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<table>
<thead>
<tr>
<th>Document number</th>
<th>Revision number</th>
<th>Description</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKU – 318537-003</td>
<td>20081031</td>
<td>Updated Intel® Cluster Toolkit Compiler Edition 3.2 for Linux* OS Getting Started Guide to reflect changes and improvements to the software components.</td>
<td>10/31/2008</td>
</tr>
</tbody>
</table>

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2. Introduction
At the time of this writing, the Intel® Cluster Toolkit Compiler Edition 3.2 release on Linux consists of:

1. Intel® C++ Compiler 11.0 Update 0xx
2. Intel® Debugger 11.0 Update 0xx
3. Intel® Fortran Compiler 11.0 Update 0xx
4. Intel® Math Kernel Library 10.1
5. Intel® MPI Benchmarks 3.2
6. Intel® MPI Library 3.2
7. Intel® Trace Analyzer and Collector 7.2

where 0xx might be a value such as 068 and represents a build number.

A prerelease license for Cluster OpenMP (for Linux only on Intel® 64 and IA-64 architectures) is available through whatif.intel.com. Please note that this prerelease license provides access to an unsupported offering of Cluster OpenMP technology.

The software architecture of the Intel Cluster Toolkit Compiler Edition for Linux is illustrated in Figure 2.1:

![Figure 2.1 – The software architecture for the Intel Cluster Toolkit Compiler Edition for Linux (The Cluster OpenMP Library is only available for Linux on Intel® 64 and IA-64 architectures)]
The following are acronyms and definitions of those acronyms that may be referenced within this document.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABI</td>
<td>Application Binary Interface – describes the low-level interface an application program and the operating system, between an application and its libraries, or between component parts of an application.</td>
</tr>
<tr>
<td>BLACS</td>
<td>Basic Linear Algebra Communication Subprograms – provides a linear algebra oriented message passing interface for distributed memory computing platforms.</td>
</tr>
<tr>
<td>BLAS</td>
<td>Basic Linear Algebra Subroutines</td>
</tr>
<tr>
<td>DAPL*</td>
<td>Direct Access Program Library - an Application Program Interface (API) for Remote Data Memory Access (RDMA).</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier Transform</td>
</tr>
<tr>
<td>Ethernet</td>
<td>Ethernet is the predominant local area networking technology. It is transports data over a variety of electrical or optical media. It transports any of several upper layer protocols via data packet transmissions.</td>
</tr>
<tr>
<td>GB</td>
<td>Gigabyte</td>
</tr>
<tr>
<td>ICT</td>
<td>Intel® Cluster Toolkit</td>
</tr>
<tr>
<td>ICTCE</td>
<td>Intel® Cluster Toolkit Compiler Edition</td>
</tr>
<tr>
<td>IMB</td>
<td>Intel® MPI Benchmarks</td>
</tr>
<tr>
<td>IP</td>
<td>Internet protocol</td>
</tr>
<tr>
<td>ITA or ita</td>
<td>Intel® Trace Analyzer</td>
</tr>
<tr>
<td>ITAC or itac</td>
<td>Intel® Trace Analyzer and Collector</td>
</tr>
<tr>
<td>ITC or itc</td>
<td>Intel® Trace Collector</td>
</tr>
<tr>
<td>MPD</td>
<td>Multi-purpose daemon protocol – a daemon that runs on each node of a cluster. These MPDs configure the nodes of the cluster into a “virtual machine” that is capable of running MPI programs.</td>
</tr>
<tr>
<td>MPI</td>
<td>Message Passing Interface - an industry standard, message-passing protocol that typically uses a two-sided send-receive model to transfer messages between processes.</td>
</tr>
</tbody>
</table>
| NFS     | The Network File System (acronym NFS) is a client/server application that lets a computer user view and optionally store and update file on a remote computer as though they were on the user’s own computer. The user's system needs to have an NFS client and the other computer needs the NFS server. Both of them require that you also have TCP/IP installed since the NFS server and client use TCP/IP as the program that sends the files and updates back and
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVM*</td>
<td>Parallel Virtual Machine</td>
</tr>
<tr>
<td>RAM</td>
<td>Random Access Memory</td>
</tr>
<tr>
<td>RDMA</td>
<td>Remote Direct Memory Access - this capability allows processes executing on one node of a cluster to be able to &quot;directly&quot; access (execute reads or writes against) the memory of processes within the same user job executing on a different node of the cluster.</td>
</tr>
<tr>
<td>RDSSM</td>
<td>TCP + shared memory + DAPL* (for SMP clusters connected via RDMA-capable fabrics)</td>
</tr>
<tr>
<td>RPM*</td>
<td>Red Hat Package Manager* - a system that eases installation, verification, upgrading, and uninstalling Linux packages.</td>
</tr>
<tr>
<td>ScaLAPACK</td>
<td>SCAlable LAPACK - an acronym for Scalable Linear Algebra Package or Scalable LAPACK.</td>
</tr>
<tr>
<td>shm</td>
<td>Shared memory only (no sockets)</td>
</tr>
<tr>
<td>SMP</td>
<td>Symmetric Multi-processor</td>
</tr>
<tr>
<td>ssm</td>
<td>TCP + shared memory (for SMP clusters connected via Ethernet)</td>
</tr>
<tr>
<td>STF</td>
<td>Structured Trace Format – a trace file format used by the Intel Trace Collector for efficiently recording data, and this trace format is used by the Intel Trace Analyzer for performance analysis.</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol - a session-oriented streaming transport protocol which provides sequencing, error detection and correction, flow control, congestion control and multiplexing.</td>
</tr>
<tr>
<td>VML</td>
<td>Vector Math Library</td>
</tr>
<tr>
<td>VSL</td>
<td>Vector Statistical Library</td>
</tr>
</tbody>
</table>
3. Intel Software Downloads and Installation on Linux*

The Intel Cluster Toolkit Compiler Edition installation process on Linux is comprised of eight basic steps. The Intel Cluster Toolkit Compiler Edition 3.2 package consists of the following components:

<table>
<thead>
<tr>
<th>Software Component</th>
<th>Default Installation Directory on IA-32 Architecture for Linux</th>
<th>Default Installation Directory on Intel® 64 Architecture for Linux</th>
<th>Default Installation Directory on IA-64 Architecture for Linux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel C++ Compiler 11.0</td>
<td>/opt/intel/ictce/3.2.0.0xx/cc</td>
<td>/opt/intel/ictce/3.2.0.0xx/cc</td>
<td>/opt/intel/ictce/3.2.0.0xx/cc</td>
</tr>
<tr>
<td>Intel Debugger 11.0</td>
<td>/opt/intel/ictce/3.2.0.0xx/cc</td>
<td>/opt/intel/ictce/3.2.0.0xx/cc</td>
<td>/opt/intel/ictce/3.2.0.0xx/cc</td>
</tr>
<tr>
<td>Intel Fortran Compiler 11.0</td>
<td>/opt/intel/ictce/3.2.0.0xx/fc</td>
<td>/opt/intel/ictce/3.2.0.0xx/fc</td>
<td>/opt/intel/ictce/3.2.0.0xx/fc</td>
</tr>
<tr>
<td>Intel MPI Benchmarks 3.2</td>
<td>/opt/intel/ictce/3.2.0.0xx/imb</td>
<td>/opt/intel/ictce/3.2.0.0xx/impi</td>
<td>/opt/intel/ictce/3.2.0.0xx/impi</td>
</tr>
<tr>
<td>Intel MPI Library 3.2</td>
<td>/opt/intel/ictce/3.2.0.0xx/impi</td>
<td>/opt/intel/ictce/3.2.0.0xx/impi</td>
<td>/opt/intel/ictce/3.2.0.0xx/impi</td>
</tr>
<tr>
<td>Intel MKL 10.1</td>
<td>/opt/intel/ictce/3.2.0.0xx/mkl</td>
<td>/opt/intel/ictce/3.2.0.0xx/mkl</td>
<td>/opt/intel/ictce/3.2.0.0xx/mkl</td>
</tr>
<tr>
<td>Intel Trace Analyzer and Collector 7.2</td>
<td>/opt/intel/ictce/3.2.0.0xx/itac</td>
<td>/opt/intel/ictce/3.2.0.0xx/itac</td>
<td>/opt/intel/ictce/3.2.0.0xx/itac</td>
</tr>
</tbody>
</table>

For the table above, references to 0xx in the directory path represents a build number such as 013. Note that the Intel Cluster Toolkit Compiler Edition installer will automatically make the appropriate selection of binaries, scripts, and text files from its installation archive based on the Intel processor architecture of the host system where the installation process is initiated. You do not have to worry about selecting the correct software component names for the given Intel architecture.
Recall that you as a user of the Intel Cluster Toolkit Compiler Edition on Linux may need assistance from your system administrator in installing the associated software packages on your cluster system, if the installation directory requires system administrative write privileges (e.g. /opt/intel on Linux). This assumes that your login account does not have administrative capabilities.

### 3.1 Linux* Installation

**Important Note:** The 4.2.2 version of RPM on Red Hat Enterprise Linux* 3.0 for Itanium® 2 has a broken relocation feature. This will be a serious problem for users trying to install on clusters where there are shared devices. A recommended solution is for you to upgrade to the latest release of RPM. A possible URL for retrieving a recent release of RPM that resolves this problem on the Itanium 2 architecture is:

http://www.redhat.com

1. For Linux systems, a `machines.LINUX` file will either need to be created, or an existing `machines.LINUX` file can be used by the Intel Cluster Toolkit Compiler Edition installer to deploy the appropriate software packages from the toolkit amongst the nodes of the cluster. This `machines.LINUX` file contains a list of the computing nodes (i.e. the hostnames) for the cluster. The format is one hostname per line:

   `hostname`

   The hostname should be the same as the result from the Linux command “hostname”. An example of the content for the file `machines.LINUX`, where a contrived cluster consists of eight nodes might be:

   - clusternode1
   - clusternode2
   - clusternode3
   - clusternode4
   - clusternode5
   - clusternode6
   - clusternode7
   - clusternode8

   A line of text above is consider a comment line if column 1 contains the “#” symbol. It is always assumed that the first node in the list is the master node. The remaining nodes are the compute nodes. The text `clusternode1` and `clusternode2`, for example, represent the names of two of the nodes in a contrived computing cluster. The contents of the `machines.LINUX` file can also be used by you to construct an `mpd.hosts` file for the multi-purpose daemon (MPD) protocol. The MPD protocol is used for running MPI applications that utilize Intel MPI Library. See Section 4.1 titled “Launching MPD Daemons”.

2. In preparation for doing the installation, you may want to create a staging area. On the system where the Intel Cluster Toolkit Compiler Edition software components are to be installed, it is recommended that a staging area be constructed in a directory such as `/tmp`. An example folder path staging area might be:
/tmp/ict_staging_area

where ict_staging_area is an acronym for Intel Cluster Toolkit Compiler Edition staging area.

3. Upon registering for Intel Cluster Toolkit Compiler Edition 3.2, you will receive a serial number (e.g., C111-12345678) for this product. Your serial number can be found within the email receipt of your product purchase. Go to the Intel® Software Development Products Registration Center site and provide the product serial number information. Once admission has been granted into the registration center, you will be able to access the Intel® Premier Support web pages for software support.

4. The license for the Intel Cluster Toolkit Compiler Edition license file that is provided to you should be placed in a directory pointed to by the INTEL_LICENSE_FILE environment variable. Do not change the file name as the ".lic" extension is critical. Common locations for the attached license file are:

    <installation path>/licenses

For example, on the cluster system where the Intel Cluster Toolkit Compiler Edition software is to be installed, all licenses for Intel-based software products might be placed in:

    /opt/intel/licenses

where licenses is a sub-directory. It is also imperative that you and/or the system administrator set the environment variable INTEL_LICENSE_FILE to the directory path where the Intel software licenses will reside prior to doing an installation of the Intel Cluster Toolkit Compiler Edition. For Bourne* Shell or Korn* Shell the syntax for setting the INTEL_LICENSE_FILE environment variable might be:

    export INTEL_LICENSE_FILE=/opt/intel/licenses

For C Shell, the syntax might be:

    setenv INTEL_LICENSE_FILE /opt/intel/licenses

Also, for using Cluster OpenMP on Linux for Intel® 64 and IA-64 architectures, go to the URL:

    whatif.intel.com

and click on the web-link for the Cluster OpenMP license. Cluster OpenMP is an unsupported software product and may be used by customers through a prerelease End User License Agreement (EULA). Place this license in the directory:

    /opt/intel/licenses
on your cluster system. This free license will allow you to use the Cluster OpenMP library.

5. Patrons can place the Intel Cluster Toolkit Compiler Edition software package into the staging area folder.

6. The installer package for the Intel Cluster Toolkit Compiler Edition has the following general nomenclature:

   \[ l_{ict}\_<major>\_<minor>\_<update>\_<package\_num>\_tar\_gz \]

   where \(<major>\_<minor>\_<update>\_<package\_num>\) is a string such as:

   \[ b\_3.2.0.xxx, \]  

   where \(b\) is an acronym for beta

   or

   \[ p\_3.2.0.xxx, \]  

   where \(p\) is an acronym for production

   The \(<package\_num>\) meta-symbol is a string such as 013. This string indicates the package number.

   The command:

   \[
   \text{tar} \ -xvzf \ l_{ict}\_<major>\_<minor>\_<update>\_<package\_num>\_tar\_gz
   \]

   will create a sub-directory called

   \[ l_{ict}\_<major>\_<minor>\_<update>\_<package\_num> \]

   Change to that directory with the shell command:

   \[
   \text{cd} \ l_{ict}\_<major>\_<minor>\_<update>\_<package\_num>
   \]

   For example, suppose the installation package is called

   \[ l_{ict}\_p\_3.2.0.013\_tar\_gz \]

   In the staging area that has been created, type the command:

   \[
   \text{tar} \ -xvzf \ l_{ict}\_p\_3.2.0.013\_tar\_gz
   \]

   This will create a sub-directory called \[ l_{ict}\_p\_3.2.0.013 \]

   Change to that directory with the shell command:

   \[
   \text{cd} \ l_{ict}\_p\_3.2.0.013
   \]

   In that folder make sure that \texttt{machines.LINUX} file, as mentioned in item 1 above, is either in this directory or you should know the directory path to this file.

7. Also within the \[ l_{ict}\_<major>\_<minor>\_<update>\_<package\_num> \] directory staging area, the \texttt{expect} shell script file called “\texttt{sshconnectivity.exp}” can be used to help you establish secure shell connectivity on a cluster system, where \texttt{expect} is a tool for automating interactive applications. To run “\texttt{sshconnectivity.exp}”, the \texttt{expect} runtime software needs to be installed on...
your Linux system. To make sure that the \texttt{expect} runtime software is properly installed, type:

\begin{verbatim}
which expect
\end{verbatim}

If you encounter a "Command not found." error message, you can download the expect software package from the following URL:

The syntax for the \texttt{"sshconnectivity.exp"} command is:

\begin{verbatim}
./sshconnectivity.exp machines.LINUX
\end{verbatim}

This \texttt{expect} shell script will create or update a \texttt{-.ssh} directory on each node of the cluster beginning with the master node which must be the first name listed in the \texttt{machines.LINUX} file. This script will prompt you for your password twice.

Enter your user password:
Re-enter your user password:

To provide security each time you enter your user password, asterisks will appear in lieu of the password text. Upon successful completion of the script, the following message fragment will appear:

\begin{verbatim}
......
Node count = 4
Secure shell connectivity was established on all nodes.
......
......
\end{verbatim}

A log of the transactions for this script will be recorded in:

\begin{verbatim}
/tmp/sshconnectivity.<login-name>.log
\end{verbatim}

where \texttt{<login-name>} is a meta-symbol for your actual login.

Note that the \texttt{expect} shell script \texttt{sshconnectivity.exp} will remove the write access capability on the group and other "permission categories" for the user's home directory folder. If this is not done, a password prompt will continue to be issued for any secure shell activity.

This process of establishing secure shell connectivity in step 7 above is demonstrated by the following complete graph\footnote{A mathematical definition of a complete graph in graph theory is a simple graph where an edge connects every pair of vertices. The complete graph on \(n\) vertices has \(n\) vertices and \(n(n - 1)/2\) edges, and is denoted by \(K_n\). Each vertex in the graph has degree \(n - 1\). All complete graphs are their own cliques (a maximal complete graph). A graph of this type is maximally connected because the only vertex cut which disconnects the graph is the complete set of vertices.} (Figure 3.1) illustration where a...
vertex in the graph represents a cluster computing node, and an edge between two vertices connotes that the two cluster computing nodes have exchanged public keys for secure shell connectivity. Secure shell connectivity is intended to provide secure, encrypted communication channels between two or more cluster nodes over an insecure network.

The script sshconnectivity.exp will call the appropriate secure shell utilities to generate a private key and a public key for each node of the cluster.

For the complete graph example in Figure 3.1, suppose there are nodes (vertices) 1 to \( n \) in the cluster. For a given node \( i \), nodes 1 to \( i - 1 \) and nodes \( i + 1 \) to \( n \) are provided with the public key from node \( i \). The user’s public keys for a given node will be stored in the \texttt{~/.ssh} folder associated with the user’s home directory for that computing node. Since there are \( n - 1 \) edges to a given node \( i \) in Figure 3.1, that node \( i \) will have \( n - 1 \) public keys in the \texttt{~/.ssh} folder that were provided by the other \( n - 1 \) nodes in the cluster. The example in Figure 3.1 represents a computing cluster that has at total of 5 nodes. The edges connecting a node indicate that that node has received 4 public keys from the remaining computing nodes. Also looking out from a given node indicates that the given node has provided its own public key to the remaining nodes that are reachable via the 4 edge paths.
Figure 3.1 – Illustration of Secure Shell Connectivity for a Computing Cluster

If the home directory for a cluster is shared by all of the nodes of the cluster, i.e., all of the nodes use the same ~/.ssh folder, the connectivity illustrated in Figure 3.1 is represented through the contents of the ~/.ssh/known_hosts file.

8. Once secure shell connectivity is established, type a variation of the install.sh command as demonstrated by the table below, and follow the prompts issued by this install script.
<table>
<thead>
<tr>
<th>Installation command</th>
<th>Is root password required initially?</th>
<th>Installer prompts to be aware of</th>
<th>Default installation area</th>
</tr>
</thead>
<tbody>
<tr>
<td>./install.sh</td>
<td>Yes</td>
<td></td>
<td>/opt/intel/ictce/...</td>
</tr>
<tr>
<td>./install.sh --nonroot</td>
<td>No</td>
<td>We recommend that you install the software using RPM (option 1). This will require root password. If you do not have root password, you can do a local installation in your home folder by choosing option 2 below. Which of the following would you like to do? 1. Install the software using RPM (root password required) - Recommended. 2. Install the software without using RPM database (root password not required). x. Exit. Please make a selection: (1/2/x) 2;</td>
<td>./intel/ictce/... in your home directory</td>
</tr>
<tr>
<td>./install.sh --nonrpm</td>
<td>No</td>
<td>If you do not have the root password, you can do a local installation in your home folder by choosing option 2 below. Which of the following would you like to do? 1. Install the software using RPM (root password required) - Recommended. 2. Install the software without using RPM database (root password not required). x. Exit. Please make a selection: (1/2/x) [2];</td>
<td>./intel/ictce/... in your home directory</td>
</tr>
<tr>
<td>./install.sh --nonroot--nonrpm</td>
<td>No</td>
<td></td>
<td>./intel/ictce/... in your home directory</td>
</tr>
</tbody>
</table>
Note that the Intel MPI Benchmarks are only installed on the master node.

By default, the global root directory for the installation of the Intel Cluster Toolkit Compiler Edition is:

```
/opt/intel/ictce/<major>.<minor>.<update>.<package_num>
```

where `<major>`, `<minor>`, `<update>`, and `<package_num>` are integers. An example would be `3.2.0.013`.

Within the folder path
```
/opt/intel/ictce/<major>.<minor>.<update>.<package_num>
```
you will find the text files:

```
ictvars.csh
ictvars.sh
```

and

```
ictsupport.txt
```

If you are using Bourne Shell or Korn Shell for the login session, you should type:

```
./ictvars.sh
```

and for a login session that uses C Shell, you should type:

```
source ./ictvars.csh
```

The file called:

```
ictcesupport.txt
```

contains the Package ID and Package Contents information. Please use the information in `ictsupport.txt` when submitting customer support requests.

For the default installation path, an index file, an FAQ file, and the Getting Started Guide are located in the directory path:

```
/opt/intel/ictce/<major>.<minor>.<update>.<package_num>/doc
```

where as mentioned above, `<major>`, `<minor>`, `<update>`, and `<package_num>` are integers. A complete default folder path to the documentation directory might be:

```
/opt/intel/ictce/3.2.0.013/doc
```
The name of the index file is:

Doc_Index.htm

The index file can be used to navigate to the FAQ, the release notes, the Getting Started Guide, and an internet accessible Intel Cluster Toolkit Compiler Edition Tutorial which is this document. This tutorial may have information within it that is more recent than that of the Getting Started Guide. **Note that for Beta programs involving the Intel Cluster Toolkit Compiler Edition, there is no web based tutorial.**

The index file will also provide links to Intel C++ Compiler documentation, Intel Debugger Documentation, Intel Fortran Compiler documentation, Intel Trace Analyzer and Collector documentation, Intel MPI Library documentation, Intel MKL documentation, and Intel MPI Benchmarks documentation. The content of the index file will look something like the following (Figure 3.2):
Figure 3.2 – A Rendering of the Intel Cluster Toolkit Compiler Edition Documentation Index File display
The name of the FAQ file is:

HelpMe_FAQ.htm

The name of the Getting Started Guide file is:

Getting Started.htm

By default, the local version of the release notes is located in the directory path:

/opt/intel/ictce/<major>.<minor>.<update>.<package_num>/release_notes

The name of the release notes file is:

Release_Notes.htm

3.2 Installation of Intel® Cluster Toolkit Compiler Edition on 32-Bit and 64-Bit Nodes that Share a Common /opt Directory for Linux*

If there are two Linux cluster systems (one which is 32-bit and the other which is 64-bit) and they share a common file structure, the Intel Cluster Toolkit Compiler Edition installer can allow the coexistence of two versions of the cluster tools. Suppose that you are working with a staging directory called l_ict_p_3.2.0.013. In the staging area, do the following:

1. From Host A, install into /opt/intel/ictce/3.2.0.013/intel64 a version of the Intel Cluster Toolkit Compiler Edition that is based on Intel® 64 (formerly Intel EM64T) architecture.

2. Install the IA-32 architecture version of the Intel Cluster Toolkit Compiler Edition from host B into /opt/intel/ictce/3.2.0.013/ia32. If Host B is a node based on Intel® 64 architecture, you can use the --arch=ia32 option (Figure 3.3).
Figure 3.3 – Installation of the Intel Cluster Toolkit Compiler Edition on a common file share for two cluster systems (one which is 32 bit and the other which is 64 bit)

The --arch=ia32 command-line option will install x86-specific binaries on a cluster platform that is based on an Intel® 64 architecture.

4. Getting Started with Intel® MPI Library

This chapter will provide some basic information about getting started with Intel MPI Library. For complete documentation please refer the Intel MPI Library documents Intel MPI Library Getting Started Guide located in `<directory-path-to-Intel-MPI-Library>/doc/Getting_Started.pdf` and Intel MPI Library Reference Manual located in `<directory-path-to-Intel-MPI-Library>/doc/Reference_Manual.pdf` on the system where Intel MPI Library is installed.

The software architecture for Intel MPI Library is described in Figure 4.1. With Intel MPI Library on Linux-based systems, you can choose the best interconnection fabric for running an application on a cluster that is based on IA-32, IA-64, or Intel® 64
architecture. This is done at runtime by setting the `I_MPI_DEVICE` environment variable (See Section 4.4). Execution failure can be avoided even if interconnect selection fails. This is especially true for batch computing. For such situations, the sockets interface will automatically be selected (Figure 4.1) as a backup.

Similarly using Intel MPI Library on Microsoft Windows CCS, you can choose the best interconnection fabric for running an application on a cluster that is based on Intel® 64 architecture.
4.1 Launching MPD Daemons

The Intel MPI Library uses a Multi-Purpose Daemon (MPD) job startup mechanism. In order to run programs compiled with `mpicc` (or related) commands, you must first set up MPD daemons. It is strongly recommended that you start and maintain your own set of MPD daemons, as opposed to having the system administrator start up the MPD daemons once for use by all users on the system. This setup enhances system security and gives you greater flexibility in controlling your execution environment.

4.2 How to Set Up MPD Daemons on Linux*

1. Set up environment variables with appropriate values and directories, e.g., in the `.cshrc` or `.bashrc` files. At a minimum, set the following environment variables:
   Ensure that the `PATH` variable includes the following:
   - The `<directory-path-to-Intel-MPI-Library>/bin` directory. For example, the `<directory-path-to-Intel-MPI-Library>/bin` directory path should be set.
   - Directory for Python* version 2.2 or greater.
   - If you are using Intel® Compilers, ensure that the `LD_LIBRARY_PATH` variable contains the directories for the compiler library. You can set this variable by using the *vars.[c]sh scripts included with the compiler. Set any additional environment variables your application uses.

2. Create a `$HOME/.mpd.conf` file that contains your MPD password. Your MPD password is not the same as any Linux login password, but rather is used for MPD only. It is an arbitrary password string that is used only to control access to the MPD daemons by various cluster users. To set up your MPD password:

   ```
   secretword=<your mpd secretword>
   ```

   Do not use any Linux login password for `<your mpd secretword>`. An arbitrary `<your mpd secretword>` string only controls access to the MPD daemons by various cluster users.

3. Set protection on the file so that you have read and write privileges, for example, and ensure that the `$HOME/.mpd.conf` file is visible on, or copied to, all the nodes in the cluster as follows:

   ```
   chmod 600 $HOME/.mpd.conf
   ```

4. Verify that `PATH` settings and `.mpd.conf` contents can be observed through `rsh` on all nodes in the cluster. For example, use the following commands with each `<node>` in the cluster:

   ```
   rsh <node> env
   rsh <node> cat $HOME/.mpd.conf
   ```

5. Create an `mpd.hosts` text file that lists the nodes in the cluster, with one machine name per line, for use by `mpdboot`. Recall that the contents of the `machines.LINUX` file that was referenced previously can be used to construct an `mpd.hosts` file.

6. Start up the MPD daemons as follows:

   ```
   mpdboot [ -d -v ] -n <#nodes> [-f <path/name of mpd.hosts file>]
   ```
For more information about the `mpdboot` command, see Setting up MPD Daemons in the `<directory-path-to-Intel-MPI-Library>/doc/Getting_Started.pdf` or the `mpdboot` section of `<directory-path-to-Intel-MPI-Library>/doc/Reference_Manual.pdf`.

7. Determine the status of the MPD daemons as follows:
    
    `mpdtrace`
    
The output should be a list of nodes that are currently running MPD daemons.

**Remarks**

- If required, shut down the MPD daemons as follows:

  `mpdallexit`

- You as a user should start your own set of MPD daemons. It is not recommended to start MPD as root due to setup problems and security issues.

### 4.3 The `mpdboot` Command for Linux*

Use the `mpdboot -f <hosts file>` option to select a specific hosts file to be used. The default is to use `$(PWD)/mpd.hosts`. A valid host file must be accessible in order for `mpdboot` to succeed. As mentioned previously, the contents of the `machines.LINUX` file can also be used by you to construct an `mpd.hosts` file.

### 4.4 Compiling and Linking with Intel® MPI Library on Linux*

This section describes the basic steps required to compile and link an MPI program, when using only the *Intel MPI Library Development Kit*. To compile and link an MPI program with the Intel MPI Library:

1. Ensure that the underlying compiler and related software appear in your `PATH`. If you are using Intel Compilers, insure that the compiler library directories appear in `LD_LIBRARY_PATH` environment variable. For example, regarding the Intel 10.1 compilers, execution of the appropriate set-up scripts will do this automatically (the build number for the compilers might be something different than “11.0.025” for your installation):

   ```
   /opt/intel/cce/11.0.025/bin/iccvars.[c]sh
   
   and
   
   /opt/intel/fce/11.0.025/bin/ifortvars.[c]sh
   ```

2. Compile your MPI program via the appropriate `mpi` compiler command. For example, C code uses the `mpiicc` command as follows:

   ```
   mpiicc <directory-path-to-Intel-MPI-Library>/test/test.c
   ```
Other supported compilers have an equivalent command that uses the prefix mpi on the standard compiler command. For example, the Intel MPI Library command for the Intel® Fortran Compiler (ifort) is mpiifort.

<table>
<thead>
<tr>
<th>Supplier of Core Compiler</th>
<th>MPI Compilation Command</th>
<th>Core Compiler Compilation Command</th>
<th>Compiler Programming Language</th>
<th>Support Application Binary Interface (ABI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNU* Compilers</td>
<td>mpicc</td>
<td>gcc, cc</td>
<td>C</td>
<td>32/64 bit</td>
</tr>
<tr>
<td></td>
<td>mpicxx</td>
<td>g++ version 3.x</td>
<td>C/C++</td>
<td>32/64 bit</td>
</tr>
<tr>
<td></td>
<td>mpiif77</td>
<td>f77 or g77</td>
<td>Fortran 77</td>
<td>32/64 bit</td>
</tr>
<tr>
<td></td>
<td>mpiif90</td>
<td>gfortran</td>
<td>Fortran 95</td>
<td>32/64 bit</td>
</tr>
<tr>
<td>Intel Compilers version 8.0, 8.1, 9.0, 9.1, 10.0, 10.1, or 11.0</td>
<td>mpiicc</td>
<td>icc</td>
<td>C</td>
<td>32/64 bit</td>
</tr>
<tr>
<td></td>
<td>mpiicpc</td>
<td>icpc</td>
<td>C++</td>
<td>32/64 bit</td>
</tr>
<tr>
<td></td>
<td>mpiifort</td>
<td>ifort</td>
<td>Fortran 77 and Fortran 95</td>
<td>32/64 bit</td>
</tr>
</tbody>
</table>

Remarks

The Compiling and Linking section of <directory-path-to-Intel-MPI-Library>/doc/Getting_Started.pdf or the Compiler Commands section of <directory-path-to-Intel-MPI-Library>/doc/Reference_Manual.pdf on the system where Intel MPI Library is installed include additional details on mpiicc and other compiler commands, including commands for other compilers and languages.

4.5 Selecting a Network Fabric

Intel MPI Library supports multiple, dynamically selectable network fabric device drivers to support different communication channels between MPI processes. The default communication method uses a built-in TCP (Ethernet, or sockets) device driver. Select alternative devices via the command line using the I_MPI_DEVICE environment variable. The following network fabric types are supported by Intel MPI Library:
Possible Interconnection-Device-Fabric Values for the I_MPIDEVICE Environment Variable

<table>
<thead>
<tr>
<th>Device Fabric</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>sock</td>
<td>TCP/Ethernet/sockets (default)</td>
</tr>
<tr>
<td>shm</td>
<td>Shared-memory only (no sockets)</td>
</tr>
<tr>
<td>ssm</td>
<td>TCP + shared-memory (for SMP clusters connected via Ethernet)</td>
</tr>
<tr>
<td>rdma[:&lt;provider&gt;]</td>
<td>InfiniBand*, Myrinet*, etc. (specified via the DAPL (Direct Access Program Library) provider)</td>
</tr>
<tr>
<td>rdssm[:&lt;provider&gt;]</td>
<td>TCP + shared-memory + DAPL (for SMP clusters connected via RDMA-capable fabrics)</td>
</tr>
</tbody>
</table>

where `<provider>` is an optional DAPL* provider name.

4.6 Running an MPI Program Using Intel® MPI Library on Linux*

Use the `mpiexec` command to launch programs linked with the Intel MPI Library example:

```
mpiexec -n <# of processes> ./myprog
```

The only required option for the `mpiexec` command is the `-n` option to set the number of processes. If your MPI application is using a network fabric other than the default fabric (sock), use the `-env` option to specify a value to be assigned to the `I_MPI_DEVICE` variable. For example, to run an MPI program while using the `ssm` device, use the following command:

```
mpiexec -n <# of processes> -env I_MPI_DEVICE ssm ./a.out
```

To run an MPI program while using the `rdma` device, use the following command:

```
mpiexec -n <# of processes> -env I_MPI_DEVICE rdma[:<provider>] ./a.out
```

where `[:<provider>]` is an optional meta-symbol which may need to be filled in by you with correct RDMA information. Note that the brackets imply an optional feature and are not part of the actual `rdma` syntax. Any supported device can be selected. See the section titled Selecting a Network Fabric in `<directory-path-to-Intel-MPI-Library>/doc/Getting_Started.pdf`, or the section titled `I_MPI_DEVICE` in `<directory-path-to-Intel-MPI-Library>/doc/Reference_Manual.pdf`.

4.7 Experimenting with Intel® MPI Library on Linux*

For the experiments that follow, it is assumed that a computing cluster has at least 2 nodes and there are two symmetric multi-processors (SMPs) per node. Start up the MPD daemons by issuing a command such as:
mpboott -n 2 -r rsh -f ~/mpd.hosts

Type the command:

mpdtrace

to verify that there are MPD daemons running on the two nodes of the cluster. The response from issuing this command should be something like:

clusternode1
clusternode2

assuming that the two nodes of the cluster are called clusternode1 and clusternode2. The actual response will be a function of your cluster configuration.

In the <directory-path-to-Intel-MPI-Library>/test folder where Intel MPI Library resides, there are source files for four MPI test cases. In your local user area, you should create a test directory called:

test_intel_mpi/

From the installation directory of Intel MPI Library, copy the test files from <directory-path-to-Intel-MPI-Library>/test to the directory above. The contents of test_intel_mpi should now be:

test.c test.cpp test.f test.f90

Compile the test applications into executables using the following commands:

mpiifort test.f -o testf
mpiifort test.f90 -o testf90
mpiicc test.c -o testc
mpiicpc test.cpp -o testcpp

Issue the mpiexec commands:

mpiexec -n 2 ./testf
mpiexec -n 2 ./testf90
mpiexec -n 2 ./testc
mpiexec -n 2 ./testcpp

The output from testcpp should look something like:

Hello world: rank 0 of 1 running on clusternode1
Hello world: rank 1 of 2 running on clusternode2

If you have successfully run the above applications using Intel MPI Library, you can now run (without re-linking) the four executables on clusters that use Direct Access Program Library (DAPL) interfaces to alternative interconnection fabrics. If you encounter problems, please see the section titled Troubleshooting within the document Intel MPI Library Getting Started Guide located in <directory-path-to-Intel-MPI-Library>/doc/Getting_Started.pdf for possible solutions.

Assuming that you have an rdma device fabric installed on the cluster, you can issue the following commands for the four executables so as to access that device fabric:
mpiexec -env I_MPIDEVICE rdma -n 2 ./testf
mpiexec -env I_MPIDEVICE rdma -n 2 ./testf90
mpiexec -env I_MPIDEVICE rdma -n 2 ./testc
mpiexec -env I_MPIDEVICE rdma -n 2 ./testcpp

The output from testf90 using the rdma device value for the I_MPIDEVICE environment variable should look something like:

Hello world: rank 0 of 2 running on clusternode1
Hello world: rank 1 of 2 running on clusternode2

4.8 Controlling MPI Process Placement on Linux*

The mpiexec command controls how the ranks of the processes are allocated to the nodes in the cluster. By default, mpiexec uses round-robin assignment of ranks to the nodes. This placement algorithm may not be the best choice for your application, particularly for clusters with SMP (symmetric multi-processor) nodes.

Suppose that the geometry is <#ranks> = 4 and <#nodes> = 2, where adjacent pairs of ranks are assigned to each node (for example, for 2-way SMP nodes). Issue the command:

cat ~/mpd.hosts

The results should be something like:

clusternode1
clusternode2

Since each node of the cluster is a 2-way SMP, and 4 processes are to be used for the application, the next experiment will distribute the 4 processes such that 2 of the processes will execute on clusternode1 and 2 will execute on clusternode2. For example, you might issue the following commands:

mpiexec -n 2 -host clusternode1 ./testf : -n 2 -host clusternode2 ./testf
mpiexec -n 2 -host clusternode1 ./testf90 : -n 2 -host clusternode2 ./testf90
mpiexec -n 2 -host clusternode1 ./testc : -n 2 -host clusternode2 ./testc
mpiexec -n 2 -host clusternode1 ./testcpp : -n 2 -host clusternode2 ./testcpp

The following output should be produced for the executable testc:

Hello world: rank 0 of 4 running on clusternode1
Hello world: rank 1 of 4 running on clusternode1
Hello world: rank 2 of 4 running on clusternode2
Hello world: rank 3 of 4 running on clusternode2

In general, if there are i nodes in the cluster and each node is j-way SMP system, then the mpiexec command-line syntax for distributing the i by j processes amongst the i by j processors within the cluster is:

mpiexec -n j -host <nodename-1> ./mpi_example : \
- n j -host <nodename-2> ./mpi_example : \

Intel Corporation Document Number: 318537-003 27
Note that you would have to fill in appropriate host names for `<nodename-i>` through `<nodename-i>` with respect to your cluster system. For a complete discussion on how to control process placement through the `mpiexec` command, see the Local Options section of the Intel MPI Library Reference Manual located in `<directory-path-to-Intel-MPI-Library>/doc/Reference_Manual.pdf`.

### 4.9 Using the Automatic Tuning Utility Called `mpitune`

The `mpitune` utility is new for Intel® MPI Library 3.2. It can be used to find optimal settings of Intel® MPI Library in regards to the cluster configuration or a user’s application for that cluster.

As an example, the executables `testc`, `testc`, `testf`, and `testf90` in the directory `test_intel_mpi` could be used. The command invocation for `mpitune` might look something like the following:

```bash
mpitune -f machines.Linux -o ./ --app mpiexec -n 4 ./testc
```

where the options above are just a subset of the following complete command-line switches:

<table>
<thead>
<tr>
<th>Command-line Option</th>
<th>Semantic Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>`-h</td>
<td>--help`</td>
</tr>
<tr>
<td>`-V</td>
<td>--version`</td>
</tr>
<tr>
<td>`-e &lt;envfile&gt;</td>
<td>--env &lt;envfile&gt;`</td>
</tr>
<tr>
<td>`-r &lt;rulesfile&gt;</td>
<td>--rules &lt;rulesfile&gt;`</td>
</tr>
<tr>
<td>`-f &lt;hostsfile&gt;</td>
<td>--file &lt;hostsfile&gt;`</td>
</tr>
<tr>
<td>`-w &lt;workdir&gt;</td>
<td>--wdir &lt;workdir&gt;`</td>
</tr>
</tbody>
</table>
### Cluster Specific Tuning

Once you have installed the Intel® cluster tools on your system you may want to use the `mpitune` utility to generate a configuration file that is targeted at optimizing the Intel® MPI Library with regards to the cluster configuration. For example, the `mpitune` command:

```
mpitune -f machines.LINUX -o ./
```

could be used, where `machines.LINUX` contains a list of the nodes in the cluster. Completion of this command may take some time. The `mpitune` utility will generate a configuration file that might have a name such as `mpiexec_shm_nn_1_np_4_ppn_4.conf`. You can then proceed to run the `mpiexec` command.
command on an application using the –tune option. For example, the mpiexec command-line syntax for the testc executable might look something like the following:

    mpiexec –tune –n 4 ./testc

4.9.2  MPI Application-Specific Tuning

The mpitune invocation:

    mpitune –f machines.Linux –o ./ --app mpiexec –n 4 ./testf90

will generate a file called app.config that is base on the application testf90. Completion of this command may take some time also. This configuration file can be used in the following manner:

    mpiexec –tune app.config –n 4 ./testf90

where the mpiexec command will load the configuration options recorded in app.config.

You might want to use mpitune utility on each of the test applications testc, testc, testf, and testf90. For a complete discussion on how to use the mpitune utility, see the Tuning Reference section of the Intel MPI Library Reference Manual located in <directory-path-to-Intel-MPI-Library>/doc/Reference_Manual.pdf.

To make inquiries about Intel MPI Library, visit the URL: http://premier.intel.com.

5. Interoperability of Intel® MPI Library with the Intel® Debugger (IDB)

As mentioned previously (e.g., Figure 2.1), components of the Intel Cluster Toolkit Compiler Edition will now work with the Intel Debugger. For 8.1 releases of the Intel Compilers, please make sure that you have installed version 8.1-23 or greater of the Intel Debugger. For the 9.1 releases of the Intel Compilers, please make sure that you have installed version 9.1-23 or greater of the Intel Debugger.

The Intel Debugger is a parallel debugger with the following software architecture:
With respect to Figure 5.1, there is a user interface to a root debugger. This is demonstrated at the bottom of Figure 5.1. The root debugger communicates with a tree of parallel debuggers. These are the leaf nodes at the top of the illustration. There are aggregation capabilities for consolidating debug information. This is done through the aggregators in Figure 5.1.

All processes with the same output are aggregated into a single and final output message. As an example, the following message represents 42 MPI processes:

\[
[0-41] \text{Linux Application Debugger for Xeon(R)-based applications, Version XX}
\]

Diagnostics which have different hexadecimal digits, but are otherwise identical, are condensed by aggregating the differing digits into a range. As an example:
5.1 Login Session Preparations for Using Intel® Debugger on Linux

The debugger executable for the Intel Debugger is called idb. In the 11.0 version of the Intel® Debugger, the idb command invokes the GUI. Alternatively for the 11.0 version of Intel® Debugger, to get the command-line interface, use idbc. On IA-64 architecture systems, the GUI is not available and the idb command invokes the command-line interface. There are three steps that should be followed in preparing your login session so that you can use the Intel Debugger.

1. The Intel® IDB Debugger graphical environment is a Java application and requires a Java Runtime Environment (JRE) to execute. The debugger will run with a version 5.0 (also called 1.5) JRE.

   Install the JRE according to the JRE provider's instructions.

   Finally you need to export the path to the JRE as follows:

   ```
   export PATH=<path_to_JRE_bin_DIR>:$PATH
   ```

2. Configure the environment variables. For the ~/.bashrc file, an example of setting environment variables and sourcing shell scripts might be the following for Intel® 64 architecture:

   ```
   export INTEL_LICENSE_FILE=/opt/intel/licenses
   . /opt/intel/ictce/3.2.0.013/ictvars.sh
   ```

   Alternatively, for ~/.cshrc the syntax might be something like:

   ```
   setenv INTEL_LICENSE_FILE /opt/intel/licenses
   source /opt/Intel/ictce/3.2.0.013/ictvars.csh
   ```

2. Edit the ~/.rhosts file in your home directory so that it contains the list of nodes that comprise the cluster. Recall that previously we referred to the contents of a file called machines.LINUX, where a contrived cluster consisting of eight nodes might be:

   ```
   clusternode1
clucknode2
   clusternode3
   clusternode4
   clusternode4
   clusternode6
   clusternode7
   clusternode8
   ```

   For example, assuming that the names listed above make up your cluster, they could be added to your ~/.rhosts file with the following general syntax:
For the list of nodes above and assuming that your login name is user01, the contents of your ~/.rhosts file might be:

```
clusternode1 user01
clusternode2 user01
clusternode3 user01
clusternode4 user01
clusternode5 user01
clusternode6 user01
clusternode7 user01
clusternode8 user01
```

The permission bit settings of ~/.rhosts should be set to 600 using the chmod command. The shell command for doing this might be:

```
chmod 600 ~/.rhosts
```

Once the three steps above are completed, you are ready to use the Intel Debugger. The general syntax for using the Intel Debugger with Intel MPI Library is as follows:

```
mpiexec -idb -n <number of processes> [other Intel MPI options] <executable> [arguments to the executable]
```

For the contents of the directory test_intel_mpi that was described in Chapter 4, there should be the four source files:

```
test.c test.cpp test.f test.f90
```

Compile the test applications into executables using the following commands:

```
mpiifort -g test.f -o testf
mpiifort -g test.f90 -o testf90
mpiicc -g test.c -o testc
mpiicpc -g test.cpp -o testcpp
```

You can issue mpiexec commands that might look something like the following:
mpiexec -idb -n 4 ./testf
mpiexec -idb -n 4 ./testf90
mpiexec -idb -n 4 ./testc
mpiexec -idb -n 4 ./testcpp

The commands above are using four MPI processes. Figure 5.2 shows what the debug session might look like after issuing the shell command:

mpiexec -idb -n 4 ./testcpp

![Figure 5.2 – idb session for the executable called testc](image)

for the executable called testc. Note that the user interface for idb is gdb*-compatible by default. To see where the MPI application is with respect to execution, you can type the IDB command called where after the prompt (idb) in Figure 5.2. This will produce a call stack something like what is shown in Figure 5.3.
Figure 5.3 – The application call stack after typing the IDB command where

Recall that the C++ application has the source file name test.cpp and according to the IDB debugger stack trace, the line referenced in test.cpp is line 29. If you would like to use a text editor to look at test.cpp, you can modify the debugging user interface from the default which is gdb* to that if idb by typing the debug command:

```
set $cmdset = "idb"
```

You can then type the command:

```
edit +29 test.cpp
```

in Figure 5.3 and the result will be something like that shown in Figure 5.4. Line 29 of test.cpp is the MPI library call to Init. The edit session in Figure 5.4 is using the vi editor. In general, the editor that is invoked is a function of the EDITOR environment variable.
You can use the command `:q!` to close the `vi` edit session. This is demonstrated in Figure 5.5.

The "run" command is disabled in MPI debugging. To continue the execution of the MPI application, use "cont". If you proceed to type the word `cont` after the `(idb)` prompt shown at the bottom of Figure 5.6, then debugging session results that might look something like that shown in Figure 5.7 will appear. Also, "Hello world" messages will appear in the login session where the `mpiexec` command was issued.
The 4 MPI processes for the example in Figure 5.7 are labeled 0 to 3.

Unfortunately, the rerun command is not yet supported within IDB. To rerun MPI application with the IDB debugger, you will have to quit IDB and then re-enter the mpiexec command.

For a complete discussion on how to use the Intel Debugger (9.1.x or greater) please review the contents of the Intel Debugger (IDB) Manual located in `<directory-path-to-Intel-Debugger>/doc/Doc_Index.htm` on your computing system.
6. Working with the Intel® Trace Analyzer and Collector Examples

In the folder path where Intel Trace Analyzer and Collector reside, there is a folder called examples. The folder path where the examples directory resides might be something like:

/opt/intel/ictce/3.2.0.013/itac/examples

If you copy the examples folder into a work area which is accessible by all of the nodes of the cluster, you might try the following sequence of commands:

```
gmake distclean

gmake all
```

This set of commands will respectively clean up the folder content and compile and execute the following C and Fortran executables:

```
vnallpair
vnallpairc
vnjacobic
vnjacobif
vtallpair
vtallpairc
vtjacobif
vtjacobic
vtjacobic
vtjacobic.
```

If you select the executable vtjacobic and run it with the following environment variable setting:

```
setenv VT_LOGFILE_PREFIX vtjacobic_inst
```

where the mpiexec command uses 4 processes as shown:

```
mpiexec -n 4 ./ vtjacobic
```

then the trace data will be placed into the folder vtjacobic_inst. The contents of vtjacobic_inst will look something like the following:

```
.
..    vtjacobic.stf.dcl    vtjacobic.stf.msg.anc
vtjacobic.prot   vtjacobic.stf.gop   vtjacobic.stf.pr.0
vtjacobic.stf   vtjacobic.stf.gop.anc vtjacobic.stf.sts
vtjacobic.stf.cache vtjacobic.stf.msg
```

when the command:

```
ls -aC --width=80 vtjacobic_inst
```

is used. If you run the Intel Trace Analyzer with the command:

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the following display panel will appear (Figure 6.1):

![Figure 6.1 - Intel Trace Analyzer Display for vtjacobic.stf](image)

**Figure 6.1 - Intel Trace Analyzer Display for vtjacobic.stf**

Figure 6.2 shows the Event Timeline display which results when following the menu path Charts->Event Timeline within Figure 6.1.
You can use the trace analyzer to view the contents of the other *.stf files in this working directory on your cluster system.

**6.1 Experimenting with Intel® Trace Analyzer and Collector in a Fail-Safe Mode**

There may be situations where an application will end prematurely, and thus trace data could be lost. The Intel Trace Collector has a trace library that works in fail-safe mode. An example shell command-line syntax for linking such a library is:

```
mpiicc test.c -o testc_fs -L${VT_LIB_DIR} -lVTfs ${VT_ADD_LIBS}
```

where the special Intel Trace Collector Library for fail-safe (acronym fs) tracing is -lVTfs.

In case of execution failure by the application, the fail-safe library freezes all MPI processes and then writes out the trace file. Figure 6.3 shows an Intel Trace Analyzer display for test.c.
Figure 6.3 – Intel Trace Analyzer display of Fail-Safe Trace Collection by Intel Trace Collector

Complete user documentation regarding -ltVfs for the Intel Trace Collector can be found within the file:

```
<directory-path-to-ITAC>/doc/ITC_Reference_Guide.pdf
```

on the system where the Intel Trace Collector is installed. You can use vtfs as a search phrase within the documentation.

6.2 Using itcpin to Instrument an Application

The itcpin utility is a binary instrumentation tool that comes with Intel Trace Analyzer and Collector. The Intel® architectures must be IA-32, Intel® 64 and IA-64.

The basic syntax for instrumenting a binary executable with the itcpin utility is as follows:
itcpin [<ITC options>] -- <application command line>

where -- is a delimiter between Intel Trace Collector (ITC) options and the application command-line.

The <ITC options> that will be used here is:

--run (off)

itcpin only runs the given executable if this option is used. Otherwise it just analyzes the executable and prints configurable information about it.

--insert

Intel Trace Collector has several libraries that can be used to do different kinds of tracing. An example library value could be VT which is the Intel Trace Collector Library. This is the default instrumentation library.

To obtain a list off all of the options simply type:

itcpin --help

To demonstrate the use of itcpin, you can compile a C programming language example for calculating the value of "pi" where the application uses the MPI parallel programming paradigm. You can download the C source from the URL:

http://rac.uits.iu.edu/hpc/mpi_tutorial/s2_computing_pi_parallel.html

For the pi.c example, the following shell commands will allow you to instrument the binary called pi.exe with Intel Trace Collector instrumentation. The shell commands before and after the invocation of itcpin should be thought of as prolog and epilog code to aid in the use of the itcpin utility.

    mpiicc -o pi.exe pi.c
    setenv VT_LOGFILE_FORMAT STF
    setenv VT_PCTRACE 5
    setenv VT_LOGFILE_PREFIX ${PWD}/itcpin_inst
    setenv VT_PROCESS "0:N ON"
    rm -rf ${VT_LOGFILE_PREFIX}
    mkdir ${VT_LOGFILE_PREFIX}
    mpiexec -n 4 itcpin --run -- pi.exe 1000000

The shell commands above could be packaged into a C Shell script. The value of 1,000,000 after the executable called pi.exe indicates the number of intervals that will be used in the calculation of “pi”. An explanation for the instrumentation environment variables can be found in the Intel Trace Collector Users’ Guide under the search topic “ITC Configuration”.

The output from the above sequence or C Shell commands looks something like the following:

The computed value of the integral is 3.141592653589764
The exact value of the integral is \( 3.141592653589793 \)

[0] Intel(R) Trace Collector INFO: Writing tracefile pi.exe.stf in /shared/scratch/itcinstrument/itcpin_inst

Figure 6.4 shows the timeline and function panel displays that were generated from the instrumentation data that was stored into the directory `${PWD}/itcpin_inst` as indicated by the environment variable `VT_LOGFILE_PREFIX`. The command that initiated the Intel Trace Analyzer with respect to the directory `${PWD}` was:

```
traceanalyzer itcpin_inst/pi.exe.stf &
```

![Intel Trace Analyzer display](image)

**Figure 6.4 – Intel Trace Analyzer display of the “pi” integration application that has been binary instrumented with itcpin**

Complete user documentation regarding itcpin for the Intel Trace Collector can be found within the file:

<directory-path-to-ITAC>/doc/ITC_Reference_Guide.pdf

on the system where the Intel Trace Collector is installed. You can use itcpin as a search phrase within the documentation. To make inquiries about the Intel Trace Analyzer, visit the URL: [http://premier.intel.com](http://premier.intel.com).
6.3 Experimenting with Intel® Trace Analyzer and Collector in Conjunction with the LD_PRELOAD Environment Variable

There is an environment variable called LD_PRELOAD which can be initialized to reference instrumentation libraries. LD_PRELOAD instructs the operating system loader to load additional libraries into a program, beyond what was specified when it was initially compiled. In general, this environment variable allows users to add or replace functionality such as inserting performance tuning instrumentation. For Bourne Shell or Korn Shell the syntax for setting the LD_PRELOAD environment variable to instrument with Intel Trace Collector might be:

```
export LD_PRELOAD="libVT.so:libdl.so"
```

For C Shell, the syntax might be:

```
setenv LD_PRELOAD "libVT.so:libdl.so"
```

For the pi.c example, the following shell commands will allow you to use the LD_PRELOAD environment variable to instrument a binary with Intel Trace Collector instrumentation.

```
mpiicc -o pi.exe pi.c
setenv VT_PCTRACE 5
setenv VT_LOGFILE_PREFIX $(PWD)/ld_preload_inst
setenv VT_PROCESS "0:N ON"
setenv LD_PRELOAD "libVT.so:libdl.so"
rm -rf $(VT_LOGFILE_PREFIX)
mkdir $(VT_LOGFILE_PREFIX)
mpiexec -n 4 ./pi.exe 1000000
```

As mentioned previously, the shell commands above could be packaged into a C Shell script. The mpiexec command uses 4 MPI processes and the value of 1,000,000 indicates the number of intervals that will be used in the calculation of "pi". Figure 6.5 shows the timeline and function panel displays that were generated from the instrumentation data that was stored in the directory $(PWD)/ld_preload_inst as indicated by the environment variable VT_LOGFILE_PREFIX. The command that initiated the Intel Trace Analyzer with respect to the directory $(PWD) was:

```
traceanalyzer ld_preload_inst/pi.exe.instr.stf &
```
Figure 6.5 – Intel Trace Analyzer display of the "pi" integration application that has been instrumented through the LD_PRELOAD environment variable

Complete user documentation regarding LD_PRELOAD for the Intel Trace Collector can be found within the file:

<directory-path-to-ITAC>/doc/ITC_Reference_Guide.pdf

on the system where the Intel Trace Collector is installed. You can use LD_PRELOAD as a search phrase within the documentation. To make inquiries about LD_PRELOAD in conjunction with Intel Trace Analyzer and Collector, visit the URL:

6.4 Experimenting with Intel® Trace Analyzer and Collector in Conjunction with PAPI* Counters

The counter analysis discussion that follows assumes that a PAPI library is installed on the cluster system. PAPI is an acronym for Performance API and it serves to gather information regarding performance counter hardware. Details can be found at the URL:
This discussion assumes that the PAPI library is installed in a directory path such as /usr/local/papi. In the examples directory for Intel Trace Analyzer and Collector, there is a subfolder called poisson. Using root privileges, the library called libVTsample.a needs to be configured in the lib directory of Intel Trace Analyzer and Collector so that PAPI instrumentation can be captured through the Intel Trace Analyzer and Collector. The library path for the Intel Trace Analyzer and Collector might be something like:

```
/opt/intel/ictce/3.2.0.013/itac/lib
```

In this directory, a system administrator can use the following `gmake` command to create the `libVTsample.a` library:

```
export PAPI_ROOT=/usr/local/papi
gmake all
```

When the `libVTsample.a` library is built, the Poisson example can be linked with PAPI instrumentation as follows:

```
gmake MPI_HOME=/opt/intel/ictce/3.2.0.013/impi
MPI_INCLUDE=/opt/intel/ictce/3.2.0.013/impi/include FLINKER=mpiifort
F90=mpiifort CC=icc CLINKER=icc LIB_PATH="" LIBS="-L${VT_ROOT}/lib -lVTsample
-lVT -L/usr/local/papi/lib -lpapi ${VT_ADD_LIBS}"
```

The `gmake` command above assumes that an Intel MPI Library is installed in the folder path `/opt/intel/ictce/3.2.0.013/impi`.

The shell commands for running the `poisson` application might be the following:

```
rmm -rf ${PWD}/papi_inst
mkdir ${PWD}/papi_inst
setenv LD_LIBRARY_PATH ${LD_LIBRARY_PATH}:/usr/local/papi/lib
setenv VT_LOGFILE_PREFIX ${PWD}/papi_inst
setenv VT_CONFIG ${PWD}/vtconfig
mpiexec -n 16 ./poisson
```

The Intel Trace Collector configuration file which is called `vtconfig` for the above example contains the following PAPI counter selection:

```
COUNTER PAPI_L1_DCM ON
```

This PAPI counter directive is for L1 data cache misses. The general syntax for counter directives is:

```
COUNTER <name of counter> ON
```

The value of ON indicates that this particular hardware counter is to be monitored by Intel Trace Collector. The names of the PAPI hardware counters can be found in the folder path `${PAPI_ROOT}/include/papiStdEventDefs.h` on the system where the PAPI library is installed.
Figure 6.6 illustrates a maximized view for the Counter Timeline Chart and the Function Profile Chart that were generated from the instrumentation data that was stored in the directory ${PWD}/papi_inst as indicated by the environment variable VT_LOGFILE_PREFIX. The command that initiated the Intel Trace Analyzer with respect to the directory ${PWD} was:

```
traceanalyzer papi_inst/poisson.stf &
```

Figure 6.6 – A maximized view for the Counter Timeline Chart and the Function Profile Chart

Notice in the Counter Timeline Chart in Figure 6.6 that the PAPI counter `PAPI_L1_DCM` appears as a label in the right margin.

In general, the shell syntax for compiling the Intel MPI Library test files called `test.c`, `test.cpp`, `test.f`, and `test.f90` with the PAPI interface involves the link options that look something like:

```
-L${VT_LIB_DIR} -lVTsample -lVT -L/usr/local/papi/lib -lpapi
${VT_ADD_LIBS}
```

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The compilation commands are:

```bash
mpiicc test.c -o testc -L${VT_LIB_DIR} -lVTsample -lVT -L/usr/local/papi/lib -lpapi ${VT_ADD_LIBS}

mpiicpc test.cpp -o testcpp -L${VT_LIB_DIR} -lVTsample -lVT -L/usr/local/papi/lib -lpapi ${VT_ADD_LIBS}

mpiifort test.f -o testf -L${VT_LIB_DIR} -lVTsample -lVT -L/usr/local/papi/lib -lpapi ${VT_ADD_LIBS}

mpiifort test.f90 -o testf90 -L${VT_LIB_DIR} -lVTsample -lVT -L/usr/local/papi/lib -lpapi ${VT_ADD_LIBS}
```

On Linux, complete user documentation regarding PAPI hardware counters for the Intel Trace Collector can be found within the file:

```
<directory-path-to-ITAC>/doc/ITC_Reference_Guide.pdf
```

on the system where the Intel Trace Collector is installed. You can use PAPI as a search phrase within the documentation. To make inquiries about PAPI in conjunction with the Intel Trace Analyzer and Collector, visit the URL:

```
```

### 6.5 Experimenting with the Message Checking Component of Intel® Trace Collector

Intel Trace Collector environment variables which should be useful for message checking are:

- `VT_DEADLOCK_TIMEOUT <delay>`, where `<delay>` is a time value. The default value is 1 minute and the notation for the meta-symbol `<delay>` could be 1m. This controls the same mechanism to detect deadlocks as in `libVTfs` which is the fail-safe library. For interactive use it is recommended to set it to a small value like “10s” to detect deadlocks quickly without having to wait long for the timeout.

- `VT_DEADLOCK_WARNING <delay>` where `<delay>` is a time value. The default value is 5 minutes and the notation for the meta-symbol `<delay>` could be 5m. If on average the MPI processes are stuck in their last MPI call for more than this threshold, then a GLOBAL:DEADLOCK:NO PROGRESS warning is generated. This is a sign of a load imbalance or a deadlock which cannot be detected because at least one process polls for progress instead of blocking inside an MPI call.

- `VT_CHECK_TRACING <on | off>`. By default, during correctness checking with `libVTmc` no events are recorded and no trace file is written. This option enables recording of all events also supported by the normal `libVT` and the writing of a trace file. The trace file will also contain the errors found during the run.

On Linux, complete user documentation regarding message checking for the Intel Trace Collector can be found within the file:

```
<directory-path-to-ITAC>/doc/ITC_Reference_Guide.pdf
```
The chapter title is called “Correctness Checking”.

An MPI application can be instrumented in four ways with the message checking library.

1) Compile the application with a static version of the message checking library:

```
mpiicc deadlock.c -o deadlock_static.exe -g -L ${VT_LIB_DIR} -lVTmc
${VT_ADD_LIBS}

mpiexec -genv VT_DEADLOCK_TIMEOUT 20s -genv VT_DEADLOCK_WARNING 25s -n 2
./deadlock_static.exe 0 80000
```

2) Compile the application with a shared object version of the message checking library:

```
mpiicc deadlock.c -o deadlock_shared.exe -g -L ${VT_SLIB_DIR} -lVTmc
${VT_ADD_LIBS} -L /opt/intel/cce/11.0.025/lib -lcxa -lunwind

mpiexec -genv VT_DEADLOCK_TIMEOUT 20s -genv VT_DEADLOCK_WARNING 25s -n 2
./deadlock_shared.exe 0 80000
```

Note that the library path for the Intel® C++ Compiler will vary from version to version.

3) Use the itcpin command:

```
mpiexec -genv VT_DEADLOCK_TIMEOUT 20s -genv VT_DEADLOCK_WARNING 25s -n 2
itcpin --insert libVTmc.so --run -- ./deadlock.exe 0 80000
```

4) Use the LD_PRELOAD environment variable with the mpiexec command. An example might be:

```
mpiexec -genv LD_PRELOAD libVTmc.so -genv VT_DEADLOCK_TIMEOUT 20s -genv
VT_DEADLOCK_WARNING 25s -n 2 ./deadlock.exe 0 80000
```

There is a sub-directory of the examples directory called checking. The checking directory has the following contents:

```
  global/  GNUmakefile  local/  misc/
```

The GNUmakefile has targets all, clean, print, and run, where all is the default. After type gmake, one can type the command:

```
gmake run
```

The output error diagnostics for the command above will be sent to stderr. If you wish to retain the output into a file, the results for stderr can be directed to a file.

Each leaf sub-folder contains a source file and an “*.ref.out” file which can be used as a point of reference for the expected diagnostics that the message checking component of the Intel® Trace Collector should capture. For example, if you search the global sub-directory, you will find a folder path of the following form:
The contents of the leaf directory consist of:

MPI_Bcast.c  MPI_Bcast.ref.out

The file MPI_Bcast.ref.out has diagnostic information that looks something like the following:

```
[0] INFO: initialization completed successfully
[0] ERROR: GLOBAL:COLLECTIVE:DATATYPE:MISMATCH: error
[0] ERROR:   Mismatch found in local rank [1] (global rank [1]),
[0] ERROR:   other processes may also be affected.
[0] ERROR:   No problem found in local rank [0] (same as global rank):
[0] ERROR:       MPI_Bcast(*buffer=0x7fbfffe9f0, count=1, datatype=MPI_INT,
    root=0, comm=MPI_COMM_WORLD)
[0] ERROR:       main (global/collective/datatype_mismatch/MPI_Bcast.c:50)
[0] ERROR:   1 elements transferred by peer but 4 expected by
[0] ERROR:   the 3 processes with local ranks [1:3] (same as global ranks):
[0] ERROR:       MPI_Bcast(*buffer=0x7fbfffe9f4, count=4, datatype=MPI_CHAR,
    root=0, comm=MPI_COMM_WORLD)
[0] ERROR:       main (global/collective/datatype_mismatch/MPI_Bcast.c:53)
[0] INFO: GLOBAL:COLLECTIVE:DATATYPE:MISMATCH: found 1 time (1 error + 0
    warnings), 0 reports were suppressed
[0] INFO: Found 1 problem (1 error + 0 warnings), 0 reports were suppressed.
```

For the text above, there are error messages of the form:

```
[0] ERROR:       main (global/collective/datatype_mismatch/MPI_Bcast.c:50)
```

and

```
[0] ERROR:       main (global/collective/datatype_mismatch/MPI_Bcast.c:53)
```

These error messages refer to the line number 50 and 53 respectively in the source file MPI_Bcast.c:

```
39 int main (int argc, char **argv)
40 {
41     int rank, size;
42     MPI_Init( &argc, &argv );
43     MPI_Comm_size( MPI_COMM_WORLD, &size );
44     MPI_Comm_rank( MPI_COMM_WORLD, &rank );
45
46     /* error: types do not match */
47     if( !rank ) {
48         int send = 0;
49         MPI_Bcast( &send, 1, MPI_INT, 0, MPI_COMM_WORLD );
50     } else {
51         char recv[4];
52         MPI_Bcast( &recv, 4, MPI_CHAR, 0, MPI_COMM_WORLD );
53     }
54 }
55
56 MPI_Finalize( );
```
At lines 52 and 53, adjustments can be made to the source which would look something like the following:

```c
52        int recv[4];
53        MPI_Bcast( &recv, 1, MPI_INT, 0, MPI_COMM_WORLD );
```

The modifications are to change the data-type definition for the object “recv” at line 52 from char to int, and at line 53, the third argument which is the MPI data-type is modified from MPI_CHAR to MPI_INT.

Upon doing this and following a process of recompiling and re-running the application will generate the following:

```
...  
...  
```

This indicates the message checking errors that were originally encountered have been eliminated for this example.

At the URL:

http://www.shodor.org/refdesk/Resources/Tutorials/BasicMPI/deadlock.c

one can obtain the source to an MPI example using C bindings that demonstrates deadlock.
When issuing the `mpiexec` command with the `LD_PRELOAD` environment variable:

```
mpiexec -genv LD_PRELOAD libVTmc.so -genv VT_DEADLOCK_TIMEOUT 20s -genv VT_DEADLOCK_WARNING 25s -n 2 ./deadlock.exe 0 80000
```

the following diagnostics are generated.

```
0/2: receiving 80000

1/2: receiving 80000
[0] ERROR: no progress observed in any process for over 0:29 minutes, aborting application
[0] WARNING: starting premature shutdown

[0] ERROR: GLOBAL:DEADLOCK:HARD: fatal error
[0] ERROR: Application aborted because no progress was observed for over 0:29 minutes,
[0] ERROR: check for real deadlock (cycle of processes waiting for data) or
[0] ERROR: potential deadlock (processes sending data to each other and getting blocked
[0] ERROR: because the MPI might wait for the corresponding receive).
[0] ERROR: [0] no progress observed for over 0:29 minutes, process is currently in MPI call:
[0] ERROR: MPI_Recv(*buf=0x7fbf9e4740, count=800000,
datatype=MPI_INT, source=1, tag=999, comm=MPI_COMM_WORLD,
*status=0x7fbfffef40)
[0] ERROR: main (/shared/scratch/test_correctness_checking/deadlock.c:49)
[0] ERROR: (/lib64/tls/libc-2.3.4.so)
[0] ERROR: (/shared/scratch/test_correctness_checking/deadlock.exe)
[0] ERROR: [1] no progress observed for over 0:29 minutes, process is currently in MPI call:
[0] ERROR: MPI_Recv(*buf=0x7fbf9e4740, count=800000,
datatype=MPI_INT, source=0, tag=999, comm=MPI_COMM_WORLD,
*status=0x7fbfffef40)

12  [0] ERROR: main (/shared/scratch/test_correctness_checking/deadlock.c:49)
13  [0] ERROR: (/lib64/tls/libc-2.3.4.so)
14  [0] ERROR: (/shared/scratch/test_correctness_checking/deadlock.exe)
15
16  [0] INFO: GLOBAL:DEADLOCK:HARD: found 1 time (1 error + 0 warnings), 0 reports were suppressed
17  [0] INFO: Found 1 problem (1 error + 0 warnings), 0 reports were suppressed.
```

The compiler option `-g` inserts debug information that allows one to map from the executable back to the source code. Because the environment variable
VT_CHECK_TRACING was set for the mpiexec command, trace information was placed into the directory referenced by VT_LOGFILE_PREFIX.

One can use the Intel® Trace Analyzer to view the deadlock problem that was reported in the output listing above. Here is what the trace information might look like (Figure 6.7):

![Figure 6.7 – Event Timeline illustrating an error as signified by the black circle](image)

For the event timeline chart, errors and warnings are represented by yellow-bordered circles (Figure 6.7). The color of each circle depends on the type of the particular diagnostic. If there is an error the circle will be filled in with a black coloring. If there is a warning, the circle will be filled in with a gray coloring.

For Figure 6.7, error messages and warnings can be suppressed by using a context menu. A context menu will appear if you right click the mouse as shown in Figure 6.8 and follow the path Show->Issues. If you uncheck the Issues item, the black and gray circles will clear.
Figure 6.8 – Context menu that can be used to suppress “Issues”. This is done by un-checking the “Issues” item

One can determine what source line is associated with an error message by using the context menu and selecting Details on Function. This will generate the following Details on Function panel (Figure 6.9):
Figure 6.9 – Illustration of the Detail on Function panel. The Show Source tab is the first item on the left

If you click on the Show Source tab in Figure 6.9, you will ultimately reach a source file panel such as what is demonstrated in Figure 6.10.
Figure 6.10 – The source panel display which shows the line in the user’s source where deadlock has taken place.

The diagnostic text messages and the illustration in Figure 6.10 reference line 49 of deadlock.c which looks something like the following:

```c
...
This is illustrated in Figure 6.11. To avoid deadlock situations, one might be able to resort to the following solutions:

1. Use a different ordering of calls between processes
2. Use non-blocking calls
3. Use `MPI_Sendrecv` or `MPI_Sendrecv_replace`
4. Buffered mode

The If-structure for the original program looks something like the following:

```c
if (sendfirst) {
    printf("%d/%d: sending %d\n", rank, size, messagelength);
    MPI_Send (buffer_out, messagelength, MPI_INT, other, 999, MPI_COMM_WORLD);
    MPI_Recv (buffer_in, MAX_ARRAY_LENGTH, MPI_INT, other, 999, MPI_COMM_WORLD, &status);
    printf("%d/%d: received %d\n", rank, size, messagelength);
} else {
    printf("%d/%d: receiving %d\n", rank, size, messagelength);
    MPI_Recv (buffer_in, MAX_ARRAY_LENGTH, MPI_INT, other, 999, MPI_COMM_WORLD, &status);
    MPI_Send (buffer_out, messagelength, MPI_INT, other, 999, MPI_COMM_WORLD);
    printf("%d/%d: sendt %d\n", rank, size, messagelength);
}
```

**Figure 6.11 – Cycle illustration for processes 0 and 1 when executing source lines 49 and 43 within application `deadlock.c`**
If you replace lines 43 to 44 and lines 49 to 52 with calls to MPI_Sendrecv so that they look something like:

```
MPI_Sendrecv (buffer_out, messagelength, MPI_INT, other, 999, buffer_in, MAX_ARRAY_LENGTH, MPI_INT, other, 999, MPI_COMM_WORLD, &status);
```

and save this information into a file called `deadlock2.c`, and proceed to compile the modified application. The result of running the `mpiexec` command:

```
mpiexec -genv LD_PRELOAD libVTmc.so -genv VT_DEADLOCK_TIMEOUT 20s -genv VT_DEADLOCK_WARNING 25s -n 2 ./deadlock2.exe 0 80000
```

is the following:

```
... 
0/2: receiving 80000
1/2: receiving 80000
0/2: sendt 80000
1/2: sendt 80000
[0] INFO: Error checking completed without finding any problems.
```

This indicates the deadlock errors that were originally encountered have been eliminated for this example. Using the Intel® Trace Analyzer to view the instrumentation results, we see that the deadlock issues have been resolved (Figure 6.12).
7. Getting Started in Using the Intel® Math Kernel Library (Intel® MKL)

On Linux-based platforms, the installation process for Intel MKL on the cluster system will produce a sub-directory that looks something like .../mkl where the build number 020 may vary. The default directory path for the library installation process is:

```
/opt/intel/ictce/3.2.0.013/mkl
```

The contents of the .../mkl sub-directory should be:

```
benchmarks/
doc/
examples/
include/
interfaces/
lib/
licenses/
man/
```

Figure 6.12 – Illustration of deadlock removal by using MPI_Sendrecv in the original source file called deadlock.c
Complete user documentation for Intel Math Kernel Library 10.1 can be found within the directory path:

```
<directory-path-to-mkl>/doc
```

where `<directory-path-to-mkl>` is the absolute directory path to where the Intel MKL files and sub-directories are installed on the cluster system.

In order to ensure that the correct support libraries are linked on Red Hat Enterprise Linux 3.0, the environment variable `LD_ASSUME_KERNEL` must be set. This environment variable was referenced in the installation section for Intel Trace Collector and Intel Trace Analyzer. The syntax for this environment variable might be:

```
export LD_ASSUME_KERNEL=2.4.1
```

To experiment with the ScaLAPACK test suite, recursively copy the contents of the directory path:

```
<directory-path-to-mkl>/tests/scalapack
```

to a scratch directory area which is sharable by all of the nodes of the cluster. In the scratch directory, issue the command:

```
cd scalapack
```

You can type the command:

```
gmake lib64 mpi=intelmpi30 LIBdir=<directory-path-to-mkl>/lib/64
```

Note that the `gmake` command above is applicable to Itanium 2-based systems. This makefile creates and runs executables for the ScaLAPACK (SCAlable LAPACK) examples.

```
<directory-path-to-mkl>/tests/scalapack/source/TESTING
```

For IA-32 architectures, the `gmake` command might be:

```
gmake lib32 mpi=intelmpi30 LIBdir=<directory-path-to-mkl>/lib/32
```

Finally, for the Intel® 64 architecture, the `gmake` command could be:

```
gmake libem64t mpi=intelmpi30 LIBdir=<directory-path-to-mkl>/lib/em64t
```

In the `scalapack` working directory where the `gmake` command was issued, the ScaLAPACK executables can be found in `source/TESTING`, and the results of the
computation will be placed into a sub-directory called _results. The _results
directory will be created in same directory from which the gmake command was
launched. Within this folder is another sub-folder which has a naming convention
that uses the following makefile variable configuration:

_{$(arch)}_{$(mpi)}_{$(comp)}_{$(opt)}_{(ADD_IFACE)}

For example, on IA-64 architecture, using Intel MPI Library 3.2, the Intel Compiler
and no compiler optimization, the sub-directory under _results might be called:

_ipf_intelmpi30_intel_noopt_lp64

For Intel® 64 architecture, using Intel MPI Library 3.2, the Intel Compiler and no
compiler optimization, the sub-directory under _results might be called:

_em64t_intelmpi30_intel_noopt_lp64

The "*.txt" files for the execution results can be found here. You can invoke an
editor to view the results in each of the "*.txt" files that have been created.

As an example result, the file “cdtlu_em64t_intelmpi30_intel_noopt_lp64.txt”
might have something like the following in terms of contents for an execution run on
a cluster using 4 MPI processes. The cluster that generated this sample output
consisted of 4 nodes. The text file was generated by the corresponding executable
xcdtlu_em64t_intelmpi30_intel_noopt_lp64.
Tests of the parallel complex single precision band matrix solve.

The following scaled residual checks will be computed:

\[ \text{Solve residual} = \frac{|Ax - b|}{(|x| * ||A|| * \text{eps} * N)} \]
\[ \text{Factorization residual} = \frac{|A - LU|}{(|A|| * \text{eps} * N)} \]

The matrix A is randomly generated for each test.

An explanation of the input/output parameters follows:

- **TIME**: Indicates whether WALL or CPU time was used.
- **N**: The number of rows and columns in the matrix A.
- **bwl, bwu**: The number of diagonals in the matrix A.
- **NB**: The size of the column panels the matrix A is split into. [-1 for default]
- **NRHS**: The total number of RHS to solve for.
- **NBRHS**: The number of RHS to be put on a column of processes before going on to the next column of processes.
- **P**: The number of process rows.
- **Q**: The number of process columns.
- **THRESH**: If a residual value is less than THRESH, CHECK is flagged as PASSED
- **Fact time**: Time in seconds to factor the matrix
- **Sol Time**: Time in seconds to solve the system.
- **MFLOPS**: Rate of execution for factor and solve using sequential operation count.
- **MFLOP2**: Rough estimate of speed using actual op count (accurate big P,N).

The following parameter values will be used:

\[
\begin{array}{cccccccc}
N & bwl & bwu & NB & NRHS & P & Q & \text{L*U Time} & \text{Solv Time} & \text{MFLOPS} & \text{MFLOP2} & \text{CHECK} \\
3 & 1 & 1 & 3 & 4 & 1 & 1 & 0.000 & 0.0001 & 1.06 & 1.00 & \text{PASSED} \\
5 & 1 & 1 & 5 & 4 & 1 & 1 & 0.000 & 0.0001 & 1.75 & 1.66 & \text{PASSED} \\
17 & 1 & 1 & 17 & 4 & 1 & 1 & 0.000 & 0.0001 & 6.10 & 5.77 & \text{PASSED} \\
3 & 1 & 1 & 2 & 4 & 1 & 2 & 0.000 & 0.0003 & 0.36 & 0.53 & \text{PASSED} \\
5 & 1 & 1 & 3 & 4 & 1 & 2 & 0.000 & 0.0002 & 0.90 & 1.35 & \text{PASSED} \\
17 & 1 & 1 & 9 & 4 & 1 & 2 & 0.000 & 0.0002 & 3.03 & 4.59 & \text{PASSED} \\
3 & 1 & 1 & 2 & 4 & 1 & 3 & 0.001 & 0.0006 & 0.19 & 0.27 & \text{PASSED} \\
5 & 1 & 1 & 2 & 4 & 1 & 3 & 0.001 & 0.0010 & 0.17 & 0.30 & \text{PASSED} \\
17 & 1 & 1 & 6 & 4 & 1 & 3 & 0.001 & 0.0010 & 0.75 & 1.16 & \text{PASSED} \\
3 & 1 & 1 & 2 & 4 & 1 & 4 & 0.001 & 0.0007 & 0.17 & 0.24 & \text{PASSED} \\
5 & 1 & 1 & 2 & 4 & 1 & 4 & 0.002 & 0.0026 & 0.08 & 0.13 & \text{PASSED} \\
17 & 1 & 1 & 5 & 4 & 1 & 4 & 0.001 & 0.0011 & 0.66 & 1.00 & \text{PASSED} \\
\end{array}
\]

Finished 12 tests, with the following results:

- 12 tests completed and passed residual checks.
- 0 tests completed and failed residual checks.
- 0 tests skipped because of illegal input values.

END OF TESTS.

The text in the table above reflects the organization of actual output that you will see.

Please recall from Intel MPI Library and Intel Trace Analyzer and Collector discussions that the above results are dependent on factors such as the processor type, the memory configuration, competing processes, and the type of interconnection network between the nodes of the cluster. Therefore, the results will vary from one cluster configuration to another.
If you proceed to load the `cdtlu_em64t_intelmpi30_intel_noopt_lp64.txt` table above into a Microsoft Excel® Spreadsheet, and build a chart to compare the Time in Seconds to Solve the System (SLV) and the Megaflop values, you might see something like the following (Figure 7.1):

![Comparison of Time to Solve a System and Floating Point Operation Rate for cdtlu_em64t_intelmpi30_intel_noopt_lp64.txt](image)

**Figure 7.1 – Display of ScaLAPACK DATA from the executable xcdtlu_em64t_intelmpi30_intel_noopt_lp64**

### 7.1 Gathering Instrumentation Data and Analyzing the ScaLAPACK Examples with the Intel® Trace Analyzer and Collector

In the chapter entitled Interoperability of Intel MPI Library with the Intel® Trace Analyzer and Collector, cursory explanations were provided in gathering trace data and opening various analyzer panels for viewing trace-file content. Analysis of the ScaLAPACK examples with Intel Trace Collector and Intel Trace Analyzer can also be done easily. This subsection will dwell further on the instrumentation and analysis process. The discussion will focus on how to alter the command-line options for the ScaLAPACK `gmake` command so that performance data collection will be possible. Note however, that you will want to have plenty of disk storage available for collecting trace information on all of the examples because there are approximately 68 ScaLAPACK executables. To instrument the ScaLAPACK examples on an IA-64 cluster that is running Linux, you could use the following `gmake` command:

```bash
gmake lib64 mpi=intelmpi30 LIBdir=/opt/intel/ictce/3.2.0.013/mkl/lib/64 INSLIB="-L${VT_LIB_DIR} -lVT ${VT_ADD_LIBS}"```

Intel Corporation Document Number: 318537-003
where the above shell command should appear on one line. For IA-32 architectures, a `gmake` command to instrument the ScaLAPACK examples on Linux might be:

```bash
gmake lib32 mpi=intelmpi30 LIBdir=/opt/intel/ictce/3.2.0.013/mkl/lib/32 INSLIB="-L${VT_LIB_DIR} -lVT ${VT_ADD_LIBS}"
```

Finally, for the Intel® 64 architecture, the `gmake` command for gathering ScaLAPACK instrumentation data on Linux could possibly be:

```bash
gmake libem64t mpi=intelmpi30 LIBdir=/opt/intel/ictce/3.2.0.013/mkl/lib/em64t INSLIB="-L${VT_LIB_DIR} -lVT ${VT_ADD_LIBS}"
```

For all three command-line examples listed above, the make file variable `INSLIB` is used to specify the library path name and the libraries used for instrumentation by the Intel® Trace Collector. The variable name `INSLIB` is simply an acronym for instrumentation library.

Recall the instrumentation processes discussed in Chapter 6. The recommended amount of disk storage for collecting trace data on all of the ScaLAPACK test cases is about 5 gigabytes. For an executable such as `xzevc_em64t_intelmpi30_intel_noopt_lp64` located in `source/TESTING` that has been instrumented with the Intel Trace Collector, a trace file called `xzevc_em64t_intelmpi30_intel_noopt_lp64.stf` will be generated. For the `gmake` commands above, the STF files will also be located in the sub-directory path `source/TESTING` and the summary reports for each ScaLAPACK executable will be placed under a sibling directory path to `source` called `_results`. Recalling the protocol that was discussed in the chapter for using Intel Trace Analyzer, you can proceed to analyze the content of `xzevc_em64t_intelmpi30_intel_noopt_lp64.stf` with the following shell command:

```bash
traceanalyzer xzevc_em64t_intelmpi30_intel_noopt_lp64.stf &
```

This command for invoking the Intel Trace Analyzer will cause the Event Timeline Chart and the Function Profile Chart (Figure 7.2) to be produced as described previously:
Figure 7.2 – Event Timeline Chart and the Function Profile Chart for the executable xzevc_em64t_intelmpi30_intel_noopt_lp64

By default, the ScaLAPACK makefile uses 4 MPI processes. If you wish to decrease or increase the number of MPI processes, you can adjust the MPIRUN makefile variable. An example for doing this on a system based on Intel® 64 architecture might be the following:

```
gmake libem64t mpi=intelmpi30
LIBdir=/opt/intel/ictce/3.2.0.013/mkl/lib/em64t MPILIB="-L${VT_LIB_DIR}
-1VT ${VT_ADD_LIBS}" MPIRUN="mpiexec -n 6"
```

You should again realize that the contents of a trace file such as xzevc_em64t_intelmpi30_intel_noopt_lp64.stf will vary from cluster configuration to cluster configuration due to factors such as the processor type, the memory configuration, competing processes, and the type of interconnection network between the nodes of the cluster.
Figure 7.3 – The Message Profile Chart (lower right) for the executable
\texttt{xzec_em64t_intelmpi30_intel_noopt_lp64}

If you proceed to select \textbf{Charts->Message Profile}, you will generate the Message Profile Chart shown in Figure 7.3. Subsequently, if \textbf{Charts->Collective Operations Profile} is selected, then the chart shown in Figure 7.4 will be produced.
Figure 7.4 – Display of the Collective Operations Profile Chart (lower right) for `xzvec_em64t_intelmpi30_intel_noopt_lp64`

You can zoom in on a particular time interval for the Event Timeline Chart in Figure 7.4. Clicking on the left-most mouse button and panning across the desired time interval will cause the zoom in function. For example, Figure 7.5 shows zooming in to the time interval which spans from approximately 3.0 seconds to approximately 3.01 seconds. Notice that the number of message lines that are shown in black in Figure 7.5 is significantly reduced with respect to Figure 7.4.
Figure 7.5 – Zooming in on the Event Timeline Chart for example xzevc_em64t_intelmpi30_intel_noopt_lp64

For Figure 7.5, the blue collective operation communication lines can be “drilled-down-to” by using the context menu as shown in Figure 7.6 in order to view the collective operation.
Figure 7.6 – Context Menu Selection for starting the process of drilling down to what the particular collective operation was executing (e.g. MPI_Allreduce) within the executable 
\texttt{xzevc_em64t_intelmpi30_intel_noopt_lp64}

Note that if you would like to do a drill-down to actual source, the source files used to build the executables would have to be compiled with the \texttt{-g} option, and the Intel Trace Collector VT_PCTRACE environment variable would have to be set. For the ScalAPACK \texttt{gmake} command, you might set the \texttt{-g} option with the following makefile variable:

\texttt{OPTS="-O0 -g"}

### 7.2 Experimenting with the Cluster DFT Software

On Linux, in the directory path:

\texttt{<directory-path-to-mkl>/examples}

you will find a set of sub-directories that look something like:

```
./    cdftc/    fftw2x_cdft/    interval/    pdepoissonf/    versionquery/
../   cdftf/    fftw2xf/        java/       pdettf/       vmlc/
blas/ dftc/    fftw3xc/        lapack/     pdettf/       vmlf/
blas95/ dftf/    fftw3xf/      lapack95/   solver/       vslc/
cblas/ fftw2xc/    gmp/         pdepoissonc/   spblas/       vslf/
```
The two sub-directories that will be discussed here are `cdftc` and `cdftf`. These two directories respectively contain C and Fortran programming language examples of the Cluster Discrete Fourier Transform (CDFT). To do experimentation with the contents of these two folders, a sequence of shell commands could be used to create instrumented executables and result information. For the C language version of the CDFT, the Bourne Shell or Korn Shell commands might look something like:
<table>
<thead>
<tr>
<th>Intel Processor Architecture</th>
<th>Command-line Sequence for Linux</th>
<th>Trace Results are Located In</th>
<th>Execution Results are Located In</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA-32</td>
<td><code>#!/bin/sh</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>export CWD=${PWD}</code></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>export VT_LOGFILE_PREFIX=${CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>rm -rf ${VT_LOGFILE_PREFIX}</code></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>mkdir ${VT_LOGFILE_PREFIX}</code></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>export VT_PCTRACE=5</code></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>export VT_DETAILED_STATES=5</code></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>cd</code></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>/usr/local/opt/intel/ictce/3.2.0.013/mkl/examples/cdftc</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>gmake</code></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><code>workdir=${VT_LOGFILE_PREFIX} CS=&quot;mpiicc -t=log&quot; RS=&quot;mpiexec -n 4&quot; RES_DIR=${VT_LOGFILE_PREFIX}</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td></td>
</tr>
</tbody>
</table>

**Intel® 64 (formerly Intel EM64T)**

<table>
<thead>
<tr>
<th>IA-64</th>
<th><code>#!/bin/sh</code></th>
<th><code>#{CWD}/cdftc_inst</code></th>
<th><code>#{CWD}/cdftc_inst</code></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><code>export CWD=${PWD}</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>export VT_LOGFILE_PREFIX=${CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>rm -rf ${VT_LOGFILE_PREFIX}</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>mkdir ${VT_LOGFILE_PREFIX}</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>export VT_PCTRACE=5</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>export VT_DETAILED_STATES=5</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>cd</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>/usr/local/opt/intel/ictce/3.2.0.013/mkl/examples/cdftc</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>gmake</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
<tr>
<td></td>
<td><code>workdir=${VT_LOGFILE_PREFIX} CS=&quot;mpiicc -t=log&quot; RS=&quot;mpiexec -n 4&quot; RES_DIR=${VT_LOGFILE_PREFIX}</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
<td><code>#{CWD}/cdftc_inst</code></td>
</tr>
</tbody>
</table>

where `<directory-path-to-mkl>/examples` in the shell command-sequence above is:

```
/usr/local/opt/intel/ictce/3.2.0.013/mkl/examples
```

Note that the folder path above will vary depending on where the Intel Cluster Toolkit Compiler Edition was installed on your system. The change directory command above (i.e. `cd ...`) transfers the Bourne Shell or Korn Shell session to:
The `gmake` command for the target `lib32` is one contiguous line that ends with `CS="mpiicc -t=log"`. This command references the makefile variables `lib32`, `mpi`, `workdir`, `CS`, and `RS`. As mentioned above, the target for the `gmake` command is `lib32`. Two other targets of this type are `lib64` and `libem64t`. The target `lib64` is used for Itanium 2-based systems and the target `libem64t` is for Intel® 64 architecture. The makefile variable `CS` is set so that the resulting executable is linked against the logging versions of Intel MPI and the Intel Trace Collector. The `RS` makefile variable allows you to control the number of MPI processes. The default for `RS` is "mpiexec --n 2" when using Intel MPI Library. You can get complete information about this makefile by looking at its contents. There is also a `help` target built within the makefile, and therefore you can type:

```
gmake help
```

Assuming that `${CWD}` has been defined from above for the Fortran language version of the CDFT, the Bourne Shell or Korn Shell commands might look something like:
<table>
<thead>
<tr>
<th>Intel Processor Architecture</th>
<th>Command-line Sequence for Linux</th>
<th>Trace Results are Located In</th>
<th>Execution Results are Located In</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA-32</td>
<td>export VT_LOGFILE_PREFIX=${CWD}/cdftf_inst rm -rf ${VT_LOGFILE_PREFIX} mkdir ${VT_LOGFILE_PREFIX} export VT_PCTRACE=5 export VT_DETAILED_STATES=5 cd /usr/local/opt/intel/ictce/3.2.0.013/mkl/examples/cdftf gmake lib32 mpi=intel3 workdir=${VT_LOGFILE_PREFIX} CS=&quot;mpiifort -t=log&quot; RS=&quot;mpiexec -n 4&quot; RES_DIR=${VT_LOGFILE_PREFIX}&quot;</td>
<td>${CWD}/cdftf_inst</td>
<td>${CWD}/cdftf_inst</td>
</tr>
<tr>
<td>Intel® 64 (formerly Intel EM64T)</td>
<td>export VT_LOGFILE_PREFIX=${CWD}/cdftf_inst rm -rf ${VT_LOGFILE_PREFIX} mkdir ${VT_LOGFILE_PREFIX} export VT_PCTRACE=5 export VT_DETAILED_STATES=5 cd /usr/local/opt/intel/ictce/3.2.0.013/mkl/examples/cdftf gmake libem64t mpi=intel3 workdir=${VT_LOGFILE_PREFIX} CS=&quot;mpiifort -t=log&quot; RS=&quot;mpiexec -n 4&quot; RES_DIR=${VT_LOGFILE_PREFIX}&quot;</td>
<td>${CWD}/cdftf_inst</td>
<td>${CWD}/cdftf_inst</td>
</tr>
<tr>
<td>IA-64</td>
<td>export VT_LOGFILE_PREFIX=${CWD}/cdftf_inst rm -rf ${VT_LOGFILE_PREFIX} mkdir ${VT_LOGFILE_PREFIX} export VT_PCTRACE=5 export VT_DETAILED_STATES=5 cd /usr/local/opt/intel/ictce/3.2.0.013/mkl/examples/cdftf gmake lib64 mpi=intel3 workdir=${VT_LOGFILE_PREFIX} CS=&quot;mpiifort -t=log&quot; RS=&quot;mpiexec -n 4&quot; RES_DIR=${VT_LOGFILE_PREFIX}&quot;</td>
<td>${CWD}/cdftf_inst</td>
<td>${CWD}/cdftf_inst</td>
</tr>
</tbody>
</table>

If you consolidate the shell script commands for performing C and Fortran Cluster Discrete Fourier computation on a particular Intel processor architecture, say Intel® 64 architecture, the complete Bourne shell script content might look something like:

```bash
#!/bin/sh
export CWD=${PWD}
export VT_LOGFILE_PREFIX=${CWD}/cdftc_inst
rm -rf ${VT_LOGFILE_PREFIX}
mkdir ${VT_LOGFILE_PREFIX}
export VT_PCTRACE=5
export VT_DETAILED_STATES=5
cd /usr/local/opt/intel/ictce/3.2.0.013/mkl/examples/cdftc
gmake libem64t mpi=intel3 workdir=${VT_LOGFILE_PREFIX} CS="mpiicc -t=log" RS="mpiexec -n 4" RES_DIR=${VT_LOGFILE_PREFIX}
export VT_LOGFILE_PREFIX=${CWD}/cdftf_inst
```
rm -rf ${VT_LOGFILE_PREFIX}
mkdir ${VT_LOGFILE_PREFIX}
export VT_PCTRACE=5
export VT_DETAILED_STATES=5
cd /usr/local/opt/intel/ictce/3.2.0.013/mkl/examples/cdftf
make libem64t mpi=intel3 workdir=${VT_LOGFILE_PREFIX} CS="mpifort -t=log" RS="mpirun -n 4" RES_DIR=${VT_LOGFILE_PREFIX}

After executing the shell script above, the ${CWD}/cdftc_inst and ${CWD}/cdftf_inst folders should contain the respective executables and the output results. The executable and result contents of each folder path might look something like:

dm_complex_2d_double_ex1.exe
dm_complex_2d_double_ex2.exe
dm_complex_2d_single_ex1.exe
dm_complex_2d_single_ex2.exe

and

dm_complex_2d_double_ex1.res
dm_complex_2d_double_ex2.res
dm_complex_2d_single_ex1.res
dm_complex_2d_single_ex2.res

The files with the suffix .res are the output results. A partial listing for results file called dm_complex_2d_double_ex1.res might be something like:

Program is running on 4 processes

DM_COMPLEX_2D_DOUBLE_EX1
Forward-Backward 2D Complex transform for double precision data inplace

Configuration parameters:

DFTI_FORWARD_DOMAIN = DFTI_COMPLEX
DFTI_PRECISION = DFTI_DOUBLE
DFTI_DIMENSION = 2
DFTI_LENGTHS (MxN) = {20,12}
DFTI_FORWARD_SCALE = 1.0
DFTI_BACKWARD_SCALE = 1.0/(m*n)

... 

Compute DftiComputeForwardDM

Forward result X, 4 columns

<table>
<thead>
<tr>
<th>Row</th>
<th>1</th>
<th>1.000, 0.000</th>
<th>1.000, 0.000</th>
<th>1.000, 0.000</th>
<th>1.000, 0.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row</td>
<td>2</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
</tr>
<tr>
<td>Row</td>
<td>3</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
</tr>
<tr>
<td>Row</td>
<td>4</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
<td>1.000, 0.000</td>
</tr>
</tbody>
</table>
Also, the setting of the environment variable VT_LOGFILE_PREFIX within the shell script results in the deposit of trace information into the directories cdftc_inst and cdftf_inst as demonstrated with a listing of the Structured Trace Format (STF) index files:

```
  cdftc_inst/dm_complex_2d_double_ex1.exe.stf
  cdftc_inst/dm_complex_2d_double_ex2.exe.stf
  cdftc_inst/dm_complex_2d_single_ex1.exe.stf
  cdftc_inst/dm_complex_2d_single_ex2.exe.stf
```

and

```
  cdftf_inst/dm_complex_2d_double_ex1.exe.stf
  cdftf_inst/dm_complex_2d_double_ex2.exe.stf
  cdftf_inst/dm_complex_2d_single_ex1.exe.stf
  cdftf_inst/dm_complex_2d_single_ex2.exe.stf
```

You can issue the following Intel Trace Analyzer shell command to initiate performance analysis on cdftc_inst/dm_complex_2d_double_ex1.exe.stf:

```
  traceanalyzer ./cdftc_inst/dm_complex_2d_double_ex1.exe.stf &
```

Figure 7.7 shows the result of simultaneously displaying the Function Profile Chart and the Event Timeline Chart.
Figure 7.7 – The Event Timeline Chart and the Function Profile Chart for a Cluster Discrete Fourier Transform Example


8. **Using the Intel® MPI Benchmarks**

The Intel MPI Benchmarks have been ported to Linux®. The directory structure for the Intel® MPI Benchmarks 3.2 looks something like the following where the parenthesized text contains descriptive information:

- `.doc` (ReadMe_IMB.txt; IMB_u-3.2.pdf, the methodology description)
- `.src` (program source code and Makefiles)
- `.license` (Source license agreement, trademark and use license agreement)
- `.versions_news` (version history and news)
- .\WINDOWS  (Microsoft* Visual Studio* projects)

The WINDOWS folder as noted above contains Microsoft* Visual Studio* 2005 and 2008 project folders which allow you to use a pre-existing ".vcproj" project file in conjunction with Microsoft* Visual Studio* to build and run the associated Intel® MPI Benchmark application. Note that this is not relevant to Linux*.

If you type the command gmake within the src subdirectory, then you will get general help information that looks something like the following:

IMB_3.2 does not have a default Makefile any more. This Makefile can be used to

gmake clean

For installing, please use:

gmake -f make_ict
to install the Intel(r) Cluster Tools (ict) version. When an Intel(r) MPI Library install and mpiicc path exists, this should work immediately.

Alternatively, use

gmake -f make_mpich
to install an mpich or similar version; for this, you normally have to edit at least the MPI_HOME variable provided in make_mpich

To clean up the directory structure, in the directory src, simply type:

    gmake clean

To compile the Intel MPI Benchmarks with the Intel Cluster Tools, simply type the command:

    gmake -f make_ict

The three executables that will be created with the all target are:

    IMB-EXT
    IMB-IO
    IMB-MPI1

Assuming that you have a four node cluster, and the Bourne Shell is being used simply type the commands:

    mpiexec -n 4 IMB-EXT > IMB-EXT.report 2>&1
    mpiexec -n 4 IMB-IO > IMB-IO.report 2>&1
    mpiexec -n 4 IMB-MPI1 > IMB-MPI1.report 2>&1

Similarly, if C Shell is the command-line interface, type the commands:

    mpiexec -n 4 IMB-EXT >&! IMB-EXT.report
9. Uninstalling the Intel® Cluster Toolkit Compiler Edition on Linux*

For Linux, if you wish to uninstall the Intel Cluster Toolkit Compiler Edition, there is a shell script called `uninstall.sh`. This script can be found in folder path:

```
<Path-to-Intel-Cluster-Toolkit>/uninstall.sh
```

An example folder might be:

```
/usr/local/opt/intel/ictce/3.2.0.013/uninstall.sh
```

When this uninstall script is invoked, it will prompt you for that location of the `machines.LINUX` file.

The uninstall script does have command-line options. Simply type a shell command referencing `uninstall.sh` such as:

```
uninstall.sh --help | less
```

and you will see a list of options that look something like:
NAME

SYNOPSIS
   uninstall.sh [options]

OPTIONS
   --help     Print this help and exit.
   --log-file=FILE
             Write log to the specified file.
   --single-node
   --singlenode
             Uninstall the product only from this node.
   --delete-update=UPDATE_NUMBER
             Delete update with the specified number.
   --list-update
             List all updates.

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10. Hardware Recommendations for Installation on Linux*

Processor System Requirements
Intel® Pentium® 4 processor, or
Intel® Xeon® processor, or
Intel® Itanium® 2 processor, or
Intel® Core™2 Duo processor (example of Intel® 64 (formerly Intel EM64T) architecture)

Note that it is assumed that the processors listed above are configured into homogeneous clusters.

Disk-Space Requirements

20 GBs of disk space (minimum)

Note that during the installation process the installer may need approximately 4 gigabytes of temporary disk storage to manage the intermediate installation files.
**Operating System Requirements for Linux***

<table>
<thead>
<tr>
<th>OS Distributions</th>
<th>IA-32 Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intel® 64 Architecture</td>
</tr>
<tr>
<td></td>
<td>32-Bit Applications</td>
</tr>
<tr>
<td>IA-32 Architecture</td>
<td>IA-64 Architecture</td>
</tr>
<tr>
<td>SGI* Propack* 5 for Linux*</td>
<td>S</td>
</tr>
<tr>
<td>Red Hat Enterprise Linux* 4.0</td>
<td>S</td>
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<tr>
<td>Red Hat Enterprise Linux* 5.0</td>
<td>S</td>
</tr>
<tr>
<td>SUSE Linux Enterprise Server* 9</td>
<td>S</td>
</tr>
<tr>
<td>SUSE Linux Enterprise Server* 10</td>
<td>S</td>
</tr>
</tbody>
</table>

*S = Supported

**Memory Requirements**

2 GB of RAM (minimum)

**11. System Administrator Checklist for Linux***

Intel license keys should be place in a common repository for access by the software components of the Intel Cluster Toolkit Compiler Edition. An example license directory path might be:

```
/opt/intel/licenses
```

**12. User Checklist for Linux***

1. The Intel® IDB Debugger graphical environment is a Java application and requires a Java Runtime Environment (JRE) to execute. The debugger will run with a version 5.0 (also called 1.5) JRE.

   Install the JRE according to the JRE provider's instructions.

   Finally you need to export the path to the JRE as follows:

   ```
   export PATH=〈path_to_JRE_bin_DIR>:PATH
   ```

2. Configure the environment variables. For the ~/.bashrc file, an example of setting environment variables and sourcing shell scripts might be the following for Intel® 64 architecture:
export INTEL_LICENSE_FILE=/opt/intel/licenses
./opt/intel/ictce/3.2.0.013/ictvars.sh

Alternatively, for ~/.cshrc the syntax might be something like:

setenv INTEL_LICENSE_FILE /opt/intel/licenses
source /opt/intel/ictce/3.2.0.013/ictvars.csh

3. When using the Intel Debugger (IDB) with Intel MPI Library, you also want to
create or update the ~/.rhosts file with the names of the nodes of the cluster. The ~/.rhosts file should have node names that use the following general syntax:

<hostname as echoed by the shell command hostname> <your username>

The permission bit settings of ~/.rhosts should be set to 600 using the chmod command. The shell command for doing this might be:

chmod 600 ~/.rhosts

13. Using the Compiler Switch -tcollect
The Intel® C++ and Intel® Fortran Compilers on Linux have the command-line
switch called -tcollect which allows functions and procedures to be instrumented
during compilation with Intel® Trace Collector calls. This compiler command-line
switch accepts an optional argument to specify the Intel® Trace Collector library to
link with.

<table>
<thead>
<tr>
<th>Library Selection</th>
<th>Meaning</th>
<th>How to Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>libVT.a</td>
<td>Default library</td>
<td>-tcollect</td>
</tr>
<tr>
<td>libVTcs.a</td>
<td>Client-server trace collection library</td>
<td>-tcollect=VTcs</td>
</tr>
<tr>
<td>libVTfs.a</td>
<td>Fail-safe trace collection library</td>
<td>-tcollect=Vtfs</td>
</tr>
</tbody>
</table>

Recall once again that in the test_intel_mpi folder for Intel MPI Library, there are four source files called:

test.c test.cpp test.f test.f90

To build executables with the -tcollect compiler option for the Intel Compilers, one might use the following compilation and link commands:

mpiicc test.c -tcollect -g -o testc_tcollect
mpiicpc test.cpp -g -tcollect -o testcpp_tcollect
mpiifort test.f -tcollect -g -o testf_tcollect
mpiifort test.f90 -tcollect -g -o testf90_tcollect

The names of the MPI executables for the above command-lines should be:

testc_tcollect
testcpp_tcollect
testf_tcollect
testf90_tcollect
So as to make a comparison with the Intel Trace Collector STF files:

```
testc.stf testcpp.stf testf.stf testf90.stf
```

within the directory test_inst, we will use the following mpiexec commands:

```
mpiexec -n 4 -env VT_LOGFILE_PREFIX test_inst testc_tcollect
mpiexec -n 4 -env VT_LOGFILE_PREFIX test_inst testcpp_tcollect
mpiexec -n 4 -env VT_LOGFILE_PREFIX test_inst testf_tcollect
mpiexec -n 4 -env VT_LOGFILE_PREFIX test_inst testf90_tcollect
```

The corresponding STF data will be placed into the folder test_inst. To do a comparison between the STF data in testcpp.stf and testcpp_tcollect.stf the following traceanalyzer command can be launched from a Linux command-line panel within the folder test_intel_mpi:

```
traceanalyzer
```

Figure 13.1 shows the base panel for the Intel Trace Analyzer as a result of invoking the command above from a Linux panel.
Figure 13.1 – Base panel for the Intel Trace Analyzer when invoking a Linux Shell Command: `traceanalyzer` without any arguments

If you select the menu path `File->Open` and click on the `test_inst` folder, the following panel will appear:

![Intel Trace Analyzer panel](image)

Figure 13.2 – Open a Tracefile Rendering for the `test_inst` Folder where `testcpp.stf` has been Highlighted

Selecting `testcpp.stf` will generate a Flat Profile panel within the Intel Trace Analyzer session that might look something like the following.
Figure 13.3 – Flat Panel Display for test_inst\testcpp.stf

For the Flat Panel Display, if you select File->Compare the following sub-panel will appear.
Figure 13.4 – Sub-panel Display for Adding a Comparison STF File

Click on the “Open another file” button and select testcpp_tcollect.stf and then proceed to push on the Open button with your mouse.
Figure 13.5 – Sub-panel Activating the Second STF File for Comparison

Click on the Ok button in Figure 13.5 and the comparison display in Figure 13.6 will appear. In Figure 13.6, notice that the timeline display for `testcpp_tcollect.stf` (i.e. the second timeline) is longer than that of the top timeline display (`testcpp.stf`).
Figure 13.6 – Comparison of testcpp.stf and testcpp_tcollect.stf

At the bottom and towards the right of this panel there are two labels with the same name, namely, Major Function Groups. Click on the top label with this name, and a sub-panel will appear with the following information:
Figure 13.7 – "Function Group Editor for file A" Display (i.e for file testcpp.stf)

Highlight the "All Functions" tree entry and press the Apply but in the low right corner of this panel. Then press the OK button. Repeat this process for the second Major Function Groups label at the bottom of the main Trace Analyzer panel. You should now see a panel rendering that looks something like:
Figure 13.8 – Comparison of STF Files testcpp.stf and testcpp_tcollect.stf after making the All Functions Selection

At the top of the display panel, if you make the menu selection Charts->Function Profile you will be able to see a function profile comparison (lower middle and lower right) for the two executables:
Figure 13.9 – Function Profile Sub-panels in the Lower Middle and Lower Right Sections of the Display for testcpp.stf and testcpp_tcollect.stf

Notice that the lower right panel (testcpp_tcollect.stf) has much more function profiling information than the lower middle panel (testcpp.stf). This is the result of using the -tcollect switch during the compilation process. You can proceed to do similar analysis with:

1) testc.stf and testc_tcollect.stf
2) testf.stf and testf_tcollect.stf
3) testf90.stf and testf90_tcollect.stf

14. Using Cluster OpenMP*

Cluster OpenMP is only available on Linux platforms. The Intel® architectures must be Intel® 64 or IA-64. The application must be written with the C and/or Fortran programming languages.

The major advantage of Cluster OpenMP is that it facilitates ordinary OpenMP*-like parallel programming but on a distributed memory system where it uses the same fork/join, and shared memory model of parallelism that ordinary OpenMP uses. This
methodology may be easier to use than message-passing paradigms such as MPI or PVM*

OpenMP is a directive-based language that annotates an underlying serial program with parallel programming semantics. The underlying serial program runs sequentially when you turn off OpenMP directive processing within the Intel Compiler. With proper planning, you can develop your parallel application just as you would develop a serial program and then enable parallelism with OpenMP. Since you can parallelize your application in an increment fashion, OpenMP usually helps you write a parallel program more quickly and easily than you could with other techniques.

Unfortunately, not all programs are suitable for Cluster OpenMP. If your application meets the following two criteria, it may be a good candidate for using Cluster OpenMP parallelization:

1) Your application shows excellent speedup with ordinary OpenMP.

If the scalability of your application is poor with ordinary OpenMP on a single node, then porting it to Cluster OpenMP is not recommended. The scalability for Cluster OpenMP is in most cases worse than for ordinary OpenMP because Cluster OpenMP has higher overheads for almost all constructs, and sharable memory accesses can be costly. Ensure that your application gets good speedup with “ordinary” OpenMP before taking steps to use Cluster OpenMP.

To test for this condition, run the OpenMP form of the program (a program compiled with the -openmp Intel Compiler option) on one node, once with one thread and once with \( n \) threads, where \( n \) is the number of processors on the single node.

For the most time-consuming parallel regions, if the speedup achieved for \( n \) threads is not close to \( n \), then the code is not suitable for Cluster OpenMP. In other words, the following formula should be true:

\[
\text{Speedup} = \frac{\text{Time(1 thread)}}{\text{Time(n threads)}} = \sim n
\]

Note that the formula above measures a scalability form of speedup. This measurement is not the same as the speedup that is associated with the quality of parallelization for a given application. That type of speedup is calculated as follows:

\[
\text{Speedup} = \frac{\text{Time(serial)}}{\text{Time(n threads)}}
\]

2) Your application has good locality of reference and little synchronization.

An OpenMP program that gets excellent speedup may get good speedup with Cluster OpenMP as well. However, the data access pattern of your application can make use of the Cluster OpenMP model scale poorly even if it scales well with ordinary OpenMP. For example, if a thread typically accesses large amounts of data that were last written by a different thread, or if there is excessive synchronization, a Cluster OpenMP program may spend large amounts of time sending messages between nodes, which can prevent good speedup.
If you are not sure whether your code meets these criteria, you can use the Cluster OpenMP utility called `clomp_forecaster.pl` that is described in Chapter 9.3 of the Cluster OpenMP Users Guide to see if Cluster OpenMP is appropriate for your application. The Cluster OpenMP Users Guide is located in:

```
.../cluster_omp/docs
```

with respect to the Intel C++ or Intel Fortran compiler directory paths. Similarly, the utility `clomp_forecaster.pl` is located in:

```
.../cluster_omp/tools
```

### 14.1 Running Cluster OpenMP Examples

In the directory path for the Intel C++ Compiler:

```
.../samples
```

there is a subfolder called `cluster`. The content of that sub-directory is the following:

```
 kmp_cluster.ini  Makefile  md.c  README.txt
```

If you copy the contents of this directory to a shared area that is accessible by all of the nodes of the cluster, and provide an `mpd.hosts` file that is unique to your cluster, you can type:

```
gmake clean
gmake build
gmake run
```

Notice in regards to the makefile target `build` within the file `Makefile` for the command `gmake build`, that the Intel Compiler switch `-cluster-openmp` is being used for the compilation of the C source file `md.c`. The `gmake run` command executes the following:

```
time md.exe > md.out
```

The output data is placed into the file `md.out`. The timing information might look something like:

```
real    0m31.563s
user    0m13.198s
sys     0m0.956s
```

Please note that the timing results that you achieve will at a minimum be a function of the number of nodes in the cluster, the interconnection fabric, the memory size, and the processor architecture.

Similarly for the directory path to the Intel Fortran Compiler:

```
.../samples/cluster
```

Intel Corporation Document Number: 318537-003
This sub-directory path contains:

```
    kmp_cluster.ini  Makefile  md.f  README.txt
```

Again, if you copy the contents of this directory to a shared area that is accessible by all of the nodes of the cluster, and provide an `mpd.hosts` file that is unique to your cluster, you can type:

```
gmake clean
gmake build
gmake run
```

When you issue the `gmake build` command for the Fortran version of the Cluster OpenMP example, you should see something like the following:

```
ifort -cluster-openmp md.f -o md.exe
```

As with the C programming example for Cluster OpenMP, the `-cluster-openmp` command-line switch instructs the Fortran compiler to use the Cluster OpenMP libraries. Similarly, regarding the `gmake run` command, the following target semantics will be invoked:

```
    time md.exe > md.out
```

for the Fortran-based executable `md.exe`.

## 14.2 Gathering Performance Instrumentation Data and Doing Analysis with Intel® Trace Analyzer and Collector

The Intel Trace Analyzer and Collector can be used to help you analyze the performance of a Cluster OpenMP* application.

To use Intel Trace Analyzer and Collector with a Cluster OpenMP application use the following sequence of steps:

1. Ensure that your `LD_LIBRARY_PATH` includes the directory where the appropriate Intel Trace Analyzer dynamic libraries exist, normally in the directory path `<directory-path-to-ITAC>/slib`. Note that this is automatically solved if you source `ictvars.csh` or `ictvars.sh` when respectively using C Shell or Bourne Shell as your command-line interface.
2. Set the environment variable `KMP_TRACE` to the value 1.
3. Add the option `"--IO=files"` to the `kmp_cluster.ini` file.
4. Run your executable on a set of nodes.

Regarding the examples `md.c` and `md.f` in the last subsection, you can set following sequence of Bourne Shell commands assuming that you are using a Bourne Shell environment:

```
export KMP_TRACE=1
```

Intel Corporation Document Number: 318537-003
export VT_LOGFILE_PREFIX=${PWD}/inst
rm -rf ${VT_LOGFILE_PREFIX}
mkdir ${VT_LOGFILE_PREFIX}
time ./md.exe > md.out 2>&1

Recall that the environment variable VT_LOGFILE_PREFIX will direct instrumentation data into a directory path such as ${PWD}/inst. After execution of md.exe, the contents of ${PWD}/inst might look something like:

./ md.exe.prot md.exe.stf.dcl md.exe.stf.gop md.exe.stf.msg
md.exe.stf.pr.0 md.exe.stf.sts
../ md.exe.stf md.exe.stf.frm md.exe.stf.gop.anc md.exe.stf.msg.anc
md.exe.stf.pr.0.anc

As your application executes, it will produce trace file data which records important events that took place inside the Cluster OpenMP runtime library. You can analyze this trace file with Intel Trace Analyzer to tune and improve the performance of your application.

As with an MPI application, you can view the Cluster OpenMP performance data by running traceanalyzer with the trace filename as an argument. For example, the executable referenced above was called md.exe. Based on the contents of ${PWD}/inst for our example, the command-line for the trace analyzer from the directory ${PWD} might be:

traceanalyzer md.exe.stf

This will produce the profile display illustrated in Figure 14.1.
Figure 14.1 – Profile Display for trace file *md.ex.stf*

Figure 14.2 shows the result of opening up the Event Timeline display through the menu selection Charts->Event Timeline:
Figure 14.2 – Intel® Trace Analyzer display showing the Event Timeline and Function profile display for md.exe

Notice that there is a large concentration of black lines shown in Figure 14.2. This represents communication between the various processor threads. You can zoom in on a particular segment of the time line by using your mouse (leftmost button) and highlighting a particular time line interval (Figure 14.3).
Figure 14.3 – Highlighting a time interval (shown in yellow) with the leftmost mouse button

Again, note that the results that you will see on your system will be at a minimum be a function of the number of nodes in the cluster, the interconnection fabric, the memory size, and the processor architecture.
Figure 14.4 – The result of zooming on the particular time line segment that was highlighted in Figure 14.3

To make inquiries about Cluster OpenMP, visit the URL: http://whatif.intel.com. At the bottom of this landing page, there is a web link titled WhatIf Alpha Software Forums where you can review past questions, read what other people are working on, post a new inquiry, get support from product authors, and read the opinions of fellow users.