ilp64`
  sets the environment for Intel MKL to use the Intel® 64 architecture, ILP64 programming interface, and Fortran modules.
- The command
  `mklvars intel64 mod`
  sets the environment for Intel MKL to use the Intel® 64 architecture, LP64 interface, and Fortran modules.

NOTE Supply the parameter specifying the architecture first, if it is needed. Values of the other two parameters can be listed in any order.

See Also

High-level Directory Structure
Interface Libraries and Modules
Fortran 95 Interfaces to LAPACK and BLAS
Setting the Number of Threads Using an OpenMP* Environment Variable

Compiler Support

Intel MKL supports compilers identified in the *Release Notes*. However, the library has been successfully used with other compilers as well.

Although Compaq no longer supports the Compaq Visual Fortran* (CVF) compiler, Intel MKL still preserves the CVF interface in the IA-32 architecture implementation. You can use this interface with the Intel® Fortran Compiler. Intel MKL provides both stdcall (default CVF interface) and cdecl (default interface of the Microsoft Visual C* application) interfaces for the IA-32 architecture.

Intel MKL provides a set of include files to simplify program development by specifying enumerated values and prototypes for the respective functions. Calling Intel MKL functions from your application without an appropriate include file may lead to incorrect behavior of the functions.

See Also

Compiling an Application that Calls the Intel® Math Kernel Library and Uses the CVF Calling Conventions
Using the cdecl and stdcall Interfaces
Include Files

Using Code Examples

The Intel MKL package includes code examples, located in the `examples` subdirectory of the installation directory. Use the examples to determine:

- Whether Intel MKL is working on your system
- How you should call the library
- How to link the library

The examples are grouped in subdirectories mainly by Intel MKL function domains and programming languages. For instance, the `examples\spblas` subdirectory contains a makefile to build the Sparse BLAS examples and the `examples\vmlc` subdirectory contains the makefile to build the C VML examples. Source code for the examples is in the next-level `sources` subdirectory.

See Also

High-level Directory Structure
Running an Intel MKL Example in the Visual Studio* 2008 IDE

What You Need to Know Before You Begin Using the Intel® Math Kernel Library

Target platform	Identify the architecture of your target machine: • IA-32 or compatible • Intel® 64 or compatible **Reason:** Because Intel MKL libraries are located in directories corresponding to your particular architecture (see Architecture Support), you should provide proper paths on your link lines (see Linking Examples). To configure your development environment for the use with Intel MKL, set your environment variables using the script corresponding to your architecture (see Setting Environment Variables for details).
Mathematical problem	Identify all Intel MKL function domains that you require: • BLAS • Sparse BLAS • LAPACK • PBLAS • ScaLAPACK • Sparse Solver routines • Vector Mathematical Library functions (VML)

	• Vector Statistical Library functions • Fourier Transform functions (FFT) • Cluster FFT • Trigonometric Transform routines • Poisson, Laplace, and Helmholtz Solver routines • Optimization (Trust-Region) Solver routines • Data Fitting Functions **Reason:** The function domain you intend to use narrows the search in the *Reference Manual* for specific routines you need. Additionally, if you are using the Intel MKL cluster software, your link line is function-domain specific (see Working with the Cluster Software). Coding tips may also depend on the function domain (see Other Tips and Techniques to Improve Performance).
Programming language	Intel MKL provides support for both Fortran and C/C++ programming. Identify the language interfaces that your function domains support (see Intel® Math Kernel Library Language Interfaces Support). **Reason:** Intel MKL provides language-specific include files for each function domain to simplify program development (see Language Interfaces Support, by Function Domain). For a list of language-specific interface libraries and modules and an example how to generate them, see also Using Language-Specific Interfaces with Intel® Math Kernel Library.
Range of integer data	If your system is based on the Intel 64 architecture, identify whether your application performs calculations with large data arrays (of more than 2^{31}-1 elements). **Reason:** To operate on large data arrays, you need to select the ILP64 interface, where integers are 64-bit; otherwise, use the default, LP64, interface, where integers are 32-bit (see Using the ILP64 Interface vs. LP64 Interface).
Threading model	Identify whether and how your application is threaded: • Threaded with the Intel compiler • Threaded with a third-party compiler • Not threaded **Reason:** The compiler you use to thread your application determines which threading library you should link with your application. For applications threaded with a third-party compiler you may need to use Intel MKL in the sequential mode (for more information, see Sequential Mode of the Library and Linking with Threading Libraries).
Number of threads	Determine the number of threads you want Intel MKL to use. **Reason:** Intel MKL is based on the OpenMP* threading. By default, the OpenMP* software sets the number of threads that Intel MKL uses. If you need a different number, you have to set it yourself using one of the available mechanisms. For more information, see Improving Performance with Threading.
Linking model	Decide which linking model is appropriate for linking your application with Intel MKL libraries: • Static • Dynamic **Reason:** The link libraries for static and dynamic linking are different. For the list of link libraries for static and dynamic models, linking examples, and other relevant topics, like how to save disk space by creating a custom dynamic library, see Linking Your Application with the Intel® Math Kernel Library.

MPI used	Decide what MPI you will use with the Intel MKL cluster software. You are strongly encouraged to use Intel® MPI 3.2 or later. MPI used **Reason:** To link your application with ScaLAPACK and/or Cluster FFT, the libraries corresponding to your particular MPI should be listed on the link line (see Working with the Cluster Software).

Structure of the Intel® Math Kernel Library

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Optimization Notice

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Architecture Support

Intel® Math Kernel Library (Intel® MKL) for Windows* OS provides architecture-specific implementations for supported platforms. The following table lists the supported architectures and directories where each architecture-specific implementation is located.

Architecture	Location
IA-32 or compatible	`<mkl directory>\lib\ia32` `<Composer XE directory>\redist\ia32\mkl` (DLLs)
Intel® 64 or compatible	`<mkl directory>\lib\intel64` `<Composer XE directory>\redist\intel64\mkl` (DLLs)

See Also

High-level Directory Structure
Detailed Structure of the IA-32 Architecture Directories
Detailed Structure of the Intel® 64 Architecture Directories

High-level Directory Structure

Directory	Contents
<mkl directory>	Installation directory of the Intel® Math Kernel Library (Intel® MKL)
Subdirectories of *<mkl directory>*	
`bin`	Batch files to set environmental variables in the user shell
`bin\ia32`	Batch files for the IA-32 architecture
`bin\intel64`	Batch files for the Intel® 64 architecture
`benchmarks\linpack`	Shared-Memory (SMP) version of the LINPACK benchmark
`benchmarks\mp_linpack`	Message-passing interface (MPI) version of the LINPACK benchmark

Directory	Contents
`lib\ia32`	Static libraries and static interfaces to DLLs for the IA-32 architecture
`lib\intel64`	Static libraries and static interfaces to DLLs for the Intel® 64 architecture
`examples`	Examples directory. Each subdirectory has source and data files
`include`	INCLUDE files for the library routines, as well as for tests and examples
`include\ia32`	Fortran 95 .mod files for the IA-32 architecture and Intel Fortran compiler
`include\intel64\lp64`	Fortran 95 .mod files for the Intel® 64 architecture, Intel® Fortran compiler, and LP64 interface
`include\intel64\ilp64`	Fortran 95 .mod files for the Intel® 64 architecture, Intel Fortran compiler, and ILP64 interface
`include\fftw`	Header files for the FFTW2 and FFTW3 interfaces
`interfaces\blas95`	Fortran 95 interfaces to BLAS and a makefile to build the library
`interfaces\fftw2x_cdft`	MPI FFTW 2.x interfaces to Intel MKL Cluster FFTs
`interfaces\fftw3x_cdft`	MPI FFTW 3.x interfaces to Intel MKL Cluster FFTs
`interfaces\fftw2xc`	FFTW 2.x interfaces to the Intel MKL FFTs (C interface)
`interfaces\fftw2xf`	FFTW 2.x interfaces to the Intel MKL FFTs (Fortran interface)
`interfaces\fftw3xc`	FFTW 3.x interfaces to the Intel MKL FFTs (C interface)
`interfaces\fftw3xf`	FFTW 3.x interfaces to the Intel MKL FFTs (Fortran interface)
`interfaces\lapack95`	Fortran 95 interfaces to LAPACK and a makefile to build the library
`tests`	Source and data files for tests
`tools`	Commad-line link tool and tools for creating custom dynamically linkable libraries
`tools\builder`	Tools for creating custom dynamically linkable libraries
Subdirectories of *`<Composer XE directory>`*	
`redist\ia32\mkl`	DLLs for applications running on processors with the IA-32 architecture
`redist\intel64\mkl`	DLLs for applications running on processors with Intel® 64 architecture
`Documentation\en_US\MKL`	Intel MKL documentation
`Documentation\vshelp\1033\intel.mkldocs`	Help2-format files for integration of the Intel MKL documentation with the Microsoft Visual Studio* 2008 IDE
`Documentation\msvhelp\1033\mkl`	Microsoft Help Viewer*-format files for integration of the Intel MKL documentation with the Microsoft Visual Studio* 2010 IDE

See Also

Notational Conventions

Layered Model Concept

Intel MKL is structured to support multiple compilers and interfaces, different OpenMP* implementations, both serial and multiple threads, and a wide range of processors. Conceptually Intel MKL can be divided into distinct parts to support different interfaces, threading models, and core computations:

1. Interface Layer
2. Threading Layer
3. Computational Layer

You can combine Intel MKL libraries to meet your needs by linking with one library in each part layer-by-layer. Once the interface library is selected, the threading library you select picks up the chosen interface, and the computational library uses interfaces and OpenMP implementation (or non-threaded mode) chosen in the first two layers.

To support threading with different compilers, one more layer is needed, which contains libraries not included in Intel MKL:

- Compiler run-time libraries (RTL).

The following table provides more details of each layer.

Layer	Description

Interface Layer	This layer matches compiled code of your application with the threading and/or computational parts of the library. This layer provides:
	• cdecl and CVF default interfaces.
	• LP64 and ILP64 interfaces.
	• Compatibility with compilers that return function values differently.
	• A mapping between single-precision names and double-precision names for applications using Cray*-style naming (SP2DP interface).
	SP2DP interface supports Cray-style naming in applications targeted for the Intel 64 architecture and using the ILP64 interface. SP2DP interface provides a mapping between single-precision names (for both real and complex types) in the application and double-precision names in Intel MKL BLAS and LAPACK. Function names are mapped as shown in the following example for BLAS functions `?GEMM`:
	`SGEMM -> DGEMM`
	`DGEMM -> DGEMM`
	`CGEMM -> ZGEMM`
	`ZGEMM -> ZGEMM`
	Mind that no changes are made to double-precision names.

Threading Layer	This layer: • Provides a way to link threaded Intel MKL with different threading compilers. • Enables you to link with a threaded or sequential mode of the library. This layer is compiled for different environments (threaded or sequential) and compilers (from Intel, Microsoft, and so on).
Computational Layer	This layer is the heart of Intel MKL. It has only one library for each combination of architecture and supported OS. The Computational layer accommodates multiple architectures through identification of architecture features and chooses the appropriate binary code at run time.
Compiler Run-time Libraries (RTL)	To support threading with Intel compilers, Intel MKL uses RTLs of the Intel® C++ Composer XE or Intel® Visual Fortran Composer XE. To thread using third-party threading compilers, use libraries in the Threading layer or an appropriate compatibility library.

See Also

Using the ILP64 Interface vs. LP64 Interface

Linking Your Application with the Intel® Math Kernel Library
Linking with Threading Libraries

Contents of the Documentation Directories

Most of Intel MKL documentation is installed at `<Composer XE directory>\Documentation\<locale>\mkl`. For example, the documentation in English is installed at `<Composer XE directory>\Documentation\en_US\mkl`. However, some Intel MKL-related documents are installed one or two levels up. The following table lists MKL-related documentation.

File name	Comment
Files in `<Composer XE directory>\Documentation`	
`<locale>\clicense.rtf` or `<locale>\flicense.rtf`	Common end user license for the Intel® C++ Composer XE or Intel® Visual Fortran Composer XE, respectively
`mklsupport.txt`	Information on package number for customer support reference
Contents of `<Composer XE directory>\Documentation\<locale>\mkl`	
`redist.txt`	List of redistributable files
`mkl_documentation.htm`	Overview and links for the Intel MKL documentation
`mklman90.pdf` †	Intel MKL 9.0 Reference Manual in Japanese
`Release_Notes.htm`	Intel MKL Release Notes
`mkl_userguide\index.htm`	Intel MKL User's Guide in an uncompressed HTML format, this document
`mkl_link_line_advisor.htm`	Intel MKL Link-line Advisor

† Included only in the Japanese versions of the Intel® C++ Composer XE and Intel® Visual Fortran Composer XE.

For more documents, search Intel MKL documentation at http://software.intel.com/en-us/articles/intel-math-kernel-library-documentation/.

Linking Your Application with the Intel® Math Kernel Library

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Linking Quick Start

Intel® Math Kernel Library (Intel® MKL) provides several options for quick linking of your application. The simplest options depend on your development environment:

Intel® Composer XE compiler	see Using the `/Qmkl` Compiler Option.
Microsoft Visual Studio* Integrated Development Environment (IDE)	see Automatically Linking a Project in the Visual Studio* IDE with Intel MKL.

Other options are independent of your development environment, but depend on the way you link:

Explicit dynamic linking	see Using the Single Dynamic Library for how to simplify your link line.
Explicitly listing libraries on your link line	see Selecting Libraries to Link with for a summary of the libraries.
Using an interactive interface	see Using the Link-line Advisor to determine libraries and options to specify on your link or compilation line.
Using an internally provided tool	see Using the Command-line Link Tool to determine libraries, options, and environment variables or even compile and build your application.

Using the /Qmkl Compiler Option

The Intel® Composer XE compiler supports the following variants of the `/Qmkl` compiler option:

`/Qmkl` or `/Qmkl:parallel`	to link with standard threaded Intel MKL.
`/Qmkl:sequential`	to link with sequential version of Intel MKL.
`/Qmkl:cluster`	to link with Intel MKL cluster components (sequential) that use Intel MPI.

For more information on the `/Qmkl` compiler option, see the Intel Compiler User and Reference Guides.

For each variant of the `/Qmkl` option, the compiler links your application using the following conventions:

- cdecl for the IA-32 architecture
- LP64 for the Intel® 64 architecture

If you specify any variant of the `/Qmkl` compiler option, the compiler automatically includes the Intel MKL libraries. In cases not covered by the option, use the Link-line Advisor or see Linking in Detail.

See Also

Using the ILP64 Interface vs. LP64 Interface
Using the Link-line Advisor
Intel® Software Documentation Library

Automatically Linking a Project in the Visual Studio* Integrated Development Environment with Intel® MKL

After a default installation of the Intel® Math Kernel Library (Intel® MKL), Intel® C++ Composer XE, or Intel® Visual Fortran Composer XE, you can easily configure your project to automatically link with Intel MKL.

Automatically Linking Your Microsoft Visual C/C++* Project with Intel® MKL

Configure your Microsoft Visual C/C++* project for automatic linking with Intel MKL as follows:

- For the Visual Studio* 2010 development system:
  1. Go to **Project**>**Properties**>**Configuration Properties**>**Intel Performance Libraries**.
  2. Change the **Use MKL** property setting by selecting **Parallel**, **Sequential**, or **Cluster** as appropriate.
- For the Visual Studio 2008 development system:
  1. Go to **Project**>**Intel C++ Composer XE 2011**>**Select Build Components**.
  2. From the **Use MKL** drop-down menu, select **Parallel**, **Sequential**, or **Cluster** as appropriate.

Specific Intel MKL libraries that link with your application may depend on more project settings. For details, see the Intel® Composer XE documentation.

See Also

Intel® Software Documentation Library

Automatically Linking Your Intel® Visual Fortran Project with Intel® MKL

Configure your Intel® Visual Fortran project for automatic linking with Intel MKL as follows:

Go to **Project** > **Properties** > **Libraries** > **Use Intel Math Kernel Library** and select **Parallel**, **Sequential**, or **Cluster** as appropriate.

Specific Intel MKL libraries that link with your application may depend on more project settings. For details see the Intel® Visual Fortran Compiler XE User and Reference Guides.

See Also

Intel® Software Documentation Library

Using the Single Dynamic Library

You can simplify your link line through the use of the Intel MKL Single Dynamic Library (SDL).

To use SDL, place `mkl_rt.lib` on your link line. For example:

```
icl.exe application.c mkl_rt.lib
```

`mkl_rt.lib` is the import library for `mkl_rt.dll`.

SDL enables you to select the interface and threading library for Intel MKL at run time. By default, linking with SDL provides:

- LP64 interface on systems based on the Intel® 64 architecture
- Intel threading

To use other interfaces or change threading preferences, including use of the sequential version of Intel MKL, you need to specify your choices using functions or environment variables as explained in section Dynamically Selecting the Interface and Threading Layer.

Selecting Libraries to Link with

To link with Intel MKL:

- Choose one library from the Interface layer and one library from the Threading layer
- Add the only library from the Computational layer and run-time libraries (RTL)

The following table lists Intel MKL libraries to link with your application.

	Interface layer	Threading layer	Computational layer	RTL
IA-32 architecture, static linking	`mkl_intel_c.lib`	`mkl_intel_thread.lib`	`mkl_core.lib`	`libiomp5md.lib`
IA-32 architecture, dynamic linking	`mkl_intel_c_dll.lib`	`mkl_intel_thread_dll.lib`	`mkl_core_dll.lib`	`libiomp5md.lib`
Intel® 64 architecture, static linking	`mkl_intel_lp64.lib`	`mkl_intel_thread.lib`	`mkl_core.lib`	`libiomp5md.lib`
Intel® 64 architecture, dynamic linking	`mkl_intel_lp64_dll.lib`	`mkl_intel_thread_dll.lib`	`mkl_core_dll.lib`	`libiomp5md.lib`

The Single Dynamic Library (SDL) automatically links interface, threading, and computational libraries and thus simplifies linking. The following table lists Intel MKL libraries for dynamic linking using SDL. See Dynamically Selecting the Interface and Threading Layer for how to set the interface and threading layers at run time through function calls or environment settings.

	SDL	RTL
IA-32 and Intel® 64 architectures	`mkl_rt.lib`	`libiomp5md.lib`†

† Linking with `libiomp5md.lib` is not required.

For exceptions and alternatives to the libraries listed above, see Linking in Detail.

See Also

Layered Model Concept
Using the Link-line Advisor
Using the /Qmkl Compiler Option
Working with the Intel® Math Kernel Library Cluster Software

Using the Link-line Advisor

Use the Intel MKL Link-line Advisor to determine the libraries and options to specify on your link or compilation line.

The latest version of the tool is available at http://software.intel.com/en-us/articles/intel-mkl-link-line-advisor. The tool is also available in the product.

The Advisor requests information about your system and on how you intend to use Intel MKL (link dynamically or statically, use threaded or sequential mode, etc.). The tool automatically generates the appropriate link line for your application.

See Also

Contents of the Documentation Directories

Using the Command-line Link Tool

Use the command-line Link tool provided by Intel MKL to simplify building your application with Intel MKL.

The tool not only provides the options, libraries, and environment variables to use, but also performs compilation and building of your application.

The tool `mkl_link_tool.exe` is installed in the `<mkl directory>\tools` directory.

See the knowledge base article at http://software.intel.com/en-us/articles/mkl-command-line-link-tool for more information.

Linking Examples

See Also

Using the Link-line Advisor

Examples for Linking with ScaLAPACK and Cluster FFT

Linking on IA-32 Architecture Systems

The following examples illustrate linking that uses Intel(R) compilers.

The examples use the `.f` Fortran source file. C/C++ users should instead specify a `.cpp` (C++) or `.c` (C) file and replace `ifort` with `icc`:

- Static linking of `myprog.f` and parallel Intel MKL supporting the cdecl interface:

  ```
  ifort myprog.f mkl_intel_c.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib
  ```
- Dynamic linking of `myprog.f` and parallel Intel MKL supporting the cdecl interface:

  ```
  ifort myprog.f mkl_intel_c_dll.lib mkl_intel_thread_dll.lib mkl_core_dll.lib
  libiomp5md.lib
  ```
- Static linking of `myprog.f` and sequential version of Intel MKL supporting the cdecl interface:

  ```
  ifort myprog.f mkl_intel_c.lib mkl_sequential.lib mkl_core.lib
  ```
- Dynamic linking of `myprog.f` and sequential version of Intel MKL supporting the cdecl interface:

  ```
  ifort myprog.f mkl_intel_c_dll.lib mkl_sequential_dll.lib mkl_core_dll.lib
  ```
- Static linking of user code `myprog.f` and parallel Intel MKL supporting the stdcall interface:

  ```
  ifort myprog.f mkl_intel_s.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib
  ```
- Dynamic linking of user code `myprog.f` and parallel Intel MKL supporting the stdcall interface:

  ```
  ifort myprog.f mkl_intel_s_dll.lib mkl_intel_thread_dll.lib mkl_core_dll.lib
  libiomp5md.lib
  ```
- Dynamic linking of user code `myprog.f` and parallel or sequential Intel MKL supporting the cdecl or stdcall interface (Call the `mkl_set_threading_layer` function or set value of the `MKL_THREADING_LAYER` environment variable to choose threaded or sequential mode):

  ```
  ifort myprog.f mkl_rt.lib
  ```
- Static linking of `myprog.f`, Fortran 95 LAPACK interface, and parallel Intel MKL supporting the cdecl interface:

```
ifort myprog.f mkl_lapack95.lib mkl_intel_c.lib mkl_intel_thread.lib mkl_core.lib
libiomp5md.lib
```

- Static linking of `myprog.f`, Fortran 95 BLAS interface, and parallel Intel MKL supporting the cdecl interface:

```
ifort myprog.f mkl_blas95.lib mkl_intel_c.lib mkl_intel_thread.lib mkl_core.lib
libiomp5md.lib
```

See Also

Fortran 95 Interfaces to LAPACK and BLAS
Examples for Linking a C Application
Examples for Linking a Fortran Application
Using the Single Dynamic Library

Linking on Intel(R) 64 Architecture Systems

The following examples illustrate linking that uses Intel(R) compilers.

The examples use the `.f` Fortran source file. C/C++ users should instead specify a `.cpp` (C++) or `.c` (C) file and replace `ifort` with `icc`:

- Static linking of `myprog.f` and parallel Intel MKL supporting the LP64 interface:

```
ifort myprog.f mkl_intel_lp64.lib mkl_intel_thread.lib mkl_core.lib
libiomp5md.lib
```

- Dynamic linking of `myprog.f` and parallel Intel MKL supporting the LP64 interface:

```
ifort myprog.f mkl_intel_lp64_dll.lib mkl_intel_thread_dll.lib mkl_core_dll.lib
libiomp5md.lib
```

- Static linking of `myprog.f` and sequential version of Intel MKL supporting the LP64 interface:

```
ifort myprog.f mkl_intel_lp64.lib mkl_sequential.lib mkl_core.lib
```

- Dynamic linking of `myprog.f` and sequential version of Intel MKL supporting the LP64 interface:

```
ifort myprog.f mkl_intel_lp64_dll.lib mkl_sequential_dll.lib mkl_core_dll.lib
```

- Static linking of `myprog.f` and parallel Intel MKL supporting the ILP64 interface:

```
ifort myprog.f mkl_intel_ilp64.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib
```

- Dynamic linking of `myprog.f` and parallel Intel MKL supporting the ILP64 interface:

```
ifort myprog.f mkl_intel_ilp64_dll.lib mkl_intel_thread_dll.lib mkl_core_dll.lib
libiomp5md.lib
```

- Dynamic linking of user code `myprog.f` and parallel or sequential Intel MKL supporting the LP64 or ILP64 interface (Call appropriate functions or set environment variables to choose threaded or sequential mode and to set the interface):

```
ifort myprog.f mkl_rt.lib
```

- Static linking of `myprog.f`, Fortran 95 LAPACK interface, and parallel Intel MKL supporting the LP64 interface:

```
ifort myprog.f mkl_lapack95_lp64.lib mkl_intel_lp64.lib mkl_intel_thread.lib
mkl_core.lib libiomp5md.lib
```

- Static linking of `myprog.f`, Fortran 95 BLAS interface, and parallel Intel MKL supporting the LP64 interface:

```
ifort myprog.f mkl_blas95_lp64.lib mkl_intel_lp64.lib mkl_intel_thread.lib
mkl_core.lib libiomp5md.lib
```

See Also

Fortran 95 Interfaces to LAPACK and BLAS
Examples for Linking a C Application
Examples for Linking a Fortran Application

Using the Single Dynamic Library

Linking in Detail

This section recommends which libraries to link with depending on your Intel MKL usage scenario and provides details of the linking.

Dynamically Selecting the Interface and Threading Layer

The Single Dynamic Library (SDL) enables you to dynamically select the interface and threading layer for Intel MKL.

Setting the Interface Layer

Available interfaces depend on the architecture of your system.

On systems based on the Intel® 64 architecture, LP64 and ILP64 interfaces are available. To set one of these interfaces at run time, use the `mkl_set_interface_layer` function or the `MKL_INTERFACE_LAYER` environment variable. The following table provides values to be used to set each interface.

Interface Layer	**Value of `MKL_INTERFACE_LAYER`**	**Value of the Parameter of `mkl_set_interface_layer`**
LP64	`LP64`	`MKL_INTERFACE_LP64`
ILP64	`ILP64`	`MKL_INTERFACE_ILP64`

If the `mkl_set_interface_layer` function is called, the environment variable `MKL_INTERFACE_LAYER` is ignored.

By default the LP64 interface is used.

See the *Intel MKL Reference Manual* for details of the `mkl_set_interface_layer` function.

On systems based on the IA-32 architecture, the cdecl and stdcall interfaces are available. These interfaces have different function naming conventions, and SDL selects between cdecl and stdcall at link time according to the function names.

Setting the Threading Layer

To set the threading layer at run time, use the `mkl_set_threading_layer` function or the `MKL_THREADING_LAYER` environment variable. The following table lists available threading layers along with the values to be used to set each layer.

Threading Layer	**Value of `MKL_THREADING_LAYER`**	**Value of the Parameter of `mkl_set_threading_layer`**
Intel threading	`INTEL`	`MKL_THREADING_INTEL`
Sequential mode of Intel MKL	`SEQUENTIAL`	`MKL_THREADING_SEQUENTIAL`
PGI threading	`PGI`	`MKL_THREADING_PGI`

If the `mkl_set_threading_layer` function is called, the environment variable `MKL_THREADING_LAYER` is ignored.

By default Intel threading is used.

See the *Intel MKL Reference Manual* for details of the `mkl_set_threading_layer` function.

Replacing Error Handling and Progress Information Routines

You can replace the Intel MKL error handling routine `xerbla` or progress information routine `mkl_progress` with your own function. If you are using SDL, to replace `xerbla` or `mkl_progress`, call the `mkl_set_xerbla` and `mkl_set_progress` function, respectively. See the *Intel MKL Reference Manual* for details.

NOTE If you are using SDL, you cannot perform the replacement by linking the object file with your implementation of `xerbla` or `mkl_progress`.

See Also

Using the Single Dynamic Library
Layered Model Concept
Using the cdecl and stdcall Interfaces
Directory Structure in Detail

Linking with Interface Libraries

Using the cdecl and stdcall Interfaces

Intel MKL provides the following interfaces in its IA-32 architecture implementation:

- stdcall
  Default Compaq Visual Fortran* (CVF) interface. Use it with the Intel® Fortran Compiler.
- cdecl
  Default interface of the Microsoft Visual C/C++* application.

To use each of these interfaces, link with the appropriate library, as specified in the following table:

Interface	Library for Static Linking	Library for Dynamic Linking
cdecl	`mkl_intel_c.lib`	`mkl_intel_c_dll.lib`
stdcall	`mkl_intel_s.lib`	`mkl_intel_s_dll.lib`

To link with the cdecl or stdcall interface library, use appropriate calling syntax in C applications and appropriate compiler options for Fortran applications.

If you are using a C compiler, to link with the cdecl or stdcall interface library, call Intel MKL routines in your code as explained in the table below:

Interface Library	Calling Intel MKL Routines
`mkl_intel_s [_dll].lib`	Call a routine with the following statement: `extern __stdcall name( <prototype variable1>, <prototype variable2>, .. );` where `stdcall` is actually the CVF compiler default compilation, which differs from the regular stdcall compilation in the way how strings are passed to the routine. Because the default CVF format is not identical with `stdcall`, you must specially handle strings in the calling sequence. See how to do it in sections on interfaces in the CVF documentation.
`mkl_intel_c [_dll].lib`	Use the following declaration: `<type> name( <prototype variable1>, <prototype  variable2>, .. );`

If you are using a Fortran compiler, to link with the cdecl or stdcall interface library, provide compiler options as explained in the table below:

Interface Library	Compiler Options	Comment
	CVF compiler	
`mkl_intel_s[_dll].lib`	Default	
`mkl_intel_c[_dll].lib`	`/iface=(cref, nomixed_str_len_arg)`	
	Intel® Fortran compiler	
`mkl_intel_c[_dll].lib`	Default	
`mkl_intel_s[_dll].lib`	`/Gm` or `/iface:cvf`	`/Gm` and `/iface:cvf` options enable compatibility of the CVF and Powerstation calling conventions

See Also

Using the stdcall Calling Convention in C/C++

Compiling an Application that Calls the Intel® Math Kernel Library and Uses the CVF Calling Conventions

Using the ILP64 Interface vs. LP64 Interface

The Intel MKL ILP64 libraries use the 64-bit integer type (necessary for indexing large arrays, with more than 2^{31}-1 elements), whereas the LP64 libraries index arrays with the 32-bit integer type.

The LP64 and ILP64 interfaces are implemented in the Interface layer. Link with the following interface libraries for the LP64 or ILP64 interface, respectively:

- `mkl_intel_lp64.lib` or `mkl_intel_ilp64.lib` for static linking
- `mkl_intel_lp64_dll.lib` or `mkl_intel_ilp64_dll.lib` for dynamic linking

The ILP64 interface provides for the following:

- Support large data arrays (with more than 2^{31}-1 elements)
- Enable compiling your Fortran code with the `/4I8` compiler option

The LP64 interface provides compatibility with the previous Intel MKL versions because "LP64" is just a new name for the only interface that the Intel MKL versions lower than 9.1 provided. Choose the ILP64 interface if your application uses Intel MKL for calculations with large data arrays or the library may be used so in future.

Intel MKL provides the same include directory for the ILP64 and LP64 interfaces.

Compiling for LP64/ILP64

The table below shows how to compile for the ILP64 and LP64 interfaces:

Fortran	
Compiling for ILP64	`ifort /4I8 /I<`*`mkl directory`*`>\include ...`
Compiling for LP64	`ifort /I<`*`mkl directory`*`>\include ...`

C or C++	
Compiling for ILP64	`icl /DMKL_ILP64 /I<`*`mkl directory`*`>\include ...`
Compiling for LP64	`icl /I<`*`mkl directory`*`>\include ...`

CAUTION Linking of an application compiled with the `/4I8` or `/DMKL_ILP64` option to the LP64 libraries may result in unpredictable consequences and erroneous output.

Coding for ILP64

You do not need to change existing code if you are not using the ILP64 interface.

To migrate to ILP64 or write new code for ILP64, use appropriate types for parameters of the Intel MKL functions and subroutines:

Integer Types	Fortran	C or C++
32-bit integers	`INTEGER*4` or `INTEGER(KIND=4)`	`int`
Universal integers for ILP64/ LP64: • 64-bit for ILP64 • 32-bit otherwise	`INTEGER` without specifying `KIND`	`MKL_INT`
Universal integers for ILP64/ LP64: • 64-bit integers	`INTEGER*8` or `INTEGER(KIND=8)`	`MKL_INT64`
FFT interface integers for ILP64/ LP64	`INTEGER` without specifying `KIND`	`MKL_LONG`

To determine the type of an integer parameter of a function, use appropriate include files. For functions that support only a Fortran interface, use the C/C++ include files `*.h`.

The above table explains which integer parameters of functions become 64-bit and which remain 32-bit for ILP64. The table applies to most Intel MKL functions except some VML and VSL functions, which require integer parameters to be 64-bit or 32-bit regardless of the interface:

- **VML:** The *`mode`* parameter of VML functions is 64-bit.
- **Random Number Generators (RNG):**

  All discrete RNG except `viRngUniformBits64` are 32-bit.

  The `viRngUniformBits64` generator function and `vslSkipAheadStream` service function are 64-bit.
- **Summary Statistics:** The *`estimate`* parameter of the `vslsSSCompute/vsldSSCompute` function is 64-bit.

Refer to the *Intel MKL Reference Manual* for more information.

To better understand ILP64 interface details, see also examples and tests.

Limitations

All Intel MKL function domains support ILP64 programming with the following exceptions:

- FFTW interfaces to Intel MKL:
  - FFTW 2.x wrappers do not support ILP64.
  - FFTW 3.2 wrappers support ILP64 by a dedicated set of functions `plan_guru64`.

See Also

High-level Directory Structure
Include Files

Language Interfaces Support, by Function Domain
Layered Model Concept
Directory Structure in Detail

Linking with Fortran 95 Interface Libraries

The `mkl_blas95*.lib` and `mkl_lapack95*.lib` libraries contain Fortran 95 interfaces for BLAS and LAPACK, respectively, which are compiler-dependent. In the Intel MKL package, they are prebuilt for the Intel® Fortran compiler. If you are using a different compiler, build these libraries before using the interface.

See Also

Fortran 95 Interfaces to LAPACK and BLAS
Compiler-dependent Functions and Fortran 90 Modules

Linking with Threading Libraries

Sequential Mode of the Library

You can use Intel MKL in a sequential (non-threaded) mode. In this mode, Intel MKL runs unthreaded code. However, it is thread-safe (except the LAPACK deprecated routine `?lacon)`, which means that you can use it in a parallel region in your OpenMP* code. The sequential mode requires no compatibility OpenMP* run-time library and does not respond to the environment variable `OMP_NUM_THREADS` or its Intel MKL equivalents.

You should use the library in the sequential mode only if you have a particular reason not to use Intel MKL threading. The sequential mode may be helpful when using Intel MKL with programs threaded with some non-Intel compilers or in other situations where you need a non-threaded version of the library (for instance, in some MPI cases). To set the sequential mode, in the Threading layer, choose the `*sequential.*` library.

See Also

Directory Structure in Detail
Improving Performance with Threading
Avoiding Conflicts in the Execution Environment
Linking Examples

Selecting the Threading Layer

Several compilers that Intel MKL supports use the OpenMP* threading technology. Intel MKL supports implementations of the OpenMP* technology that these compilers provide. To make use of this support, you need to link with the appropriate library in the Threading Layer and Compiler Support Run-time Library (RTL).

Threading Layer

Each Intel MKL threading library contains the same code compiled by the respective compiler (Intel and PGI* compilers on Windows OS).

RTL

This layer includes `libiomp`, the compatibility OpenMP* run-time library of the Intel compiler. In addition to the Intel compiler, `libiomp` provides support for one more threading compiler on Windows OS (Microsoft Visual C++*). That is, a program threaded with the Microsoft Visual C++ compiler can safely be linked with Intel MKL and `libiomp`.

The table below helps explain what threading library and RTL you should choose under different scenarios when using Intel MKL (static cases only):

Compiler	Application Threaded?	Threading Layer	RTL Recommended	Comment
Intel	Does not matter	`mkl_intel_thread.lib`	`libiomp5md.lib`	
PGI	Yes	`mkl_pgi_thread.lib` or `mkl_sequential.lib`	PGI* supplied	Use of `mkl_sequential.lib` removes threading from Intel MKL calls.
PGI	No	`mkl_intel_thread.lib`	`libiomp5md.lib`	
PGI	No	`mkl_pgi_thread.lib`	PGI* supplied	
PGI	No	`mkl_sequential.lib`	None	
Microsoft	Yes	`mkl_intel_thread.lib`	`libiomp5md.lib`	For the OpenMP* library of the Microsoft Visual Studio* IDE version 2008 or later.
Microsoft	Yes	`mkl_sequential.lib`	None	For Win32 threading.
Microsoft	No	`mkl_intel_thread.lib`	`libiomp5md.lib`	
other	Yes	`mkl_sequential.lib`	None	
other	No	`mkl_intel_thread.lib`	`libiomp5md.lib`	

Linking with Computational Libraries

If you are not using the Intel MKL cluster software, you need to link your application with only one computational library, depending on the linking method:

Static Linking	Dynamic Linking
`mkl_core.lib`	`mkl_core_dll.lib`

Computational Libraries for Applications that Use the Intel MKL Cluster Software

ScaLAPACK and Cluster Fourier Transform Functions (Cluster FFTs) require more computational libraries, which may depend on your architecture.

The following table lists computational libraries for IA-32 architecture applications that use ScaLAPACK or Cluster FFTs.

Computational Libraries for IA-32 Architecture

Function domain	Static Linking	Dynamic Linking
ScaLAPACK †	`mkl_scalapack_core.lib`	`mkl_scalapack_core_dll.lib`

Function domain	Static Linking	Dynamic Linking
	`mkl_core.lib`	`mkl_core_dll.lib`
Cluster Fourier Transform Functions†	`mkl_cdft_core.lib` `mkl_core.lib`	`mkl_cdft_core_dll.lib` `mkl_core_dll.lib`

† Also add the library with BLACS routines corresponding to the MPI used.

The following table lists computational libraries for Intel® 64 architecture applications that use ScaLAPACK or Cluster FFTs.

Computational Libraries for the Intel® 64 Architecture

Function domain	Static Linking	Dynamic Linking
ScaLAPACK, LP64 interface‡	`mkl_scalapack_lp64.lib` `mkl_core.lib`	`mkl_scalapack_lp64_dll.lib` `mkl_core_dll.lib`
ScaLAPACK, ILP64 interface‡	`mkl_scalapack_ilp64.lib` `mkl_core.lib`	`mkl_scalapack_ilp64_dll.lib` `mkl_core_dll.lib`
Cluster Fourier Transform Functions‡	`mkl_cdft_core.lib` `mkl_core.lib`	`mkl_cdft_core_dll.lib` `mkl_core_dll.lib`

‡ Also add the library with BLACS routines corresponding to the MPI used.

See Also

Linking with ScaLAPACK and Cluster FFTs
Using the Link-line Advisor
Using the ILP64 Interface vs. LP64 Interface

Linking with Compiler Run-time Libraries

Dynamically link `libiomp5`, the compatibility OpenMP* run-time library, even if you link other libraries statically.

Linking to the `libiomp5` statically can be problematic because the more complex your operating environment or application, the more likely redundant copies of the library are included. This may result in performance issues (oversubscription of threads) and even incorrect results.

To link `libiomp5` dynamically, be sure the `PATH` environment variable is defined correctly.

Sometimes you may improve performance of your application with threaded Intel MKL by using the `/MT` compiler option. The compiler driver will pass the option to the linker and the latter will load multi-thread (MT) static run-time libraries.

However, to link a Vector Math Library application that uses the *`errno`* variable for error reporting, compile and link your code using the option that depends on the linking model:

- `/MT` for linking with static Intel MKL libraries
- `/MD` for linking with dynamic Intel MKL libraries

See Also

Setting Environment Variables
Layered Model Concept

Linking with System Libraries

If your system is based on the Intel® 64 architecture, be aware that Microsoft SDK builds 1289 or higher provide the `bufferoverflowu.lib` library to resolve the `__security_cookie` external references. Makefiles for examples and tests include this library by using the `buf_lib=bufferoverflowu.lib` macro. If you are using older SDKs, leave this macro empty on your command line as follows: `buf_lib=` .

See Also

Linking Examples

Building Custom Dynamic-link Libraries

Custom dynamic-link libraries (DLL) reduce the collection of functions available in Intel MKL libraries to those required to solve your particular problems, which helps to save disk space and build your own dynamic libraries for distribution.

The Intel MKL custom DLL builder enables you to create a dynamic library containing the selected functions and located in the `tools\builder` directory. The builder contains a makefile and a definition file with the list of functions.

Using the Custom Dynamic-link Library Builder in the Command-line Mode

To build a custom DLL, use the following command:

`nmake target [<options>]`

The following table lists possible values of `target` and explains what the command does for each value:

Value	Comment
`libia32`	The builder uses static Intel MKL interface, threading, and core libraries to build a custom DLL for the IA-32 architecture.
`libintel64`	The builder uses static Intel MKL interface, threading, and core libraries to build a custom DLL for the Intel® 64 architecture.
`dllia32`	The builder uses the single dynamic library `libmkl_rt.dll` to build a custom DLL for the IA-32 architecture.
`dllintel64`	The builder uses the single dynamic library `libmkl_rt.dll` to build a custom DLL for the Intel® 64 architecture.
`help`	The command prints Help on the custom DLL builder

The *`<options>`* placeholder stands for the list of parameters that define macros to be used by the makefile. The following table describes these parameters:

Parameter [Values]	Description
`interface`	Defines which programming interface to use.Possible values: • For the IA-32 architecture, `{cdecl|stdcall}`. The default value is `cdecl`. • For the Intel 64 architecture, `{lp64|ilp64}`. The default value is `lp64`.
`threading = {parallel| sequential}`	Defines whether to use the Intel MKL in the threaded or sequential mode. The default value is `parallel`.

Parameter [Values]	**Description**
`export = <file name>`	Specifies the full name of the file that contains the list of entry-point functions to be included in the DLL. The default name is `user_example_list` (no extension).
`name = <dll name>`	Specifies the name of the dll and interface library to be created. By default, the names of the created libraries are `mkl_custom.dll` and `mkl_custom.lib`.
`xerbla = <error handler>`	Specifies the name of the object file `<user_xerbla>.obj` that contains the user's error handler. The makefile adds this error handler to the library for use instead of the default Intel MKL error handler *`xerbla`*. If you omit this parameter, the native Intel MKL *`xerbla`* is used. See the description of the *`xerbla`* function in the Intel MKL Reference Manual on how to develop your own error handler. For the IA-32 architecture, the object file should be in the interface defined by the interface macro (cdecl or stdcall).
`MKLROOT = <mkl directory>`	Specifies the location of Intel MKL libraries used to build the custom DLL. By default, the builder uses the Intel MKL installation directory.
`buf_lib`	Manages resolution of the `__security_cookie` external references in the custom DLL on systems based on the Intel® 64 architecture. By default, the makefile uses the `bufferoverflowu.lib` library of Microsoft SDK builds 1289 or higher. This library resolves the `__security_cookie` external references. To avoid using this library, set the empty value of this parameter. Therefore, if you are using an older SDK, set `buf_lib=` . **CAUTION** Use the `buf_lib` parameter only with the empty value. Incorrect value of the parameter causes builder errors.
`crt = <c run-time library>`	Specifies the name of the Microsoft C run-time library to be used to build the custom DLL. By default, the builder uses `msvcrt.lib`.
`manifest = {yes|no|embed}`	Manages the creation of a Microsoft manifest for the custom DLL: • If `manifest=yes`, the manifest file with the name defined by the name parameter above and the `manifest` extension will be created. • If `manifest=no`, the manifest file will not be created. • If `manifest=embed`, the manifest will be embedded into the DLL. By default, the builder does not use the `manifest` parameter.

All the above parameters are optional.

In the simplest case, the command line is `nmake ia32`, and the missing options have default values. This command creates the `mkl_custom.dll` and `mkl_custom.lib` libraries with the cdecl interface for processors using the IA-32 architecture. The command takes the list of functions from the `functions_list` file and uses the native Intel MKL error handler *`xerbla`*.

An example of a more complex case follows:

```
nmake ia32 interface=stdcall export=my_func_list.txt name=mkl_small
xerbla=my_xerbla.obj
```

In this case, the command creates the `mkl_small.dll` and `mkl_small.lib` libraries with the stdcall interface for processors using the IA-32 architecture. The command takes the list of functions from `my_func_list.txt` file and uses the user's error handler `my_xerbla.obj`.

The process is similar for processors using the Intel® 64 architecture.

See Also

Linking with System Libraries

Composing a List of Functions

To compose a list of functions for a minimal custom DLL needed for your application, you can use the following procedure:

1. Link your application with installed Intel MKL libraries to make sure the application builds.
2. Remove all Intel MKL libraries from the link line and start linking.

   Unresolved symbols indicate Intel MKL functions that your application uses.
3. Include these functions in the list.

Important Each time your application starts using more Intel MKL functions, update the list to include the new functions.

See Also

Specifying Function Names

Specifying Function Names

In the file with the list of functions for your custom DLL, adjust function names to the required interface. For example, you can list the cdecl entry points as follows:

```
DGEMM

DTRSM

DDOT

DGETRF

DGETRS

cblas_dgemm

cblas_ddot
```

You can list the stdcall entry points as follows:

```
_DGEMM@60

_DDOT@20

_DGETRF@24
```

For more examples, see domain-specific lists of function names in the `<mkl directory>\tools\builder` folder. This folder contains lists of function names for both cdecl or stdcall interfaces.

NOTE The lists of function names are provided in the `<mkl directory>\tools\builder` folder merely as examples. See Composing a List of Functions for how to compose lists of functions for your custom DLL.

TIP Names of Fortran-style routines (BLAS, LAPACK, etc.) can be both upper-case or lower-case, with or without the trailing underscore. For example, these names are equivalent:
BLAS: `dgemm`, `DGEMM`, `dgemm_`, `DGEMM_`
LAPACK: `dgetrf`, `DGETRF`, `dgetrf_`, `DGETRF_`.

Properly capitalize names of C support functions in the function list. To do this, follow the guidelines below:

1. In the `mkl_service.h` include file, look up a `#define` directive for your function (`mkl_service.h` is included in the `mkl.h` header file).
2. Take the function name from the replacement part of that directive.

For example, the `#define` directive for the `mkl_disable_fast_mm` function is `#define mkl_disable_fast_mm MKL_Disable_Fast_MM`.

Capitalize the name of this function in the list like this: `MKL_Disable_Fast_MM`.

For the names of the Fortran support functions, see the tip.

Building a Custom Dynamic-link Library in the Visual Studio* Development System

You can build a custom dynamic-link library (DLL) in the Microsoft Visual Studio* Development System (VS*) . To do this, use projects available in the `tools\builder\MSVS_Projects` subdirectory of the Intel MKL directory. The directory contains the `VS2008` and `VS2010` subdirectories with projects for the respective versions of the Visual Studio Development System. For each version of VS two solutions are available:

- `libia32.sln` builds a custom DLL for the IA-32 architecture.
- `libintel64.sln` builds a custom DLL for the Intel® 64 architecture.

The builder uses the following default settings for the custom DLL:

Interface:	cdecl for the IA-32 architecture and LP64 for the Intel 64 architecture
Error handler:	Native Intel MKL `xerbla`
Create Microsoft manifest:	yes
List of functions:	in the project's source file `examples.def`

To build a custom DLL:

1. Set the `MKLROOT` environment variable with the installation directory of the Intel MKL version you are going to use.
2. Open the `libia32.sln` or `libintel64.sln` solution depending on the architecture of your system.

   The solution includes the following projects:

   - `i_malloc_dll`
   - `vml_dll_core`
   - `cdecl_parallel` (in `libia32.sln`) or `lp64_parallel` (in `libintel64.sln`)
   - `cdecl_sequential` (in `libia32.sln`) or `lp64_sequential` (in `libintel64.sln`)
3. [Optional] To change any of the default settings, select the project depending on whether the DLL will use Intel MKL functions in the sequential or multi-threaded mode:

   - In the `libia32` solution, select the `cdecl_sequential` or `cdecl_parallel` project.
   - In the `libintel64` solution, select the `lp64_sequential` or `lp64_parallel` project.
4. [Optional] To build the DLL that uses the stdcall interface for the IA-32 architecture or the ILP64 interface for the Intel 64 architecture:

   a. Select **Project**>**Properties**>**Configuration Properties**>**Linker**>**Input**>**Additional Dependencies**.
   b. In the `libia32` solution, change `mkl_intel_c.lib` to `mkl_intel_s.lib`.
      In the `libintel64` solution, change `mkl_intel_lp64.lib` to `mkl_intel_ilp64.lib`.
5. [Optional] To include your own error handler in the DLL:

   a. Select **Project**>**Properties**>**Configuration Properties**>**Linker**>**Input**.
   b. Add `<user_xerbla>.obj`
6. [Optional] To turn off creation of the manifest:

   a. Select **Project**>**Properties**>**Configuration Properties**>**Linker**>**Manifest File**>**Generate Manifest**.
   b. Select: no.

7. [Optional] To change the list of functions to be included in the DLL:
   a. Select **Source Files**.
   b. Edit the `examples.def` file. Refer to Specifying Function Names for how to specify entry points.
8. To build the library:
   - In VS2005 - VS2008, select **Build**>**Project Only**>**Link Only** and link projects in this order: `i_malloc_dll`, `vml_dll_core`, `cdecl_sequential/lp64_sequential` or `cdecl_parallel/lp64_parallel`.
   - In VS2010, select **Build**>**Build Solution**.

See Also

Using the Custom Dynamic-link Library Builder in the Command-line Mode

Distributing Your Custom Dynamic-link Library

To enable use of your custom DLL in a threaded mode, distribute `libiomp5md.dll` along with the custom DLL.

Managing Performance and Memory 5

Optimization Notice

Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice.

Notice revision #20110804

Improving Performance with Threading

Intel MKL is extensively parallelized. See Threaded Functions and Problems for lists of threaded functions and problems that can be threaded.

Intel MKL is *thread-safe*, which means that all Intel MKL functions (except the LAPACK deprecated routine `?lacon)` work correctly during simultaneous execution by multiple threads. In particular, any chunk of threaded Intel MKL code provides access for multiple threads to the same shared data, while permitting only one thread at any given time to access a shared piece of data. Therefore, you can call Intel MKL from multiple threads and not worry about the function instances interfering with each other.

The library uses OpenMP* threading software, so you can use the environment variable `OMP_NUM_THREADS` to specify the number of threads or the equivalent OpenMP run-time function calls. Intel MKL also offers variables that are independent of OpenMP, such as `MKL_NUM_THREADS`, and equivalent Intel MKL functions for thread management. The Intel MKL variables are always inspected first, then the OpenMP variables are examined, and if neither is used, the OpenMP software chooses the default number of threads.

By default, Intel MKL uses the number of threads equal to the number of physical cores on the system.

To achieve higher performance, set the number of threads to the number of real processors or physical cores, as summarized in Techniques to Set the Number of Threads.

See Also

Managing Multi-core Performance

Threaded Functions and Problems

The following Intel MKL function domains are threaded:

- Direct sparse solver.
- LAPACK.

  For the list of threaded routines, see Threaded LAPACK Routines.
- Level1 and Level2 BLAS.

  For the list of threaded routines, see Threaded BLAS Level1 and Level2 Routines.
- All Level 3 BLAS and all Sparse BLAS routines except Level 2 Sparse Triangular solvers.
- All mathematical VML functions.
- FFT.

  For the list of FFT transforms that can be threaded, see Threaded FFT Problems.

Threaded LAPACK Routines

In the following list, `?` stands for a precision prefix of *each* flavor of the respective routine and may have the value of `s`, `d`, `c`, or `z`.

The following LAPACK routines are threaded:

- Linear equations, computational routines:
    - Factorization: `?getrf, ?gbtrf, ?potrf, ?pptrf, ?sytrf, ?hetrf, ?sptrf, ?hptrf`
    - Solving: `?dttrsb, ?gbtrs, ?gttrs, ?pptrs, ?pbtrs, ?pttrs, ?sytrs, ?sptrs, ?hptrs, ?tptrs, ?tbtrs`
- Orthogonal factorization, computational routines:
  `?geqrf, ?ormqr, ?unmqr, ?ormlq, ?unmlq, ?ormql, ?unmql, ?ormrq, ?unmrq`
- Singular Value Decomposition, computational routines:
  `?gebrd, ?bdsqr`
- Symmetric Eigenvalue Problems, computational routines:
  `?sytrd, ?hetrd, ?sptrd, ?hptrd, ?steqr, ?stedc.`
- Generalized Nonsymmetric Eigenvalue Problems, computational routines:
  `chgeqz/zhgeqz.`

A number of other LAPACK routines, which are based on threaded LAPACK or BLAS routines, make effective use of parallelism:
`?gesv, ?posv, ?gels, ?gesvd, ?syev, ?heev, cgegs/zgegs, cgegv/zgegv, cgges/zgges, cggesx/zggesx, cggev/zggev, cggevx/zggevx`, and so on.

Threaded BLAS Level1 and Level2 Routines

In the following list, `?` stands for a precision prefix of *each* flavor of the respective routine and may have the value of `s`, `d`, `c`, or `z`.

The following routines are threaded for Intel® Core™2 Duo and Intel® Core™ i7 processors:

- Level1 BLAS:
  `?axpy, ?copy, ?swap, ddot/sdot, cdotc, drot/srot`
- Level2 BLAS:
  `?gemv, ?trmv, dsyr/ssyr, dsyr2/ssyr2, dsymv/ssymv`

Threaded FFT Problems

The following characteristics of a specific problem determine whether your FFT computation may be threaded:

- rank
- domain
- size/length
- precision (single or double)
- placement (in-place or out-of-place)
- strides
- number of transforms
- layout (for example, interleaved or split layout of complex data)

Most FFT problems are threaded. In particular, computation of multiple transforms in one call (number of transforms > 1) is threaded. Details of which transforms are threaded follow.

One-dimensional (1D) transforms

1D transforms are threaded in many cases.

1D complex-to-complex (c2c) transforms of size N using interleaved complex data layout are threaded under the following conditions depending on the architecture:

Architecture	Conditions
Intel® 64	N is a power of 2, $log_2(N) > 9$, the transform is double-precision out-of-place, and input/output strides equal 1.
IA-32	N is a power of 2, $log_2(N) > 13$, and the transform is single-precision.
	N is a power of 2, $log_2(N) > 14$, and the transform is double-precision.
Any	N is composite, $log_2(N) > 16$, and input/output strides equal 1.

1D complex-to-complex transforms using split-complex layout are not threaded.

Multidimensional transforms

All multidimensional transforms on large-volume data are threaded.

Avoiding Conflicts in the Execution Environment

Certain situations can cause conflicts in the execution environment that make the use of threads in Intel MKL problematic. This section briefly discusses why these problems exist and how to avoid them.

If you thread the program using OpenMP directives and compile the program with Intel compilers, Intel MKL and the program will both use the same threading library. Intel MKL tries to determine if it is in a parallel region in the program, and if it is, it does not spread its operations over multiple threads unless you specifically request Intel MKL to do so via the `MKL_DYNAMIC` functionality. However, Intel MKL can be aware that it is in a parallel region only if the threaded program and Intel MKL are using the same threading library. If your program is threaded by some other means, Intel MKL may operate in multithreaded mode, and the performance may suffer due to overuse of the resources.

The following table considers several cases where the conflicts may arise and provides recommendations depending on your threading model:

Threading model	Discussion
You thread the program using OS threads (Win32* threads on Windows* OS).	If more than one thread calls Intel MKL, and the function being called is threaded, it may be important that you turn off Intel MKL threading. Set the number of threads to one by any of the available means (see Techniques to Set the Number of Threads).
You thread the program using OpenMP directives and/or pragmas and compile the program using a compiler other than a compiler from Intel.	This is more problematic because setting of the `OMP_NUM_THREADS` environment variable affects both the compiler's threading library and `libiomp5`. In this case, choose the threading library that matches the layered Intel MKL with the OpenMP compiler you employ (see Linking Examples on how to do this). If this is not possible, use Intel MKL in the sequential mode. To do this, you should link with the appropriate threading library: `mkl_sequential.lib` or `mkl_sequential.dll` (see High-level Directory Structure).
There are multiple programs running on a multiple-cpu system, for example, a parallelized program that runs using MPI for communication in which each processor is treated as a node.	The threading software will see multiple processors on the system even though each processor has a separate MPI process running on it. In this case, one of the solutions is to set the number of threads to one by any of the available means (see Techniques to Set the Number of Threads). Section Intel(R) Optimized MP LINPACK Benchmark for Clusters discusses another solution for a Hybrid (OpenMP* + MPI) mode.

Using the `mkl_set_num_threads` and `mkl_domain_set_num_threads` functions to control parallelism of Intel MKL from parallel user threads may result in a race condition that impacts the performance of the application because these functions operate on internal control variables that are global, that is, apply to all threads. For example, if parallel user threads call these functions to set different numbers of threads for the same function domain, the number of threads actually set is unpredictable. To avoid this kind of data races, use the `mkl_set_num_threads_local` function (see the "Support Functions" chapter in the *Intel MKL Reference Manual* for the function description).

See Also
Using Additional Threading Control
Linking with Compiler Run-time Libraries

Techniques to Set the Number of Threads

Use the following techniques to specify the number of threads to use in Intel MKL:

- Set one of the OpenMP or Intel MKL environment variables:
  - `OMP_NUM_THREADS`
  - `MKL_NUM_THREADS`
  - `MKL_DOMAIN_NUM_THREADS`
- Call one of the OpenMP or Intel MKL functions:
  - `omp_set_num_threads()`
  - `mkl_set_num_threads()`
  - `mkl_domain_set_num_threads()`
  - `mkl_set_num_threads_local()`

When choosing the appropriate technique, take into account the following rules:

- The Intel MKL threading controls take precedence over the OpenMP controls because they are inspected first.
- A function call takes precedence over any environment settings. The exception, which is a consequence of the previous rule, is that a call to the OpenMP subroutine `omp_set_num_threads()` does not have precedence over the settings of Intel MKL environment variables such as `MKL_NUM_THREADS`. See Using Additional Threading Control for more details.
- You cannot change run-time behavior in the course of the run using the environment variables because they are read only once at the first call to Intel MKL.

Setting the Number of Threads Using an OpenMP* Environment Variable

You can set the number of threads using the environment variable `OMP_NUM_THREADS`. To change the number of threads, in the command shell in which the program is going to run, enter:

`set OMP_NUM_THREADS=<`*`number of threads to use`*`>`.

Some shells require the variable and its value to be exported:

`export OMP_NUM_THREADS=<`*`number of threads to use`*`>`.

You can alternatively assign value to the environment variable using Microsoft Windows* OS Control Panel.

Note that you will not benefit from setting this variable on Microsoft Windows* 98 or Windows* ME because multiprocessing is not supported.

See Also
Using Additional Threading Control

Changing the Number of Threads at Run Time

You cannot change the number of threads during run time using environment variables. However, you can call OpenMP API functions from your program to change the number of threads during run time. The following sample code shows how to change the number of threads during run time using the `omp_set_num_threads()` routine. See also Techniques to Set the Number of Threads.

The following example shows both C and Fortran code examples. To run this example in the C language, use the `omp.h` header file from the Intel(R) compiler package. If you do not have the Intel compiler but wish to explore the functionality in the example, use Fortran API for `omp_set_num_threads()` rather than the C version. For example, `omp_set_num_threads_( &i_one );`

```
// ******* C language *******
#include "omp.h"
#include "mkl.h"
#include <stdio.h>
#define SIZE 1000
int main(int args, char *argv[]){
double *a, *b, *c;
a = (double*)malloc(sizeof(double)*SIZE*SIZE);
b = (double*)malloc(sizeof(double)*SIZE*SIZE);
c = (double*)malloc(sizeof(double)*SIZE*SIZE);
double alpha=1, beta=1;
int m=SIZE, n=SIZE, k=SIZE, lda=SIZE, ldb=SIZE, ldc=SIZE, i=0, j=0;
char transa='n', transb='n';
for( i=0; i<SIZE; i++){
for( j=0; j<SIZE; j++){
a[i*SIZE+j]= (double)(i+j);
b[i*SIZE+j]= (double)(i*j);
c[i*SIZE+j]= (double)0;
}
}
cblas_dgemm(CblasRowMajor, CblasNoTrans, CblasNoTrans,
m, n, k, alpha, a, lda, b, ldb, beta, c, ldc);
printf("row\ta\tc\n");
for ( i=0;i<10;i++){
printf("%d:\t%f\t%f\n", i, a[i*SIZE], c[i*SIZE]);
}
omp_set_num_threads(1);
for( i=0; i<SIZE; i++){
for( j=0; j<SIZE; j++){
a[i*SIZE+j]= (double)(i+j);
b[i*SIZE+j]= (double)(i*j);
c[i*SIZE+j]= (double)0;
}
}
cblas_dgemm(CblasRowMajor, CblasNoTrans, CblasNoTrans,
m, n, k, alpha, a, lda, b, ldb, beta, c, ldc);
printf("row\ta\tc\n");
for ( i=0;i<10;i++){
printf("%d:\t%f\t%f\n", i, a[i*SIZE], c[i*SIZE]);
}
omp_set_num_threads(2);
for( i=0; i<SIZE; i++){
for( j=0; j<SIZE; j++){
a[i*SIZE+j]= (double)(i+j);
b[i*SIZE+j]= (double)(i*j);
c[i*SIZE+j]= (double)0;
}
}
cblas_dgemm(CblasRowMajor, CblasNoTrans, CblasNoTrans,
m, n, k, alpha, a, lda, b, ldb, beta, c, ldc);
printf("row\ta\tc\n");
for ( i=0;i<10;i++){
printf("%d:\t%f\t%f\n", i, a[i*SIZE],
c[i*SIZE]);
}
free (a);
free (b);
free (c);
return 0;
}
```

```
// ******* Fortran language *******
PROGRAM DGEMM_DIFF_THREADS
```

```
INTEGER N, I, J
PARAMETER (N=100)
REAL*8 A(N,N),B(N,N),C(N,N)
REAL*8 ALPHA, BETA

ALPHA = 1.1
BETA = -1.2
DO I=1,N
DO J=1,N
A(I,J) = I+J
B(I,J) = I*j
C(I,J) = 0.0
END DO
END DO
CALL DGEMM('N','N',N,N,N,ALPHA,A,N,B,N,BETA,C,N)
print *,'Row A C'
DO i=1,10
write(*,'(I4,F20.8,F20.8)') I, A(1,I),C(1,I)
END DO
CALL OMP_SET_NUM_THREADS(1);
DO I=1,N
DO J=1,N
A(I,J) = I+J
B(I,J) = I*j
C(I,J) = 0.0
END DO
END DO
CALL DGEMM('N','N',N,N,N,ALPHA,A,N,B,N,BETA,C,N)
print *,'Row A C'
DO i=1,10
write(*,'(I4,F20.8,F20.8)') I, A(1,I),C(1,I)
END DO
CALL OMP_SET_NUM_THREADS(2);
DO I=1,N
DO J=1,N
A(I,J) = I+J
B(I,J) = I*j
C(I,J) = 0.0
END DO
END DO
CALL DGEMM('N','N',N,N,N,ALPHA,A,N,B,N,BETA,C,N)
print *,'Row A C'
DO i=1,10
write(*,'(I4,F20.8,F20.8)') I, A(1,I),C(1,I)
END DO
STOP
END
```

Using Additional Threading Control

Intel MKL-specific Environment Variables for Threading Control

Intel MKL provides optional threading controls, that is, the environment variables and support functions that are independent of OpenMP. They behave similar to their OpenMP equivalents, but take precedence over them in the meaning that the Intel MKL-specific threading controls are inspected first. By using these controls along with OpenMP variables, you can thread the part of the application that does not call Intel MKL and the library independently of each other.

These controls enable you to specify the number of threads for Intel MKL independently of the OpenMP settings. Although Intel MKL may actually use a different number of threads from the number suggested, the controls will also enable you to instruct the library to try using the suggested number when the number used in the calling application is unavailable.

NOTE Sometimes Intel MKL does not have a choice on the number of threads for certain reasons, such as system resources.

Use of the Intel MKL threading controls in your application is optional. If you do not use them, the library will mainly behave the same way as Intel MKL 9.1 in what relates to threading with the possible exception of a different default number of threads.

Section "Number of User Threads" in the "Fourier Transform Functions" chapter of the *Intel MKL Reference Manual* shows how the Intel MKL threading controls help to set the number of threads for the FFT computation.

The table below lists the Intel MKL environment variables for threading control, their equivalent functions, and OMP counterparts:

Environment Variable	Support Function	Comment	Equivalent OpenMP* Environment Variable
`MKL_NUM_THREADS`	`mkl_set_num_threads` `mkl_set_num_threads_local`	Suggests the number of threads to use.	`OMP_NUM_THREADS`
`MKL_DOMAIN_NUM_THREADS`	`mkl_domain_set_num_threads`	Suggests the number of threads for a particular function domain.	
`MKL_DYNAMIC`	`mkl_set_dynamic`	Enables Intel MKL to dynamically change the number of threads.	`OMP_DYNAMIC`

NOTE The functions take precedence over the respective environment variables. Therefore, if you want Intel MKL to use a given number of threads in your application and do not want users of your application to change this number using environment variables, set the number of threads by a call to `mkl_set_num_threads()`, which will have full precedence over any environment variables being set.

The example below illustrates the use of the Intel MKL function `mkl_set_num_threads()` to set one thread.

```
// ******* C language *******
#include <omp.h>
#include <mkl.h>
...
mkl_set_num_threads ( 1 );
```

```
// ******* Fortran language *******
...
call mkl_set_num_threads( 1 )
```

See the *Intel MKL Reference Manual* for the detailed description of the threading control functions, their parameters, calling syntax, and more code examples.

MKL_DYNAMIC

The `MKL_DYNAMIC` environment variable enables Intel MKL to dynamically change the number of threads.

The default value of `MKL_DYNAMIC` is `TRUE`, regardless of `OMP_DYNAMIC`, whose default value may be `FALSE`.

When MKL_DYNAMIC is TRUE, Intel MKL tries to use what it considers the best number of threads, up to the maximum number you specify.

For example, MKL_DYNAMIC set to TRUE enables optimal choice of the number of threads in the following cases:

- If the requested number of threads exceeds the number of physical cores (perhaps because of using the Intel® Hyper-Threading Technology), and MKL_DYNAMIC is not changed from its default value of TRUE, Intel MKL will scale down the number of threads to the number of physical cores.
- If you are able to detect the presence of MPI, but cannot determine if it has been called in a thread-safe mode (it is impossible to detect this with MPICH 1.2.x, for instance), and MKL_DYNAMIC has not been changed from its default value of TRUE, Intel MKL will run one thread.

When MKL_DYNAMIC is FALSE, Intel MKL tries not to deviate from the number of threads the user requested. However, setting MKL_DYNAMIC=FALSE does not ensure that Intel MKL will use the number of threads that you request. The library may have no choice on this number for such reasons as system resources. Additionally, the library may examine the problem and use a different number of threads than the value suggested. For example, if you attempt to do a size one matrix-matrix multiply across eight threads, the library may instead choose to use only one thread because it is impractical to use eight threads in this event.

Note also that if Intel MKL is called in a parallel region, it will use only one thread by default. If you want the library to use nested parallelism, and the thread within a parallel region is compiled with the same OpenMP compiler as Intel MKL is using, you may experiment with setting MKL_DYNAMIC to FALSE and manually increasing the number of threads.

In general, set MKL_DYNAMIC to FALSE only under circumstances that Intel MKL is unable to detect, for example, to use nested parallelism where the library is already called from a parallel section.

MKL_DOMAIN_NUM_THREADS

The MKL_DOMAIN_NUM_THREADS environment variable suggests the number of threads for a particular function domain.

MKL_DOMAIN_NUM_THREADS accepts a string value <MKL-env-string>, which must have the following format:

<MKL-env-string> ::= *<MKL-domain-env-string>* { *<delimiter><MKL-domain-env-string>* }

<delimiter> ::= [*<space-symbol>**] (*<space-symbol>* | *<comma-symbol>* | *<semicolon-symbol>* | *<colon-symbol>*) [*<space-symbol>**]

<MKL-domain-env-string> ::= *<MKL-domain-env-name><uses><number-of-threads>*

<MKL-domain-env-name> ::= MKL_DOMAIN_ALL | MKL_DOMAIN_BLAS | MKL_DOMAIN_FFT | MKL_DOMAIN_VML | MKL_DOMAIN_PARDISO

<uses> ::= [*<space-symbol>**] (*<space-symbol>* | *<equality-sign>* | *<comma-symbol>*) [*<space-symbol>**]

<number-of-threads> ::= *<positive-number>*

<positive-number> ::= *<decimal-positive-number>* | *<octal-number>* | *<hexadecimal-number>*

In the syntax above, values of *<MKL-domain-env-name>* indicate function domains as follows:

MKL_DOMAIN_ALL	All function domains
MKL_DOMAIN_BLAS	BLAS Routines
MKL_DOMAIN_FFT	non-cluster Fourier Transform Functions
MKL_DOMAIN_VML	Vector Mathematical Functions
MKL_DOMAIN_PARDISO	PARDISO

For example,

```
MKL_DOMAIN_ALL 2 : MKL_DOMAIN_BLAS 1 : MKL_DOMAIN_FFT 4
```

```
MKL_DOMAIN_ALL=2 : MKL_DOMAIN_BLAS=1 : MKL_DOMAIN_FFT=4
MKL_DOMAIN_ALL=2,  MKL_DOMAIN_BLAS=1,  MKL_DOMAIN_FFT=4
MKL_DOMAIN_ALL=2;  MKL_DOMAIN_BLAS=1;  MKL_DOMAIN_FFT=4
MKL_DOMAIN_ALL   = 2  MKL_DOMAIN_BLAS 1 ,  MKL_DOMAIN_FFT  4
MKL_DOMAIN_ALL,2: MKL_DOMAIN_BLAS 1, MKL_DOMAIN_FFT,4 .
```

The global variables `MKL_DOMAIN_ALL`, `MKL_DOMAIN_BLAS`, `MKL_DOMAIN_FFT`, `MKL_DOMAIN_VML`, and `MKL_DOMAIN_PARDISO`, as well as the interface for the Intel MKL threading control functions, can be found in the `mkl.h` header file.

The table below illustrates how values of `MKL_DOMAIN_NUM_THREADS` are interpreted.

Value of **MKL_DOMAIN_NUM_THREADS**	Interpretation
`MKL_DOMAIN_ALL=4`	All parts of Intel MKL should try four threads. The actual number of threads may be still different because of the `MKL_DYNAMIC` setting or system resource issues. The setting is equivalent to `MKL_NUM_THREADS` = 4.
`MKL_DOMAIN_ALL=1, MKL_DOMAIN_BLAS=4`	All parts of Intel MKL should try one thread, except for BLAS, which is suggested to try four threads.
`MKL_DOMAIN_VML=2`	VML should try two threads. The setting affects no other part of Intel MKL.

Be aware that the domain-specific settings take precedence over the overall ones. For example, the "`MKL_DOMAIN_BLAS=4`" value of `MKL_DOMAIN_NUM_THREADS` suggests trying four threads for BLAS, regardless of later setting `MKL_NUM_THREADS`, and a function call "`mkl_domain_set_num_threads ( 4, MKL_DOMAIN_BLAS );`" suggests the same, regardless of later calls to `mkl_set_num_threads()`. However, a function call with input "`MKL_DOMAIN_ALL`", such as "`mkl_domain_set_num_threads (4, MKL_DOMAIN_ALL);`" is equivalent to "`mkl_set_num_threads(4)`", and thus it will be overwritten by later calls to `mkl_set_num_threads`. Similarly, the environment setting of `MKL_DOMAIN_NUM_THREADS` with "`MKL_DOMAIN_ALL=4`" will be overwritten with `MKL_NUM_THREADS` = 2.

Whereas the `MKL_DOMAIN_NUM_THREADS` environment variable enables you set several variables at once, for example, "`MKL_DOMAIN_BLAS=4,MKL_DOMAIN_FFT=2`", the corresponding function does not take string syntax. So, to do the same with the function calls, you may need to make several calls, which in this example are as follows:

```
mkl_domain_set_num_threads ( 4, MKL_DOMAIN_BLAS );
mkl_domain_set_num_threads ( 2, MKL_DOMAIN_FFT );
```

Setting the Environment Variables for Threading Control

To set the environment variables used for threading control, in the command shell in which the program is going to run, enter:

```
set <VARIABLE NAME>=<value>
```

For example:

```
set MKL_NUM_THREADS=4
set MKL_DOMAIN_NUM_THREADS="MKL_DOMAIN_ALL=1, MKL_DOMAIN_BLAS=4"
set MKL_DYNAMIC=FALSE
```

Some shells require the variable and its value to be exported:

```
export <VARIABLE NAME>=<value>
```

For example:

```
export MKL_NUM_THREADS=4
export MKL_DOMAIN_NUM_THREADS="MKL_DOMAIN_ALL=1, MKL_DOMAIN_BLAS=4"
export MKL_DYNAMIC=FALSE
```

You can alternatively assign values to the environment variables using Microsoft Windows* OS Control Panel.

Other Tips and Techniques to Improve Performance

Coding Techniques

To improve performance of your application that calls Intel MKL, align your arrays on 64-byte boundaries and ensure that the leading dimensions of the arrays are divisible by 64.

LAPACK Packed Routines

The routines with the names that contain the letters `HP, OP, PP, SP, TP, UP` in the matrix type and storage position (the second and third letters respectively) operate on the matrices in the packed format (see LAPACK "Routine Naming Conventions" sections in the Intel MKL Reference Manual). Their functionality is strictly equivalent to the functionality of the unpacked routines with the names containing the letters `HE, OR, PO, SY, TR, UN` in the same positions, but the performance is significantly lower.

If the memory restriction is not too tight, use an unpacked routine for better performance. In this case, you need to allocate $N^2/2$ more memory than the memory required by a respective packed routine, where N is the problem size (the number of equations).

For example, to speed up solving a symmetric eigenproblem with an expert driver, use the unpacked routine:

```
call dsyevx(jobz, range, uplo, n, a, lda, vl, vu, il, iu, abstol, m, w, z, ldz, work, lwork, iwork,
ifail, info)
```

where `a` is the dimension *`lda`*`-by-`*`n`*, which is at least N^2 elements,
instead of the packed routine:

```
call dspevx(jobz, range, uplo, n, ap, vl, vu, il, iu, abstol, m, w, z, ldz, work, iwork, ifail, info)
```

where `ap` is the dimension $N*(N+1)/2$.

Hardware Configuration Tips

Dual-Core Intel® Xeon® processor 5100 series systems

To get the best performance with Intel MKL on Dual-Core Intel® Xeon® processor 5100 series systems, enable the Hardware DPL (streaming data) Prefetcher functionality of this processor. To configure this functionality, use the appropriate BIOS settings, as described in your BIOS documentation.

Intel® Hyper-Threading Technology

Intel® Hyper-Threading Technology (Intel® HT Technology) is especially effective when each thread performs different types of operations and when there are under-utilized resources on the processor. However, Intel MKL fits neither of these criteria because the threaded portions of the library execute at high efficiencies using most of the available resources and perform identical operations on each thread. You may obtain higher performance by disabling Intel HT Technology.

If you run with Intel HT Technology enabled, performance may be especially impacted if you run on fewer threads than physical cores. Moreover, if, for example, there are two threads to every physical core, the thread scheduler may assign two threads to some cores and ignore the other cores altogether. If you are using the OpenMP* library of the Intel Compiler, read the respective User Guide on how to best set the thread affinity interface to avoid this situation. For Intel MKL, apply the following setting:

```
set KMP_AFFINITY=granularity=fine,compact,1,0
```

See Also

Improving Performance with Threading

Managing Multi-core Performance

You can obtain best performance on systems with multi-core processors by requiring that threads do not migrate from core to core. To do this, bind threads to the CPU cores by setting an affinity mask to threads. Use one of the following options:

- OpenMP facilities (recommended, if available), for example, the `KMP_AFFINITY` environment variable using the Intel OpenMP library
- A system function, as explained below

Consider the following performance issue:

- The system has two sockets with two cores each, for a total of four cores (CPUs)
- Performance of t he four -thread parallel application using the Intel MKL LAPACK is unstable

The following code example shows how to resolve this issue by setting an affinity mask by operating system means using the Intel compiler. The code calls the system function `SetThreadAffinityMask` to bind the threads to appropriate cores , thus preventing migration of the threads. Then the Intel MKL LAPACK routine is called:

```
        // Set affinity mask
        #include <windows.h>
        #include <omp.h>
        int main(void) {
        #pragma omp parallel default(shared)
        {
        int tid = omp_get_thread_num();
        // 2 packages x 2 cores/pkg x 1 threads/core (4 total cores)
        DWORD_PTR mask = (1 << (tid == 0 ? 0 : 2 ));
        SetThreadAffinityMask( GetCurrentThread(), mask );
        }
        // Call Intel MKL LAPACK routine
        return 0;
        }
```

Compile the application with the Intel compiler using the following command:

```
icl /Qopenmp test_application.c
```

where `test_application.c` is the filename for the application.

Build the application. Run it in four threads, for example, by using the environment variable to set the number of threads:

```
set OMP_NUM_THREADS=4
test_application.exe
```

See Windows API documentation at msdn.microsoft.com/ for the restrictions on the usage of Windows API routines and particulars of the `SetThreadAffinityMask` function used in the above example.

See also a similar example at en.wikipedia.org/wiki/Affinity_mask .

Operating on Denormals

The IEEE 754-2008 standard, "An IEEE Standard for Binary Floating-Point Arithmetic", defines *denormal* (or *subnormal*) numbers as non-zero numbers smaller than the smallest possible normalized numbers for a specific floating-point format. Floating-point operations on denormals are slower than on normalized operands because denormal operands and results are usually handled through a software assist mechanism rather than directly in hardware. This software processing causes Intel MKL functions that consume denormals to run slower than with normalized floating-point numbers.

You can mitigate this performance issue by setting the appropriate bit fields in the MXCSR floating-point control register to flush denormals to zero (FTZ) or to replace any denormals loaded from memory with zero (DAZ). Check your compiler documentation to determine whether it has options to control FTZ and DAZ. Note that these compiler options may slightly affect accuracy.

FFT Optimized Radices

You can improve the performance of Intel MKL FFT if the length of your data vector permits factorization into powers of optimized radices.

In Intel MKL, the optimized radices are 2, 3, 5, 7, 11, and 13.

Using Memory Management

Intel MKL Memory Management Software

Intel MKL has memory management software that controls memory buffers for the use by the library functions. New buffers that the library allocates when your application calls Intel MKL are not deallocated until the program ends. To get the amount of memory allocated by the memory management software, call the `mkl_mem_stat()` function. If your program needs to free memory, call `mkl_free_buffers()`. If another call is made to a library function that needs a memory buffer, the memory manager again allocates the buffers and they again remain allocated until either the program ends or the program deallocates the memory. This behavior facilitates better performance. However, some tools may report this behavior as a memory leak.

The memory management software is turned on by default. To turn it off, set the `MKL_DISABLE_FAST_MM` environment variable to any value or call the `mkl_disable_fast_mm()` function. Be aware that this change may negatively impact performance of some Intel MKL routines, especially for small problem sizes.

Redefining Memory Functions

In C/C++ programs, you can replace Intel MKL memory functions that the library uses by default with your own functions. To do this, use the *memory renaming* feature.

Memory Renaming

Intel MKL memory management by default uses standard C run-time memory functions to allocate or free memory. These functions can be replaced using memory renaming.

Intel MKL accesses the memory functions by pointers `i_malloc`, `i_free`, `i_calloc`, and `i_realloc`, which are visible at the application level. These pointers initially hold addresses of the standard C run-time memory functions `malloc`, `free`, `calloc`, and `realloc`, respectively. You can programmatically redefine values of these pointers to the addresses of your application's memory management functions.

Redirecting the pointers is the only correct way to use your own set of memory management functions. If you call your own memory functions without redirecting the pointers, the memory will get managed by two independent memory management packages, which may cause unexpected memory issues.

How to Redefine Memory Functions

To redefine memory functions, use the following procedure:

If you are using the statically linked Intel MKL,

1. Include the `i_malloc.h` header file in your code.
   This header file contains all declarations required for replacing the memory allocation functions. The header file also describes how memory allocation can be replaced in those Intel libraries that support this feature.
2. Redefine values of pointers `i_malloc, i_free, i_calloc`, and `i_realloc` prior to the first call to MKL functions, as shown in the following example:

```
            #include "i_malloc.h"
              . . .
              i_malloc  = my_malloc;
              i_calloc  = my_calloc;
              i_realloc = my_realloc;
              i_free    = my_free;
              . . .
            // Now you may call Intel MKL functions
```

If you are using the dynamically linked Intel MKL,

1. Include the `i_malloc.h` header file in your code.
2. Redefine values of pointers `i_malloc_dll, i_free_dll, i_calloc_dll`, and `i_realloc_dll` prior to the first call to MKL functions, as shown in the following example:

```
#include "i_malloc.h"
  . . .
  i_malloc_dll  = my_malloc;
  i_calloc_dll  = my_calloc;
  i_realloc_dll = my_realloc;
  i_free_dll    = my_free;
. . .
// Now you may call Intel MKL functions
```

Language-specific Usage Options 6

The Intel® Math Kernel Library (Intel® MKL) provides broad support for Fortran and C/C++ programming. However, not all functions support both Fortran and C interfaces. For example, some LAPACK functions have no C interface. You can call such functions from C using mixed-language programming.

If you want to use LAPACK or BLAS functions that support Fortran 77 in the Fortran 95 environment, additional effort may be initially required to build compiler-specific interface libraries and modules from the source code provided with Intel MKL.

Optimization Notice

Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice.

Notice revision #20110804

Using Language-Specific Interfaces with Intel® Math Kernel Library

This section discusses mixed-language programming and the use of language-specific interfaces with Intel MKL.

See also the "FFTW Interface to Intel® Math Kernel Library" Appendix in the Intel MKL Reference Manual for details of the FFTW interfaces to Intel MKL.

Interface Libraries and Modules

You can create the following interface libraries and modules using the respective makefiles located in the interfaces directory.

File name	Contains
Libraries, in Intel MKL architecture-specific directories	
`mkl_blas95.lib`[1]	Fortran 95 wrappers for BLAS (BLAS95) for IA-32 architecture.
`mkl_blas95_ilp64.lib`[1]	Fortran 95 wrappers for BLAS (BLAS95) supporting LP64 interface.
`mkl_blas95_lp64.lib`[1]	Fortran 95 wrappers for BLAS (BLAS95) supporting ILP64 interface.
`mkl_lapack95.lib`[1]	Fortran 95 wrappers for LAPACK (LAPACK95) for IA-32 architecture.
`mkl_lapack95_lp64.lib`[1]	Fortran 95 wrappers for LAPACK (LAPACK95) supporting LP64 interface.
`mkl_lapack95_ilp64.lib`[1]	Fortran 95 wrappers for LAPACK (LAPACK95) supporting ILP64 interface.

File name	Contains
`fftw2xc_intel.lib`[1]	Interfaces for FFTW version 2.x (C interface for Intel compilers) to call Intel MKL FFTs.
`fftw2xc_ms.lib`	Contains interfaces for FFTW version 2.x (C interface for Microsoft compilers) to call Intel MKL FFTs.
`fftw2xf_intel.lib`	Interfaces for FFTW version 2.x (Fortran interface for Intel compilers) to call Intel MKL FFTs.
`fftw3xc_intel.lib`[2]	Interfaces for FFTW version 3.x (C interface for Intel compiler) to call Intel MKL FFTs.
`fftw3xc_ms.lib`	Interfaces for FFTW version 3.x (C interface for Microsoft compilers) to call Intel MKL FFTs.
`fftw3xf_intel.lib`[2]	Interfaces for FFTW version 3.x (Fortran interface for Intel compilers) to call Intel MKL FFTs.
`fftw2x_cdft_SINGLE.lib`	Single-precision interfaces for MPI FFTW version 2.x (C interface) to call Intel MKL cluster FFTs.
`fftw2x_cdft_DOUBLE.lib`	Double-precision interfaces for MPI FFTW version 2.x (C interface) to call Intel MKL cluster FFTs.
`fftw3x_cdft.lib`	Interfaces for MPI FFTW version 3.x (C interface) to call Intel MKL cluster FFTs.
`fftw3x_cdft_ilp64.lib`	Interfaces for MPI FFTW version 3.x (C interface) to call Intel MKL cluster FFTs supporting the ILP64 interface.
Modules, in architecture- and interface-specific subdirectories of the Intel MKL include directory	
`blas95.mod`[1]	Fortran 95 interface module for BLAS (BLAS95).
`lapack95.mod` [1]	Fortran 95 interface module for LAPACK (LAPACK95).
`f95_precision.mod`[1]	Fortran 95 definition of precision parameters for BLAS95 and LAPACK95.
`mkl95_blas.mod`[1]	Fortran 95 interface module for BLAS (BLAS95), identical to blas95.mod. To be removed in one of the future releases.
`mkl95_lapack.mod`[1]	Fortran 95 interface module for LAPACK (LAPACK95), identical to lapack95.mod. To be removed in one of the future releases.
`mkl95_precision.mod`[1]	Fortran 95 definition of precision parameters for BLAS95 and LAPACK95, identical to `f95_precision.mod`. To be removed in one of the future releases.
`mkl_service.mod`[1]	Fortran 95 interface module for Intel MKL support functions.

[1] Prebuilt for the Intel® Fortran compiler

[2] FFTW3 interfaces are integrated with Intel MKL. Look into `<mkl directory>\interfaces\fftw3x*\makefile` for options defining how to build and where to place the standalone library with the wrappers.

See Also

Fortran 95 Interfaces to LAPACK and BLAS

Fortran 95 Interfaces to LAPACK and BLAS

Fortran 95 interfaces are compiler-dependent. Intel MKL provides the interface libraries and modules precompiled with the Intel® Fortran compiler. Additionally, the Fortran 95 interfaces and wrappers are delivered as sources. (For more information, see Compiler-dependent Functions and Fortran 90 Modules). If you are using a different compiler, build the appropriate library and modules with your compiler and link the library as a user's library:

1. Go to the respective directory `<mkl directory>\interfaces\blas95` or `<mkl directory>\interfaces\lapack95`
2. Type one of the following commands depending on your architecture:
   - For the IA-32 architecture,

     ```
     nmake libia32 install_dir=<user dir>
     ```
   - For the Intel® 64 architecture,

     ```
     nmake libintel64 [interface=lp64|ilp64] install_dir=<user dir>
     ```

Important The parameter `install_dir` is required.

As a result, the required library is built and installed in the `<user dir>\lib` directory, and the `.mod` files are built and installed in the `<user dir>\include\<arch>[\{lp64|ilp64}]` directory, where `<arch>` is one of `{ia32, intel64}`.

By default, the ifort compiler is assumed. You may change the compiler with an additional parameter of `nmake`:
`FC=<compiler>`.

For example, the command

```
nmake libintel64 FC=f95 install_dir=<userf95 dir> interface=lp64
```

builds the required library and `.mod` files and installs them in subdirectories of `<userf95 dir>`.

To delete the library from the building directory, use one of the following commands:

- For the IA-32 architecture,

  ```
  nmake cleania32 install_dir=<user dir>
  ```
- For the Intel® 64 architecture,

  ```
  nmake cleanintel64 [interface=lp64|ilp64] install_dir=<user dir>
  ```
- For all the architectures,

  ```
  nmake clean install_dir=<user dir>
  ```

CAUTION Even if you have administrative rights, avoid setting `install_dir=..\..` or `install_dir=<mkl directory>` in a build or clean command above because these settings replace or delete the Intel MKL prebuilt Fortran 95 library and modules.

Compiler-dependent Functions and Fortran 90 Modules

Compiler-dependent functions occur whenever the compiler inserts into the object code function calls that are resolved in its run-time library (RTL). Linking of such code without the appropriate RTL will result in undefined symbols. Intel MKL has been designed to minimize RTL dependencies.

In cases where RTL dependencies might arise, the functions are delivered as source code and you need to compile the code with whatever compiler you are using for your application.

In particular, Fortran 90 modules result in the compiler-specific code generation requiring RTL support. Therefore, Intel MKL delivers these modules compiled with the Intel compiler, along with source code, to be used with different compilers.

Using the stdcall Calling Convention in C/C++

Intel MKL supports stdcall calling convention for the following function domains:

- BLAS Routines
- Sparse BLAS Routines
- LAPACK Routines
- Vector Mathematical Functions
- Vector Statistical Functions
- PARDISO
- Direct Sparse Solvers
- RCI Iterative Solvers
- Support Functions

To use the stdcall calling convention in C/C++, follow the guidelines below:

- In your function calls, pass lengths of character strings to the functions. For example, compare the following calls to `dgemm`:

  cdecl: `dgemm("N", "N", &n, &m, &k, &alpha, b, &ldb, a, &lda, &beta, c, &ldc);`

  stdcall: `dgemm("N", 1, "N", 1, &n, &m, &k, &alpha, b, &ldb, a, &lda, &beta, c, &ldc);`
- Define the `MKL_STDCALL` macro using either of the following techniques:
  - Define the macro in your source code before including Intel MKL header files:

    ```
    ...
    #define MKL_STDCALL
    #include "mkl.h"
    ...
    ```
  - Pass the macro to the compiler. For example:

    ```
    icl -DMKL_STDCALL foo.c
    ```
- Link your application with the following library:
  - `mkl_intel_s.lib` for static linking
  - `mkl_intel_s_dll.lib` for dynamic linking

See Also
Using the cdecl and stdcall Interfaces
Compiling an Application that Calls the Intel® Math Kernel Library and Uses the CVF Calling Conventions
Include Files

Compiling an Application that Calls the Intel® Math Kernel Library and Uses the CVF Calling Conventions

The IA-32 architecture implementation of Intel MKL supports the Compaq Visual Fortran* (CVF) calling convention by providing the stdcall interface.

Although the Intel MKL does not provide the CVF interface in its Intel® 64 architecture implementation, you can use the Intel® Visual Fortran Compiler to compile your Intel® 64 architecture application that calls Intel MKL and uses the CVF calling convention. To do this:

- Provide the following compiler options to enable compatibility with the CVF calling convention:
  `/Gm` or `/iface:cvf`
- Additionally provide the following options to enable calling Intel MKL from your application:
  `/iface:nomixed_str_len_arg`

See Also

Using the cdecl and stdcall Interfaces
Compiler Support

Mixed-language Programming with the Intel Math Kernel Library

Appendix A: Intel(R) Math Kernel Library Language Interfaces Support lists the programming languages supported for each Intel MKL function domain. However, you can call Intel MKL routines from different language environments.

Calling LAPACK, BLAS, and CBLAS Routines from C/C++ Language Environments

Not all Intel MKL function domains support both C and Fortran environments. To use Intel MKL Fortran-style functions in C/C++ environments, you should observe certain conventions, which are discussed for LAPACK and BLAS in the subsections below.

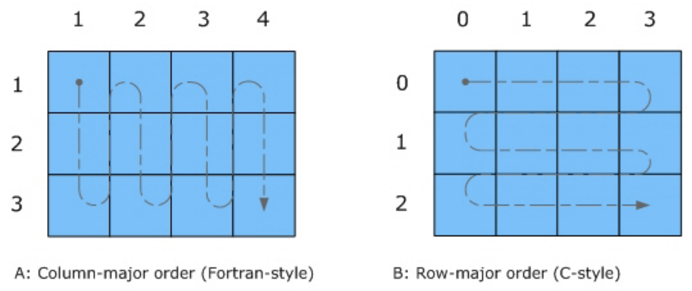
CAUTION Avoid calling BLAS 95/LAPACK 95 from C/C++. Such calls require skills in manipulating the descriptor of a deferred-shape array, which is the Fortran 90 type. Moreover, BLAS95/LAPACK95 routines contain links to a Fortran RTL.

LAPACK and BLAS

Because LAPACK and BLAS routines are Fortran-style, when calling them from C-language programs, follow the Fortran-style calling conventions:

- Pass variables by *address*, not by *value*.
  Function calls in Example "Calling a Complex BLAS Level 1 Function from C++" and Example "Using CBLAS Interface Instead of Calling BLAS Directly from C" illustrate this.
- Store your data in Fortran style, that is, column-major rather than row-major order.

With row-major order, adopted in C, the last array index changes most quickly and the first one changes most slowly when traversing the memory segment where the array is stored. With Fortran-style column-major order, the last index changes most slowly whereas the first index changes most quickly (as illustrated by the figure below for a two-dimensional array).


1
2
3
4
1
2
3
A: Column-major order (Fortran-style)
0
1
2
3
0
1
2
B: Row-major order (C-style)

For example, if a two-dimensional matrix A of size `mxn` is stored densely in a one-dimensional array B, you can access a matrix element like this:

`A[i][j] = B[i*n+j]` in C (`i=0, ... , m-1, j=0, ... , -1`)

`A(i,j) = B((j-1)*m+i)` in Fortran (`i=1, ... , m, j=1, ... , n`).

When calling LAPACK or BLAS routines from C, be aware that because the Fortran language is case-insensitive, the routine names can be both upper-case or lower-case, with or without the trailing underscore. For example, the following names are equivalent:

- LAPACK: `dgetrf`, `DGETRF`, `dgetrf_`, and `DGETRF_`
- BLAS: `dgemm`, `DGEMM`, `dgemm_`, and `DGEMM_`

See Example "Calling a Complex BLAS Level 1 Function from C++" on how to call BLAS routines from C.

See also the Intel(R) MKL Reference Manual for a description of the C interface to LAPACK functions.

CBLAS

Instead of calling BLAS routines from a C-language program, you can use the CBLAS interface.

CBLAS is a C-style interface to the BLAS routines. You can call CBLAS routines using regular C-style calls. Use the `mkl.h` header file with the CBLAS interface. The header file specifies enumerated values and prototypes of all the functions. It also determines whether the program is being compiled with a C++ compiler, and if it is, the included file will be correct for use with C++ compilation. Example "Using CBLAS Interface Instead of Calling BLAS Directly from C" illustrates the use of the CBLAS interface.

C Interface to LAPACK

Instead of calling LAPACK routines from a C-language program, you can use the C interface to LAPACK provided by Intel MKL.

The C interface to LAPACK is a C-style interface to the LAPACK routines. This interface supports matrices in row-major and column-major order, which you can define in the first function argument *`matrix_order`*. Use the `mkl.h` header file with the C interface to LAPACK. `mkl.h` includes the `mkl_lapacke.h` header file, which specifies constants and prototypes of all the functions. It also determines whether the program is being compiled with a C++ compiler, and if it is, the included file will be correct for use with C++ compilation. You can find examples of the C interface to LAPACK in the `examples\lapacke` subdirectory in the Intel MKL installation directory.

Using Complex Types in C/C++

As described in the documentation for the Intel© Visual Fortran Compiler XE, C/C++ does not directly implement the Fortran types `COMPLEX(4)` and `COMPLEX(8)`. However, you can write equivalent structures. The type `COMPLEX(4)` consists of two 4-byte floating-point numbers. The first of them is the real-number component, and the second one is the imaginary-number component. The type `COMPLEX(8)` is similar to `COMPLEX(4)` except that it contains two 8-byte floating-point numbers.

Intel MKL provides complex types `MKL_Complex8` and `MKL_Complex16`, which are structures equivalent to the Fortran complex types `COMPLEX(4)` and `COMPLEX(8)`, respectively. The `MKL_Complex8` and `MKL_Complex16` types are defined in the `mkl_types.h` header file. You can use these types to define complex data. You can also redefine the types with your own types before including the `mkl_types.h` header file. The only requirement is that the types must be compatible with the Fortran complex layout, that is, the complex type must be a pair of real numbers for the values of real and imaginary parts.

For example, you can use the following definitions in your C++ code:

```
#define MKL_Complex8 std::complex<float>
```

and

```
#define MKL_Complex16 std::complex<double>
```

See Example "Calling a Complex BLAS Level 1 Function from C++" for details. You can also define these types in the command line:

```
-DMKL_Complex8="std::complex<float>"
-DMKL_Complex16="std::complex<double>"
```

See Also

Intel® Software Documentation Library

Calling BLAS Functions that Return the Complex Values in C/C++ Code

Complex values that functions return are handled differently in C and Fortran. Because BLAS is Fortran-style, you need to be careful when handling a call from C to a BLAS function that returns complex values. However, in addition to normal function calls, Fortran enables calling functions as though they were subroutines, which provides a mechanism for returning the complex value correctly when the function is called from a C program. When a Fortran function is called as a subroutine, the return value is the first parameter in the calling sequence. You can use this feature to call a BLAS function from C.

The following example shows how a call to a Fortran function as a subroutine converts to a call from C and the hidden parameter result gets exposed:

Normal Fortran function call:	`result = cdotc( n, x, 1, y, 1 )`
A call to the function as a subroutine:	`call cdotc( result, n, x, 1, y, 1)`
A call to the function from C:	`cdotc( &result, &n, x, &one, y, &one )`

NOTE Intel MKL has both upper-case and lower-case entry points in the Fortran-style (case-insensitive) BLAS, with or without the trailing underscore. So, all these names are equivalent and acceptable: `cdotc`, `CDOTC`, `cdotc_`, and `CDOTC_`.

The above example shows one of the ways to call several level 1 BLAS functions that return complex values from your C and C++ applications. An easier way is to use the CBLAS interface. For instance, you can call the same function using the CBLAS interface as follows:

```
cblas_cdotu( n, x, 1, y, 1, &result )
```

NOTE The complex value comes last on the argument list in this case.

The following examples show use of the Fortran-style BLAS interface from C and C++, as well as the CBLAS (C language) interface:

- Example "Calling a Complex BLAS Level 1 Function from C"
- Example "Calling a Complex BLAS Level 1 Function from C++"
- Example "Using CBLAS Interface Instead of Calling BLAS Directly from C"

Example "Calling a Complex BLAS Level 1 Function from C"

The example below illustrates a call from a C program to the complex BLAS Level 1 function `zdotc()`. This function computes the dot product of two double-precision complex vectors.

In this example, the complex dot product is returned in the structure `c`.

```
#include "mkl.h"
#define N 5
int main()
{
int n = N, inca = 1, incb = 1, i;
MKL_Complex16 a[N], b[N], c;
for( i = 0; i < n; i++ ){
a[i].real = (double)i; a[i].imag = (double)i * 2.0;
b[i].real = (double)(n - i); b[i].imag = (double)i * 2.0;
}
zdotc( &c, &n, a, &inca, b, &incb );
printf( "The complex dot product is: ( %6.2f, %6.2f)\n", c.real, c.imag );
return 0;
}
```

Example "Calling a Complex BLAS Level 1 Function from C++"

Below is the C++ implementation:

```
#include <complex>
#include <iostream>
#define MKL_Complex16 std::complex<double>
#include "mkl.h"

#define N 5

int main()
{
    int n, inca = 1, incb = 1, i;
    std::complex<double> a[N], b[N], c;
    n = N;

    for( i = 0; i < n; i++ ){
        a[i] = std::complex<double>(i,i*2.0);
        b[i] = std::complex<double>(n-i,i*2.0);
    }
    zdotc(&c, &n, a, &inca, b, &incb );
    std::cout << "The complex dot product is: " << c << std::endl;
    return 0;
}
```

Example "Using CBLAS Interface Instead of Calling BLAS Directly from C"

This example uses CBLAS:

```
#include <stdio.h>
#include "mkl.h"
typedef struct{ double re; double im; } complex16;
#define N 5
int main()
{
int n, inca = 1, incb = 1, i;
complex16 a[N], b[N], c;
n = N;
for( i = 0; i < n; i++ ){
a[i].re = (double)i; a[i].im = (double)i * 2.0;
b[i].re = (double)(n - i); b[i].im = (double)i * 2.0;
}
cblas_zdotc_sub(n, a, inca, b, incb, &c );
printf( "The complex dot product is: ( %6.2f, %6.2f)\n", c.re, c.im );
return 0;
}
```

Support for Boost uBLAS Matrix-matrix Multiplication

If you are used to uBLAS, you can perform BLAS matrix-matrix multiplication in C++ using Intel MKL substitution of Boost uBLAS functions. uBLAS is the Boost C++ open-source library that provides BLAS functionality for dense, packed, and sparse matrices. The library uses an expression template technique for passing expressions as function arguments, which enables evaluating vector and matrix expressions in one pass without temporary matrices. uBLAS provides two modes:

- Debug (safe) mode, default.
  Checks types and conformance.
- Release (fast) mode.
  Does not check types and conformance. To enable this mode, use the `NDEBUG` preprocessor symbol.

The documentation for the Boost uBLAS is available at www.boost.org.

Intel MKL provides overloaded `prod()` functions for substituting uBLAS dense matrix-matrix multiplication with the Intel MKL `gemm` calls. Though these functions break uBLAS expression templates and introduce temporary matrices, the performance advantage can be considerable for matrix sizes that are not too small (roughly, over 50).

You do not need to change your source code to use the functions. To call them:

- Include the header file `mkl_boost_ublas_matrix_prod.hpp` in your code (from the Intel MKL include directory)
- Add appropriate Intel MKL libraries to the link line.

The list of expressions that are substituted follows:

```
prod( m1, m2 )

prod( trans(m1), m2 )

prod( trans(conj(m1)), m2 )

prod( conj(trans(m1)), m2 )

prod( m1, trans(m2) )

prod( trans(m1), trans(m2) )

prod( trans(conj(m1)), trans(m2) )

prod( conj(trans(m1)), trans(m2) )

prod( m1, trans(conj(m2)) )

prod( trans(m1), trans(conj(m2)) )

prod( trans(conj(m1)), trans(conj(m2)) )

prod( conj(trans(m1)), trans(conj(m2)) )

prod( m1, conj(trans(m2)) )

prod( trans(m1), conj(trans(m2)) )

prod( trans(conj(m1)), conj(trans(m2)) )

prod( conj(trans(m1)), conj(trans(m2)) )
```

These expressions are substituted in the *release* mode only (with `NDEBUG` preprocessor symbol defined). Supported uBLAS versions are Boost 1.34.1 and higher. To get them, visit www.boost.org.

A code example provided in the `<mkl directory>\examples\ublas\source\sylvester.cpp` file illustrates usage of the Intel MKL uBLAS header file for solving a special case of the Sylvester equation.

To run the Intel MKL ublas examples, specify the `boost_root` parameter in the `n make` command, for instance, when using Boost version 1.37.0:

```
nmake libia32 boost_root = <your_path>\boost_1_37_0
```

Intel MKL ublas examples on default Boost uBLAS configuration support only:

- Microsoft Visual C++* Compiler versions 2008 and higher
- Intel C++ Compiler versions 11.1 and higher with Microsoft Visual Studio IDE versions 2008 and higher

See Also

Using Code Examples

Invoking Intel MKL Functions from Java* Applications

Intel MKL Java* Examples

To demonstrate binding with Java, Intel MKL includes a set of Java examples in the following directory:

`<mkl directory>\examples\java`.

The examples are provided for the following MKL functions:

- `?gemm`, `?gemv`, and `?dot` families from CBLAS
- The complete set of non-cluster FFT functions
- ESSL[1]-like functions for one-dimensional convolution and correlation
- VSL Random Number Generators (RNG), except user-defined ones and file subroutines
- VML functions, except `GetErrorCallBack`, `SetErrorCallBack`, and `ClearErrorCallBack`

You can see the example sources in the following directory:

`<mkl directory>\examples\java\examples`.

The examples are written in Java. They demonstrate usage of the MKL functions with the following variety of data:

- 1- and 2-dimensional data sequences
- Real and complex types of the data
- Single and double precision

However, the wrappers, used in the examples, do not:

- Demonstrate the use of large arrays (>2 billion elements)
- Demonstrate processing of arrays in native memory
- Check correctness of function parameters
- Demonstrate performance optimizations

The examples use the Java Native Interface (JNI* developer framework) to bind with Intel MKL. The JNI documentation is available from http://java.sun.com/javase/6/docs/technotes/guides/jni/.

The Java example set includes JNI wrappers that perform the binding. The wrappers do not depend on the examples and may be used in your Java applications. The wrappers for CBLAS, FFT, VML, VSL RNG, and ESSL-like convolution and correlation functions do not depend on each other.

To build the wrappers, just run the examples. The makefile builds the wrapper binaries. After running the makefile, you can run the examples, which will determine whether the wrappers were built correctly. As a result of running the examples, the following directories will be created in `<mkl directory>\examples\java`:

- `docs`
- `include`
- `classes`
- `bin`
- `_results`

The directories `docs`, `include`, `classes`, and `bin` will contain the wrapper binaries and documentation; the directory `_results` will contain the testing results.

For a Java programmer, the wrappers are the following Java classes:

- `com.intel.mkl.CBLAS`
- `com.intel.mkl.DFTI`
- `com.intel.mkl.ESSL`
- `com.intel.mkl.VML`
- `com.intel.mkl.VSL`

Documentation for the particular wrapper and example classes will be generated from the Java sources while building and running the examples. To browse the documentation, open the index file in the `docs` directory (created by the build script):

<mkl directory>`\examples\java\docs\index.html`.

The Java wrappers for CBLAS, VML, VSL RNG, and FFT establish the interface that directly corresponds to the underlying native functions, so you can refer to the Intel MKL Reference Manual for their functionality and parameters. Interfaces for the ESSL-like functions are described in the generated documentation for the `com.intel.mkl.ESSL` class.

Each wrapper consists of the interface part for Java and JNI stub written in C. You can find the sources in the following directory:

<mkl directory>`\examples\java\wrappers`.

Both Java and C parts of the wrapper for CBLAS and VML demonstrate the straightforward approach, which you may use to cover additional CBLAS functions.

The wrapper for FFT is more complicated because it needs to support the lifecycle for FFT descriptor objects. To compute a single Fourier transform, an application needs to call the FFT software several times with the same copy of the native FFT descriptor. The wrapper provides the handler class to hold the native descriptor, while the virtual machine runs Java bytecode.

The wrapper for VSL RNG is similar to the one for FFT. The wrapper provides the handler class to hold the native descriptor of the stream state.

The wrapper for the convolution and correlation functions mitigates the same difficulty of the VSL interface, which assumes a similar lifecycle for "task descriptors". The wrapper utilizes the ESSL-like interface for those functions, which is simpler for the case of 1-dimensional data. The JNI stub additionally encapsulates the MKL functions into the ESSL-like wrappers written in C and so "packs" the lifecycle of a task descriptor into a single call to the native method.

The wrappers meet the JNI Specification versions 1.1 and 5.0 and should work with virtually every modern implementation of Java.

The examples and the Java part of the wrappers are written for the Java language described in "The Java Language Specification (First Edition)" and extended with the feature of "inner classes" (this refers to late 1990s). This level of language version is supported by all versions of the Sun Java Development Kit* (JDK*) developer toolkit and compatible implementations starting from version 1.1.5, or by all modern versions of Java.

The level of C language is "Standard C" (that is, C89) with additional assumptions about integer and floating-point data types required by the Intel MKL interfaces and the JNI header files. That is, the native `float` and `double` data types must be the same as JNI `jfloat` and `jdouble` data types, respectively, and the native `int` must be 4 bytes long.

[1] IBM Engineering Scientific Subroutine Library (ESSL*).

See Also

Running the Java* Examples

Running the Java* Examples

The Java examples support all the C and C++ compilers that Intel MKL does. The makefile intended to run the examples also needs the n make utility, which is typically provided with the C/C++ compiler package.

To run Java examples, the JDK* developer toolkit is required for compiling and running Java code. A Java implementation must be installed on the computer or available via the network. You may download the JDK from the vendor website.

The examples should work for all versions of JDK. However, they were tested only with the following Java implementation s for all the supported architectures:

- J2SE* SDK 1.4.2, JDK 5.0 and 6.0 from Sun Microsystems, Inc. (http://sun.com/).
- JRockit* JDK 1.4.2 and 5.0 from Oracle Corporation (http://oracle.com/).

Note that the Java run-time environment* (JRE*) system, which may be pre-installed on your computer, is not enough. You need the JDK* developer toolkit that supports the following set of tools:

- java
- javac
- javah
- javadoc

To make these tools available for the examples makefile, set the `JAVA_HOME` environment variable and add the JDK binaries directory to the system `PATH`, for example :

```
SET JAVA_HOME=C:\Program Files\Java\jdk1.5.0_09
```

```
SET PATH=%JAVA_HOME%\bin;%PATH%
```

You may also need to clear the `JDK_HOME` environment variable, if it is assigned a value:

```
SET JDK_HOME=
```

To start the examples, use the makefile found in the Intel MKL Java examples directory:

```
nmake {dllia32|dllintel64|libia32|libintel64} [function=...] [compiler=...]
```

If you type the make command and omit the target (for example, `dllia32`), the makefile prints the help info, which explains the targets and parameters.

For the examples list, see the `examples.lst` file in the Java examples directory.

Known Limitations of the Java* Examples

This section explains limitations of Java examples.

Functionality

Some Intel MKL functions may fail to work if called from the Java environment by using a wrapper, like those provided with the Intel MKL Java examples. Only those specific CBLAS, FFT, VML, VSL RNG, and the convolution/correlation functions listed in the Intel MKL Java Examples section were tested with the Java environment. So, you may use the Java wrappers for these CBLAS, FFT, VML, VSL RNG, and convolution/correlation functions in your Java applications.

Performance

The Intel MKL functions must work faster than similar functions written in pure Java. However, the main goal of these wrappers is to provide code examples, not maximum performance. So, an Intel MKL function called from a Java application will probably work slower than the same function called from a program written in C/C++ or Fortran.

Known bugs

There are a number of known bugs in Intel MKL (identified in the Release Notes), as well as incompatibilities between different versions of JDK. The examples and wrappers include workarounds for these problems. Look at the source code in the examples and wrappers for comments that describe the workarounds.

Obtaining Numerically Reproducible Results 7

Intel® Math Kernel Library (Intel® MKL) offers functions and environment variables that help you obtain Conditional Numerical Reproducibility (CNR) of floating-point results when calling the library functions from your application. These new controls enable Intel MKL to run in a special mode, when functions return bitwise reproducible floating-point results from run to run under the following conditions:

- Calls to Intel MKL occur in a single executable
- Input and output arrays in function calls are properly aligned
- The number of computational threads used by the library does not change in the run

It is well known that for general single and double precision IEEE floating-point numbers, the associative property does not always hold, meaning (a+b)+c may not equal a +(b+c). Let's consider a specific example. In infinite precision arithmetic $2^{-63} + 1 + -1 = 2^{-63}$. If this same computation is done on a computer using double precision floating-point numbers, a rounding error is introduced, and the order of operations becomes important:

$(2^{-63} + 1) + (-1) \simeq 1 + (-1) = 0$

versus

$2^{-63} + (1 + (-1)) \simeq 2^{-63} + 0 = 2^{-63}$

This inconsistency in results due to order of operations is precisely what the new functionality addresses.

The application related factors that affect the order of floating-point operations within a single executable program include selection of a code path based on run-time processor dispatching, alignment of data arrays, variation in number of threads, threaded algorithms and internal floating-point control settings. You can control most of these factors by controlling the number of threads and floating-point settings and by taking steps to align memory when it is allocated (see the Getting Reproducible Results with Intel® MKL knowledge base article for details). However, run-time dispatching and certain threaded algorithms did not allow users to make changes that can ensure the same order of operations from run to run.

Intel MKL does run-time processor dispatching in order to identify the appropriate internal code paths to traverse for the Intel MKL functions called by the application. The code paths chosen may differ across a wide range of Intel processors and Intel architecture compatible processors and may provide differing levels of performance. For example, an Intel MKL function running on an Intel® Pentium® 4 processor may run one code path, while on the latest Intel® Xeon® processor it will run another code path. This happens because each unique code path has been optimized to match the features available on the underlying processor. One key way that the new features of a processor are exposed to the programmer is through the instruction set architecture (ISA). Because of this, code branches in Intel MKL are designated by the latest ISA they use for optimizations: from the Intel® Streaming SIMD Extensions 2 (Intel® SSE2) to the Intel® Advanced Vector Extensions (Intel® AVX). The feature-based approach introduces a challenge: if any of the internal floating-point operations are done in a different order or are re-associated, the computed results may differ.

Dispatching optimized code paths based on the capabilities of the processor on which the code is running is central to the optimization approach used by Intel MKL. So it is natural that consistent results require some performance trade-offs. If limited to a particular code path, performance of Intel MKL can in some circumstances degrade by more than a half. To understand this, note that matrix-multiply performance nearly doubled with the introduction of new processors supporting Intel AVX instructions. Even if the code branch is not restricted, performance can degrade by 10-20% because the new functionality restricts algorithms to maintain the order of operations.

Getting Started with Conditional Numerical Reproducibility

Intel MKL offers functions and environment variables to increase your chances of getting reproducible results. You can configure Intel MKL using functions or environment variables, but the functions provide more flexibility.

The following specific examples introduce you to the conditional numerical reproducibility.

Intel CPUs supporting Intel AVX

To ensure Intel MKL calls return the same results on every Intel CPU supporting Intel AVX instructions:

1. Make sure that:
   - Your application uses a fixed number of threads
   - Input and output arrays in Intel MKL function calls are aligned properly
2. Do either of the following:
   - Call

     ```
     mkl_cbwr_set(MKL_CBWR_AVX)
     ```
   - Set the environment variable

     ```
     MKL_CBWR_BRANCH = AVX
     ```

NOTE On non-Intel CPUs and on Intel CPUs that do not support Intel AVX, this environment setting may cause results to differ because the `AUTO` branch is used instead, while the above function call returns an error and does not enable the CNR mode.

Intel CPUs supporting Intel SSE2

To ensure Intel MKL calls return the same results on every Intel CPU supporting Intel SSE2 instructions:

1. Make sure that:
   - Your application uses a fixed number of threads
   - Input and output arrays in Intel MKL function calls are aligned properly
2. Do either of the following:
   - Call

     ```
     mkl_cbwr_set(MKL_CBWR_SSE2)
     ```
   - Set the environment variable

     ```
     MKL_CBWR_BRANCH = SSE2
     ```

NOTE On non-Intel CPUs and on Intel CPUs that do not support Intel SSE2, this environment setting may cause results to differ because the `AUTO` branch is used instead, while the above function call returns an error and does not enable the CNR mode.

Intel or Intel compatible CPUs supporting Intel SSE2

On non-Intel CPUs, only the `MKL_CBWR_AUTO` and `MKL_CBWR_COMPATIBLE` options are supported for function calls and only `AUTO` and `COMPATIBLE` options for environment settings.

To ensure Intel MKL calls return the same results on all Intel or Intel compatible CPUs supporting Intel SSE2 instructions:

1. Make sure that:

- Your application uses a fixed number of threads
- Input and output arrays in Intel MKL function calls are aligned properly

2. Do either of the following:

- Call

  `mkl_cbwr_set(MKL_CBWR_COMPATIBLE)`
- Set the environment variable

  `MKL_CBWR_BRANCH = COMPATIBLE`

NOTE The special `MKL_CBWR_COMPATIBLE/COMPATIBLE` option is provided because Intel and Intel compatible CPUs have two approximation instructions(rcpps/rsqrtps) that may return different results. This option ensures that Intel MKL does not use these instructions and forces a single Intel SSE2 only code path to be executed.

Next steps

See Specifying the Code Branches	for details of specifying the branch using environment variables.

See the following sections in the *Intel MKL Reference Manual*:

Support Functions for Conditional Numerical Reproducibility	for how to configure the CNR mode of Intel MKL using functions.
PARDISO* - Parallel Direct Sparse Solver Interface	for how to configure the CNR mode for PARDISO.

See Also
Code Examples

Specifying the Code Branches

Intel MKL provides conditional numerically reproducible results for a code branch determined by the supported instruction set architecture (ISA). The values you can specify for the `MKL_CBWR` environment variable may have one of the following equivalent formats:

- `MKL_CBWR="`*`<branch>`*`"`
- `MKL_CBWR="BRANCH=`*`<branch>`*`"`

The *`<branch>`* placeholder specifies the CNR branch with one of the following values:

Value	Description
`AUTO`	CNR mode uses:

Value	Description
	• The standard ISA-based dispatching model on Intel processors while ensuring fixed cache sizes, deterministic reductions, and static scheduling • The branch corresponding to `COMPATIBLE` otherwise
	CNR mode uses the branch for the following ISA:
`COMPATIBLE`	Intel® Streaming SIMD Extensions 2 (Intel® SSE2) without rcpps/ rsqrtps instructions
`SSE2`	Intel SSE2
`SSE3`	Intel® Streaming SIMD Extensions 3 (Intel® SSE3)
`SSSE3`	Supplemental Streaming SIMD Extensions 3 (SSSE3)
`SSE4_1`	Intel® Streaming SIMD Extensions 4-1 (Intel® SSE4-1)
`SSE4_2`	Intel® Streaming SIMD Extensions 4-2 (Intel® SSE4-2)
`AVX`	Intel® Advanced Vector Extensions (Intel® AVX)
`AVX2`	Intel® Advanced Vector Extensions 2 (Intel® AVX2)

When specifying the CNR branch, be aware of the following:

- Reproducible results are provided under certain conditions.
- Settings other than `AUTO` or `COMPATIBLE` are available only for Intel processors. The code branch specified by `COMPATIBLE` is run on all non-Intel processors.
- To get the CNR branch optimized for the processor where your program is currently running, choose the value of `AUTO` or call the `mkl_cbwr_get_auto_branch` function.

Setting the `MKL_CBWR` environment variable or a call to an equivalent `mkl_set_cbwr_branch` function fixes the code branch and sets the reproducibility mode.

- If the value of the branch is incorrect or your processor does not support the specified branch, CNR ignores this value and uses the `AUTO` branch without providing any warning messages.
- Calls to functions that define the behavior of CNR must precede any of the math library functions that they control.
- Settings specified by the functions take precedence over the settings specified by the environment variable.

See the *Intel MKL Reference Manual* for how to specify the branches using functions.

See Also

Getting Started with Conditional Numerical Reproducibility

Reproducibility Conditions

Reproducible results are provided under these conditions:

- The number of threads is fixed and constant.

  Specifically:

  - If you are running your program on different processors, explicitly specify the number of threads.
  - To ensure that your application has deterministic behavior with OpenMP* parallelization and does not adjust the number of threads dynamically at run time, set `MKL_DYNAMIC` and `OMP_DYNAMIC` to FALSE. This is especially needed if you are running your program on different systems.

- Input and output arrays are aligned on 128-byte boundaries.

  Instead of the general 128-byte alignment, you can use a more specific alignment depending on the ISA. For example: 16-byte alignment suffices for Intel SSE2 or higher and 32-byte alignment suffices for Intel AVX or Intel AVX2. To ensure proper alignment of arrays, allocate memory for them using `mkl_malloc`.

Setting the Environment Variable for Conditional Numerical Reproducibility

The following examples illustrate the use of the `MKL_CBWR` environment variable. The first command sets Intel MKL to run in the CNR mode based on the default dispatching for your platform. The other two commands are equivalent and set the CNR branch to Intel AVX:

- `set MKL_CBWR="AUTO"`
- `set MKL_CBWR="AVX"`
- `set MKL_CBWR="BRANCH=AVX"`

See Also

Specifying the Code Branches

Code Examples

The following simple programs show how to obtain reproducible results from run to run of Intel MKL functions. See the *Intel MKL Reference Manual* for more examples.

C Example of CNR

```
#include <mkl.h>
int main(void) {
    int my_cbwr_branch;
    /* Align all input/output data on 128-byte boundaries to get reproducible results of Intel MKL
function calls */
    void *darray;
    int darray_size=1000;
    /* Set alignment value in bytes */
    int alignment=128;
    /* Allocate aligned array */
    darray = mkl_malloc (sizeof(double)*darray_size, alignment);
    /* Find the available MKL_CBWR_BRANCH automatically */
    my_cbwr_branch = mkl_cbwr_get_auto_branch();
    /* User code without Intel MKL calls */
    /* Piece of the code where CNR of Intel MKL is needed */
    /* The performance of Intel MKL functions might be reduced for CNR mode */
    if (mkl_cbwr_set(my_cbwr_branch)) {
        printf("Error in setting MKL_CBWR_BRANCH! Aborting…\n");
        return;
    }
    /* CNR calls to Intel MKL + any other code with aligned input\output data */
    /* Free the allocated aligned array */
    mkl_free(darray);
}
```

Fortran Example of CNR

```
    PROGRAM MAIN
    INCLUDE 'mkl.fi'
    INTEGER*4 MY_CBWR_BRANCH
! Align all input/output data on 128-byte boundaries to get reproducible results of Intel MKL function
calls
! Declare Intel MKL memory allocation routine
#ifdef _IA32
    INTEGER MKL_MALLOC
```

```
#else
    INTEGER*8 MKL_MALLOC
#endif
    EXTERNAL MKL_MALLOC, MKL_FREE
    DOUBLE PRECISION DARRAY
    POINTER (P_DARRAY,DARRAY(1))
    INTEGER DARRAY_SIZE
    PARAMETER (DARRAY_SIZE=1000)
! Set alignment value in bytes
    INTEGER ALIGNMENT
    PARAMETER (ALIGNMENT=128)
! Allocate aligned array
    P_DARRAY = MKL_MALLOC (%VAL(8*DARRAY_SIZE), %VAL(ALIGNMENT));
! Find the available MKL_CBWR_BRANCH automatically
    MY_CBWR_BRANCH = MKL_CBWR_GET_AUTO_BRANCH()
! User code without Intel MKL calls
! Piece of the code where CNR of Intel MKL is needed
! The performance of Intel MKL functions may be reduced for CNR mode
    IF (MKL_CBWR_SET (MY_CBWR_BRANCH) .NE. MKL_CBWR_SUCCESS) THEN
        PRINT *, 'Error in setting MKL_CBWR_BRANCH! Aborting…'
        RETURN
    ENDIF
! CNR calls to Intel MKL + any other code
! Free the allocated aligned array
    CALL MKL_FREE(P_DARRAY)

    END
```

Coding Tips

8

This section provides coding tips for managing data alignment and version-specific compilation.

Example of Data Alignment

Needs for best performance with Intel MKL or for reproducible results from run to run of Intel MKL functions require alignment of data arrays. The following example shows how to align an array on 64-byte boundaries. To do this, use `mkl_malloc()` in place of system provided memory allocators, as shown in the code example below.

Aligning Addresses on 64-byte Boundaries

```
// ******* C language *******
...
#include <stdlib.h>
#include <mkl.h>
...
void *darray;
int workspace;
// Set value of alignment
int alignment=64;
...
// Allocate aligned workspace
darray = mkl_malloc( sizeof(double)*workspace, alignment );
...
// call the program using MKL
mkl_app( darray );
...
// Free workspace
mkl_free( darray );
```

```
! ******* Fortran language *******
...
! Set value of alignment
integer    alignment
parameter (alignment=64)
...
! Declare Intel MKL routines
#ifdef _IA32
integer mkl_malloc
#else
integer*8 mkl_malloc
#endif
external mkl_malloc, mkl_free, mkl_app
...
double precision darray
pointer (p_wrk,darray(1))
integer workspace
...
! Allocate aligned workspace
p_wrk = mkl_malloc( %val(8*workspace), %val(alignment) )
...
! call the program using Intel MKL
call mkl_app( darray )
...
! Free workspace
call mkl_free(p_wrk)
```

Using Predefined Preprocessor Symbols for Intel® MKL Version-Dependent Compilation

Preprocessor symbols (macros) substitute values in a program before it is compiled. The substitution is performed in the preprocessing phase.

The following preprocessor symbols are available:

Predefined Preprocessor Symbol	Description
`__INTEL_MKL__`	Intel MKL major version
`__INTEL_MKL_MINOR__`	Intel MKL minor version
`__INTEL_MKL_UPDATE__`	Intel MKL update number
`INTEL_MKL_VERSION`	Intel MKL full version in the following format: `INTEL_MKL_VERSION` = (`__INTEL_MKL__`*100+`__INTEL_MKL_MINOR__`)*100+`__INTEL_MKL_UPDATE__`

These symbols enable conditional compilation of code that uses new features introduced in a particular version of the library.

To perform conditional compilation:

1. Include in your code the file where the macros are defined:
   - `mkl.h` for C/C++
   - `mkl.fi` for Fortran
2. [Optionally] Use the following preprocessor directives to check whether the macro is defined:
   - `#ifdef, #endif` for C/C++
   - `!DEC$IF DEFINED, !DEC$ENDIF` for Fortran
3. Use preprocessor directives for conditional inclusion of code:
   - `#if, #endif` for C/C++
   - `!DEC$IF, !DEC$ENDIF` for Fortran

Example

This example shows how to compile a code segment conditionally for a specific version of Intel MKL. In this case, the version is 10.3 Update 4:

C/C++:

```
#include "mkl.h"
#ifdef INTEL_MKL_VERSION
#if INTEL_MKL_VERSION ==  100304
//     Code to be conditionally compiled
#endif
#endif
```

Fortran:

```
    include "mkl.fi"
!DEC$IF DEFINED INTEL_MKL_VERSION
!DEC$IF INTEL_MKL_VERSION .EQ. 100304
*     Code to be conditionally compiled
!DEC$ENDIF
!DEC$ENDIF
```

Working with the Intel® Math Kernel Library Cluster Software

9

Optimization Notice

Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice.

Notice revision #20110804

MPI Support

Intel MKL ScaLAPACK and Cluster FFTs support MPI implementations identified in the *Intel® Math Kernel Library (Intel® MKL) Release Notes*.

To link applications with ScaLAPACK or Cluster FFTs, you need to configure your system depending on your message-passing interface (MPI) implementation as explained below.

If you are using MPICH2, do the following:

1. Add `mpich2\include` to the include path (assuming the default MPICH2 installation).
2. Add `mpich2\lib` to the library path.
3. Add `mpi.lib` to your link command.
4. Add `fmpich2.lib` to your Fortran link command.
5. Add `cxx.lib` to your Release target link command and `cxxd.lib` to your Debug target link command for C++ programs.

If you are using the Microsoft MPI, do the following:

1. Add `Microsoft Compute Cluster Pack\include` to the include path (assuming the default installation of the Microsoft MPI).
2. Add `Microsoft Compute Cluster Pack\Lib\AMD64` to the library path.
3. Add `msmpi.lib` to your link command.

If you are using the Intel® MPI, do the following:

1. Add the following string to the include path: `%ProgramFiles%\Intel\MPI\<ver>\<arch>\include`, where *`<ver>`* is the directory for a particular MPI version and *`<arch>`* is `ia32` or `intel64`, for example, `%ProgramFiles%\Intel\MPI\3.1\intel64\include`.
2. Add the following string to the library path: `%ProgramFiles%\Intel\MPI\<ver>\<arch>\lib`, for example, `%ProgramFiles%\Intel\MPI\3.1\intel64\lib`.
3. Add `impi.lib` and `impicxx.lib` to your link command.

Check the documentation that comes with your MPI implementation for implementation-specific details of linking.

Linking with ScaLAPACK and Cluster FFTs

To link with Intel MKL ScaLAPACK and/or Cluster FFTs, use the following commands :

```
set lib =<path to MKL libraries>;<path to MPI libraries>;%lib%
```

```
<linker> <files to link> <MKL cluster library> <BLACS> <MKL core libraries> <MPI
libraries>
```

where the placeholders stand for paths and libraries as explained in the following table:

<path to MKL libraries>	*<mkl directory>*`\lib\{ia32|intel64}`, depending on your architecture. If you performed the Setting Environment Variables step of the Getting Started process, you do not need to add this directory to the `lib` environment variable.
<path to MPI libraries>	Typically the `lib` subdirectory in the MPI installation directory. For example, `C:\Program Files (x86)\Intel\MPI\3.2.0.005\ia32\lib` for a default installation of Intel MPI 3.2.
<linker>	One of `icl, ifort, xilink`.
<MKL cluster library>	One of ScaLAPACK or Cluster FFT libraries for the appropriate architecture, which are listed in Directory Structure in Detail. For example, for the IA-32 architecture, it is one of `mkl_scalapack_core.lib` or `mkl_cdft_core.lib`.
<BLACS>	The BLACS library corresponding to your architecture, programming interface (LP64 or ILP64), and MPI version. These libraries are listed in Directory Structure in Detail. For example, for the IA-32 architecture, choose one of `mkl_blacs_mpich2.lib` or `mkl_blacs_intelmpi.lib` in case of static linking or `mkl_blacs_dll.lib` in case of dynamic linking; specifically, for MPICH2, choose `mkl_blacs_mpich2.lib` in case of static linking.
<MKL core libraries>	Intel MKL libraries other than ScaLAPACK or Cluster FFTs libraries.

TIP Use the Link-line Advisor to quickly choose the appropriate set of *<MKL cluster Library>*, *<BLACS>*, and *<MKL core libraries>*.

Intel MPI provides prepackaged scripts for its linkers to help you link using the respective linker. Therefore, if you are using Intel MPI, the best way to link is to use the following commands:

```
<path to Intel MPI binaries>\mpivars.bat
```

```
set lib = <path to MKL libraries>;%lib%
```

```
<mpilinker> <files to link> <MKL cluster Library> <BLACS> <MKL core libraries>
```

where the placeholders that are not yet defined are explained in the following table:

<path to MPI binaries>	By default, the `bin` subdirectory in the MPI installation directory. For example, `C:\Program Files (x86)\Intel\MPI\3.2.0.005\ia32\lib` for a default installation of Intel MPI 3.2;
<MPI linker>	`mpicl` or `mpiifort`

See Also

Linking Your Application with the Intel® Math Kernel Library
Examples for Linking with ScaLAPACK and Cluster FFT

Determining the Number of Threads

The OpenMP* software responds to the environment variable `OMP_NUM_THREADS`. Intel MKL also has other mechanisms to set the number of threads, such as the `MKL_NUM_THREADS` or `MKL_DOMAIN_NUM_THREADS` environment variables (see Using Additional Threading Control).

Make sure that the relevant environment variables have the same and correct values on all the nodes. Intel MKL versions 10.0 and higher no longer set the default number of threads to one, but depend on the OpenMP libraries used with the compiler to set the default number. For the threading layer based on the Intel compiler (`mkl_intel_thread.lib`), this value is the number of CPUs according to the OS.

CAUTION Avoid over-prescribing the number of threads, which may occur, for instance, when the number of MPI ranks per node and the number of threads per node are both greater than one. The product of MPI ranks per node and the number of threads per node should not exceed the number of physical cores per node.

The `OMP_NUM_THREADS` environment variable is assumed in the discussion below.

Set `OMP_NUM_THREADS` so that the product of its value and the number of MPI ranks per node equals the number of real processors or cores of a node. If the Intel® Hyper-Threading Technology is enabled on the node, use only half number of the processors that are visible on Windows OS.

See Also

Setting Environment Variables on a Cluster

Using DLLs

All the needed DLLs must be visible on all the nodes at run time, and you should install Intel® Math Kernel Library (Intel® MKL) on each node of the cluster. You can use Remote Installation Services (RIS) provided by Microsoft to remotely install the library on each of the nodes that are part of your cluster. The best way to make the DLLs visible is to point to these libraries in the `PATH` environment variable. See Setting Environment Variables on a Cluster on how to set the value of the PATH environment variable.

The ScaLAPACK DLLs for the IA-32 and Intel® 64 architectures (in the *<Composer XE directory>*`\redist\ia32\mkl` and *<Composer XE directory>*`\redist\intel64\mkl` directories, respectively) use the MPI dispatching mechanism. MPI dispatching is based on the `MKL_BLACS_MPI` environment variable. The BLACS DLL uses MKL_BLACS_MPI for choosing the needed MPI libraries. The table below lists possible values of the variable.

Value	Comment
`MPICH2`	Default value. MPICH2 1.0.x for Windows* OS is used for message passing
`INTELMPI`	Intel MPI is used for message passing

Value	Comment
`MSMPI`	Microsoft MPI is used for message passing

If you are using a non-default MPI, assign the same appropriate value to `MKL_BLACS_MPI` on all nodes.

See Also

Setting Environment Variables on a Cluster

Setting Environment Variables on a Cluster

If you are using MPICH2 or Intel MPI, to set an environment variable on the cluster, use `-env`, `-genv`, `-genvlist` keys of `mpiexec`.

See the following MPICH2 examples on how to set the value of `OMP_NUM_THREADS`:

```
mpiexec -genv OMP_NUM_THREADS 2 ....
```

```
mpiexec -genvlist OMP_NUM_THREADS ....
```

```
mpiexec -n 1 -host first -env OMP_NUM_THREADS 2 test.exe : -n 1 -host second -env
OMP_NUM_THREADS 3 test.exe ....
```

See the following Intel MPI examples on how to set the value of `MKL_BLACS_MPI`:

```
mpiexec -genv MKL_BLACS_MPI INTELMPI ....
```

```
mpiexec -genvlist MKL_BLACS_MPI ....
```

```
mpiexec -n 1 -host first -env MKL_BLACS_MPI INTELMPI test.exe : -n 1 -host second -env
MKL_BLACS_MPI INTELMPI test.exe.
```

When using MPICH2, you may have problems with getting the global environment, such as `MKL_BLACS_MPI`, by the `-genvlist` key. In this case, set up user or system environments on each node as follows:
From the **Start** menu, select **Settings** > **Control Panel** > **System** > **Advanced** > **Environment Variables**.

If you are using Microsoft MPI, the above ways of setting environment variables are also applicable if the Microsoft Single Program Multiple Data (SPMD) process managers are running in a debug mode on all nodes of the cluster. However, the best way to set environment variables is using the Job Scheduler with the Microsoft Management Console (MMC) and/or the Command Line Interface (CLI) to submit a job and pass environment variables. For more information about MMC and CLI, see the Microsoft Help and Support page at the Microsoft Web site (http://www.microsoft.com/).

Building ScaLAPACK Tests

To build ScaLAPACK tests:

- For the IA-32 architecture, add `mkl_scalapack_core.lib` to your link command.
- For the Intel® 64 architecture, add `mkl_scalapack_lp64.lib` or `mkl_scalapack_ilp64.lib`, depending on the desired interface.

Examples for Linking with ScaLAPACK and Cluster FFT

This section provides examples of linking with ScaLAPACK and Cluster FFT.

Note that a binary linked with ScaLAPACK runs the same way as any other MPI application (refer to the documentation that comes with your MPI implementation).

For further linking examples, see the support website for Intel products at http://www.intel.com/software/products/support/.

See Also

Directory Structure in Detail

Examples for Linking a C Application

These examples illustrate linking of an application whose main module is in C under the following conditions:

- MPICH2 1.0.x is installed in `c:\mpich2x64`.
- You use the Intel® C++ Compiler 10.0 or higher.

To link with ScaLAPACK using LP64 interface for a cluster of Intel® 64 architecture based systems, set the environment variable and use the link line as follows:

```
set lib=c:\mpich2x64\lib;<mkl directory>\lib\intel64;%lib%
```

```
icl <user files to link> mkl_scalapack_lp64.lib mkl_blacs_mpich2_lp64.lib
mkl_intel_lp64.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib mpi.lib cxx.lib
bufferoverflowu.lib
```

To link with Cluster FFT using LP64 interface for a cluster of Intel® 64 architecture based systems, set the environment variable and use the link line as follows:

```
set lib=c:\mpich2x64\lib;<mkl directory>\lib\intel64;%lib%
```

```
icl <user files to link> mkl_cdft_core.lib mkl_blacs_mpich2_lp64.lib mkl_intel_lp64.lib
mkl_intel_thread.lib mkl_core.lib libiomp5md.lib mpi.lib cxx.lib bufferoverflowu.lib
```

See Also

Linking with ScaLAPACK and Cluster FFTs
Linking with System Libraries

Examples for Linking a Fortran Application

These examples illustrate linking of an application whose main module is in Fortran under the following conditions:

- Microsoft Windows Compute Cluster Pack SDK is installed in `c:\MS CCP SDK`.
- You use the Intel® Fortran Compiler 10.0 or higher.

To link with ScaLAPACK using LP64 interface for a cluster of Intel® 64 architecture based systems, set the environment variable and use the link line as follows:

```
set lib="c:\MS CCP SDK\Lib\AMD64";<mkl directory>\lib\intel64;%lib%
```

```
ifort <user files to link> mkl_scalapack_lp64.lib mkl_blacs_mpich2_lp64.lib
mkl_intel_lp64.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib msmpi.lib
bufferoverflowu.lib
```

To link with Cluster FFTs using LP64 interface for a cluster of Intel® 64 architecture based systems, set the environment variable and use the link line as follows:

```
set lib="c:\MS CCP SDK\Lib\AMD64";<mkl directory>\lib\intel64;%lib%
```

```
ifort <user files to link> mkl_cdft_core.lib mkl_blacs_mpich2_lp64.lib
mkl_intel_lp64.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib msmpi.lib
bufferoverflowu.lib
```

See Also

Linking with ScaLAPACK and Cluster FFTs
Linking with System Libraries

Programming with Intel® Math Kernel Library in Integrated Development Environments (IDE) 10

Configuring Your Integrated Development Environment to Link with Intel Math Kernel Library

Configuring the Microsoft Visual C/C++* Development System to Link with Intel® MKL

Steps for configuring Microsoft Visual C/C++* development system for linking with Intel® Math Kernel Library (Intel® MKL) depend on whether If you installed the C++ Integration(s) in Microsoft Visual Studio* component of the Intel® Composer XE:

- If you installed the integration component, see Automatically Linking Your Microsoft Visual C/C++ Project with Intel MKL.
- If you did not install the integration component or need more control over Intel MKL libraries to link, you can configure the Microsoft Visual C++* development system by performing the following steps. Though some versions of the Visual C++* development system may vary slightly in the menu items mentioned below, the fundamental configuring steps are applicable to all these versions.

  1. In Solution Explorer, right-click your project and click **Properties** (for Visual C++* 2010 or higher) or select **Tools** > **Options** (for Visual C++* 2008)
  2. Select **Configuration Properties** > **VC++ Directories** (for Visual C++* 2010 or higher) or select **Projects and Solutions** > **VC++ Directories** (for Visual C++* 2008)
  3. Select **Include Directories**. Add the directory for the Intel MKL include files, that is, `<mkl directory>\include`
  4. Select **Library Directories**. Add architecture-specific directories for Intel MKL and OpenMP* libraries,
     for example: `<mkl directory>\lib\ia32` and `<Composer XE directory>\compiler\lib\ia32`
  5. Select **Executable Directories**. Add architecture-specific directories with dynamic-link libraries:
     - For OpenMP* support, for example: `<Composer XE directory>\redist\ia32\compiler`
     - For Intel MKL (only if you link dynamically), for example: `<Composer XE directory>\redist\ia32\mkl`
  6. Select **Configuration Properties** > **Custom Build Setup** > **Additional Dependencies**. Add the libraries required, for example, `mkl_intel_c.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib`

See Also

Intel® Software Documentation Library

Linking in Detail

Configuring Intel® Visual Fortran to Link with Intel MKL

Steps for configuring Intel® Visual Fortran for linking with Intel® Math Kernel Library (Intel® MKL) depend on whether you installed the Visual Fortran Integration(s) in Microsoft Visual Studio* component of the Intel® Composer XE:

- If you installed the integration component, see Automatically Linking Your Intel® Visual Fortran Project with Intel® MKL.
- If you did not install the integration component or need more control over Intel MKL libraries to link, you can configure your project as follows:

  1. Select **Project** > **Properties** > **Linker** > **General** > **Additional Library Directories**. Add architecture-specific directories for Intel MKL and OpenMP* libraries, for example: `<mkl directory>\lib\ia32` and `<Composer XE directory>\compiler\lib\ia32`
  2. Select **Project** > **Properties** > **Linker** > **Input** > **Additional Dependencies**. Insert names of the required libraries, for example: `mkl_intel_c.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib`
  3. Select **Project** > **Properties** > **Debugging** > **Environment**. Add architecture-specific paths to dynamic-link libraries:

     - For OpenMP* support; for example: enter `PATH=%PATH%;<Composer XE directory>\redist\ia32\compiler`
     - For Intel MKL (only if you link dynamically); for example: enter `PATH=%PATH%;<Composer XE directory>\redist\ia32\mkl`

See Also

Intel® Software Documentation Library

Running an Intel MKL Example in the Visual Studio* 2008 IDE

This section explains how to create and configure projects with the Intel® Math Kernel Library (Intel® MKL) examples in Microsoft Visual Studio* 2008. For Intel MKL examples where the instructions below do not work, see Known Limitations.

To run the Intel MKL C examples in Microsoft Visual Studio 2008:

1. Do either of the following:

   - Install Intel® C/C++ Compiler and integrate it into Visual Studio (recommended).
   - Use the Microsoft Visual C++* 2008 Compiler integrated into Visual Studio*.
2. Create, configure, and run the Intel C/C++ and/or Microsoft Visual C++* 2008.

To run the Intel MKL Fortran examples in Microsoft Visual Studio 2008:

1. Install Intel® Visual Fortran Compiler and integrate it into Visual Studio.
   The default installation of the Intel Visual Fortran Compiler performs this integration. For more information, see the *Intel Visual Fortran Compiler documentation*.
2. Create, configure, and run the Intel Visual Fortran project.

Creating, Configuring, and Running the Intel® C/C++ and/or Visual C++* 2008 Project

This section demonstrates how to create a Visual C/C++ project using an Intel® Math Kernel Library (Intel® MKL) example in Microsoft Visual Studio 2008.

The instructions below create a Win32/Debug project running one Intel MKL example in a Console window. For details on creation of different kinds of Microsoft Visual Studio projects, refer to MSDN Visual Studio documentation at http://www.microsoft.com.

To create and configure the Win32/Debug project running an Intel MKL C example with the Intel® C/C++ Compiler integrated into Visual Studio and/or Microsoft Visual C++* 2008, perform the following steps:

1. Create a C Project:

   a. Open Visual Studio 2008.
   b. On the main menu, select **File** > **New** > **Project** to open the **New Project** window.
   c. Select **Project Types** > **Visual C++** > **Win32**, then select **Templates** > **Win32 Console Application**. In the **Name** field, type `<project name>`, for example, MKL_CBLAS_CAXPYIX, and click **OK**.

The **New Project** window closes, and the **Win32 Application Wizard - <project name>** window opens.

d. Select **Next**, then select **Application Settings**, check **Additional options** > **Empty project**, and click **Finish**.
The **Win32 Application Wizard - <project name>** window closes.

The next steps are performed inside the **Solution Explorer** window. To open it, select **View** > **Solution Explorer** from the main menu.

2. (optional) To switch to the Intel C/C++ project, right-click **<project name>** and from the drop-down menu, select **Convert** to use Intel® C++ Project System. (The menu item is available if the Intel® C/C+ + Compiler is integrated into Visual Studio.)

3. Add sources of the Intel MKL example to the project:

a. Right-click the **Source Files** folder under **<project name>** and select **Add** > **Existing Item...** from the drop-down menu.
The **Add Existing Item - <project name>** window opens.

b. Browse to the Intel MKL example directory, for example, `<mkl directory>\examples\cblas\source`. Select the example file and supporting files with extension "`.c`" (C sources), for example, select files `cblas_caxpyix.c` and `common_func.c` For the list of supporting files in each example directory, see Support Files for Intel MKL Examples. Click **Add**.
The **Add Existing Item - <project name>** window closes, and selected files appear in the **Source Files** folder in Solution Explorer.

The next steps adjust the properties of the project.

4. Select **<project name>** .

5. On the main menu, select **Project** > **Properties** to open the **<project name> Property Pages** window.

6. Set Intel MKL Include dependencies:

a. Select **Configuration Properties** > **C/C++** > **General**. In the right-hand part of the window, select **Additional Include Directories** > **...** (the browse button).
The **Additional Include Directories** window opens.

b. Click the **New Line** button (the first button in the uppermost row). When the new line appears in the window, click the browse button.
The **Select Directory** window opens.

c. Browse to the `<mkl directory>\include` directory and click **OK**.
The **Select Directory** window closes, and full path to the Intel MKL include directory appears in the **Additional Include Directories** window.

d. Click **OK** to close the window.

7. Set library dependencies:

a. Select Configuration Properties > **Linker** > **General**. In the right-hand part of the window, select **Additional Library Directories** > **...** (the browse button).
The **Additional Library Directories** window opens.

b. Click the **New Line** button (the first button in the uppermost row). When the new line appears in the window, click the browse button.
The **Select Directory** window opens.

c. Browse to the directory with the Intel MKL libraries `<mkl directory>\lib\<architecture>`, where `<architecture>` is one of {`ia32`, `intel64`}, for example: `<mkl directory>\lib\ia32`. (For most laptop and desktop computers, `<architecture>` is `ia32`.). Click **OK**.
The **Select Directory** window closes, and the full path to the Intel MKL libraries appears in the **Additional Library Directories** window.

d. Click the **New Line** button again. When the new line appears in the window, click the browse button.
The **Select Directory** window opens.

e. Browse to the `<Composer XE directory>compiler\lib\<architecture>`, where `<architecture>` is one of { `ia32`, `intel64` }, for example: `<Composer XE directory>\compiler\lib\ia32`. Click **OK**.
The **Select Directory** window closes, and the specified full path appears in the **Additional Library Directories** window.

f. Click **OK** to close the **Additional Library Directories** window.

   g. Select **Configuration Properties** > **Linker** > **Input**. In the right-hand part of the window, select **Additional Dependencies** > **...** (the browse button).
   The **Additional Dependencies** window opens.
   h. Type the libraries required, for example, if *<architecture>* =ia32, type `mkl_intel_c.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib` For more details, see Linking in Detail.
   i. Click **OK** to close the **Additional Dependencies** window.
   j. If the Intel MKL example directory does not contain a data directory, skip the next step.

8. Set data dependencies for the Intel MKL example:

   a. Select **Configuration Properties** > **Debugging**. In the right-hand part of the window, select **Command Arguments** > ▼ > **<Edit...>**.
   The **Command Arguments** window opens.
   b. Type the path to the proper data file in quotes. The name of the data file is the same as the name of the example file, with a "`d`" extension, for example, "`<mkl directory>\examples\cblas\data\cblas_caxpyix.d`".
   c. Click **OK** to close the **Command Arguments** window.

9. Click **OK** to close the **<project name> Property Pages** window.
10. Certain examples do not pause before the end of execution. To see the results printed in the Console window, set a breakpoint at the very last `'return 0;'` statement or add a call to `'getchar();'` before the last `'return 0'` statement.
11. To build the solution, select **Build** > **Build Solution** .

NOTE You may see warnings about unsafe functions and variables. To get rid of these warnings, go to **Project** > **Properties**, and when the **<project name> Property Pages** window opens, go to **Configuration Properties** > **C/C++** > **Preprocessor**. In the right-hand part of the window, select **Preprocessor Definitions**, add `_CRT_SECURE_NO_WARNINGS`, and click **OK**.

12. To run the example, select **Debug** > **Start Debugging**.
    The Console window opens.
13. You can see the results of the example in the Console window. If you used the `'getchar();'` statement to pause execution of the program, press **Enter** to complete the run. If you used a breakpoint to pause execution of the program, select **Debug** > **Continue**.
    The Console window closes.

See Also

Running an Intel MKL Example in the Visual Studio* 2008 IDE

Creating, Configuring, and Running the Intel Visual Fortran Project

This section demonstrates how to create an Intel Visual Fortran project running an Intel MKL example in Microsoft Visual Studio 2008.

The instructions below create a Win32/Debug project running one Intel MKL example in a Console window. For details on creation of different kinds of Microsoft Visual Studio projects, refer to MSDN Visual Studio documentation at http://www.microsoft.com.

To create and configure a Win32/Debug project running the Intel MKL Fortran example with the Intel Visual Fortran Compiler integrated into Visual Studio, perform the following steps:

1. Create a Visual Fortran Project:

   a. Open Visual Studio 2008.
   b. On the main menu, select **File** > **New** > **Project** to open the **New Project** window.
   c. Select **Project Types** > **Intel® Fortran** > **Console Application**, then select **Templates** > **Empty Project**. When done, in the **Name** field, type *<project name>* for example, MKL_PDETTF_D_TRIG_TRANSFORM_BVP, and click **OK**.
   The **New Project** window closes.

   The next steps are performed inside the Solution Explorer window. To open it, select **View**>**Solution Explorer** from the main menu.

2. Add sources of Intel MKL example to the project:

  a. Right-click the **Source Files** folder under **<project name>** and select **Add** > **Existing Item...** from the drop-down menu.
  The **Add Existing Item - <project name>** window opens.

  b. Browse to the Intel MKL example directory, for example, `<mkl directory>\examples\pdettf\source`. Select the example file and supporting files with extension "`.f`" or "`.f90`" (Fortran sources). For example, select the `d_trig_tforms_bvp.f90` file. For the list of supporting files in each example directory, see Support Files for Intel MKL Examples. Click **Add**.
  The **Add Existing Item - <project name>** window closes, and the selected files appear in the **Source Files** folder in Solution Explorer. Some examples with the "`use`" statements require the next two steps.

  c. Right-click the **Header Files** folder under **<project name>** and select **Add** > **Existing Item...** from the drop-down menu.
  The **Add Existing Item - <project name>** window opens.

  d. Browse to the `<mkl directory>\include` directory. Select the header files that appear in the "`use`" statements. For example, select the `mkl_dfti.f90` and `mkl_trig_transforms.f90` files. Click **Add**.
  The **Add Existing Item - <project name>**window closes, and the selected files to appear in the**Header Files**folder in Solution Explorer.

The next steps adjust the properties of the project:

3. Select the **<project name>**.

4. On the main menu, select **Project** > **Properties** to open the **<project name> Property Pages** window.

5. Set the Intel MKL include dependencies:

  a. Select **Configuration Properties** > **Fortran** > **General**. In the right-hand part of the window, select **Additional Include Directories** > ▼ > **<Edit...>**.
  The **Additional Include Directories** window opens.

  b. Type the Intel MKL include directory in quotes: "`<mkl directory>\include`". Click **OK** to close the window.

6. Select **Configuration Properties** > **Fortran** > **Preprocessor**. In the right-hand part of the window, select **Preprocess Source File** > **Yes** (default is **No**). This step is recommended because some examples require preprocessing.

7. Set library dependencies:

  a. Select **Configuration Properties** > **Linker** > **General**. In the right-hand part of the window, select **Additional Library Directories** > ▼ > **<Edit...>**.
  The **Additional Library Directories** window opens.

  b. Type the directory with the Intel MKL libraries in quotes, that is, "`<mkl directory>\lib\<architecture>`", where `<architecture>` is one of { `ia32`, `intel64` }, for example: "`<mkl directory>\lib\ia32`". (For most laptop and desktop computers `<architecture>` is `ia32`.) Click **OK** to close the window.

  c. Select **Configuration Properties** > **Linker** > **Input**. In the right-hand part of the window, select **Additional Dependencies** and type the libraries required, for example, if `<architecture>=ia32`, type `mkl_intel_c.lib mkl_intel_thread.lib mkl_core.lib libiomp5md.lib`.

8. In the **<project name> Property Pages** window, click **OK** to close the window.

9. Some examples do not pause before the end of execution. To see the results printed in the Console window, set a breakpoint at the very end of the program or add the `'pause'` statement before the last `'end'` statement.

10. To build the solution, select **Build** > **Build Solution**.

11. To run the example, select **Debug** > **Start Debugging**.
The Console window opens.

12. You can see the results of the example in the Console window. If you used `'pause'` statement to pause execution of the program, press **Enter** to complete the run. If you used a breakpoint to pause execution of the program, select **Debug** > **Continue**.
The Console window closes.

Support Files for Intel® Math Kernel Library Examples

Below is the list of support files that have to be added to the project for respective examples:

`examples\cblas\source: common_func.c`

`examples\dftc\source: dfti_example_status_print.c dfti_example_support.c`

Known Limitations of the Project Creation Procedure

You cannot create a Visual Studio* project using the instructions from Creating, Configuring, and Running the Intel® C/C++ and/or Visual C++* 2008 Project or Creating, Configuring, and Running the Intel® Visual Fortran Project for examples from the following directories:

`examples\blas`

`examples\blas95`

`examples\cdftc`

`examples\cdftf`

`examples\dftf`

`examples\fftw2x_cdf`

`examples\fftw2xc`

`examples\fftw2xf`

`examples\fftw3xc`

`examples\fftw3xf`

`examples\java`

`examples\lapack`

`examples\lapack95`

Getting Assistance for Programming in the Microsoft Visual Studio* IDE

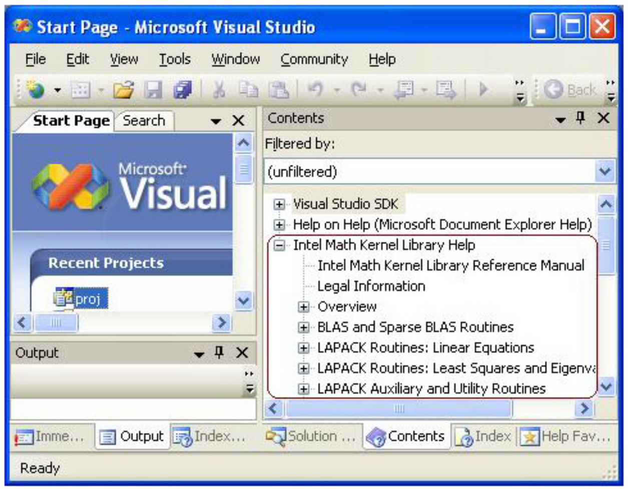
Viewing Intel MKL Documentation in Visual Studio* IDE

Viewing Intel MKL Documentation in Document Explorer (Visual Studio* 2008 IDE)

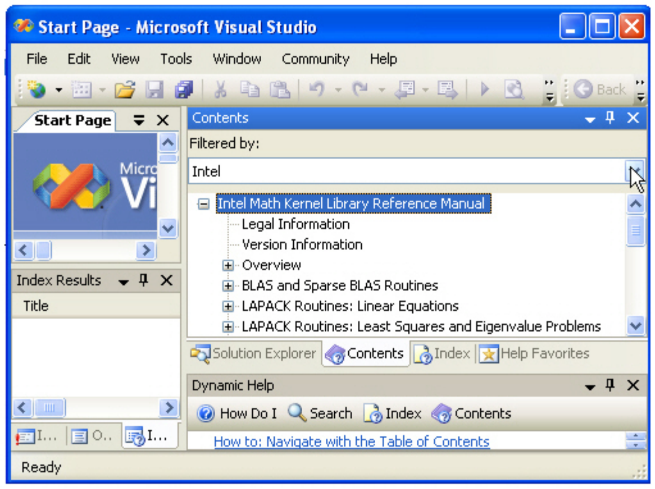
Intel MKL documentation is integrated in the Visual Studio IDE (VS) help collection. To open Intel MKL help,

1. Select **Help** > **Contents** from the menu.
   This displays the list of **VS Help** collections.
2. Click Intel **Math Kernel Library Help**.
3. In the help tree that expands, click **Intel MKL Reference Manual**.

To open the help index, select **Help** > **Index** from the menu. To search in the help, select **Help** > **Search** from the menu and enter a search string.


Start Page - Microsoft Visual Studio
File Edit View Tools Window Community Help
Start Page Search
Contents
Filtered by:
(unfiltered)
Visual Studio SDK
Help on Help (Microsoft Document Explorer Help)
Intel Math Kernel Library Help
Intel Math Kernel Library Reference Manual
Legal Information
Overview
BLAS and Sparse BLAS Routines
LAPACK Routines: Linear Equations
LAPACK Routines: Least Squares and Eigenva
LAPACK Auxiliary and Utility Routines
Recent Projects
proj
Output
Ready

You can filter Visual Studio Help collections to show only content related to installed Intel tools. To do this, select "Intel" from the Filtered by list. This hides the contents and index entries for all collections that do not refer to Intel.


Start Page - Microsoft Visual Studio
File Edit View Tools Window Community Help
Start Page
Contents
Filtered by:
Intel
Intel Math Kernel Library Reference Manual
Legal Information
Version Information
Overview
BLAS and Sparse BLAS Routines
LAPACK Routines: Linear Equations
LAPACK Routines: Least Squares and Eigenvalue Problems
Solution Explorer Contents Index Help Favorites
Index Results
Title
Dynamic Help
How Do I Search Index Contents
How to: Navigate with the Table of Contents
Ready

Accessing Intel MKL Documentation in Visual Studio* 2010 IDE

To access the Intel MKL documentation in Visual Studio* 2010 IDE:

- Configure the IDE to use local help (once). To do this,

  Go to **Help** > **Manage Help Settings** and check **I want to use online help**
- Use the **Help** > **View Help** menu item to view a list of available help collections and open the Intel MKL documentation.

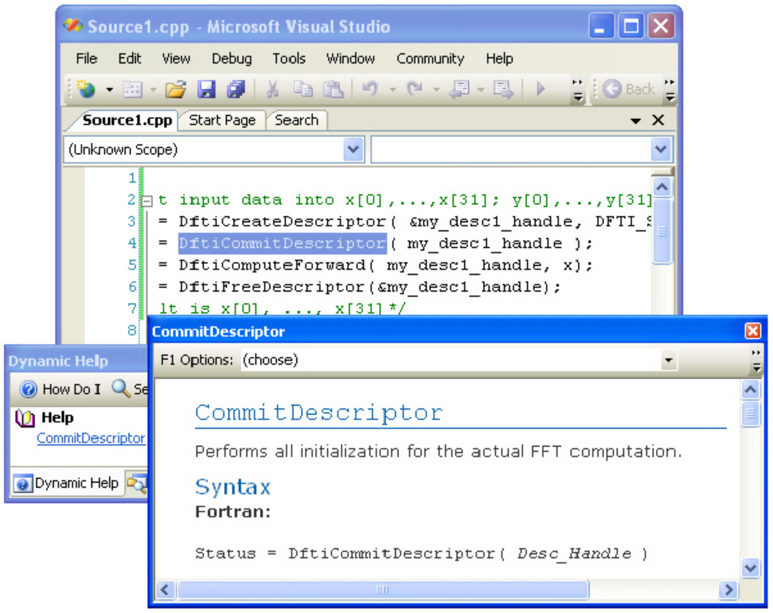
Using Context-Sensitive Help

When typing your code in the Visual Studio* (VS) IDE Code Editor, you can get context-sensitive help using the F1 Help and Dynamic Help features.

F1 Help

To open the help topic relevant to the current selection, press F1.

In particular, to open the help topic describing an Intel MKL function called in your code, select the function name and press F1. The topic with the function description opens in the window that displays search results:



```
t input data into x[0],...,x[31]; y[0],...,y[31]
= DftiCreateDescriptor( &my_desc1_handle, DFTI_S
= DftiCommitDescriptor( my_desc1_handle );
= DftiComputeForward( my_desc1_handle, x);
= DftiFreeDescriptor(&my_desc1_handle);
lt is x[0], ..., x[31] */
```

CommitDescriptor

Performs all initialization for the actual FFT computation.

Syntax

Fortran:

```
Status = DftiCommitDescriptor( Desc_Handle )
```

Dynamic Help

Dynamic Help also provides access to topics relevant to the current selection or to the text being typed. Links to all relevant topics are displayed in the Dynamic Help window.

To get the list of relevant topics each time you select the Intel MKL function name or as you type it in your code, open the Dynamic Help window by selecting **Help** > **Dynamic Help** from the menu.

To open a topic from the list, click the appropriate link in the Dynamic Help window, shown in the above figure. Typically only one link corresponds to each Intel MKL function.

Using the IntelliSense* Capability

IntelliSense is a set of native Visual Studio*(VS) IDE features that make language references easily accessible.

The user programming with Intel MKL in the VS Code Editor can employ two IntelliSense features: Parameter Info and Complete Word.

Both features use header files. Therefore, to benefit from IntelliSense, make sure the path to the include files is specified in the VS or solution settings. For example, see Configuring the Microsoft Visual C/C++* Development System to Link with Intel® MKL on how to do this.

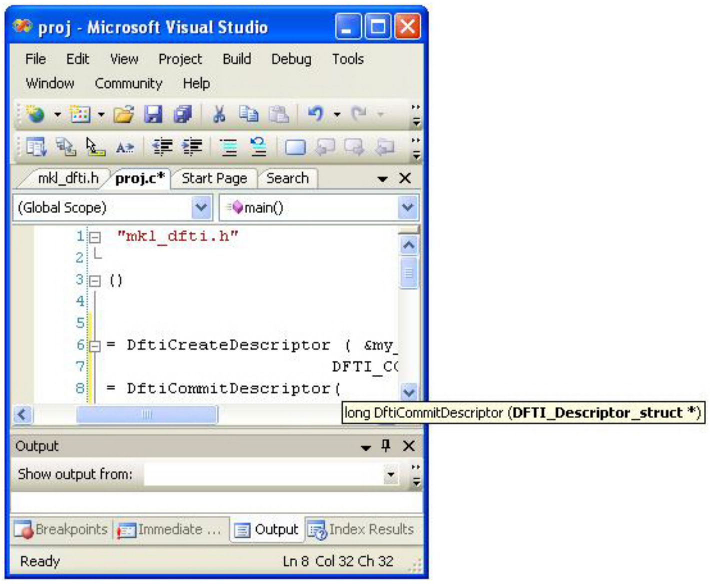
Parameter Info

The Parameter Info feature displays the parameter list for a function to give information on the number and types of parameters. This feature requires adding the `include` statement with the appropriate Intel MKL header file to your code.

To get the list of parameters of a function specified in the header file,

1. Type the function name.
2. Type the opening parenthesis.

This brings up the tooltip with the list of the function parameters:



```
"mkl_dfti.h"

()


= DftiCreateDescriptor ( &my_
                         DFTI_C(
= DftiCommitDescriptor(
```

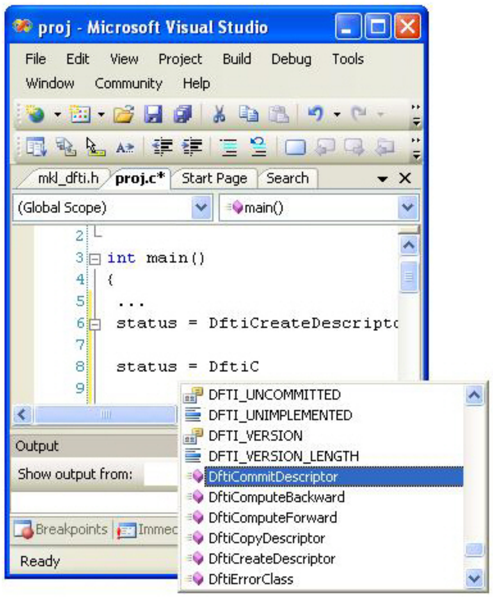
long DftiCommitDescriptor (**DFTI_Descriptor_struct** *)

Complete Word

For a software library, the Complete Word feature types or prompts for the rest of the name defined in the header file once you type the first few characters of the name in your code. This feature requires adding the `include` statement with the appropriate Intel MKL header file to your code.

To complete the name of the function or named constant specified in the header file,

1. Type the first few characters of the name.
2. Press Alt+RIGHT ARROW or Ctrl+SPACEBAR.
   If you have typed enough characters to disambiguate the name, the rest of the name is typed automatically. Otherwise, a pop-up list appears with the names specified in the header file
3. Select the name from the list, if needed.



```
int main()
{
 ...
 status = DftiCreateDescripto

 status = DftiC
```

```
DFTI_UNCOMMITTED
DFTI_UNIMPLEMENTED
DFTI_VERSION
DFTI_VERSION_LENGTH
DftiCommitDescriptor
DftiComputeBackward
DftiComputeForward
DftiCopyDescriptor
DftiCreateDescriptor
DftiErrorClass
```

LINPACK and MP LINPACK Benchmarks 11

Optimization Notice

Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice.

Notice revision #20110804

Intel® Optimized LINPACK Benchmark for Windows* OS

Intel® Optimized LINPACK Benchmark is a generalization of the LINPACK 1000 benchmark. It solves a dense (`real`*8) system of linear equations (*Ax=b*), measures the amount of time it takes to factor and solve the system, converts that time into a performance rate, and tests the results for accuracy. The generalization is in the number of equations (*N*) it can solve, which is not limited to 1000. It uses partial pivoting to assure the accuracy of the results.

Do not use this benchmark to report LINPACK 100 performance because that is a compiled-code only benchmark. This is a shared-memory (SMP) implementation which runs on a single platform. Do not confuse this benchmark with:

- MP LINPACK, which is a distributed memory version of the same benchmark.
- LINPACK, the library, which has been expanded upon by the LAPACK library.

Intel provides optimized versions of the LINPACK benchmarks to help you obtain high LINPACK benchmark results on your genuine Intel processor systems more easily than with the High Performance Linpack (HPL) benchmark. Use this package to benchmark your SMP machine.

Additional information on this software as well as other Intel software performance products is available at http://www.intel.com/software/products/.

Contents of the Intel® Optimized LINPACK Benchmark

The Intel Optimized LINPACK Benchmark for Windows* OS contains the following files, located in the `benchmarks\linpack\` subdirectory of the Intel® Math Kernel Library (Intel® MKL) directory:

File in `benchmarks\linpack\`	**Description**
`linpack_xeon32.exe`	The 32-bit program executable for a system based on Intel® Xeon® processor or Intel® Xeon® processor MP with or without Streaming SIMD Extensions 3 (SSE3).
`linpack_xeon64.exe`	The 64-bit program executable for a system with Intel Xeon processor using Intel® 64 architecture.
`runme_xeon32.bat`	A sample shell script for executing a pre-determined problem set for `linpack_xeon32.exe`.
`runme_xeon64.bat`	A sample shell script for executing a pre-determined problem set for `linpack_xeon64.exe`.

File in `benchmarks\linpack\`	**Description**
`lininput_xeon32`	Input file for a pre-determined problem for the `runme_xeon32` script.
`lininput_xeon64`	Input file for a pre-determined problem for the `runme_xeon64` script.
`win_xeon32.txt`	Result of the `runme_xeon32` script execution.
`win_xeon64.txt`	Result of the `runme_xeon64` script execution.
`help.lpk`	Simple help file.
`xhelp.lpk`	Extended help file.

See Also

High-level Directory Structure

Running the Software

To obtain results for the pre-determined sample problem sizes on a given system, type one of the following, as appropriate:

```
runme_xeon32.bat
```

```
runme_xeon64.bat
```

To run the software for other problem sizes, see the extended help included with the program. Extended help can be viewed by running the program executable with the `-e` option:

```
linpack_xeon32.exe -e
```

```
linpack_xeon64.exe -e
```

The pre-defined data input files `lininput_xeon32` and `lininput_xeon64` are provided merely as examples. Different systems have different numbers of processors or amounts of memory and thus require new input files. The extended help can be used for insight into proper ways to change the sample input files.

Each input file requires at least the following amount of memory:

`lininput_xeon32`	2 GB
`lininput_xeon64`	16 GB

If the system has less memory than the above sample data input requires, you may need to edit or create your own data input files, as explained in the extended help.

Each sample script uses the `OMP_NUM_THREADS` environment variable to set the number of processors it is targeting. To optimize performance on a different number of physical processors, change that line appropriately. If you run the Intel Optimized LINPACK Benchmark without setting the number of threads, it will default to the number of cores according to the OS. You can find the settings for this environment variable in the `runme_*` sample scripts. If the settings do not yet match the situation for your machine, edit the script.

Optimization Notice

Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice.

Notice revision #20110804

Known Limitations of the Intel® Optimized LINPACK Benchmark

The following limitations are known for the Intel Optimized LINPACK Benchmark for Windows* OS:

- Intel Optimized LINPACK Benchmark is threaded to effectively use multiple processors. So, in multi-processor systems, best performance will be obtained with the Intel® Hyper-Threading Technology turned off, which ensures that the operating system assigns threads to physical processors only.
- If an incomplete data input file is given, the binaries may either hang or fault. See the sample data input files and/or the extended help for insight into creating a correct data input file.

Intel® Optimized MP LINPACK Benchmark for Clusters

Overview of the Intel® Optimized MP LINPACK Benchmark for Clusters

The Intel® Optimized MP LINPACK Benchmark for Clusters is based on modifications and additions to HPL 2.0 from Innovative Computing Laboratories (ICL) at the University of Tennessee, Knoxville (UTK). The Intel Optimized MP LINPACK Benchmark for Clusters can be used for Top 500 runs (see http://www.top500.org). To use the benchmark you need be intimately familiar with the HPL distribution and usage. The Intel Optimized MP LINPACK Benchmark for Clusters provides some additional enhancements and bug fixes designed to make the HPL usage more convenient, as well as explain Intel® Message-Passing Interface (MPI) settings that may enhance performance. The `.\benchmarks\mp_linpack` directory adds techniques to minimize search times frequently associated with long runs.

The Intel® Optimized MP LINPACK Benchmark for Clusters is an implementation of the Massively Parallel MP LINPACK benchmark by means of HPL code. It solves a random dense (`real`*8) system of linear equations ($Ax=b$), measures the amount of time it takes to factor and solve the system, converts that time into a performance rate, and tests the results for accuracy. You can solve any size (N) system of equations that fit into memory. The benchmark uses full row pivoting to ensure the accuracy of the results.

Use the Intel Optimized MP LINPACK Benchmark for Clusters on a distributed memory machine. On a shared memory machine, use the Intel Optimized LINPACK Benchmark.

Intel provides optimized versions of the LINPACK benchmarks to help you obtain high LINPACK benchmark results on your systems based on genuine Intel processors more easily than with the HPL benchmark. Use the Intel Optimized MP LINPACK Benchmark to benchmark your cluster. The prebuilt binaries require that you first install Intel® MPI 3.x be installed on the cluster. The run-time version of Intel MPI is free and can be downloaded from www.intel.com/software/products/ .

The Intel package includes software developed at the University of Tennessee, Knoxville, Innovative Computing Laboratories and neither the University nor ICL endorse or promote this product. Although HPL 2.0 is redistributable under certain conditions, this particular package is subject to the Intel MKL license.

Intel MKL has introduced a new functionality into MP LINPACK, which is called a *hybrid* build, while continuing to support the older version. The term *hybrid* refers to special optimizations added to take advantage of mixed OpenMP*/MPI parallelism.

If you want to use one MPI process per node and to achieve further parallelism by means of OpenMP, use the hybrid build. In general, the hybrid build is useful when the number of MPI processes per core is less than one. If you want to rely exclusively on MPI for parallelism and use one MPI per core, use the non-hybrid build.

In addition to supplying certain hybrid prebuilt binaries, Intel MKL supplies some hybrid prebuilt libraries for Intel® MPI to take advantage of the additional OpenMP* optimizations.

If you wish to use an MPI version other than Intel MPI, you can do so by using the MP LINPACK source provided. You can use the source to build a non-hybrid version that may be used in a hybrid mode, but it would be missing some of the optimizations added to the hybrid version.

Non-hybrid builds are the default of the source code makefiles provided. In some cases, the use of the hybrid mode is required for external reasons. If there is a choice, the non-hybrid code may be faster. To use the non-hybrid code in a hybrid mode, use the threaded version of Intel MKL BLAS, link with a thread-safe MPI, and call function `MPI_init_thread()` so as to indicate a need for MPI to be thread-safe.

Contents of the Intel® Optimized MP LINPACK Benchmark for Clusters

The Intel Optimized MP LINPACK Benchmark for Clusters (MP LINPACK Benchmark) includes the HPL 2.0 distribution in its entirety, as well as the modifications delivered in the files listed in the table below and located in the `benchmarks\mp_linpack\` subdirectory of the Intel MKL directory.

NOTE Because MP LINPACK Benchmark includes the *entire* HPL 2.0 distribution, which provides a configuration for Linux* OS only, some Linux OS files remain in the directory.

Directory/File in `benchmarks\mp_linpack\`	**Contents**
`testing\ptest\HPL_pdtest.c`	HPL 2.0 code modified to display captured `DGEMM` information in `ASYOUGO2_DISPLAY` if it was captured (for details, see New Features).
`src\blas\HPL_dgemm.c`	HPL 2.0 code modified to capture `DGEMM` information, if desired, from `ASYOUGO2_DISPLAY`.
`src\grid\HPL_grid_init.c`	HPL 2.0 code modified to do additional grid experiments originally not in HPL 2.0.
`src\pgesv\HPL_pdgesvK2.c`	HPL 2.0 code modified to do `ASYOUGO` and `ENDEARLY` modifications.
`src\pgesv\HPL_pdgesv0.c`	HPL 2.0 code modified to do `ASYOUGO`, `ASYOUGO2`, and `ENDEARLY` modifications.
`testing\ptest\HPL.dat`	HPL 2.0 sample `HPL.dat` modified.
`makes`	All the makefiles in this directory have been rebuilt in the Windows OS distribution.
`testing\ptimer\`	Some files in here have been modified in the Windows OS distribution.
`testing\timer\`	Some files in here have been modified in the Windows OS distribution.
`Make`	(New) Sample architecture makefile for nmake utility to be used on processors based on the IA-32 and Intel® 64 architectures and Windows OS.
`bin_intel\ia32\xhpl_ia32.exe`	(New) Prebuilt binary for the IA-32 architecture, Windows OS, and Intel® MPI.
`bin_intel\intel64\xhpl_intel64.exe`	(New) Prebuilt binary for the Intel® 64 architecture, Windows OS, and Intel MPI.

Directory/File in `benchmarks\mp_linpack\`	**Contents**
`lib_hybrid\ia32\libhpl_hybrid.lib`	(New) Prebuilt library with the hybrid version of MP LINPACK for the IA-32 architecture and Intel MPI.
`lib_hybrid\intel64\libhpl_hybrid.lib`	(New) Prebuilt library with the hybrid version of MP LINPACK for the Intel® 64 architecture and Intel MPI.
`bin_intel\ia32\xhpl_hybrid_ia32.exe`	(New) Prebuilt hybrid binary for the IA-32 architecture, Windows OS, and Intel MPI.
`bin_intel\intel64\xhpl_hybrid_intel64.exe`	(New) Prebuilt hybrid binary for the Intel® 64 architecture, Windows OS, and Intel MPI.
`nodeperf.c`	(New) Sample utility that tests the `DGEMM` speed across the cluster.

See Also

High-level Directory Structure

Building the MP LINPACK

The MP LINPACK Benchmark contains a few sample architecture makefiles. You can edit them to fit your specific configuration. Specifically:

- Set `TOPdir` to the directory that MP LINPACK is being built in.
- Set MPI variables, that is, `MPdir`, `MPinc`, and `MPlib`.
- Specify the location Intel MKL and of files to be used (`LAdir`, `LAinc`, `LAlib`).
- Adjust compiler and compiler/linker options.
- Specify the version of MP LINPACK you are going to build (hybrid or non-hybrid) by setting the version parameter for the `nmake` command. For example:

```
nmake arch=intel64 mpi=intelmpi version=hybrid install
```

For some sample cases, the makefiles contain values that must be common. However, you need to be familiar with building an HPL and picking appropriate values for these variables.

New Features of Intel® Optimized MP LINPACK Benchmark

The toolset is basically identical with the HPL 2.0 distribution. There are a few changes that are optionally compiled in and disabled until you specifically request them. These new features are:

ASYOUGO: Provides non-intrusive performance information while runs proceed. There are only a few outputs and this information does not impact performance. This is especially useful because many runs can go for hours without any information.

ASYOUGO2: Provides slightly intrusive additional performance information by intercepting every `DGEMM` call.

ASYOUGO2_DISPLAY: Displays the performance of all the significant `DGEMMs` inside the run.

ENDEARLY: Displays a few performance hints and then terminates the run early.

FASTSWAP: Inserts the LAPACK-optimized `DLASWP` into HPL's code. You can experiment with this to determine best results.

HYBRID: Establishes the Hybrid OpenMP/MPI mode of MP LINPACK, providing the possibility to use threaded Intel MKL and prebuilt MP LINPACK hybrid libraries.

CAUTION Use this option only with an Intel compiler and the Intel® MPI library version 3.1 or higher. You are also recommended to use the compiler version 10.0 or higher.

Benchmarking a Cluster

To benchmark a cluster, follow the sequence of steps below (some of them are optional). Pay special attention to the iterative steps 3 and 4. They make a loop that searches for HPL parameters (specified in `HPL.dat`) that enable you to reach the top performance of your cluster.

1. Install HPL and make sure HPL is functional on all the nodes.
2. You may run `nodeperf.c` (included in the distribution) to see the performance of `DGEMM` on all the nodes.

   Compile `nodeperf.c` with your MPI and Intel MKL. For example:

   ```
   icl /Za /O3 /w /D_WIN_ /I"<Home directory of MPI>\include" "<Home directory of MPI libraries>\<MPI
   library>"
   "<mkl directory>\lib\intel64\mkl_core.lib"
   "<Composer XE directory>\lib\intel64\libiomp5md.lib" nodeperf.c
   ```

   where *<MPI library>* is `msmpi.lib` in the case of Microsoft* MPI and `mpi.lib` in the case of MPICH.

   Launching `nodeperf.c` on all the nodes is especially helpful in a very large cluster. `nodeperf` enables quick identification of the potential problem spot without numerous small MP LINPACK runs around the cluster in search of the bad node. It goes through all the nodes, one at a time, and reports the performance of `DGEMM` followed by some host identifier. Therefore, the higher the `DGEMM` performance, the faster that node was performing.
3. Edit `HPL.dat` to fit your cluster needs.
   Read through the HPL documentation for ideas on this. Note, however, that you should use at least 4 nodes.
4. Make an HPL run, using compile options such as `ASYOUGO`, `ASYOUGO2`, or `ENDEARLY` to aid in your search. These options enable you to gain insight into the performance sooner than HPL would normally give this insight.

   When doing so, follow these recommendations:

   - Use MP LINPACK, which is a patched version of HPL, to save time in the search.

     All performance intrusive features are compile-optional in MP LINPACK. That is, if you do not use the new options to reduce search time, these features are disabled. The primary purpose of the additions is to assist you in finding solutions.

     HPL requires a long time to search for many different parameters. In MP LINPACK, the goal is to get the best possible number.

     Given that the input is not fixed, there is a large parameter space you must search over. An exhaustive search of all possible inputs is improbably large even for a powerful cluster. MP LINPACK optionally prints information on performance as it proceeds. You can also terminate early.
   - Save time by compiling with `-DENDEARLY -DASYOUGO2` and using a negative threshold (do not use a negative threshold on the final run that you intend to submit as a Top500 entry). Set the threshold in line 13 of the HPL 2.0 input file `HPL.dat`
   - If you are going to run a problem to completion, do it with `-DASYOUGO`.
5. Using the quick performance feedback, return to step 3 and iterate until you are sure that the performance is as good as possible.

See Also

Options to Reduce Search Time

Options to Reduce Search Time

Running large problems to completion on large numbers of nodes can take many hours. The search space for MP LINPACK is also large: not only can you run any size problem, but over a number of block sizes, grid layouts, lookahead steps, using different factorization methods, and so on. It can be a large waste of time to run a large problem to completion only to discover it ran 0.01% slower than your previous best problem.

Use the following options to reduce the search time:

- `-DASYOUGO`
- `-DENDEARLY`
- `-DASYOUGO2`

  Use `-DASYOUGO2` cautiously because it does have a marginal performance impact. To see `DGEMM` internal performance, compile with `-DASYOUGO2` and `-DASYOUGO2_DISPLAY`. These options provide a lot of useful `DGEMM` performance information at the cost of around 0.2% performance loss.

If you want to use the old HPL, simply omit these options and recompile from scratch. To do this, try "`nmake arch=`*`<arch>`*` clean_arch_all`".

-DASYOUGO

`-DASYOUGO` gives performance data as the run proceeds. The performance always starts off higher and then drops because this actually happens in LU decomposition (a decomposition of a matrix into a product of a lower (L) and upper (U) triangular matrices). The `ASYOUGO` performance estimate is usually an overestimate (because the LU decomposition slows down as it goes), but it gets more accurate as the problem proceeds. The greater the lookahead step, the less accurate the first number may be. `ASYOUGO` tries to estimate where one is in the LU decomposition that MP LINPACK performs and this is always an overestimate as compared to `ASYOUGO2`, which measures actually achieved `DGEMM` performance. Note that the `ASYOUGO` output is a subset of the information that `ASYOUGO2` provides. So, refer to the description of the `-DASYOUGO2` option below for the details of the output.

-DENDEARLY

`-DENDEARLY t`erminates the problem after a few steps, so that you can set up 10 or 20 HPL runs without monitoring them, see how they all do, and then only run the fastest ones to completion. `-DENDEARLY` assumes `-DASYOUGO`. You do not need to define both, although it doesn't hurt. To avoid the residual check for a problem that terminates early, set the "threshold" parameter in `HPL.dat` to a negative number when testing `ENDEARLY`. It also sometimes gives a better picture to compile with `-DASYOUGO2` when using `-DENDEARLY`.

Usage notes on `-DENDEARLY` follow:

- `-DENDEARLY` stops the problem after a few iterations of `DGEMM` on the block size (the bigger the blocksize, the further it gets). It prints only 5 or 6 "updates", whereas `-DASYOUGO` prints about 46 or so output elements before the problem completes.
- Performance for `-DASYOUGO` and `-DENDEARLY` always starts off at one speed, slowly increases, and then slows down toward the end (because that is what LU does). `-DENDEARLY` is likely to terminate before it starts to slow down.
- `-DENDEARLY` terminates the problem early with an HPL Error exit. It means that you need to ignore the missing residual results, which are wrong because the problem never completed. However, you can get an idea what the initial performance was, and if it looks good, then run the problem to completion without `-DENDEARLY`. To avoid the error check, you can set HPL's threshold parameter in `HPL.dat` to a negative number.
- Though `-DENDEARLY` terminates early, HPL treats the problem as completed and computes Gflop rating as though the problem ran to completion. Ignore this erroneously high rating.
- The bigger the problem, the more accurately the last update that `-DENDEARLY` returns is close to what happens when the problem runs to completion. `-DENDEARLY` is a poor approximation for small problems. It is for this reason that you are suggested to use `ENDEARLY` in conjunction with `ASYOUGO2`, because `ASYOUGO2` reports actual `DGEMM` performance, which can be a closer approximation to problems just starting.

-DASYOUGO2

-DASYOUGO2 gives detailed single-node DGEMM performance information. It captures all DGEMM calls (if you use Fortran BLAS) and records their data. Because of this, the routine has a marginal intrusive overhead. Unlike -DASYOUGO, which is quite non-intrusive, -DASYOUGO2 interrupts every DGEMM call to monitor its performance. You should beware of this overhead, although for big problems, it is, less than 0.1%.

Here is a sample ASYOUGO2 output (the first 3 non-intrusive numbers can be found in ASYOUGO and ENDEARLY), so it suffices to describe these numbers here:

```
Col=001280 Fract=0.050 Mflops=42454.99 (DT=9.5 DF=34.1 DMF=38322.78).
```

The problem size was N=16000 with a block size of 128. After 10 blocks, that is, 1280 columns, an output was sent to the screen. Here, the fraction of columns completed is 1280/16000=0.08. Only up to 40 outputs are printed, at various places through the matrix decomposition: fractions

```
0.005 0.010 0.015 0.020 0.025 0.030 0.035 0.040 0.045 0.050 0.055 0.060 0.065 0.070
0.075 0.080 0.085 0.090 0.095 0.100 0.105 0.110 0.115 0.120 0.125 0.130 0.135 0.140
0.145 0.150 0.155 0.160 0.165 0.170 0.175 0.180 0.185 0.190 0.195 0.200 0.205 0.210
0.215 0.220 0.225 0.230 0.235 0.240 0.245 0.250 0.255 0.260 0.265 0.270 0.275 0.280
0.285 0.290 0.295 0.300 0.305 0.310 0.315 0.320 0.325 0.330 0.335 0.340 0.345 0.350
0.355 0.360 0.365 0.370 0.375 0.380 0.385 0.390 0.395 0.400 0.405 0.410 0.415 0.420
0.425 0.430 0.435 0.440 0.445 0.450 0.455 0.460 0.465 0.470 0.475 0.480 0.485 0.490
0.495 0.515 0.535 0.555 0.575 0.595 0.615 0.635 0.655 0.675 0.695 0.795 0.895.
```

However, this problem size is so small and the block size so big by comparison that as soon as it prints the value for 0.045, it was already through 0.08 fraction of the columns. On a really big problem, the fractional number will be more accurate. It never prints more than the 112 numbers above. So, smaller problems will have fewer than 112 updates, and the biggest problems will have precisely 112 updates.

Mflops is an estimate based on 1280 columns of LU being completed. However, with lookahead steps, sometimes that work is not actually completed when the output is made. Nevertheless, this is a good estimate for comparing identical runs.

The 3 numbers in parenthesis are intrusive ASYOUGO2 addins. DT is the total time processor 0 has spent in DGEMM. DF is the number of billion operations that have been performed in DGEMM by one processor. Hence, the performance of processor 0 (in Gflops) in DGEMM is always DF/DT. Using the number of DGEMM flops as a basis instead of the number of LU flops, you get a lower bound on performance of the run by looking at DMF, which can be compared to Mflops above (It uses the global LU time, but the DGEMM flops are computed under the assumption that the problem is evenly distributed amongst the nodes, as only HPL's node (0,0) returns any output.)

Note that when using the above performance monitoring tools to compare different HPL.dat input data sets, you should be aware that the pattern of performance drop-off that LU experiences is sensitive to some input data. For instance, when you try very small problems, the performance drop-off from the initial values to end values is very rapid. The larger the problem, the less the drop-off, and it is probably safe to use the first few performance values to estimate the difference between a problem size 700000 and 701000, for instance. Another factor that influences the performance drop-off is the grid dimensions (P and Q). For big problems, the performance tends to fall off less from the first few steps when P and Q are roughly equal in value. You can make use of a large number of parameters, such as broadcast types, and change them so that the final performance is determined very closely by the first few steps.

Using these tools will greatly assist the amount of data you can test.

See Also

Benchmarking a Cluster

Intel® Math Kernel Library Language Interfaces Support

A

Language Interfaces Support, by Function Domain

The following table shows language interfaces that Intel® Math Kernel Library (Intel® MKL) provides for each function domain. However, Intel MKL routines can be called from other languages using mixed-language programming. See Mixed-language Programming with Intel® MKL for an example of how to call Fortran routines from C/C++.

Function Domain	FORTRAN 77 interface	Fortran 90/95 interface	C/C++ interface
Basic Linear Algebra Subprograms (BLAS)	Yes	Yes	via CBLAS
BLAS-like extension transposition routines	Yes		Yes
Sparse BLAS Level 1	Yes	Yes	via CBLAS
Sparse BLAS Level 2 and 3	Yes	Yes	Yes
LAPACK routines for solving systems of linear equations	Yes	Yes	Yes
LAPACK routines for solving least-squares problems, eigenvalue and singular value problems, and Sylvester's equations	Yes	Yes	Yes
Auxiliary and utility LAPACK routines	Yes		Yes
Parallel Basic Linear Algebra Subprograms (PBLAS)	Yes		
ScaLAPACK routines	Yes		†
DSS/PARDISO* solvers	Yes	Yes	Yes
Other Direct and Iterative Sparse Solver routines	Yes	Yes	Yes
Vector Mathematical Library (VML) functions	Yes	Yes	Yes
Vector Statistical Library (VSL) functions	Yes	Yes	Yes
Fourier Transform functions (FFT)		Yes	Yes
Cluster FFT functions		Yes	Yes
Trigonometric Transform routines		Yes	Yes
Fast Poisson, Laplace, and Helmholtz Solver (Poisson Library) routines		Yes	Yes
Optimization (Trust-Region) Solver routines	Yes	Yes	Yes
Data Fitting functions	Yes	Yes	Yes
Support functions (including memory allocation)	Yes	Yes	Yes

† Supported using a mixed language programming call. See Intel® MKL Include Files for the respective header file.

Include Files

The table below lists Intel MKL include files.

NOTE The `*.f90` include files supersede the `*.f77` include files and can be used for FORTRAN 77 as well as for later versions of Fortran. However, the `*.f77` files are kept for backward compatibility.

Function domain	Fortran Include Files	C/C++ Include Files
All function domains	`mkl.fi`	`mkl.h`
BLACS Routines		`mkl_blacs.h`‡‡
BLAS Routines	`blas.f90` `mkl_blas.fi`†	`mkl_blas.h`‡
BLAS-like Extension Transposition Routines	`mkl_trans.fi`†	`mkl_trans.h`‡
CBLAS Interface to BLAS		`mkl_cblas.h`‡
Sparse BLAS Routines	`mkl_spblas.fi`†	`mkl_spblas.h`‡
LAPACK Routines	`lapack.f90` `mkl_lapack.fi`†	`mkl_lapack.h`‡
C Interface to LAPACK		`mkl_lapacke.h`‡
PBLAS Routines		`mkl_pblas.h`‡‡
ScaLAPACK Routines		`mkl_scalapack.h`‡‡
All Sparse Solver Routines	`mkl_solver.f90` `mkl_solver.fi`†	`mkl_solver.h`‡
PARDISO	`mkl_pardiso.f90` `mkl_pardiso.fi`†	`mkl_pardiso.h`‡
DSS Interface	`mkl_dss.f90` `mkl_dss.fi`†	`mkl_dss.h`‡
RCI Iterative Solvers ILU Factorization	`mkl_rci.fi`†	`mkl_rci.h`‡
Optimization Solver Routines	`mkl_rci.fi`†	`mkl_rci.h`‡

Vector Mathematical Functions	`mkl_vml.90`
	`mkl_vml.fi`†
	`mkl_vml.f77`
		`mkl_vml.h`‡

Vector Statistical Functions	`mkl_vsl.f90`
	`mkl_vsl.fi`†
	`mkl_vsl.f77`
		`mkl_vsl.h`‡

Fourier Transform Functions	`mkl_dfti.f90`	`mkl_dfti.h`‡
Cluster Fourier Transform Functions	`mkl_cdft.f90`	`mkl_cdft.h`‡‡
Partial Differential Equations Support Routines		

Function domain	Fortran Include Files	C/C++ Include Files
Trigonometric Transforms	`mkl_trig_transforms.f90`	`mkl_trig_transform.h`‡
Poisson Solvers	`mkl_poisson.f90`	`mkl_poisson.h`‡
Data Fitting functions	`mkl_df.f90` `mkl_df.f77`	`mkl_df.h`‡
Support functions	`mkl_service.f90` `mkl_service.fi`†	`mkl_service.h`‡
Declarations for replacing memory allocation functions. See Redefining Memory Functions for details.		`i_malloc.h`

† You can use the `mkl.fi` include file in your code instead.

‡ You can include the `mkl.h` header file in your code instead.

‡‡ Also include the `mkl.h` header file in your code.

See Also

Language Interfaces Support, by Function Domain

Support for Third-Party Interfaces

B

FFTW Interface Support

Intel® Math Kernel Library (Intel® MKL) offers two collections of wrappers for the FFTW interface (www.fftw.org). The wrappers are the superstructure of FFTW to be used for calling the Intel MKL Fourier transform functions. These collections correspond to the FFTW versions 2.x and 3.x and the Intel MKL versions 7.0 and later.

These wrappers enable using Intel MKL Fourier transforms to improve the performance of programs that use FFTW without changing the program source code. See the "*FFTW Interface to Intel® Math Kernel Library*" appendix in the Intel MKL Reference Manual for details on the use of the wrappers.

Important For ease of use, FFTW3 interface is also integrated in Intel MKL.

C Directory Structure in Detail

Tables in this section show contents of the Intel(R) Math Kernel Library (Intel(R) MKL) architecture-specific directories.

Optimization Notice
Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice. Notice revision #20110804

Detailed Structure of the IA-32 Architecture Directories

Static Libraries in the `lib\ia32` Directory

File	Contents
Interface layer	
`mkl_intel_c.lib`	cdecl interface library
`mkl_intel_s.lib`	CVF default interface library
`mkl_blas95.lib`	Fortran 95 interface library for BLAS. Supports the Intel® Fortran compiler
`mkl_lapack95.lib`	Fortran 95 interface library for LAPACK. Supports the Intel® Fortran compiler
Threading layer	
`mkl_intel_thread.lib`	Threading library for the Intel compilers
`mkl_pgi_thread.lib`	Threading library for the PGI* compiler
`mkl_sequential.lib`	Sequential library
Computational layer	
`mkl_core.lib`	Kernel library for IA-32 architecture
`mkl_solver.lib`	Deprecated. Empty library for backward compatibility
`mkl_solver_sequential.lib`	Deprecated. Empty library for backward compatibility
`mkl_scalapack_core.lib`	ScaLAPACK routines
`mkl_cdft_core.lib`	Cluster version of FFTs
Run-time Libraries (RTL)	

File	Contents
`mkl_blacs_intelmpi.lib`	BLACS routines supporting Intel MPI
`mkl_blacs_mpich2.lib`	BLACS routines supporting MPICH2

Dynamic Libraries in the `lib\ia32` Directory

File	Contents
`mkl_rt.lib`	Single Dynamic Library to be used for linking
Interface layer	
`mkl_intel_c_dll.lib`	cdecl interface library for dynamic linking
`mkl_intel_s_dll.lib`	CVF default interface library for dynamic linking
Threading layer	
`mkl_intel_thread_dll.lib`	Threading library for dynamic linking with the Intel compilers
`mkl_pgi_thread_dll.lib`	Threading library for dynamic linking with the PGI* compiler
`mkl_sequential_dll.lib`	Sequential library for dynamic linking
Computational layer	
`mkl_core_dll.lib`	Core library for dynamic linking
`mkl_scalapack_core_dll.lib`	ScaLAPACK routine library for dynamic linking
`mkl_cdft_core_dll.lib`	Cluster FFT library for dynamic linking
Run-time Libraries (RTL)	
`mkl_blacs_dll.lib`	BLACS interface library for dynamic linking

Contents of the `redist\ia32\mkl` Directory

File	Contents
`mkl_rt.dll`	Single Dynamic Library
Threading layer	
`mkl_intel_thread.dll`	Dynamic threading library for the Intel compilers
`mkl_pgi_thread.dll`	Dynamic threading library for the PGI* compiler
`mkl_sequential.dll`	Dynamic sequential library
Computational layer	
`mkl_core.dll`	Core library containing processor-independent code and a dispatcher for dynamic loading of processor-specific code
`mkl_def.dll`	Default kernel (Intel® Pentium®, Pentium® Pro, Pentium® II, and Pentium® III processors)

File	Contents
`mkl_p4.dll`	Pentium® 4 processor kernel
`mkl_p4p.dll`	Kernel for the Intel® Pentium® 4 processor with Intel® Streaming SIMD Extensions 3 (Intel® SSE3), including Intel® Core™ Duo and Intel® Core™ Solo processors.
`mkl_p4m.dll`	Kernel for processors based on the Intel® Core™ microarchitecture (except Intel® Core™ Duo and Intel® Core™ Solo processors, for which `mkl_p4p.dll` is intended)
`mkl_p4m3.dll`	Kernel for the Intel® Core™ i7 processors
`mkl_vml_def.dll`	Vector Math Library (VML)/Vector Statistical Library (VSL)/Data Fitting (DF) part of default kernel for old Intel® Pentium® processors
`mkl_vml_ia.dll`	VML/VSL/DF default kernel for newer Intel® architecture processors
`mkl_vml_p4.dll`	VML/VSL/DF part of Pentium® 4 processor kernel
`mkl_vml_p4p.dll`	VML/VSL/DF for Pentium® 4 processor with Intel SSE3
`mkl_vml_p4m.dll`	VML/VSL/DF for processors based on the Intel® Core™ microarchitecture (except Intel® Core™ Duo and Intel® Core™ Solo processors, for which `mkl_vml_p4p.dll` is intended).
`mkl_vml_p4m2.dll`	VML/VSL/DF for 45nm Hi-k Intel® Core™2 and Intel Xeon® processor families
`mkl_vml_p4m3.dll`	VML/VSL/DF for the Intel® Core™ i7 processors
`mkl_vml_avx.dll`	VML/VSL/DF optimized for the Intel® Advanced Vector Extensions (Intel® AVX)
`libmkl_vml_cmpt.dll`	VML/VSL/DF library for conditional numerical reproducibility
`mkl_scalapack_core.dll`	ScaLAPACK routines
`mkl_cdft_core.dll`	Cluster FFT dynamic library
`libimalloc.dll`	Dynamic library to support renaming of memory functions
Run-time Libraries (RTL)	
`mkl_blacs.dll`	BLACS routines
`mkl_blacs_intelmpi.dll`	BLACS routines supporting Intel MPI
`mkl_blacs_mpich2.dll`	BLACS routines supporting MPICH2
`1033\mkl_msg.dll`	Catalog of Intel® Math Kernel Library (Intel® MKL) messages in English
`1041\mkl_msg.dll`	Catalog of Intel MKL messages in Japanese. Available only if the Intel® C++ Composer XE or Intel® Visual Fortran Composer XE that includes Intel MKL provides Japanese localization. Please see the Release Notes for this information.

Detailed Structure of the Intel® 64 Architecture Directories

Static Libraries in the `lib\intel64` Directory

File	Contents
Interface layer	
`mkl_intel_lp64.lib`	LP64 interface library for the Intel compilers
`mkl_intel_ilp64.lib`	ILP64 interface library for the Intel compilers
`mkl_intel_sp2dp.a`	SP2DP interface library for the Intel compilers
`mkl_blas95_lp64.lib`	Fortran 95 interface library for BLAS. Supports the Intel® Fortran compiler and LP64 interface
`mkl_blas95_ilp64.lib`	Fortran 95 interface library for BLAS. Supports the Intel® Fortran compiler and ILP64 interface
`mkl_lapack95_lp64.lib`	Fortran 95 interface library for LAPACK. Supports the Intel® Fortran compiler and LP64 interface
`mkl_lapack95_ilp64.lib`	Fortran 95 interface library for LAPACK. Supports the Intel® Fortran compiler and ILP64 interface
Threading layer	
`mkl_intel_thread.lib`	Threading library for the Intel compilers
`mkl_pgi_thread.lib`	Threading library for the PGI* compiler
`mkl_sequential.lib`	Sequential library
Computational layer	
`mkl_core.lib`	Kernel library for the Intel® 64 architecture
`mkl_solver_lp64.lib`	Deprecated. Empty library for backward compatibility
`mkl_solver_lp64_sequential.lib`	Deprecated. Empty library for backward compatibility
`mkl_solver_ilp64.lib`	Deprecated. Empty library for backward compatibility
`mkl_solver_ilp64_sequential.lib`	Deprecated. Empty library for backward compatibility
`mkl_scalapack_lp64.lib`	ScaLAPACK routine library supporting the LP64 interface
`mkl_scalapack_ilp64.lib`	ScaLAPACK routine library supporting the ILP64 interface
`mkl_cdft_core.lib`	Cluster version of FFTs
Run-time Libraries (RTL)	
`mkl_blacs_intelmpi_lp64.lib`	LP64 version of BLACS routines supporting Intel MPI
`mkl_blacs_intelmpi_ilp64.lib`	ILP64 version of BLACS routines supporting Intel MPI
`mkl_blacs_mpich2_lp64.lib`	LP64 version of BLACS routines supporting MPICH2
`mkl_blacs_mpich2_ilp64.lib`	ILP64 version of BLACS routines supporting MPICH2
`mkl_blacs_msmpi_lp64.lib`	LP64 version of BLACS routines supporting Microsoft* MPI
`mkl_blacs_msmpi_ilp64.lib`	ILP64 version of BLACS routines supporting Microsoft* MPI

Dynamic Libraries in the `lib\intel64` Directory

File	Contents
`mkl_rt.lib`	Single Dynamic Library to be used for linking
Interface layer	
`mkl_intel_lp64_dll.lib`	LP64 interface library for dynamic linking with the Intel compilers
`mkl_intel_ilp64_dll.lib`	ILP64 interface library for dynamic linking with the Intel compilers
Threading layer	
`mkl_intel_thread_dll.lib`	Threading library for dynamic linking with the Intel compilers
`mkl_pgi_thread_dll.lib`	Threading library for dynamic linking with the PGI* compiler
`mkl_sequential_dll.lib`	Sequential library for dynamic linking
Computational layer	
`mkl_core_dll.lib`	Core library for dynamic linking
`mkl_scalapack_lp64_dll.lib`	ScaLAPACK routine library for dynamic linking supporting the LP64 interface
`mkl_scalapack_ilp64_dll.lib`	ScaLAPACK routine library for dynamic linking supporting the ILP64 interface
`mkl_cdft_core_dll.lib`	Cluster FFT library for dynamic linking
Run-time Libraries (RTL)	
`mkl_blacs_lp64_dll.lib`	LP64 version of BLACS interface library for dynamic linking
`mkl_blacs_ilp64_dll.lib`	ILP64 version of BLACS interface library for dynamic linking

Contents of the `redist\intel64\mkl` Directory

File	Contents
`mkl_rt.dll`	Single Dynamic Library
Threading layer	
`mkl_intel_thread.dll`	Dynamic threading library for the Intel compilers
`mkl_pgi_thread.dll`	Dynamic threading library for the PGI* compiler
`mkl_sequential.dll`	Dynamic sequential library
Computational layer	

File	Contents
mkl_core.dll	Core library containing processor-independent code and a dispatcher for dynamic loading of processor-specific code
mkl_def.dll	Default kernel for the Intel® 64 architecture
mkl_p4n.dll	Kernel for the Intel® Xeon® processor using the Intel® 64 architecture
mkl_mc.dll	Kernel for processors based on the Intel® Core™ microarchitecture
mkl_mc3.dll	Kernel for the Intel® Core™ i7 processors
mkl_avx.dll	Kernel optimized for the Intel® Advanced Vector Extensions (Intel® AVX)
mkl_vml_def.dll	Vector Math Library (VML)/Vector Statistical Library (VSL)/Data Fitting (DF) part of default kernel
mkl_vml_p4n.dll	VML/VSL/DF for the Intel® Xeon® processor using the Intel® 64 architecture
mkl_vml_mc.dll	VML/VSL/DF for processors based on the Intel® Core™ microarchitecture
mkl_vml_mc2.dll	VML/VSL/DF for 45nm Hi-k Intel® Core™2 and Intel Xeon® processor families
mkl_vml_mc3.dll	VML/VSL/DF for the Intel® Core® i7 processors
mkl_vml_avx.dll	VML/VSL/DF optimized for the Intel® Advanced Vector Extensions (Intel® AVX)
libmkl_vml_cmpt.dll	VML/VSL/DF library for conditional numerical reproducibility
mkl_scalapack_lp64.dll	ScaLAPACK routine library supporting the LP64 interface
mkl_scalapack_ilp64.dll	ScaLAPACK routine library supporting the ILP64 interface
mkl_cdft_core.dll	Cluster FFT dynamic library
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Run-time Libraries (RTL)	
mkl_blacs_lp64.dll	LP64 version of BLACS routines
mkl_blacs_ilp64.dll	ILP64 version of BLACS routines
mkl_blacs_intelmpi_lp64.dll	LP64 version of BLACS routines supporting Intel MPI
mkl_blacs_intelmpi_ilp64.dll	ILP64 version of BLACS routines supporting Intel MPI
mkl_blacs_mpich2_lp64.dll	LP64 version of BLACS routines supporting MPICH2
mkl_blacs_mpich2_ilp64.dll	ILP64 version of BLACS routines supporting MPICH2
mkl_blacs_msmpi_lp64.dll	LP64 version of BLACS routines supporting Microsoft* MPI
mkl_blacs_msmpi_ilp64.dll	ILP64 version of BLACS routines supporting Microsoft* MPI
1033\mkl_msg.dll	Catalog of Intel® Math Kernel Library (Intel® MKL) messages in English

File	Contents
`1041\mkl_msg.dll`	Catalog of Intel MKL messages in Japanese. Available only if the Intel® C++ Composer XE or Intel® Visual Fortran Composer XE that includes Intel MKL provides Japanese localization. Please see the Release Notes for this information.

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