Intel® Cluster Toolkit Compiler Edition 4.0 for Linux* OS

Tutorial

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Contents

Revision History

Document Number	Revision Number	Description	Revision Date
318654-006	20100602	Updated Intel® Cluster Toolkit Compiler Edition 4.0 for Linux OS Tutorial to reflect changes and improvements to the software components.	06/02/2010

Disclaimer and Legal Information

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2. Introduction

The Intel® Cluster Toolkit Compiler Edition 4.0 release on Linux* OS consists of:

1. Intel® C++ Compiler 11.1 Update 6
2. Intel® Debugger 11.1 Update 6
3. Intel® Fortran Compiler 11.1 Update 6
4. Intel® Math Kernel Library 10.2 Update 5
5. Intel® MPI Benchmarks 3.2.1
6. Intel® MPI Library 4.0
7. Intel® Trace Analyzer and Collector 8.0

A prerelease license for Cluster OpenMP* (for Linux only on Intel® 64 architecture) is available through whatif.intel.com.

NOTE: 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:

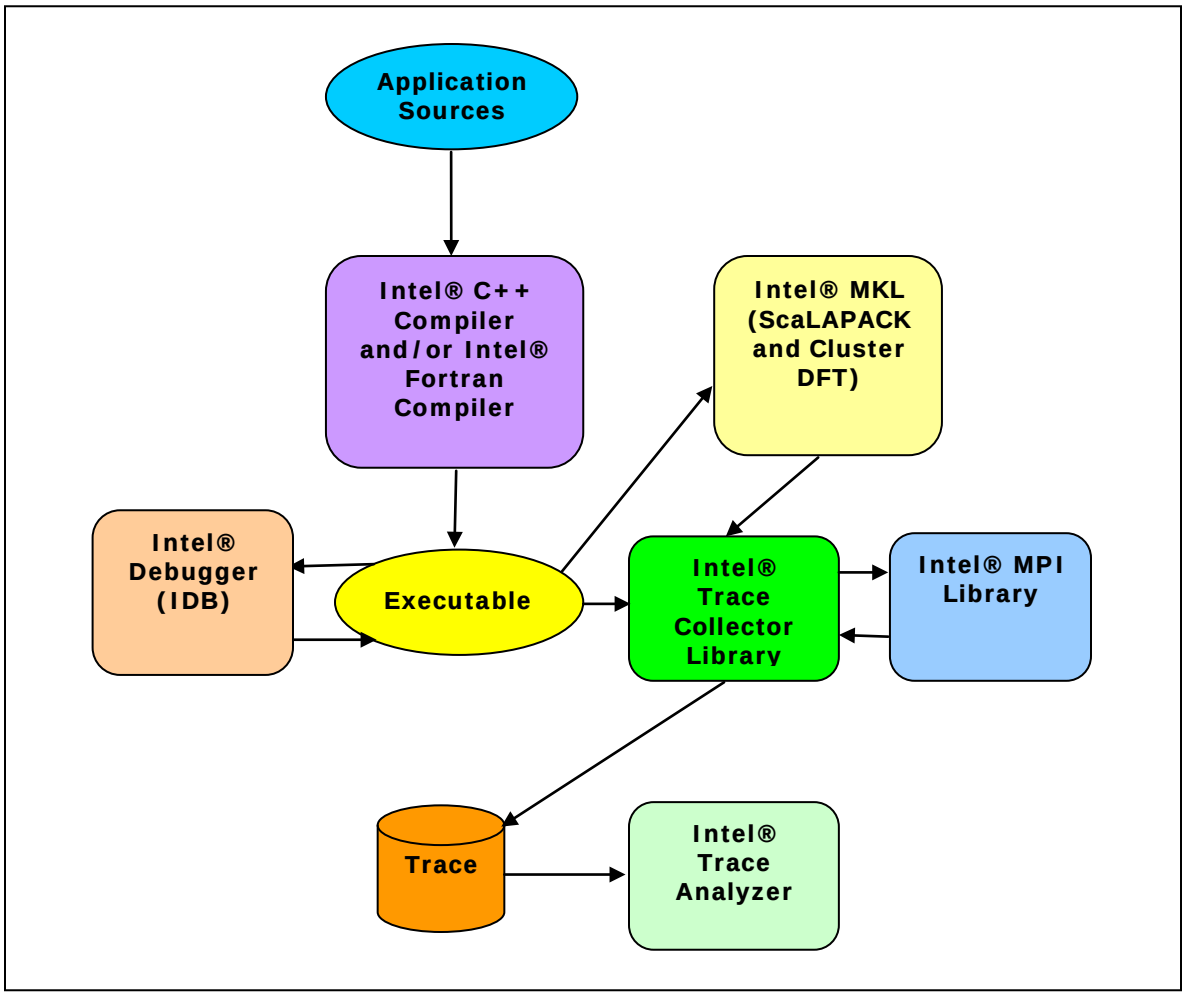

Figure 2.1 – The software architecture for the Intel Cluster Toolkit Compiler Edition for Linux (The Cluster OpenMP Library is only available for Linux on Intel® 64 architecture)

The following are acronyms and definitions of those acronyms that may be referenced within this document.

Acronym	Definition
ABI	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.
BLACS	Basic Linear Algebra Communication Subprograms – provides a linear algebra oriented message passing interface for distributed memory computing platforms.

BLAS	Basic Linear Algebra Subroutines
DAPL*	Direct Access Program Library - an Application Program Interface (API) for Remote Data Memory Access (RDMA).
DFT	Discrete Fourier Transform
Ethernet	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.
GB	Gigabyte
ICT	Intel® Cluster Toolkit
ICTCE	Intel® Cluster Toolkit Compiler Edition
IMB	Intel® MPI Benchmarks
IP	Internet protocol
ITA or ita	Intel® Trace Analyzer
ITAC or itac	Intel® Trace Analyzer and Collector
ITC or itc	Intel® Trace Collector
MPD	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.
MPI	Message Passing Interface - an industry standard, message-passing protocol that typically uses a two-sided send-receive model to transfer messages between processes.
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 forth.
PVM*	Parallel Virtual Machine
RAM	Random Access Memory
RDMA	Remote Direct Memory Access - this capability allows processes executing on one node of a cluster to be able to "directly" access (execute reads or writes against) the memory of processes within the same user job executing on a different node of the cluster.
RDSSM	TCP + shared memory + DAPL* (for SMP clusters connected via RDMA-capable fabrics)

RPM*	Red Hat Package Manager* - a system that eases installation, verification, upgrading, and uninstalling Linux packages.
ScaLAPACK*	SCAlable LAPACK - an acronym for Scalable Linear Algebra Package or Scalable LAPACK.
shm	Shared memory only (no sockets)
SMP	Symmetric Multi-processor
ssm	TCP + shared memory (for SMP clusters connected via Ethernet)
STF	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.
TCP	Transmission Control Protocol - a session-oriented streaming transport protocol which provides sequencing, error detection and correction, flow control, congestion control and multiplexing.
VML	Vector Math Library
VSL	Vector Statistical Library

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3. Intel Software Downloads and Installation on Linux* OS

The Intel Cluster Toolkit Compiler Edition installation process on Linux OS is comprised of eight basic steps. The Intel Cluster Toolkit Compiler Edition 4.0 package consists of the following components:

Software Component	Default Installation Directory on IA-32 Architecture for Linux	Default Installation Directory on Intel® 64 Architecture for Linux
Intel C++ Compiler 11.1 Update 6	/opt/intel/ictce/4.0.0.0xx/cc	/opt/intel/ictce/4.0.0.0xx/cc/bin/ia32 /opt/intel/ictce/4.0.0.0xx/cc/bin/intel64
Intel Debugger 11.1 Update 6	/opt/intel/ictce/4.0.0.0xx/idb	/opt/intel/ictce/4.0.0.0xx/idb/bin/ia32 /opt/intel/ictce/4.0.0.0xx/idb/bin/intel64
Intel Fortran Compiler 11.1 Update 6	/opt/intel/ictce/4.0.0.0xx/fc	/opt/intel/ictce/4.0.0.0xx/fc/bin/ia32 /opt/intel/ictce/4.0.0.0xx/fc/bin/intel64
Intel MPI Benchmarks 3.2.1	/opt/intel/ictce/4.0.0.0xx/imb	/opt/intel/ictce/4.0.0.0xx/imb
Intel MPI Library 4.0	/opt/intel/ictce/4.0.0.0xx/impi	/opt/intel/ictce/4.0.0.0xx/impi
Intel MKL 10.2 Update 5	/opt/intel/ictce/4.0.0.0xx/mkl	/opt/intel/ictce/4.0.0.0xx/mkl
Intel Trace Analyzer and Collector 8.0	/opt/intel/ictce/4.0.0.0xx/itac	/opt/intel/ictce/4.0.0.0xx/itac

For the table above, references to 0xx in the directory path represents a build number such as 017.

NOTE: 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 OS). This assumes that your login account does not have administrative capabilities.

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3.1 Linux* OS Installation

To begin installation on Linux*:

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.

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 4.0, 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 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

where licenses is a sub-directory. 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

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 architecture, 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_4.0.0.xxx, where b is an acronym for beta

   or

   p_4.0.0.xxx, where p is an acronym for production

   The <*package_num*> meta-symbol is a string such as 017. This string indicates the package number.

   The command:

   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:

   cd l_ict_<*major*>.<*minor*>.<*update*>.<*package_num*>

   For example, suppose the installation package is called l_ict_p_4.0.0.017.tar.gz. In the staging area that has been created, type the command:

   tar –xvzf l_ict_p_4.0.0.017.tar.gz

   This will create a sub-directory called l_ictce_p_4.0.0.017. Change to that directory with the shell command:

   cd l_ict_p_4.0.0.017

In that folder make sure that 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_<*version*>.<*release*> directory staging area, the expect shell script file called "sshconnectivity.exp" can be used to help you establish secure shell connectivity on a cluster system, where expect is a tool for automating interactive applications. To run "sshconnectivity.exp", the expect runtime software needs to be installed on your Linux system. To make sure that the expect runtime software is properly installed, type:

```
which expect
```

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

http://expect.nist.gov/

The syntax for the "sshconnectivity.exp" command is:

```
./sshconnectivity.exp machines.LINUX
```

This expect shell script will create or update a ~/.ssh directory on each node of the cluster beginning with the master node which must be the first name listed in the 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:

```
                                    ...
**********************************************************************
Node count = 4
Secure shell connectivity was established on all nodes.
                                    ...
**********************************************************************

                                    ...
```

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

```
/tmp/sshconnectivity.<login-name>.log
```

where <*login-name*> is a meta-symbol for your actual login.

Note that the expect shell script `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[1] (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.

[1] 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.

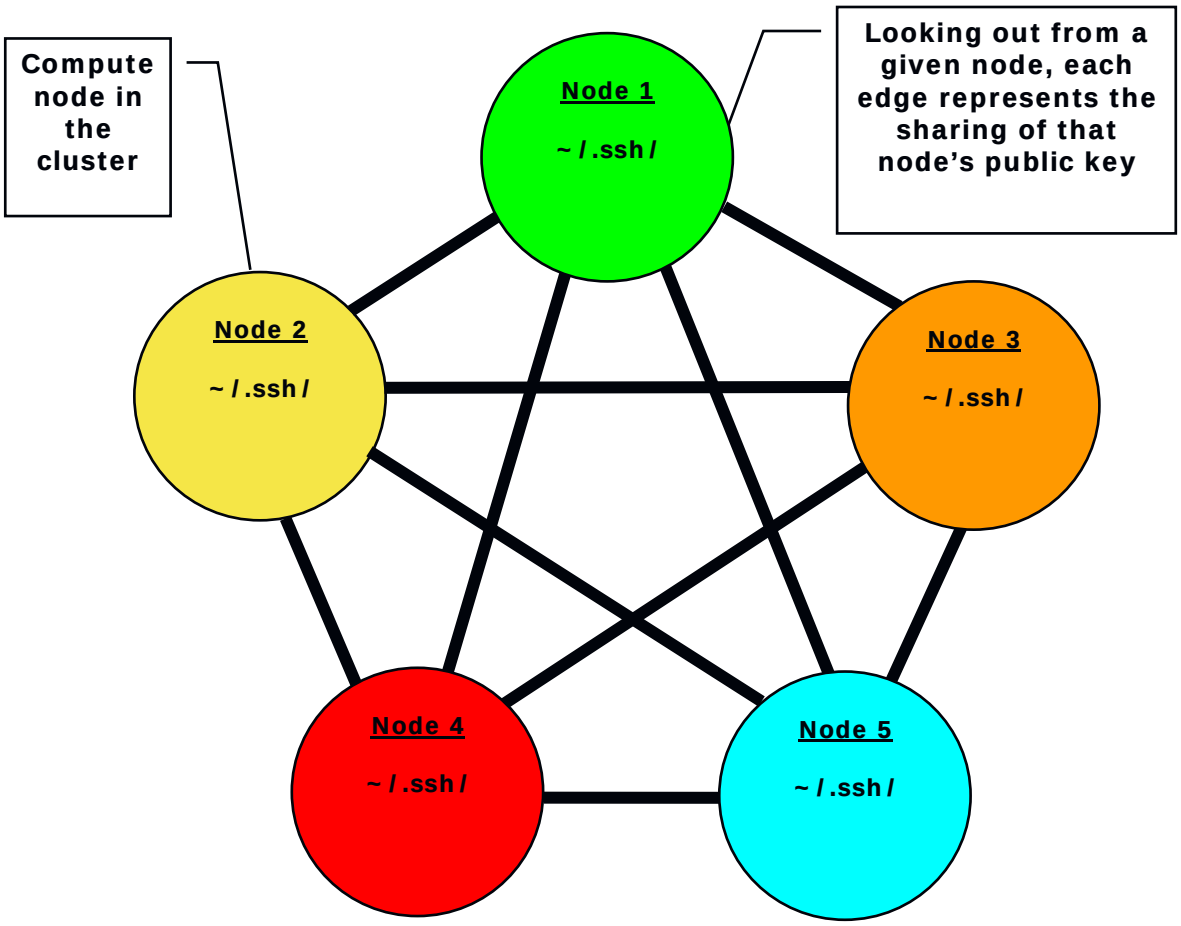


Figure 3.1 – Illustration of Secure Shell Connectivity for a Computing Cluster

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 ~/.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 ~/.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.

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` as illustrated in Figure 3.2.

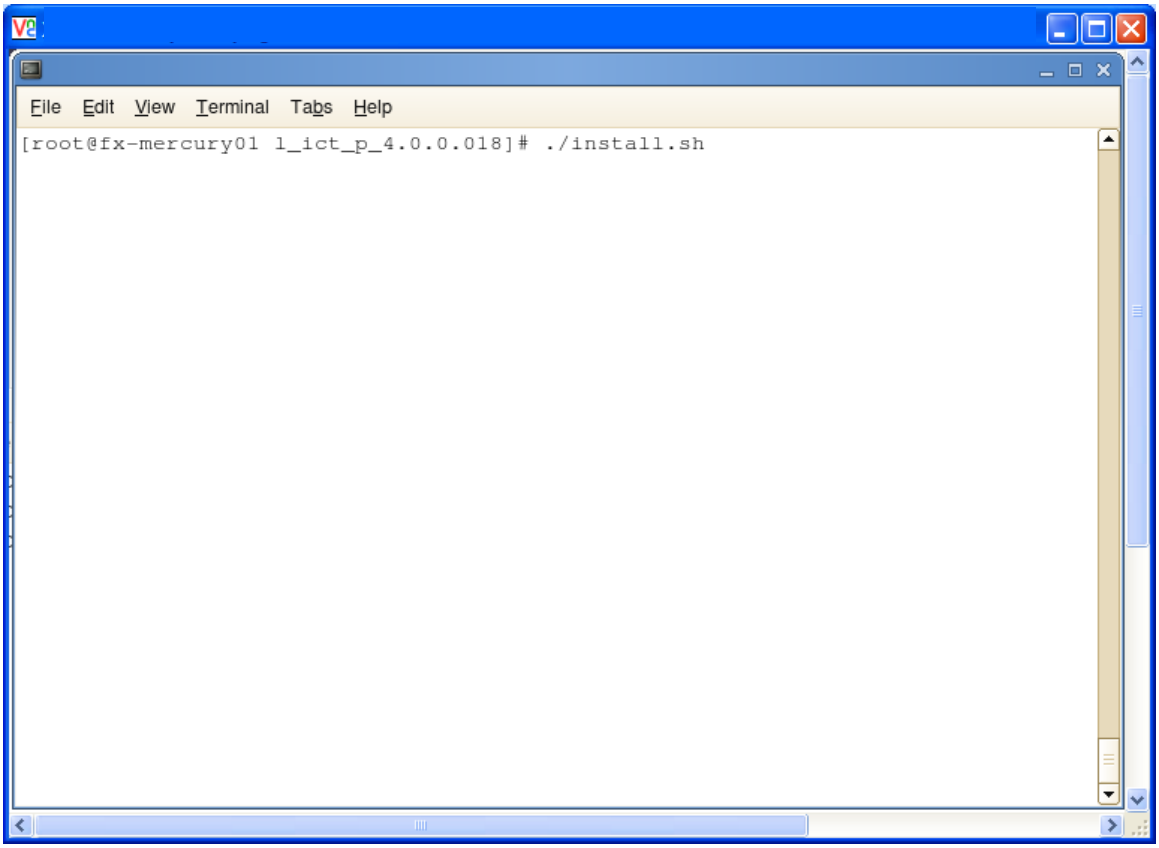


Figure 3.2 – Initiating the installation process with the command `install.sh`

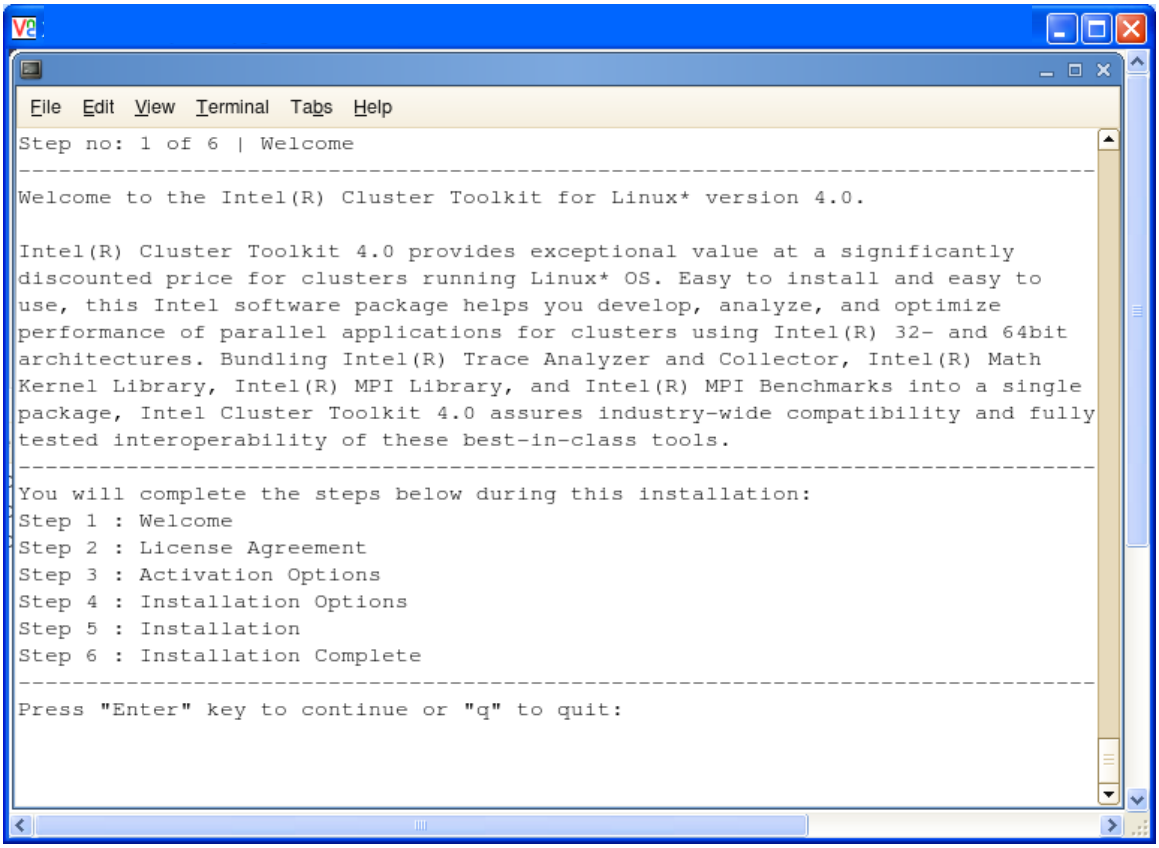


Figure 3.3 – The six steps in the installation process

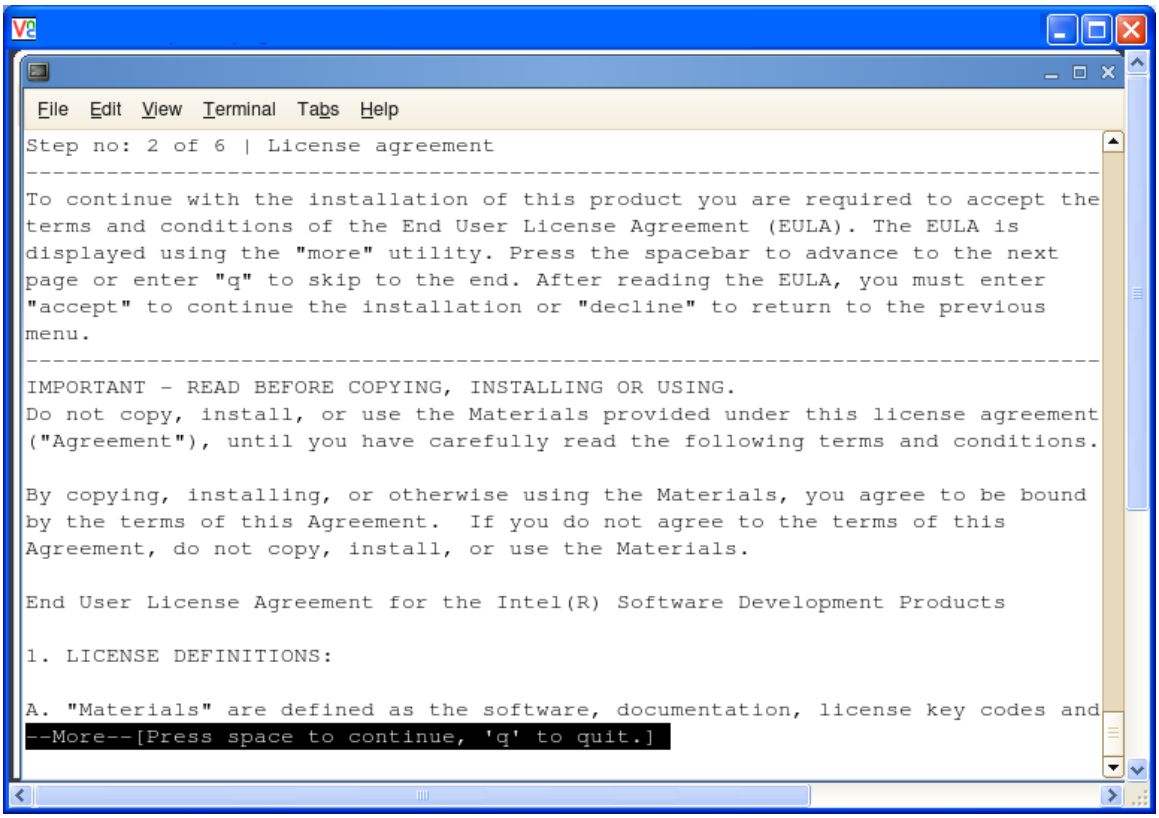


Figure 3.4 – License agreement

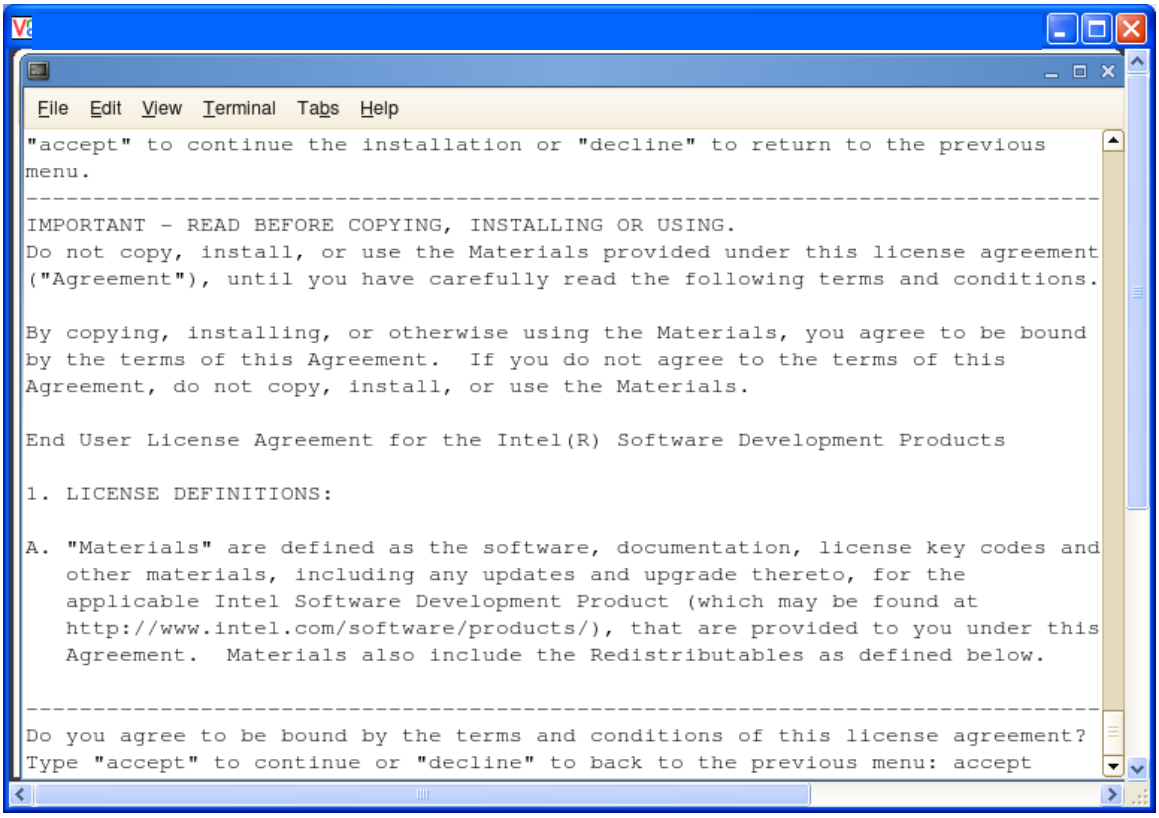


Figure 3.5 – Enter the accept word to acknowledge the terms of the license agreement

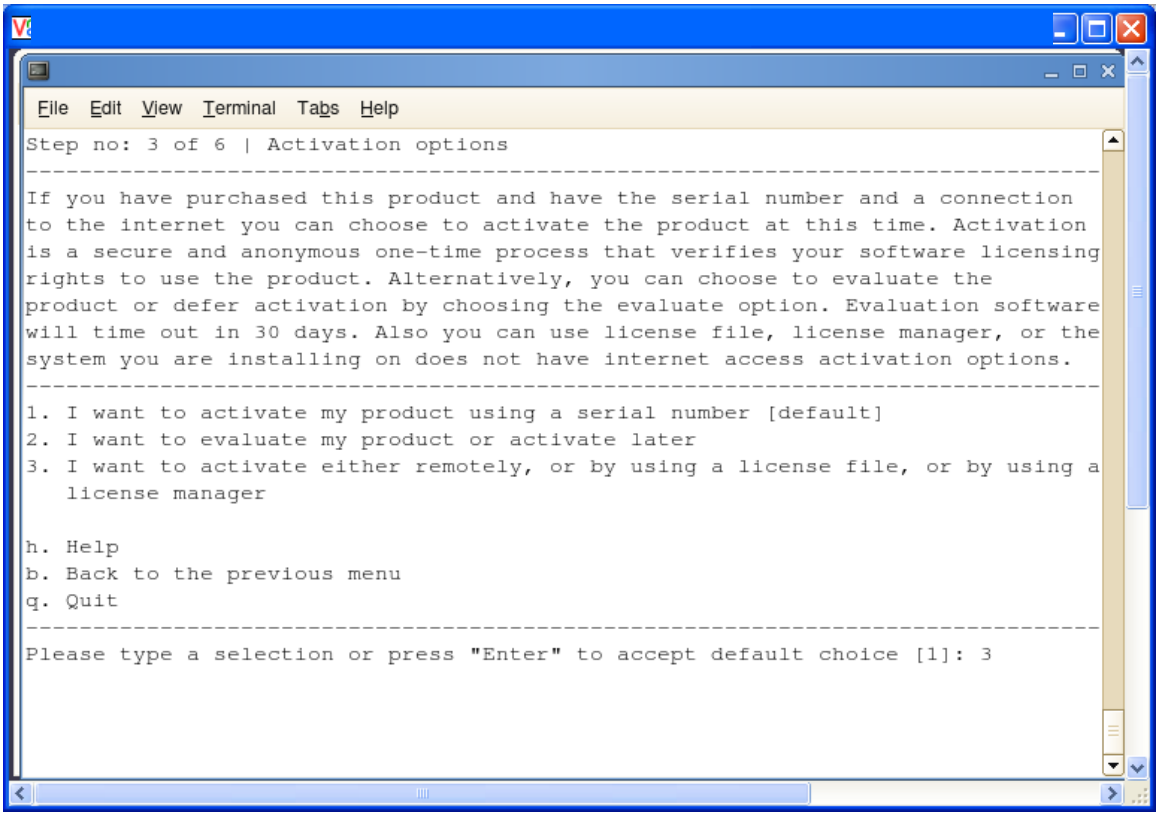


Figure 3.6 – Step 3 – Select option 3 where you want to provide a license file to complete the installation process

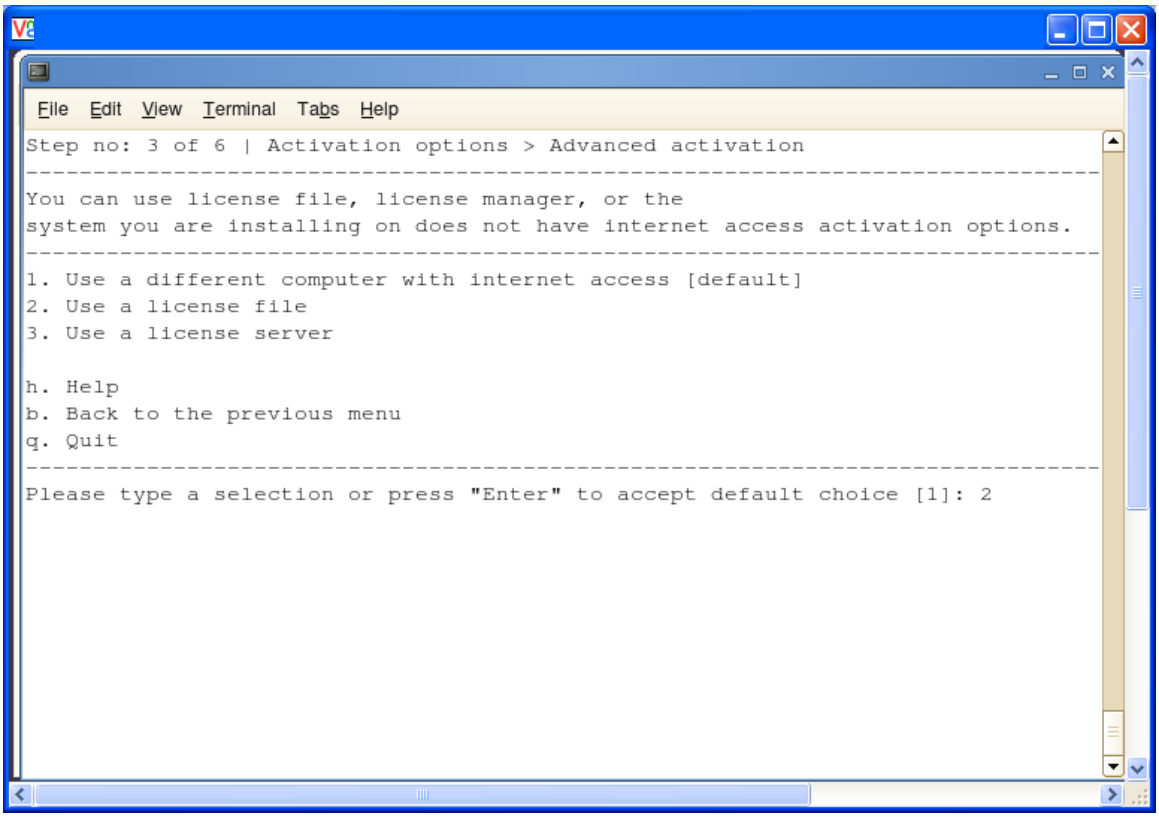


Figure 3.7 - Step 3 Continued – Selection option 2 to direct the installer to ask for a license file

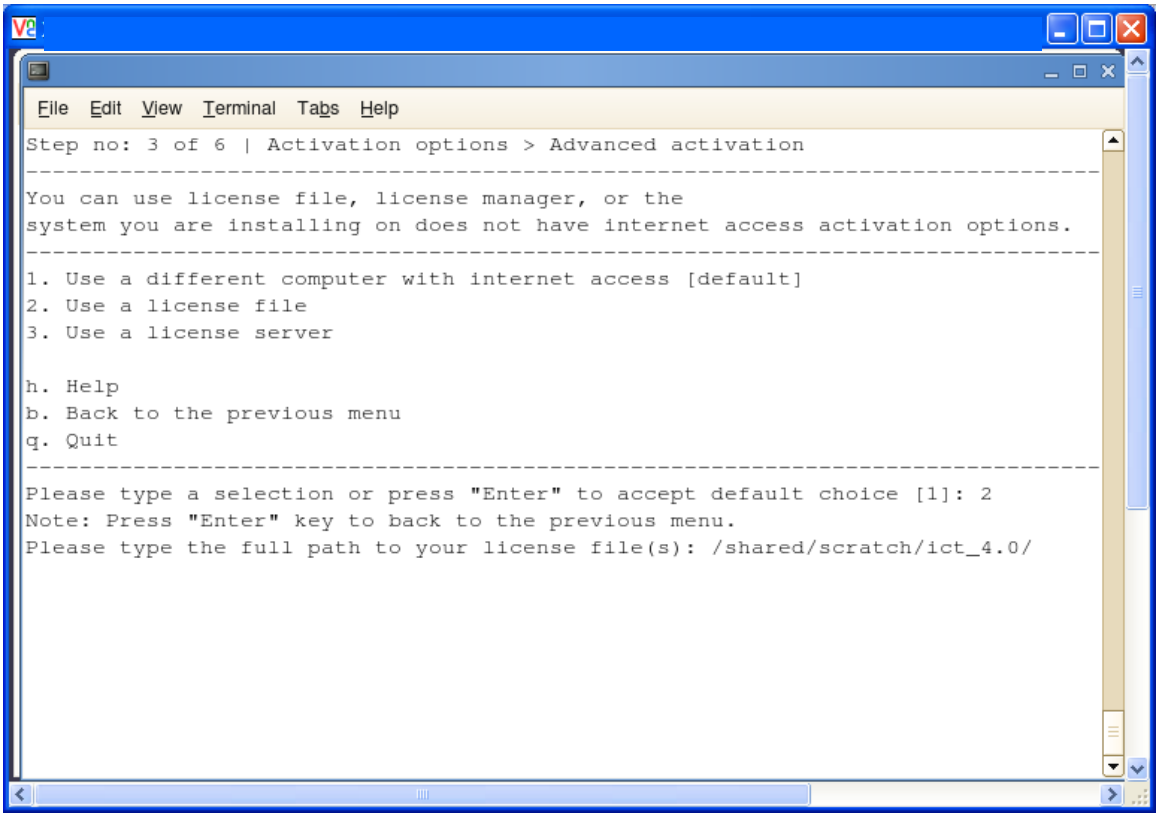


Figure 3.8 – Step 3 Continued – Provide a directory path to where the license file resides

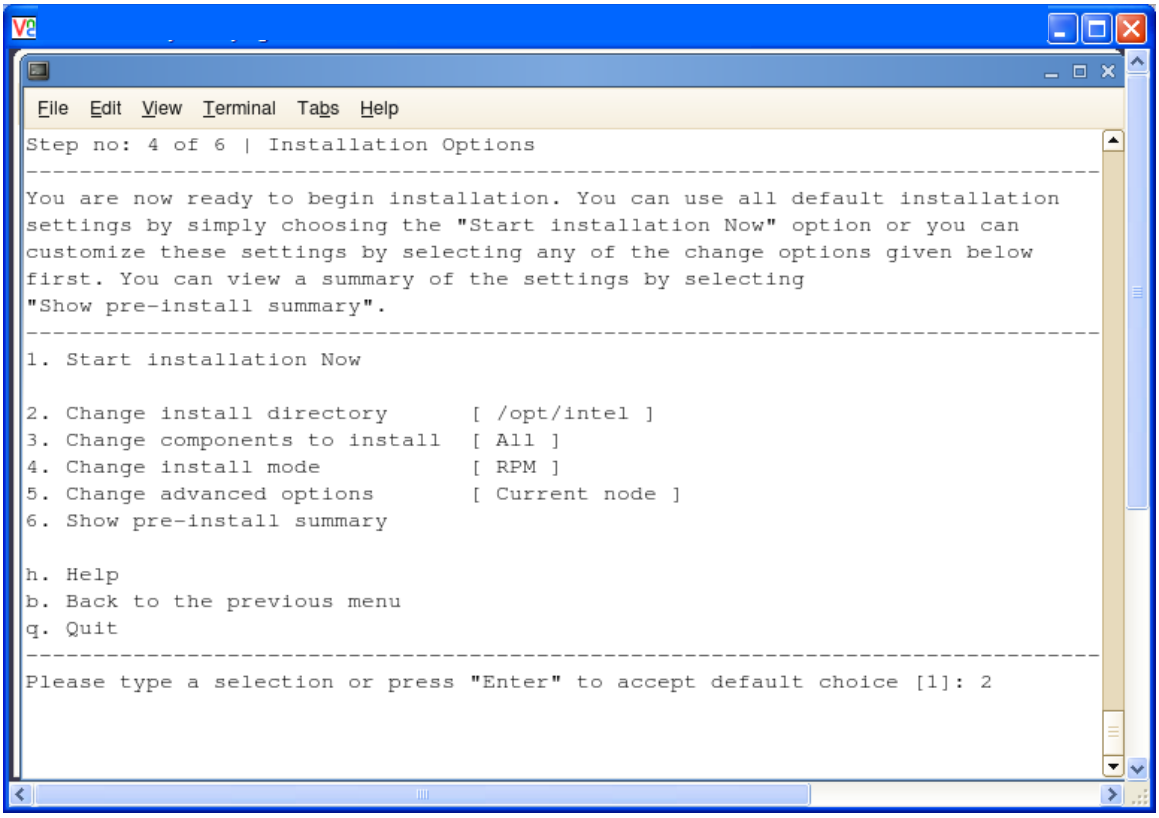


Figure 3.9 – Step 4 – Select option 2 in order to change the install directory from the default which is `/opt/intel`

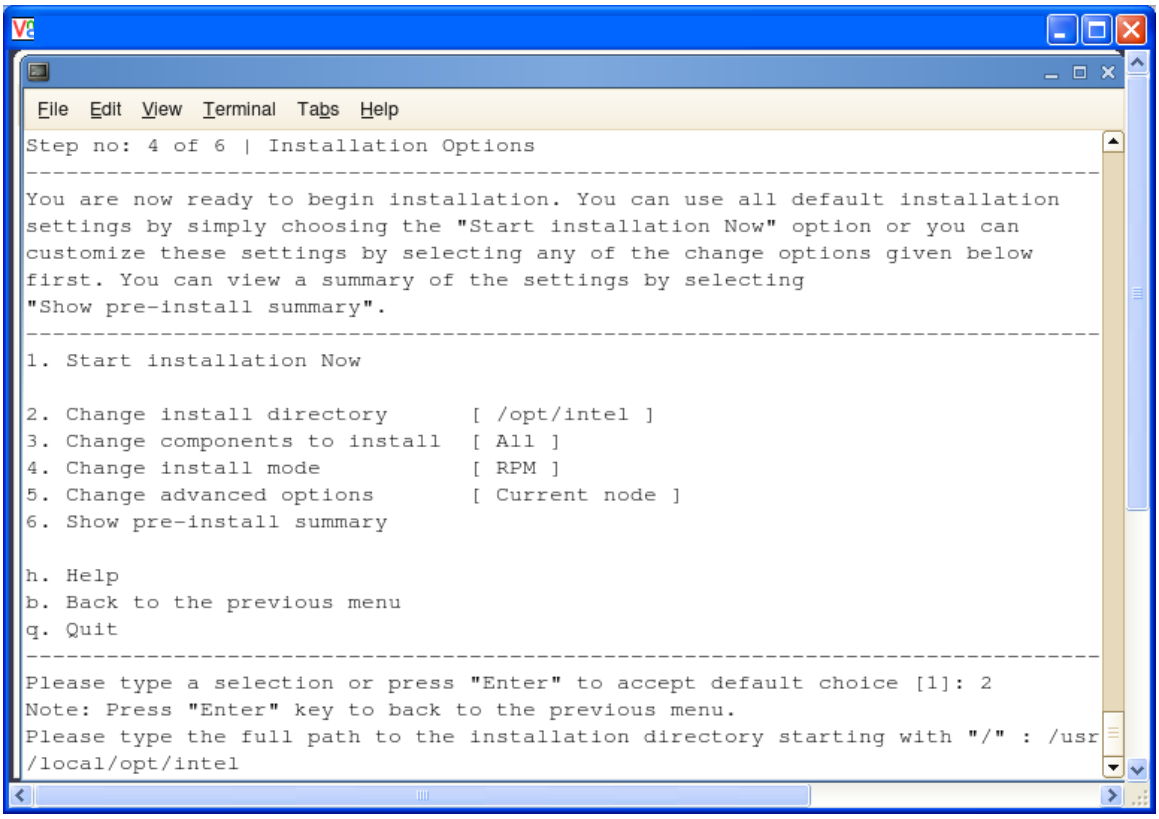


Figure 3.10 - Step 4 Continued – Provide the alternative directory path

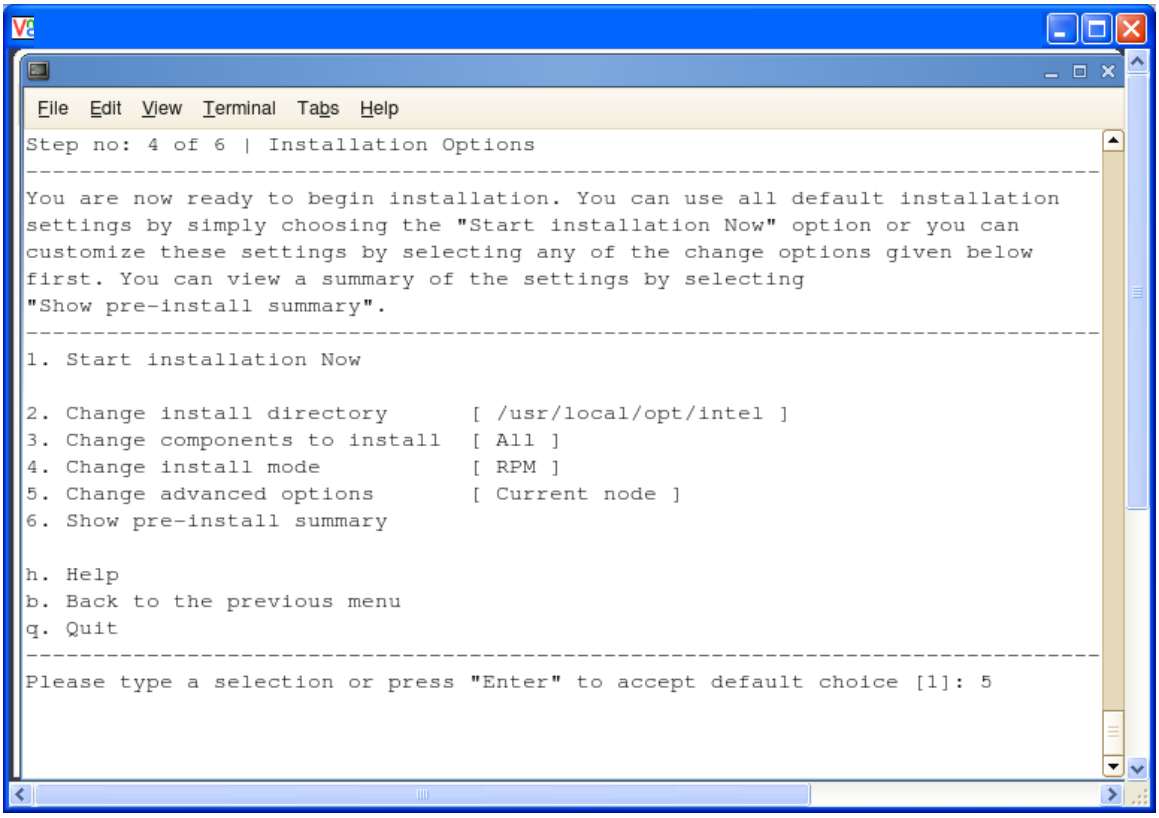


Figure 3.11 – Step 4 Continued – Select option 5 so as to do a distributed install as opposed to installing only on the current (I.e., the master) node

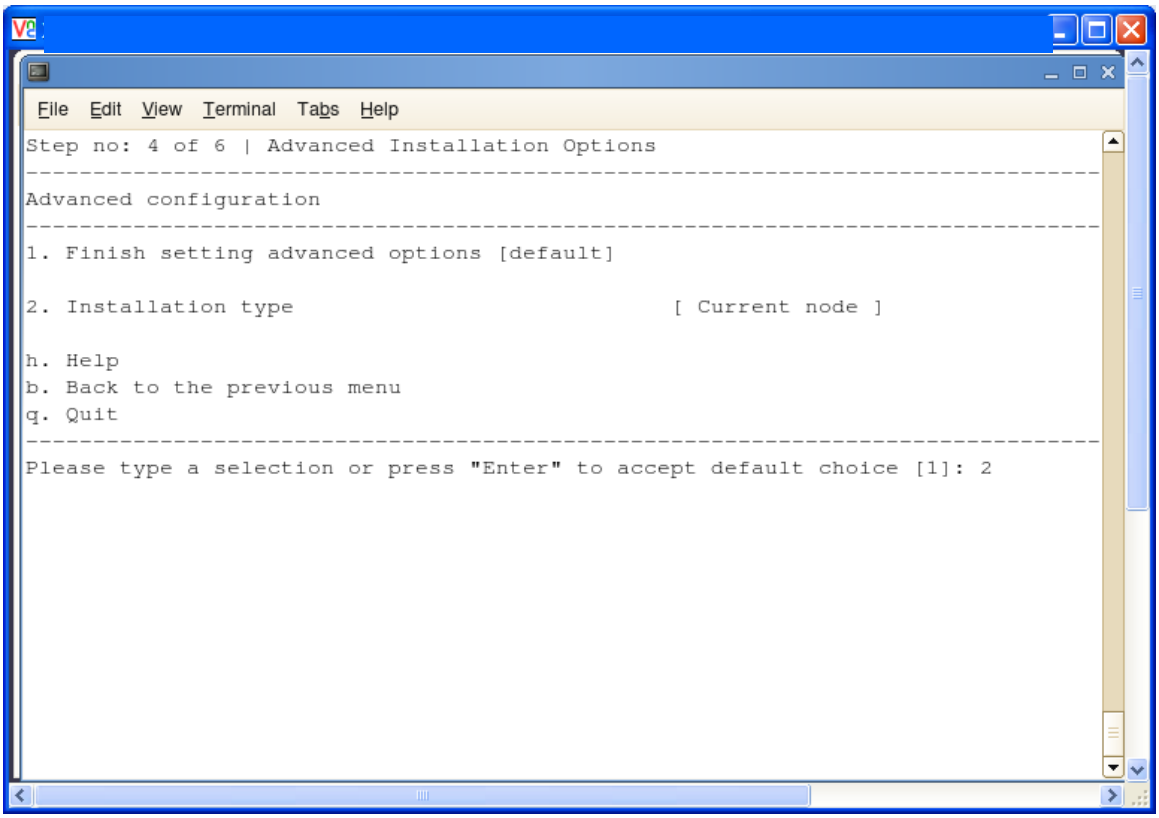


Figure 3.12 – Step 4 Continued – Select option 2 to continue the process of doing a distributed install

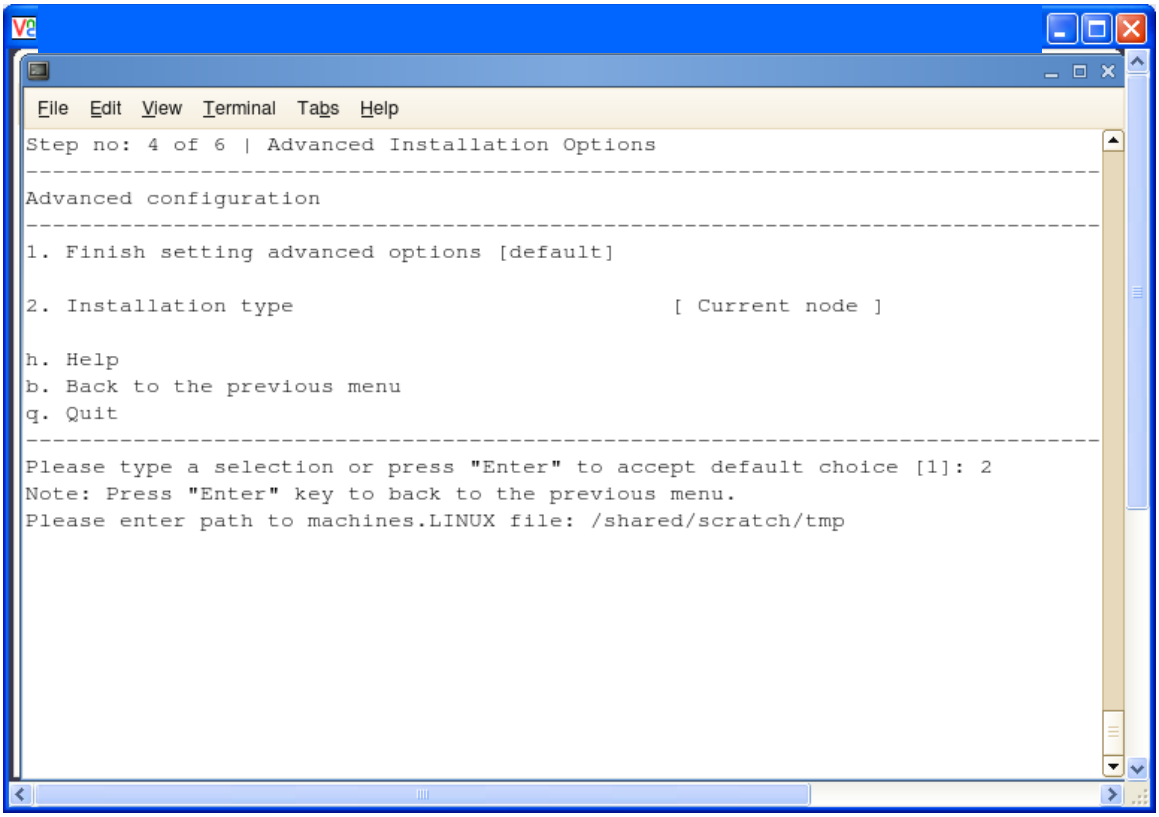


Figure 3.13 – Step 4 Continued – Provide a directory path to a file that contains a list of the nodes for the cluster

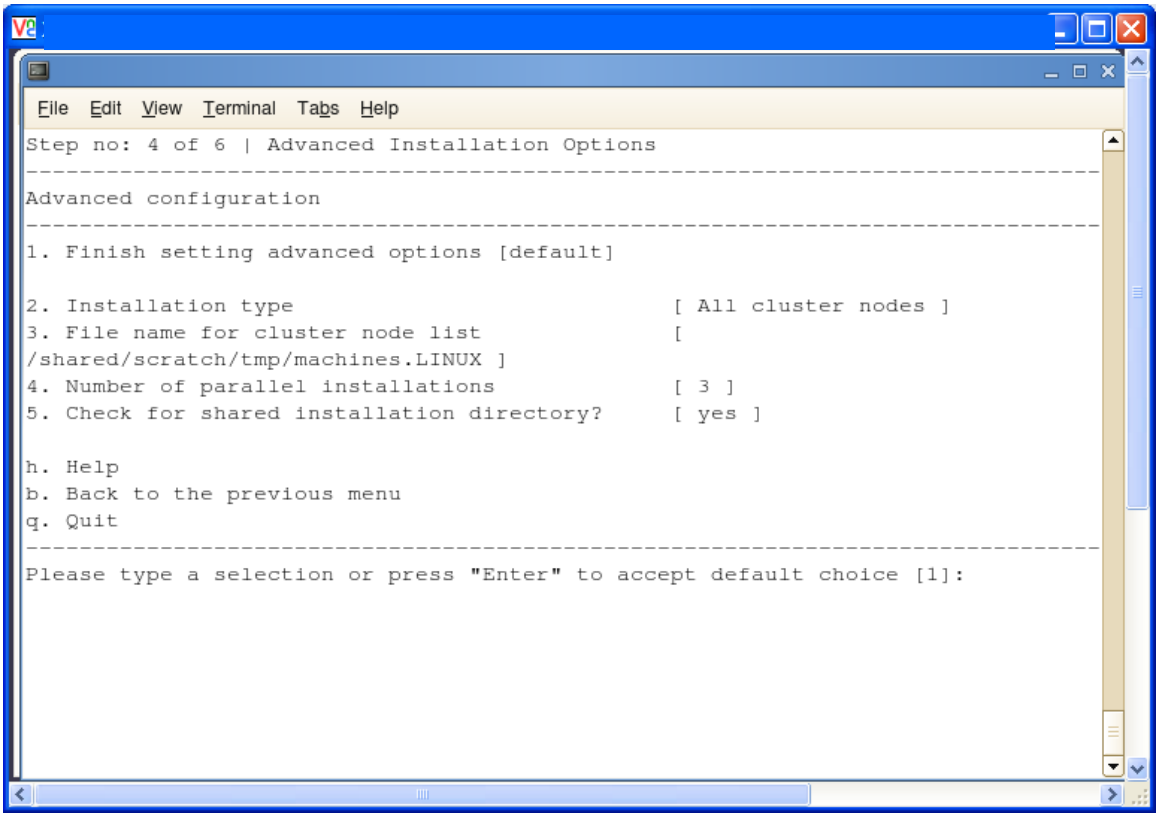


Figure 3.14 – Step 4 Continued – Select the default option of 1 as an indication that all advanced configuration options have been exercised

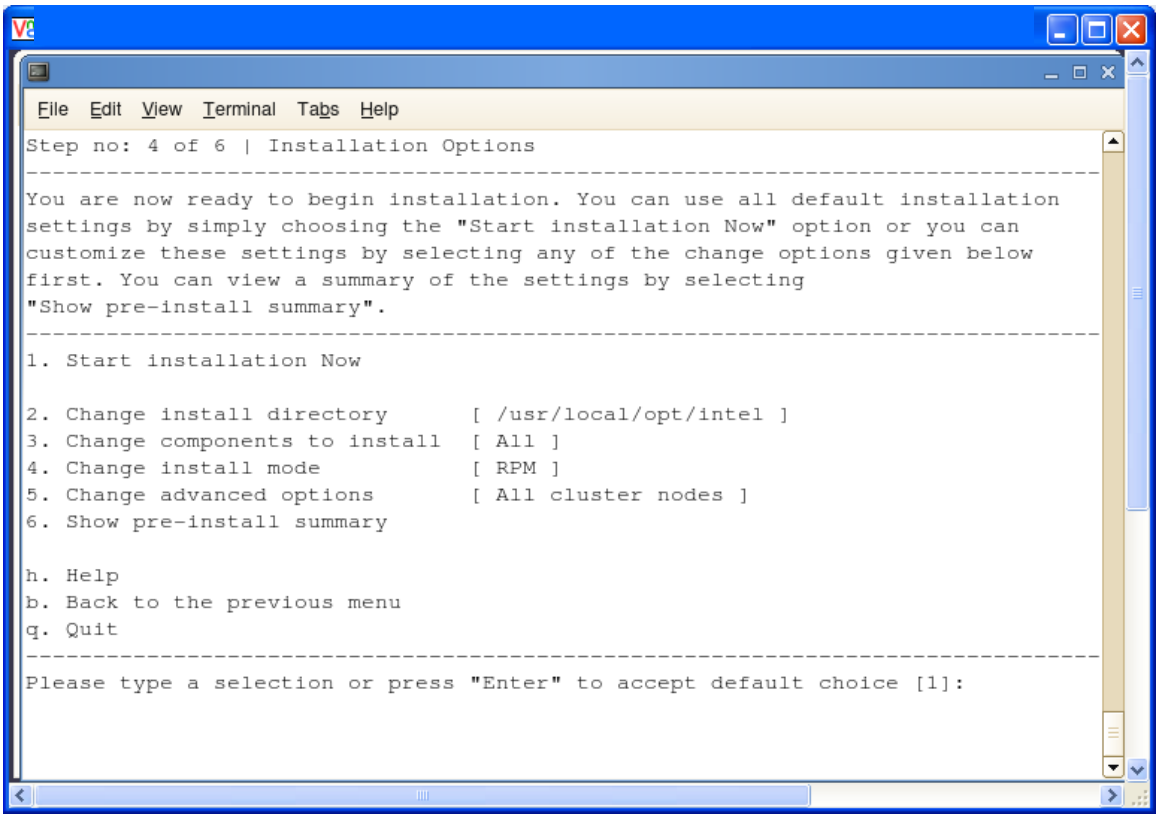


Figure 3.15 – Step 4 Continued – Select the default option of 1 as an indication that all installation options have been exercised

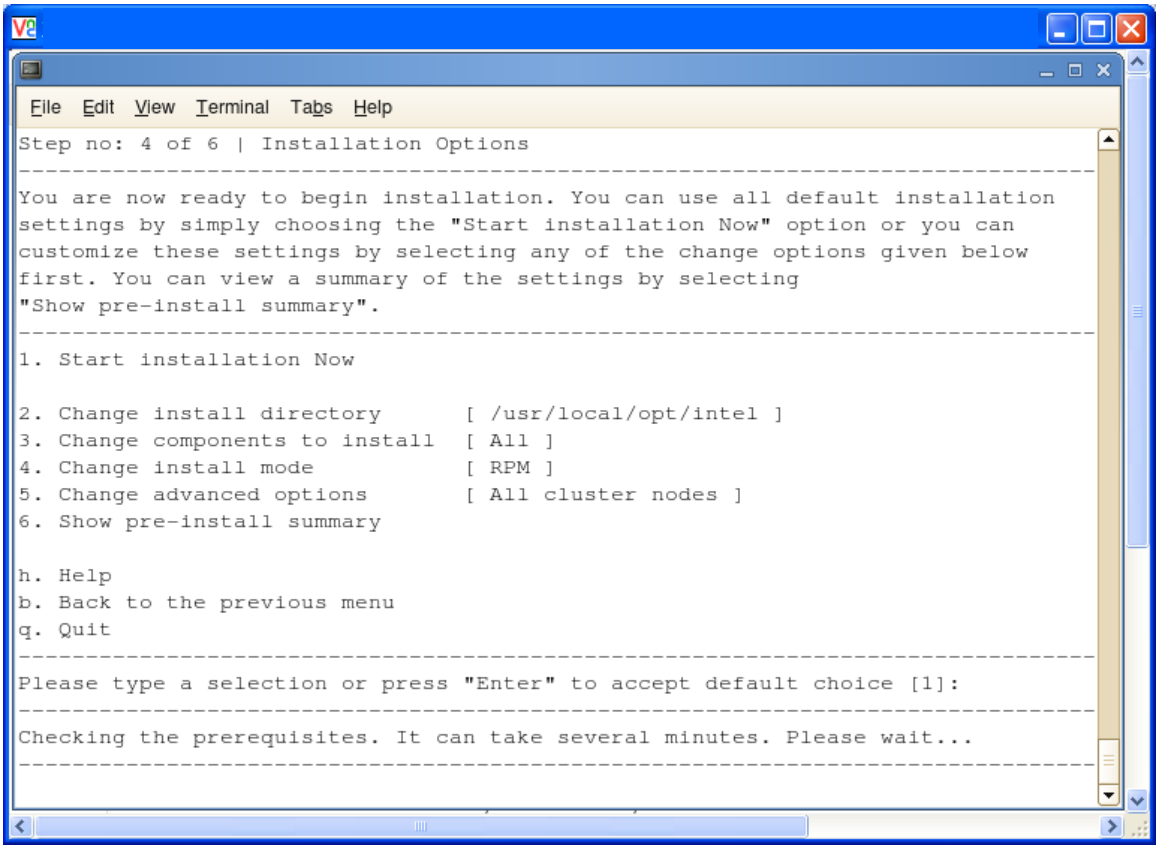


Figure 3.16 – Step 4 Continued – Let the install process proceed

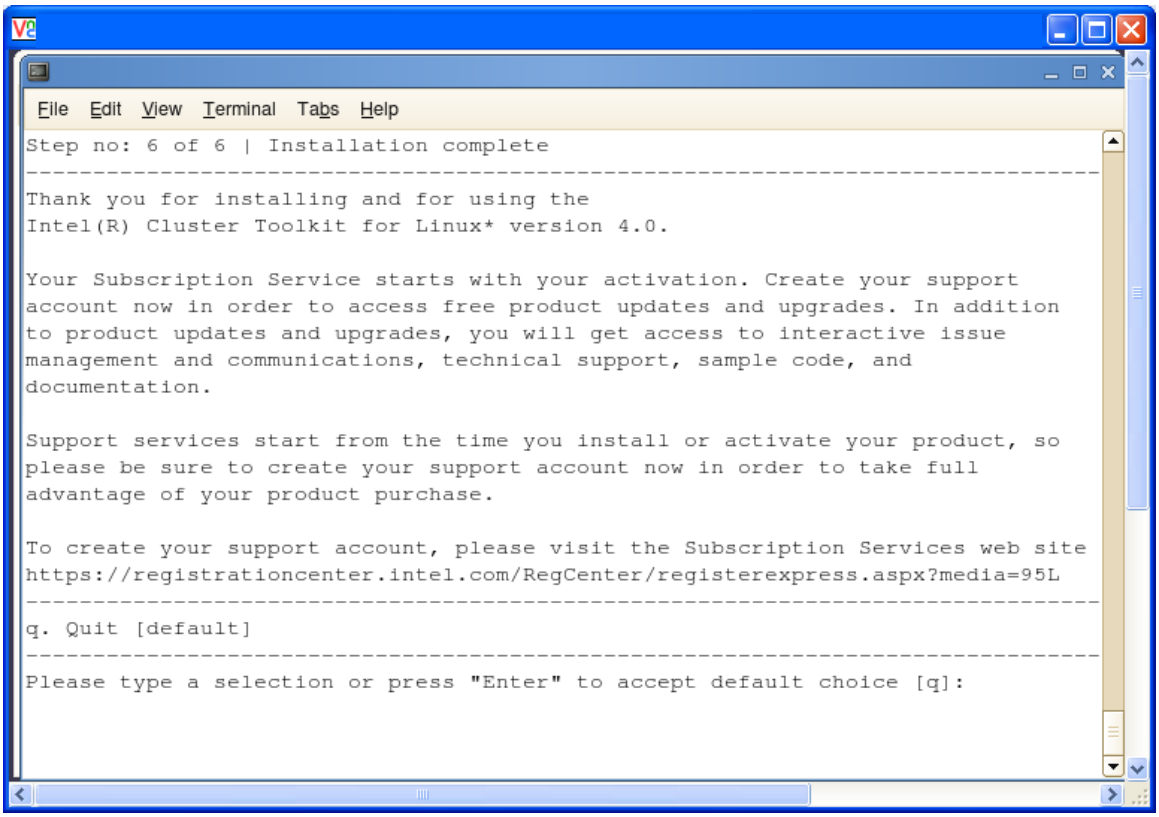


Figure 3.17 - Step 6 – The install process has completed and press the enter key to close the installer session

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 `4.0.0.017`.

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

`ictvars.csh`

`ictvars.sh`

and

`ictcesupport.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 `ictcesupport.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:

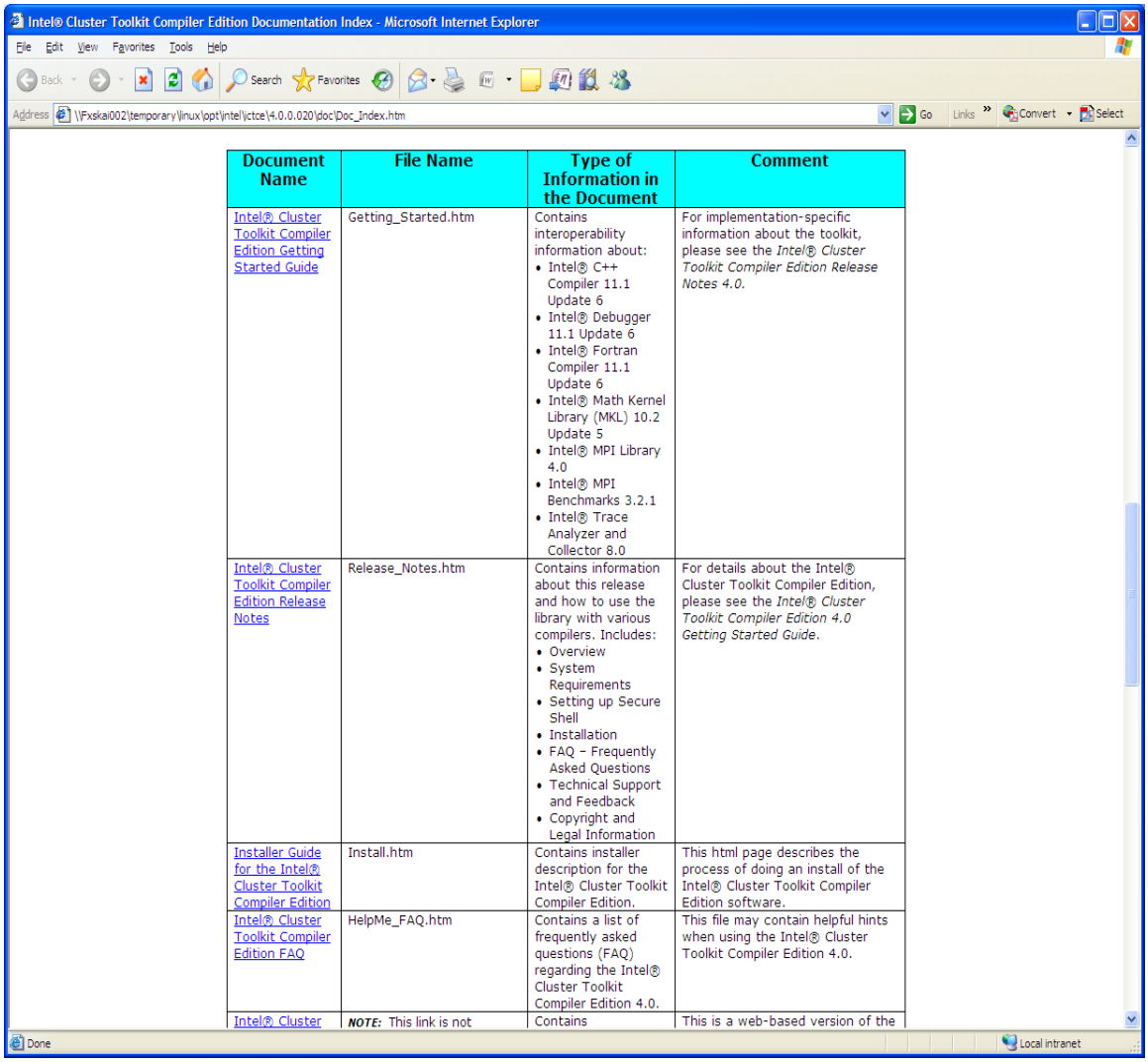
```
/opt/intel/ictce/4.0.0.017/doc
```

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 *Intel® Cluster Toolkit Compiler Edition 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 3.18):



Document Name	File Name	Type of Information in the Document	Comment
Intel® Cluster Toolkit Compiler Edition Getting Started Guide	Getting_Started.htm	Contains interoperability information about: • Intel® C++ Compiler 11.1 Update 6 • Intel® Debugger 11.1 Update 6 • Intel® Fortran Compiler 11.1 Update 6 • Intel® Math Kernel Library (MKL) 10.2 Update 5 • Intel® MPI Library 4.0 • Intel® MPI Benchmarks 3.2.1 • Intel® Trace Analyzer and Collector 8.0	For implementation-specific information about the toolkit, please see the *Intel® Cluster Toolkit Compiler Edition Release Notes 4.0.*
Intel® Cluster Toolkit Compiler Edition Release Notes	Release_Notes.htm	Contains information about this release and how to use the library with various compilers. Includes: • Overview • System Requirements • Setting up Secure Shell • Installation • FAQ - Frequently Asked Questions • Technical Support and Feedback • Copyright and Legal Information	For details about the Intel® Cluster Toolkit Compiler Edition, please see the *Intel® Cluster Toolkit Compiler Edition 4.0 Getting Started Guide*.
Installer Guide for the Intel® Cluster Toolkit Compiler Edition	Install.htm	Contains installer description for the Intel® Cluster Toolkit Compiler Edition.	This html page describes the process of doing an install of the Intel® Cluster Toolkit Compiler Edition software.
Intel® Cluster Toolkit Compiler Edition FAQ	HelpMe_FAQ.htm	Contains a list of frequently asked questions (FAQ) regarding the Intel® Cluster Toolkit Compiler Edition 4.0.	This file may contain helpful hints when using the Intel® Cluster Toolkit Compiler Edition 4.0.
Intel® Cluster	***NOTE:*** This link is not	Contains	This is a web-based version of the

Figure 3.18 – 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

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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, or Intel® 64 architecture. This is done at runtime by setting the I_MPI_FABRICS 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.

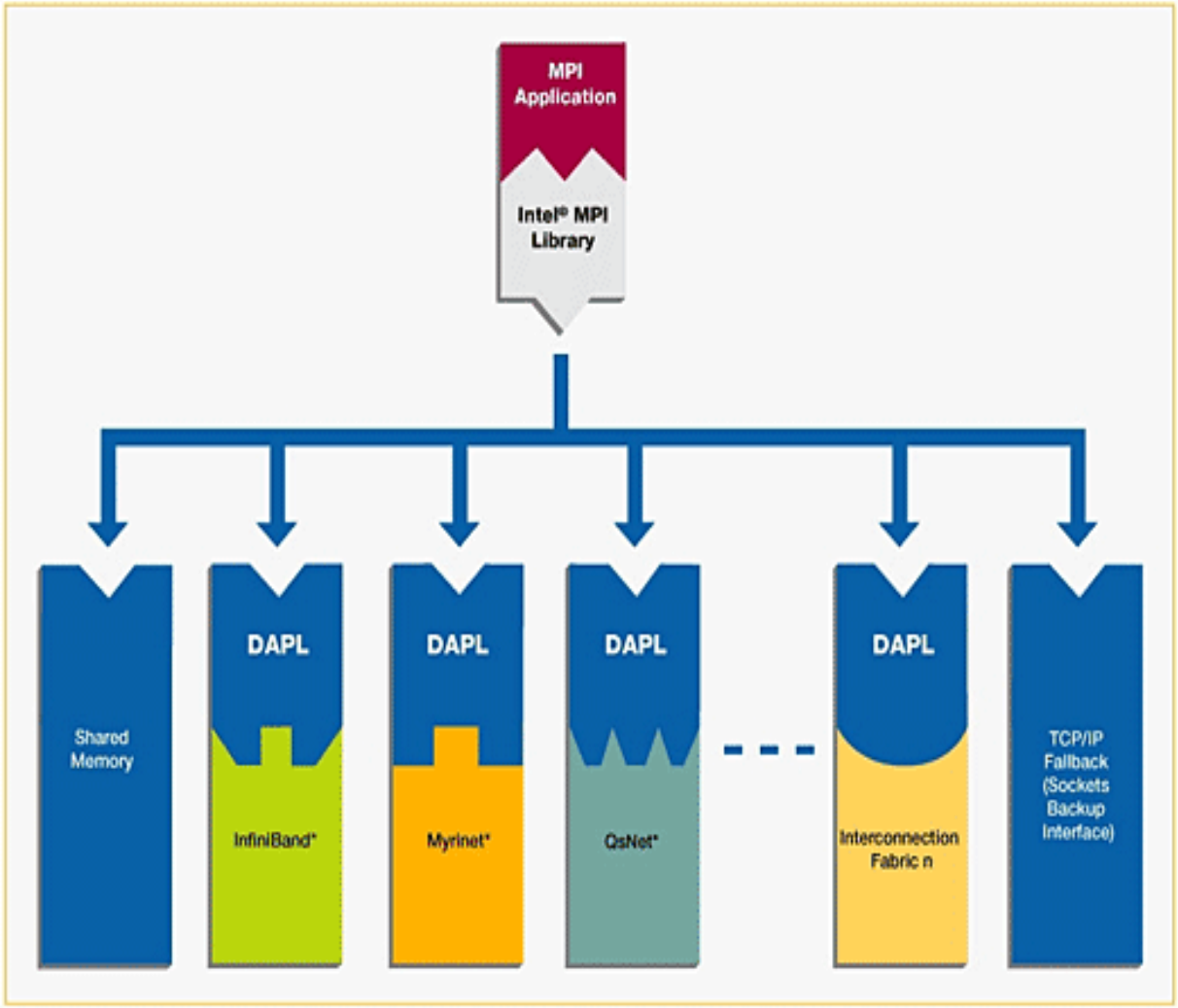

Figure 4.1 – Software architecture of the Intel® MPI Library Interface to Multiple Fast Interconnection Fabrics via shared memory, DAPL (Direct Access Programming Library), and the TCP / IP fallback

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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.

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4.2 How to Set Up MPD Daemons on Linux* OS

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® C++ and/or Intel® Fortran 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.*

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4.3 The mpdboot Command for Linux* OS

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.

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

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 C++ and Fortran Compilers 11.1, execution of the appropriate set-up scripts will do this automatically (the build number for the compilers might be something different than “11.1/035” for your installation):

```
/opt/intel/Compiler/11.1/035/bin/iccvars.[c]sh
```

and

```
/opt/intel/Compiler/11.1/035/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`.

Supplier of Core Compiler	MPI Compilation Command	Core Compiler Compilation Command	Compiler Programming Language	Support Application Binary Interface (ABI)
GNU* Compilers	`mpicc`	`gcc, cc`	C	32/64 bit
	`mpicxx`	`g++ version 3.x` `g++ version 4.x`	C/C++	32/64 bit
	`mpif77`	`f77 or g77`	Fortran 77	32/64 bit
	`mpif90`	`gfortran`	Fortran 95	32/64 bit
Intel Compilers version 10.1, 11.0, or 11.1	`mpiicc`	`icc`	C	32/64 bit
	`mpiicpc`	`icpc`	C++	32/64 bit
	`mpiifort`	`ifort`	Fortran 77 and Fortran 95	32/64 bit

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*.

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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. Prior to the introduction of Intel® MPI Library 4.0, selection of alternative devices was done via the command line using the `I_MPI_DEVICE` environment variable. With Intel® MPI Library 4.0 and its successors, the `I_MPI_FABRICS` environment variable is to be used, and the environment variable `I_MPI_DEVICE` is

considered a deprecated syntax. The following network fabric types for I_MPI_FABRICS are supported by Intel MPI Library 4.0 and its successors:

Possible Interconnection-Device-Fabric Values for the I_MPI_FABRICS Environment Variable	Interconnection Device Fabric Meaning
shm	Shared-memory
dapl	DAPL–capable network fabrics, such as InfiniBand*, iWarp*, Dolphin*, and XPMEM* (through DAPL*)
tcp	TCP/IP-capable network fabrics, such as Ethernet and InfiniBand* (through IPoIB*)
tmi	Network fabrics with tag matching capabilities through the Tag Matching Interface (TMI), such as Qlogic* and Myrinet*
ofa	Network fabric, such as InfiniBand* (through OpenFabrics* Enterprise Distribution (OFED*) verbs) provided by the Open Fabrics Alliance* (OFA*)

The environment variable I_MPI_FABRICS has the following syntax:

I_MPI_FABRICS=<*fabric*> | <*intra-node fabric*>:<*internodes-fabric*>

where the <*fabric*> value meta-symbol can have the values shm, dapl, tcp, tmi, or ofe. The <*intra-node fabric*> value meta-symbol can have the values shm, dapl, tcp, tmi, or ofe. Finally, the <*inter-node fabric*> value meta-symbol can have the values dapl, tcp, tmi, or ofe.

The next section will provide some examples for using the I_MPI_FABRICS environment variable within the mpiexec command-line.

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

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, use the –env option to specify a value to be assigned to the I_MPI_FABRICS variable. For example, to run an MPI program while using the shared memory for intra-node communication and sockets for inter-node communication, use the following command:

```
mpiexec -n <# of processes> -env I_MPI_FABRICS shm:tcp .\myprog.exe
```

As an example of running an MPI application on a cluster system with a combined shared-memory and DAPL-enabled network fabric, the following mpiexec command-line might be used:

```
mpiexec -n <# of processes> -env I_MPI_FABRICS shm:dapl .\myprog.exe
```

See the section titled *Selecting a Network Fabric* in <*directory-path-to-Intel-MPI-Library*>\doc\Getting_Started.pdf, or the section titled *Fabrics Control* in <*directory-path-to-Intel-MPI-Library*>\doc\Reference_Manual.pdf.

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4.7 Experimenting with Intel® MPI Library on Linux* OS

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:

```
mpdboot -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 2 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 a dapl 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_MPI_FABRICS dapl -n 2 ./testf
mpiexec -env I_MPI_FABRICS dapl -n 2 ./testf90
mpiexec –env I_MPI_FABRICS dapl -n 2 ./testc
mpiexec -env I_MPI_FABRICS dapl -n 2 ./testcpp
```

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

```
Hello world: rank            0  of            2  running on
 clusternode1

Hello world: rank            1  of            2  running on
 clusternode2
```

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4.8 Controlling MPI Process Placement on Linux* OS

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 : \
                -n j -host <nodename-3> ./mpi_example : \
                        ...
                -n j -host <nodename-i> ./mpi_example
```

Note that you would have to fill in appropriate host names for <*nodename-1*> 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.

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4.9 Using the Automatic Tuning Utility Called *mpitune*

The mpitune utility was first introduced with 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, testcpp, testf, and testf90 in the directory test_intel_mpi could be used. The command invocation for mpitune might look something like the following:

```
mpitune –-host-file machines.LINUX –-output-file testc.conf --
            application \"mpiexec –n 4 testc\"
```

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

Command-line Option	Semantic Meaning
-a \"<*app_cmd_line*>\" | --application \"<*app_cmd_line*>\"	Switch on the application tuning mode. Quote the full command line as shown
-cm | --cluster-mode {exclusive | full}	Set the cluster usage mode exclusive – only one task will executed on the cluster at a time full – maximum number of tasks will be execute. This is the default mode
-d | --debug	Print debug information
-dl *[d1[,d2…[,dN]]]* | --device-list *[d1[,d2…[,dN]]]*	Select the device(s) you want to tune. By default use all of the devices mentioned in the <*installdir*>/<*arch*>/etc/devices.xml file
-er | --existing-ring	Try to use an existing MPD ring. By default, create a new MPD ring
-fl *[f1[,f2…[,fN]]]* | --fabric-list *[f1[,f2…[,fN]]]*	Select the fabric(s) you want to tune. By default use all of the fabrics mentioned in the <*installdir*>/<*arch*>/etc/fabrics.xml file
-h | --help	Display a help message

-hf <*hostsfile*> | --host-file <*hostsfile*>	Specify an alternative host file name. By default, use the $PWD/mpd.hosts
-hr | --host-range *{min*:*max* | *min*: | :*max}*	Set the range of hosts used for testing. The default minimum value is 1. The default maximum value is the number of hosts defined by the mpd.hosts or the existing MPD ring. The *min*: or :*max* format will use the default values as appropriate
-i <*count*> | --iterations <*count*>	Define how many times to run each tuning step. Higher iteration counts increase the tuning time, but may also increase the accuracy of the results. The default value is 3
-mh | --master-host	Dedicate a single host to mpitune
--message-range *{min*:*max* | *min*: | :*max}*	Set the message size range. The default minimum value is 0. The default maximum value is 4194304 (4mb). By default, the values are given in bytes. They can also be given in the following format: 16kb, 8mb, or 2gb. The *min:* or *:max* format will use the default values as appropriate
-of <*file-name*> | --output-file <*file-name*>	Specify the application configuration file to be generated in the application-specific mode. By default, use the $PWD/app.conf
-od <*outputdir*> | --output-directory <*outputdir*>	Specify the directory name for all output files. By default, use the current directory. The directory should be accessible from all hosts
-pr *{min*:*max* | *min*: | :*max}* | --ppn-range *{min*:*max* | *min*: | :*max}* | --perhost-range *{min*:*max* | *min*: | :*max}*	Set the maximum number of processes per host. The default minimum value is 1. The default maximum value is the number of cores of the processor. The min: or *:max* format will use the default values as appropriate
-sf *[file-path]* | --session-file *[file-path]*	Continue the tuning process starting from the state saved in the *file-path* session file
-s | --silent	Suppress all diagnostic output
-td <*dir-path*> | --temp-directory <*dir-path*>	Specify a directory name for the temporary data. By default, use the $PWD/mpitunertemp. This directory should be accessible from all hosts
-t \"<*test_cmd_line*>\" | --test \"<*test_cmd_line*>\"	Replace the default Intel® MPI Benchmarks by the indicated benchmarking program in the cluster-

	specific mode. Quote the full command line as shown
-tl *<minutes>* | --time-limit *<minutes>*	Set mpitune execution time limit in minutes. The default value is 0, which means no limitations
-V | --version	Print out the version information

Details on optimizing the settings for Intel® MPI Library with regards to the cluster configuration or a user's application for that cluster are described in the next two subsections.

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4.9.1 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 –hf machines.LINUX –of testc.conf –-test \"testc\"
```

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 app.conf. You can then proceed to run the mpiexec 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
```

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4.9.2 MPI Application-Specific Tuning

The mpitune invocation:

```
mpitune –hf machines.Linux –of testf90.conf --application \"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 testf90.conf –n 4 testf90
```

where the mpiexec command will load the configuration options recorded in testf90.conf.

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

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4.10 Extended File I/O System Support on Linux* OS

Intel® MPI Library provides loadable shared library modules to provide native support for the following file I/O systems:

- Panasas* ActiveScale* File System (PanFS)
- Parallel Virtual File System*, Version 2 (Pvfs2)

Set the `I_MPI_EXTRA_FILESYSTEM` environment variable to `on` to enable parallel file system support. Set the `I_MPI_EXTRA_FILESYSTEM_LIST` environment variable to request native support for the specific file system. For example, to request native support for the Panasas* ActiveScale* File System, do the following:

```
mpiexec –env I_MPI_EXTRA_FILESYSTEM on –env I_MPI_EXTRA_FILESYSTEM_LIST
panfs –n 4 ./myprog
```

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4.10.1 How to Use the Environment Variables I_MPI_EXTRA_FILESYSTEM and I_MPI_EXTRA_FILESYSTEM_LIST

The environment variable `I_MPI_EXTRA_FILESYSTEM` is used to enable parallel I/O file system support. The general syntax for this environment variable is:

`I_MPI_EXTRA_FILESYSTEM=<value>`

where `<value>` can be:

Value	Meaning
`enable` or `yes` or `on` or `1`	Turn on native support for a parallel file I/O system
`disable` or `no` or `off` or `0`	Turn off native support for a parallel file I/O system. This is the default setting.

In conjunction with the `I_MPI_EXTRA_FILESYSTEM` environment variable, the environment variable `I_MPI_EXTRA_FILESYSTEM_LIST` will control which file I/O

system or systems are used. In general, the syntax for the I_MPI_EXTRA_FILESYSTEM_LIST environment variable is:

I_MPI_EXTRA_FILESYSTEM_LIST=<*file-system*$_1$>[,<*file-system*$_2$>,<*file-system*$_3$>, … , <*file-system*$_n$>]

where <*file-system*$_i$> can be:

File I/O System <*file-system*$_i$>	**Meaning**
panfs	Panasas* ActiveScale* File system
Pvfs2	Parallel Virtual File System, Version 2

The mpiexec and mpirun commands associated with Intel® MPI Library will load the shared I/O libraries associated with the I_MPI_EXTRA_FILESYSTEM_LIST environment variable. As mentioned previously, the environment variables I_MPI_EXTRA_FILESYSTEM and I_MPI_EXTRA_FILESYSTEM_LIST must be used together.

For a complete discussion on how to use the environment variables I_MPI_EXTRA_FILESYSTEM and I_MPI_EXTRA_FILESYSTEM_LIST, see the *Extended File System Support* section of the *Intel MPI Library for Linux* OS 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.

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

As mentioned previously (for example, Figure 2.1), components of the Intel Cluster Toolkit Compiler Edition will now work with the Intel Debugger. The Intel Debugger is a parallel debugger with the following software architecture (Figure 5.1):

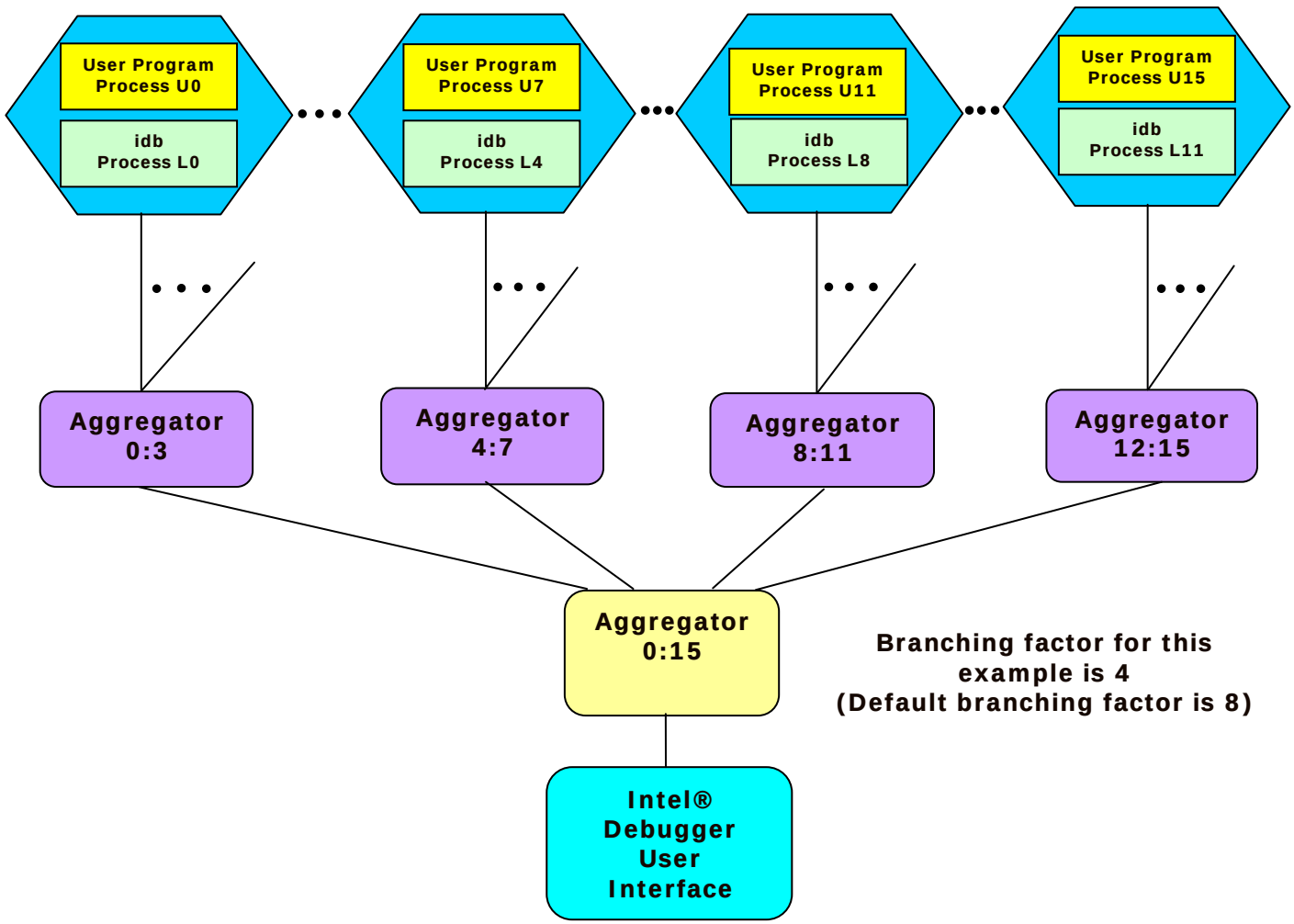

Figure 5.1 – The Software Architecture of the Intel Debugger

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] 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:

```
[0-41]>2 0x120006d6c in
feedback(myid=[0;41],np=42,name=0x11fffe018="mytest") "mytest.c":41
```

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5.1 Login Session Preparations for Using Intel® Debugger on Linux* OS

The debugger executable for the Intel Debugger is called `idb`. In the 11.1 version of the Intel® Debugger, the `idb` command invokes the GUI. Alternatively for the 11.1 version of Intel® Debugger, to get the command-line interface, use `idbc`. 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. Set the environment variable `IDB_HOME` to the folder path where the Intel Debugger executable, `idb`, resides. Also, you will want to source either `idbvars.sh` or `idbvars.csh` through `ifortvars.[c]sh` or `iccvars.[c]sh` depending on which command-line shell you are using. For example in augmenting your `.bashrc` file for the Bourne Shell or the Korn Shell, you can source the Intel® Compiler Pro C++ file called `iccvars.sh` or the Intel® Compiler Pro Fortran file `ifortvars.sh` which are located within the `bin`

directory of the Intel® Compiler Pro installation directory on your system. Regarding your .bashrc file, the Bourne Shell or the Korn Shell sourcing syntax might look something like the following for Intel® 64 architecture:

```
. /opt/intel/Compiler/11.1/060/bin/iccvars.sh intel64
export IDB_HOME=/opt/intel/Compiler/11.1/060/bin/intel64
```

or

```
. /opt/intel/Compiler/11.1/060/bin/ifortvars.sh intel64
export IDB_HOME=/opt/intel/Compiler/11.1/060/bin/intel64
```

For augmenting your .cshrc file, the C Shell syntax should be something like:

```
source /opt/intel/Compiler/11.1/060/bin/iccvars.csh intel64
setenv IDB_HOME /opt/intel/Compiler/11.1/060/bin/intel64
```

or

```
source /opt/intel/Compiler/11.1/060/bin/ifortvars.csh intel64
setenv IDB_HOME /opt/intel/Compiler/11.1/060/bin/intel64
```

Depending on the Intel® architecture, the argument to iccvars.[c]sh and ifortvars.[c]sh can be ia32, or intel64. Sourcing iccvars.[c]sh or ifortvars.[c]sh will update the PATH and MANPATH environment variables also.

3. 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
clusternode2
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:

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

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 –genv MPIEXEC_DEBUG 1 -n <*number of processes*> *[other Intel MPI options]* <*executable*> *[arguments to the executable]*

The environment variable MPIEXEC_DEBUG needs to be referenced so that MPI processes will suspend their execution to wait for the debuggers to attach to them. For the command-line example above, the –genv command-line option sets the environment variable MPIEXEC_DEBUG for *all* MPI processes. In general, the global environment variable command line switch –genv has the syntax:

–genv <*environment variable*> <*value*>

where <*environment variable*> is a meta-symbol that is a stand-in for a relevant environment variable, and <*value*> is a stand-in for setting an appropriate value for the preceding environment variable name.

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 –genv MPIEXEC_DEBUG 1 -n 4 ./testf
mpiexec –idb –genv MPIEXEC_DEBUG 1 -n 4 ./testf90
mpiexec –idb –genv MPIEXEC_DEBUG 1 -n 4 ./testc
mpiexec –idb –genv MPIEXEC_DEBUG 1 -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 –genv MPIEXEC_DEBUG 1 -n 4 ./testcpp
```

In Figure 5.2, the debugger stops the `testcpp` application at the C++ method `MPI::Init(argc, argv)`.

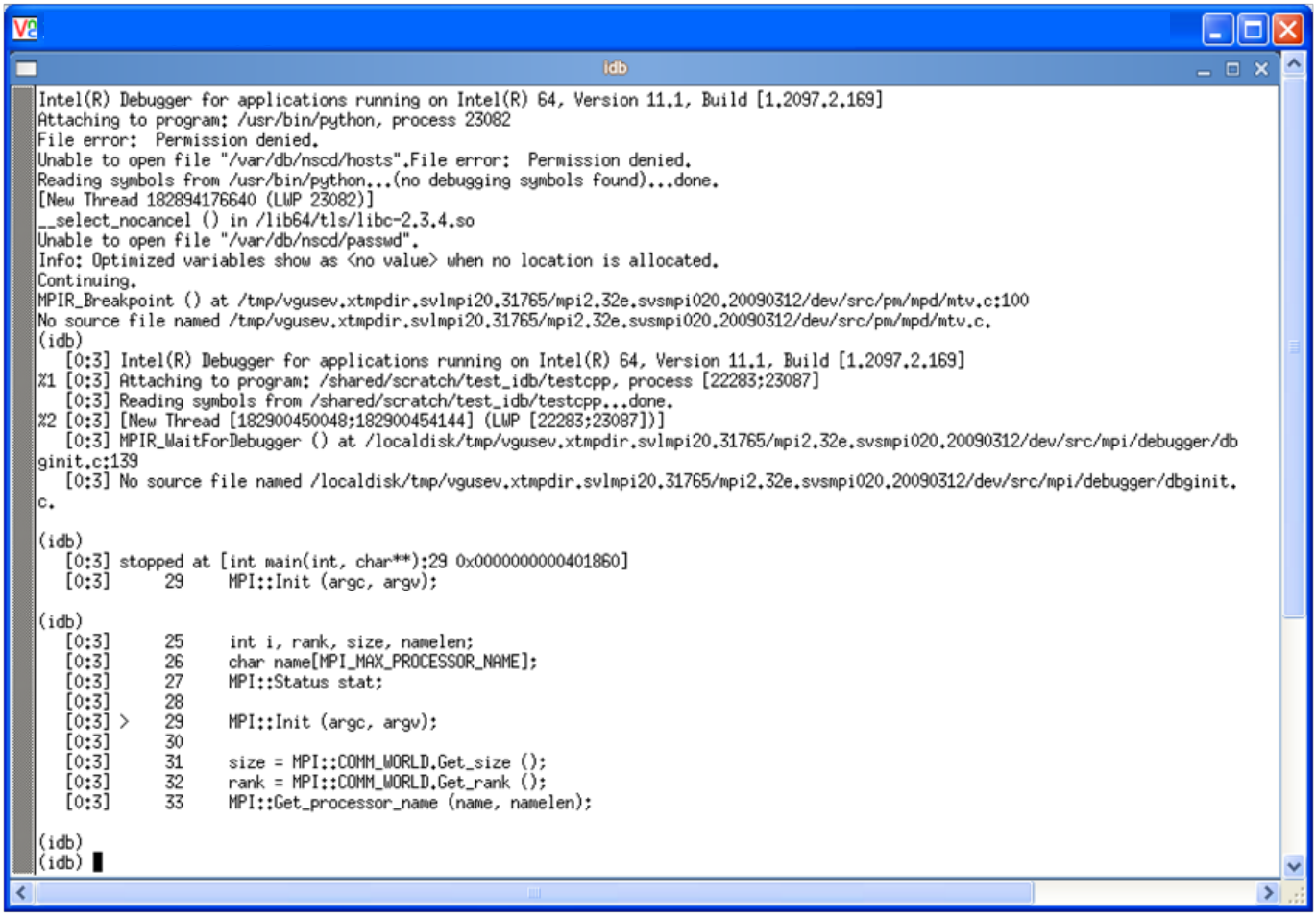

Figure 5.2 – `idb` session for the executable called `testc`

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.

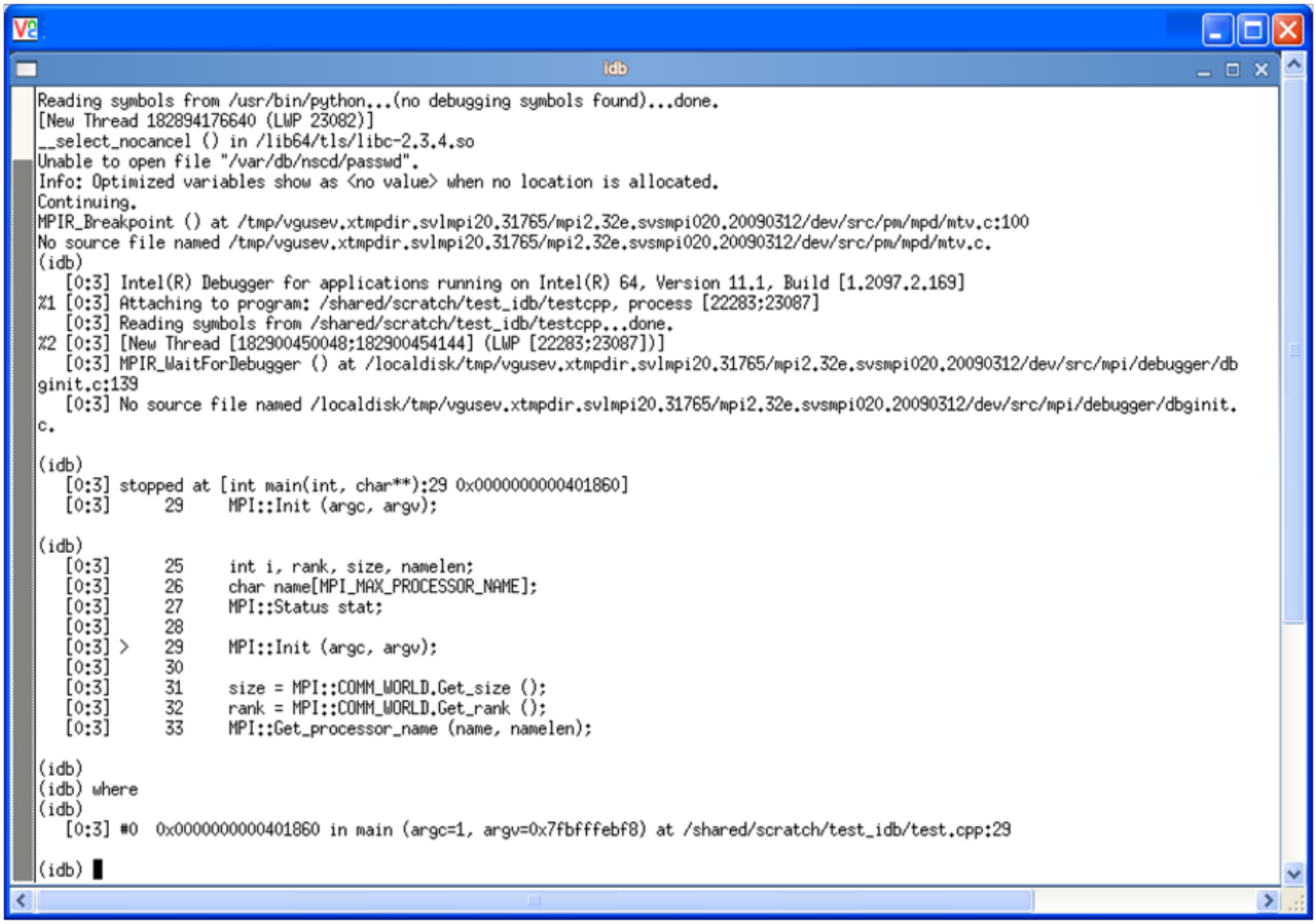

Figure 5.3 – The application call stack after typing the IDB command `where`

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.

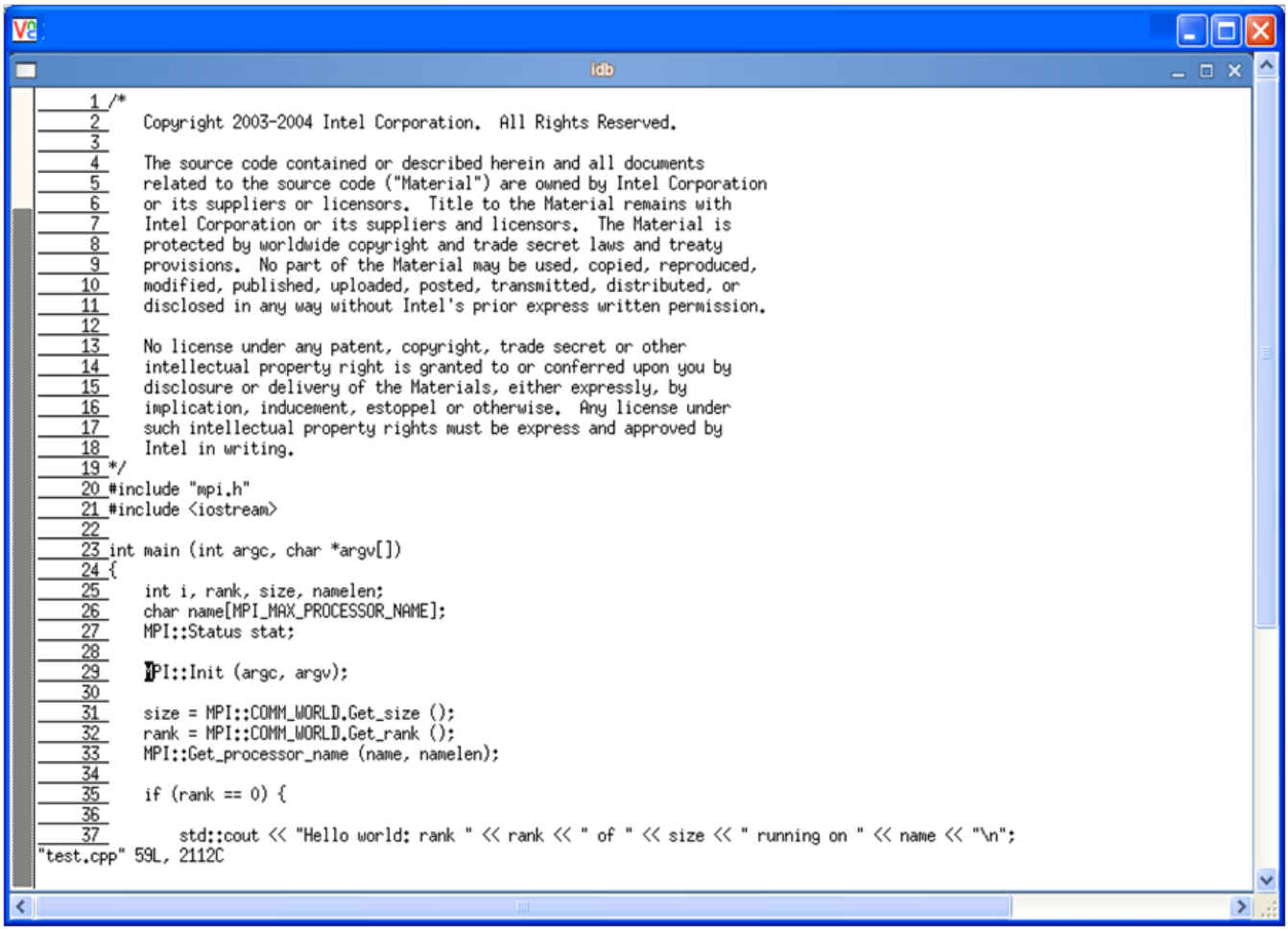

Figure 5.4 – Launching of an edit session from the Intel Debugger

You can use the command :q! to close the vi edit session. This is demonstrated in Figure 5.5.

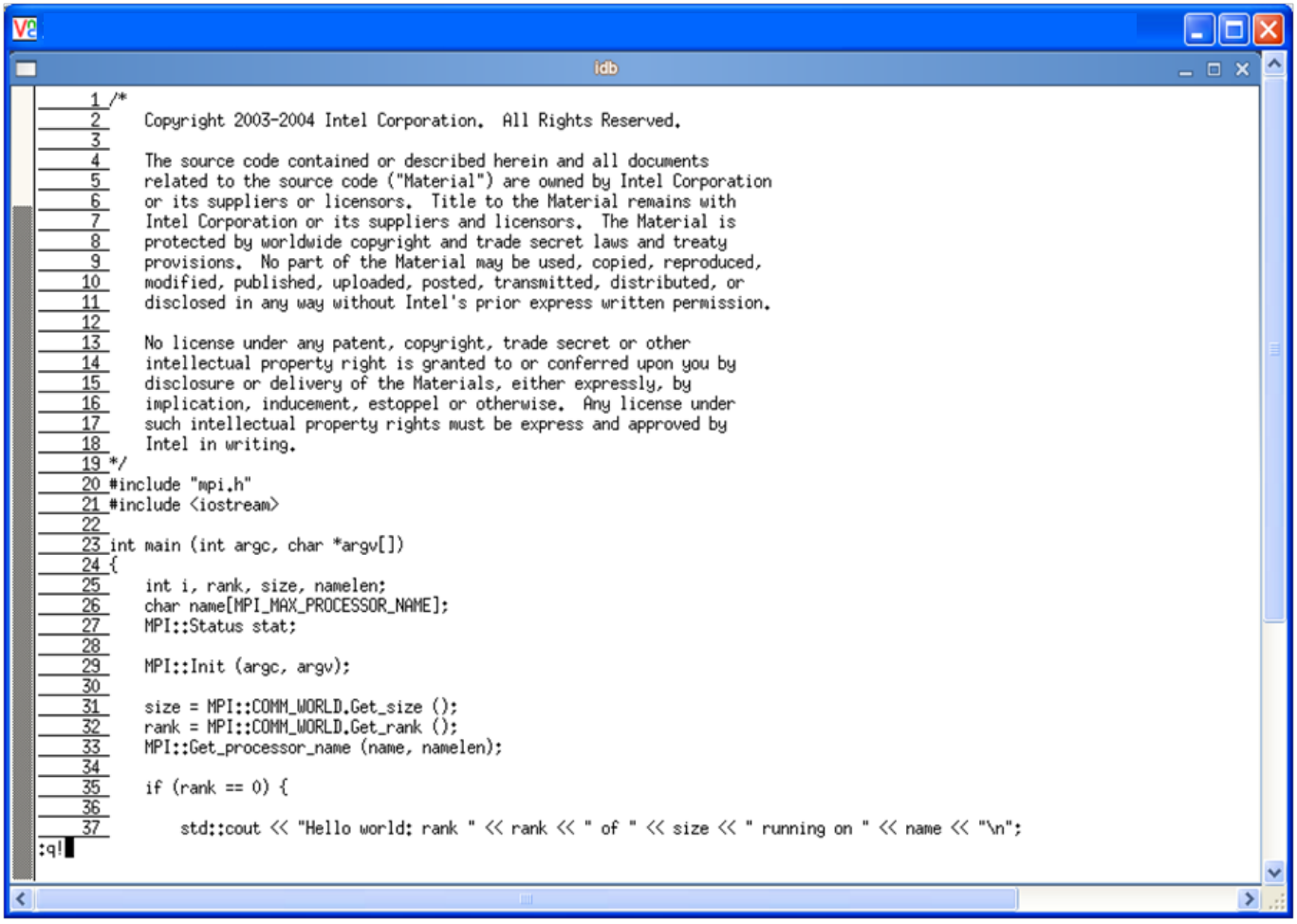

Figure 5.5 – Terminating the vi editing session using the command `:q!`

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.

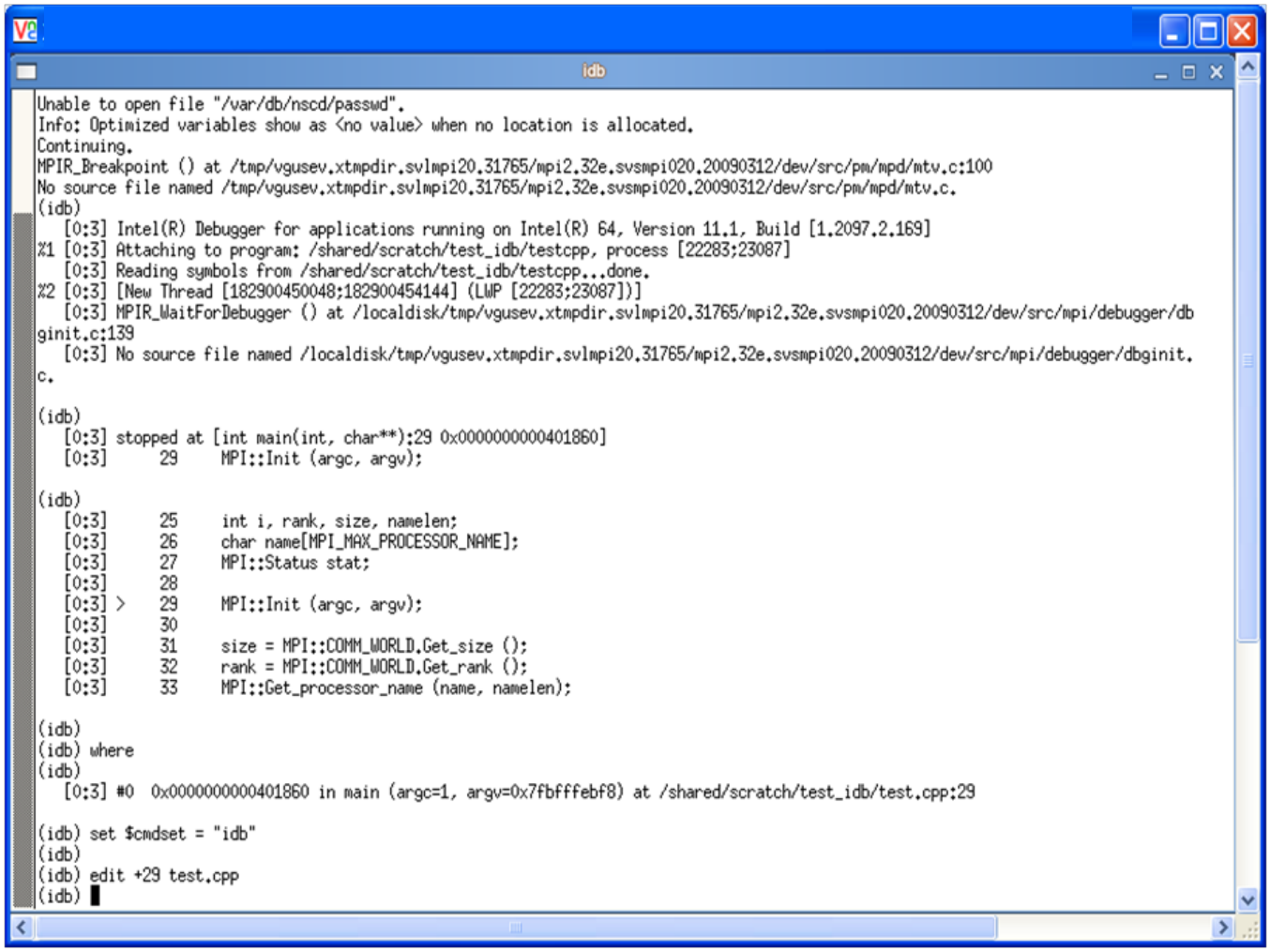

Figure 5.6 – Returning control back to IDB after terminating the editing session

The 4 MPI processes for the example in Figure 5.7 are labeled 0 to 3.

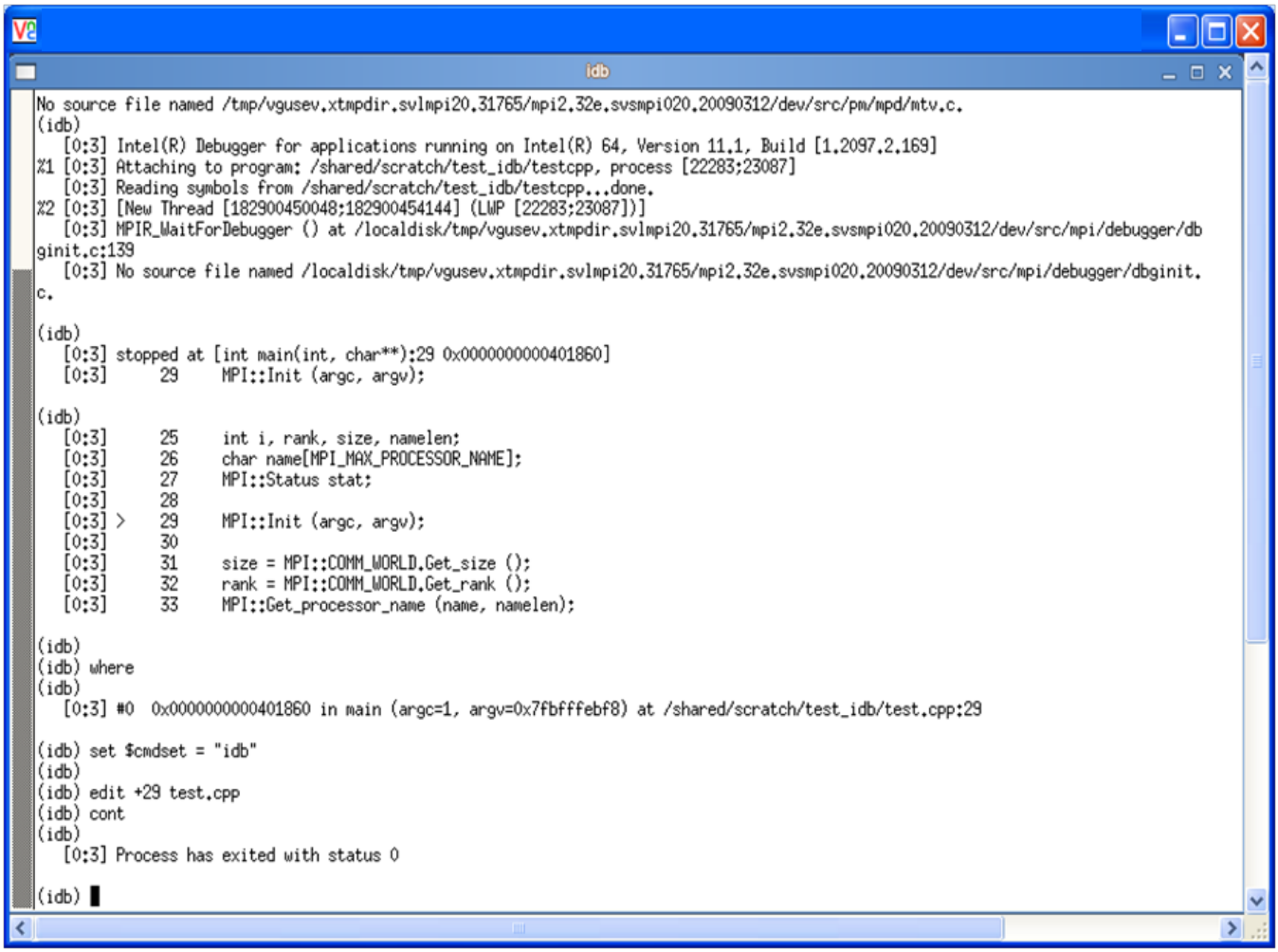

Figure 5.7 – State of the IDB session as a result of issuing the IDB command cont

You can type the word quit to end the IDB debug session, and therefore close the display shown in Figure 5.7.

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.

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

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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/4.0.0.017/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
vtcounterscopec
vtjacobic
vtjacobif
```

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.stf.frm      vtjacobic.stf.pr.0
vtjacobic.prot     vtjacobic.stf.gop      vtjacobic.stf.pr.0.anc
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:

```
traceanalyzer vtjacobic_inst/vtjacobic.stf
```

the following display panel will appear (Figure 6.1):

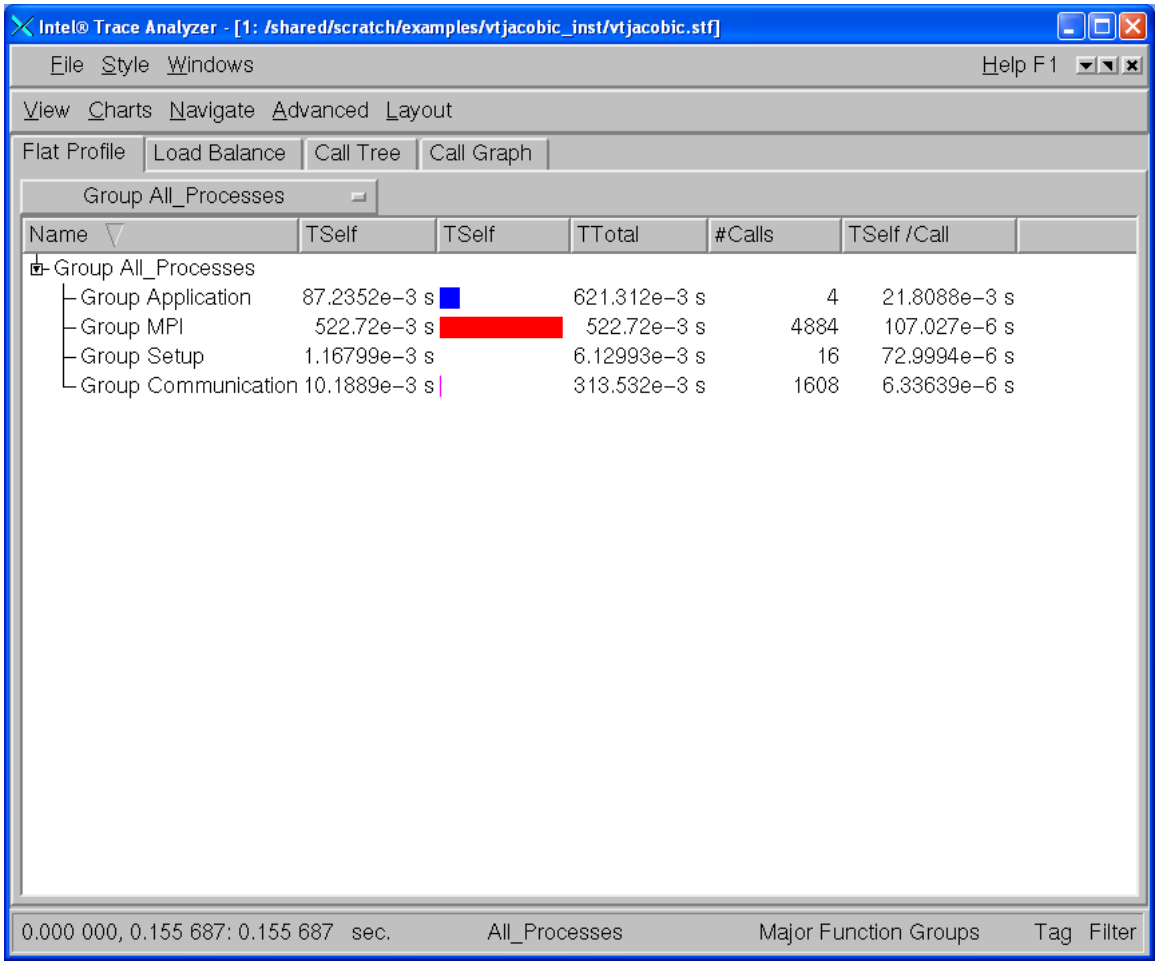

Figure 6.1 - Intel Trace Analyzer Display for `vtjacobic.stf`

Figure 6.2 shows the Event Timeline display which results when following the menu path Charts->Event Timeline within Figure 6.1.

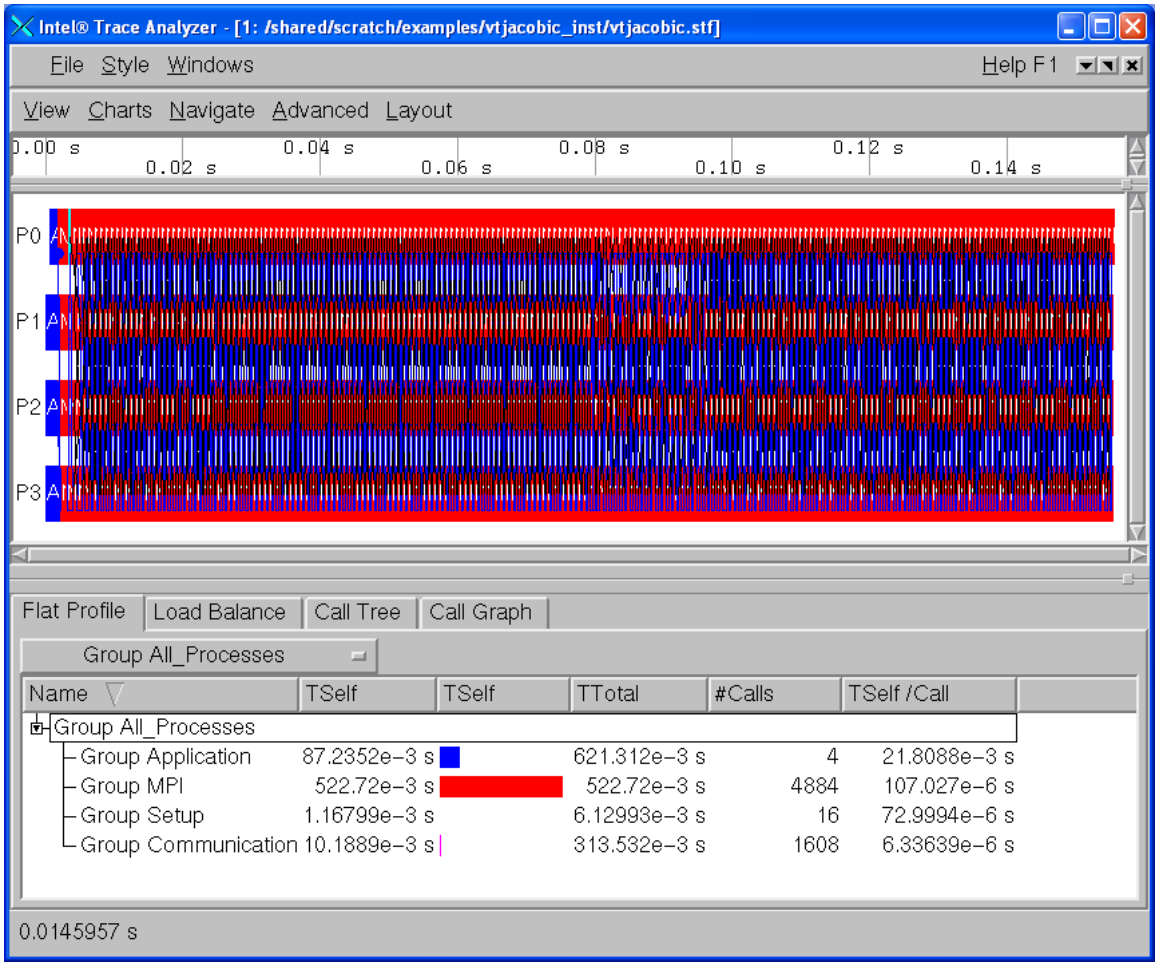

Figure 6.2 - Intel Trace Analyzer Display for `vtjacobic.stf` using Charts->Event Timeline

You can use the trace analyzer to view the contents of the other `*.stf` files in this working directory on your cluster system.

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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`.

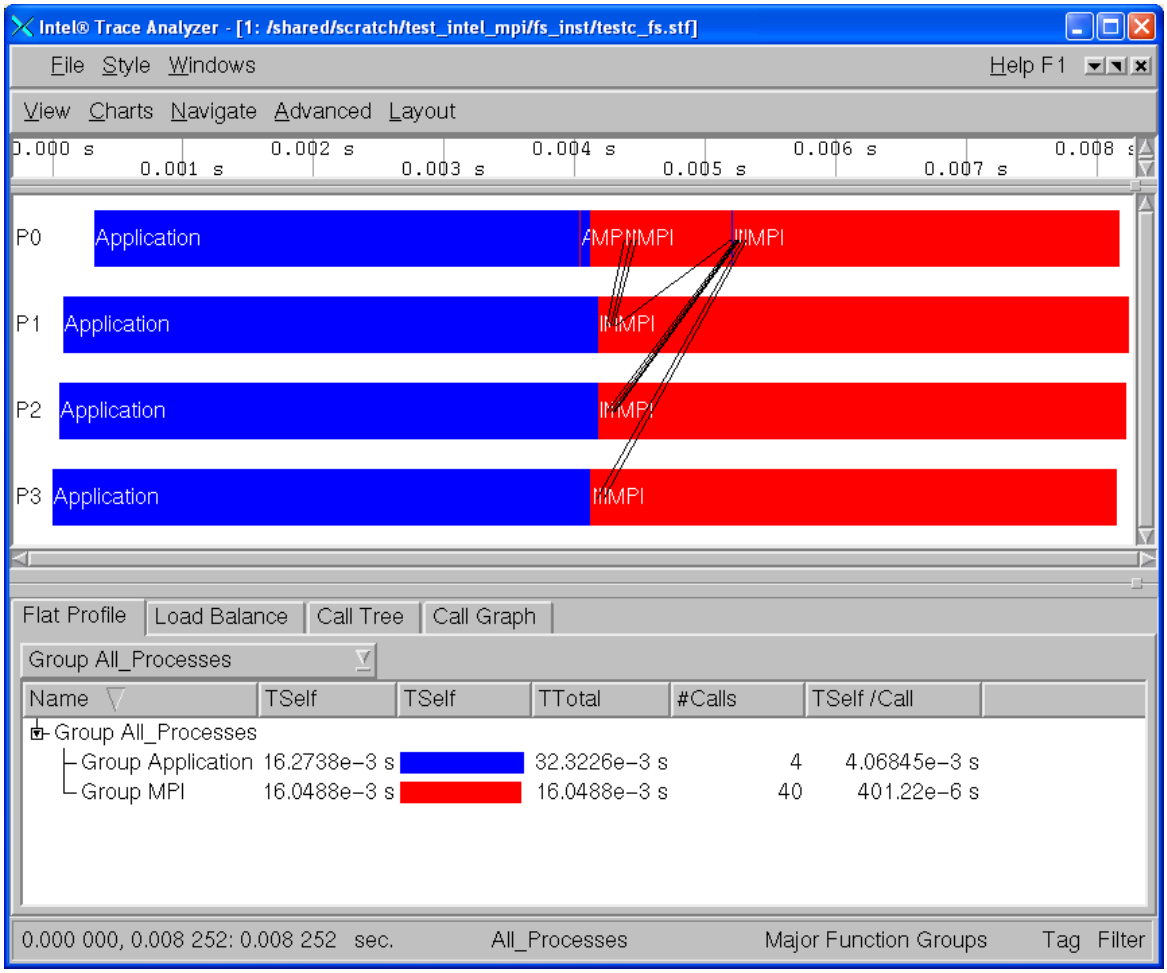

Figure 6.3 – Intel Trace Analyzer display of Fail-Safe Trace Collection by Intel Trace Collector

Complete user documentation regarding `-lVTfs` 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.

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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, or Intel® 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 of 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://www.nccs.gov/wp-content/training/mpi-examples/C/pical.c

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
```

The shell commands above could be packaged into a C Shell script. An explanation for the *instrumentation* environment variables can be found in the Intel Trace Collector Users' Guide under the search topic "ITC Configuration".

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 &
```

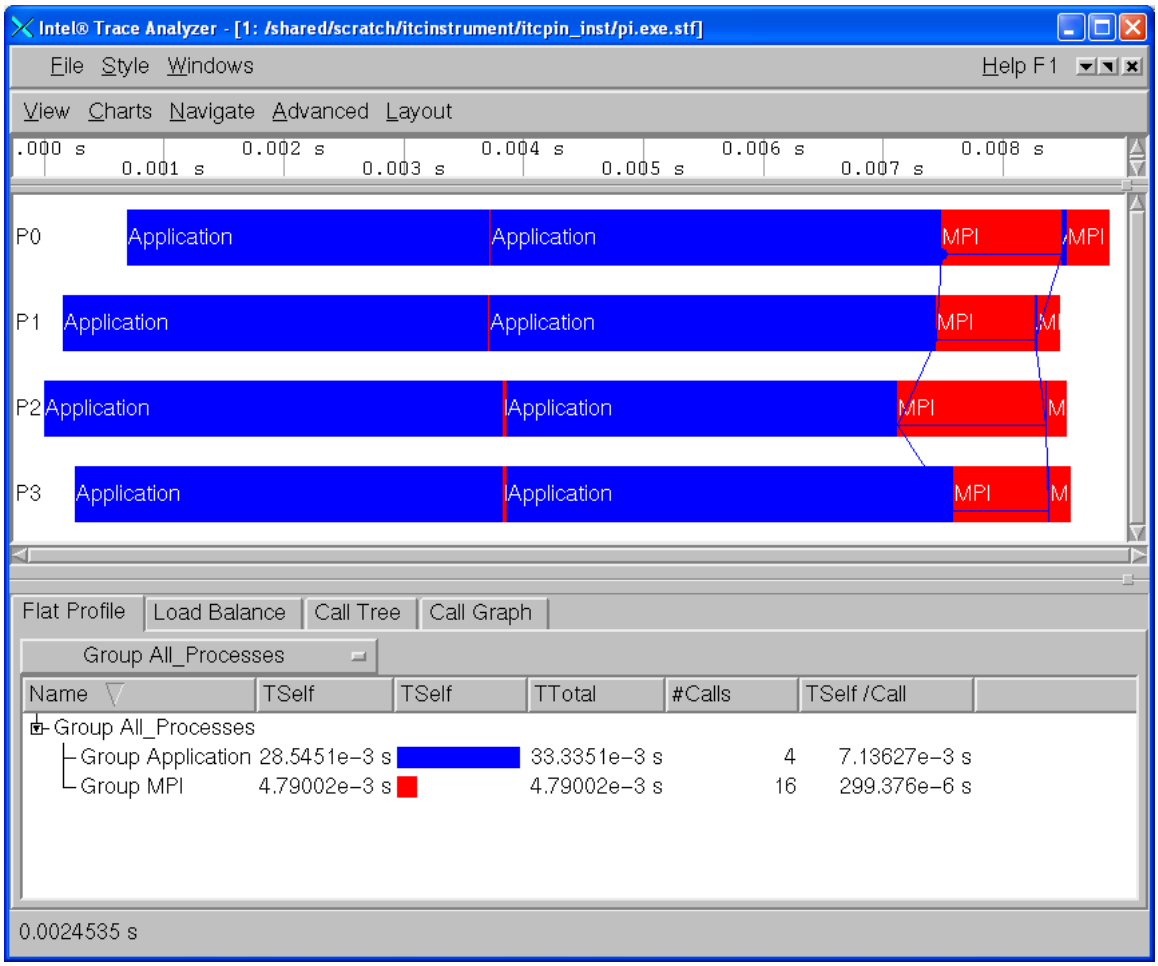

Figure 6.4 – Intel Trace Analyzer display of the "pi" integration application that has been binary instrumented with `itcpin`

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.

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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 &
```

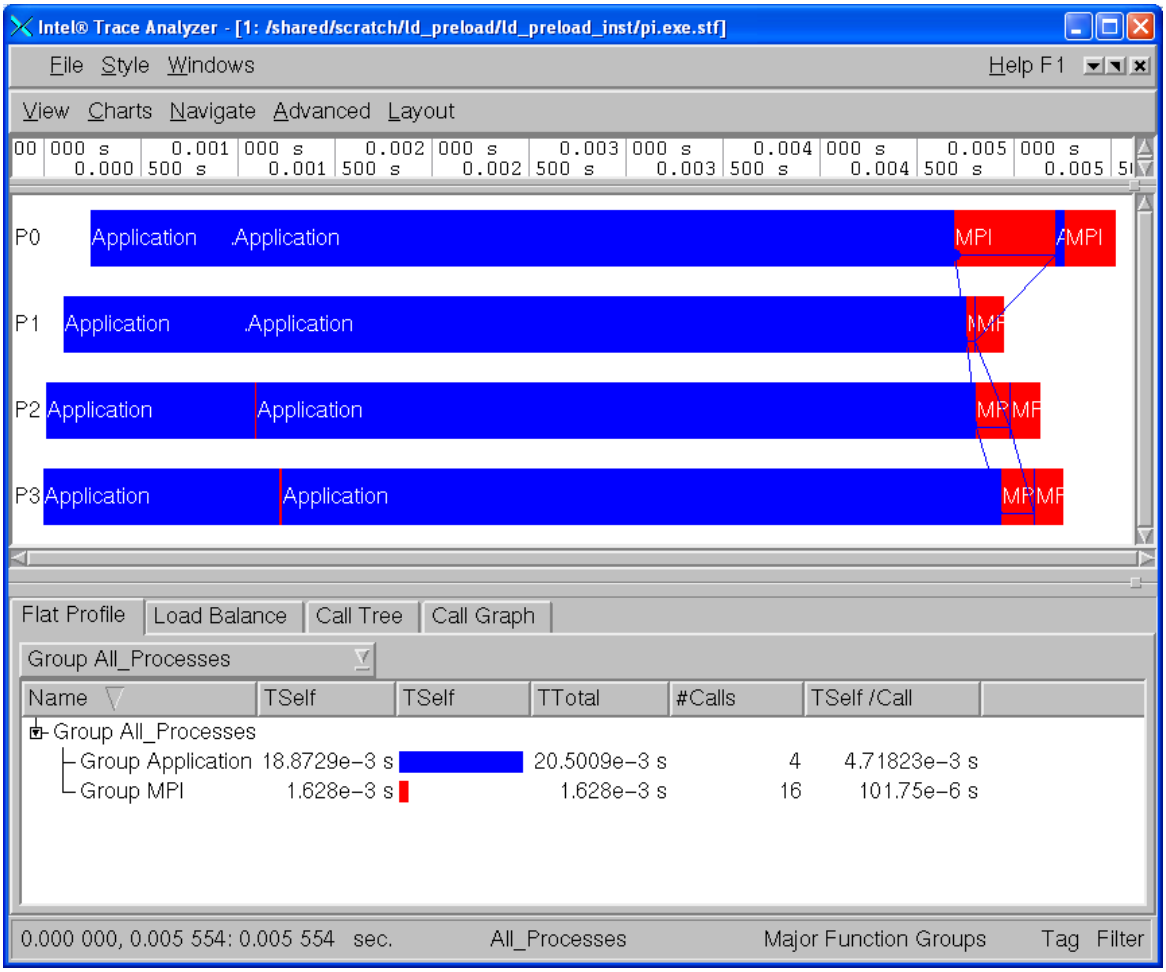

Figure 6.5 – Intel Trace Analyzer display of the "pi" integration application that has been instrumented through the LD_PRELOAD environment variable

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: http://premier.intel.com.

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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:

http://icl.cs.utk.edu/papi/

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:

```
${VT_ROOT}/lib
```

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

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

The environment variable `PAPI_ROOT` is used by the makefile to formulate the path to `${PAPI_ROOT}/include` which is a directory that contains PAPI header files. When the `libVTsample.a` library is built, the Poisson example can be linked with PAPI instrumentation as follows:

```
gmake MPI_HOME=${I_MPI_ROOT} make_dir=./ LIB_PATH="" LIBS="-
L${VT_ROOT}/lib –lVTsample –lVT –L${PAPI_ROOT}/papi/lib –lpapi
${VT_ADD_LIBS}"
```

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

```
rm -rf ${PWD}/papi_inst
mkdir ${PWD}/papi_inst
setenv LD_LIBRARY_PATH ${LD_LIBRARY_PATH}:${PAPI_ROOT}/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 &
```

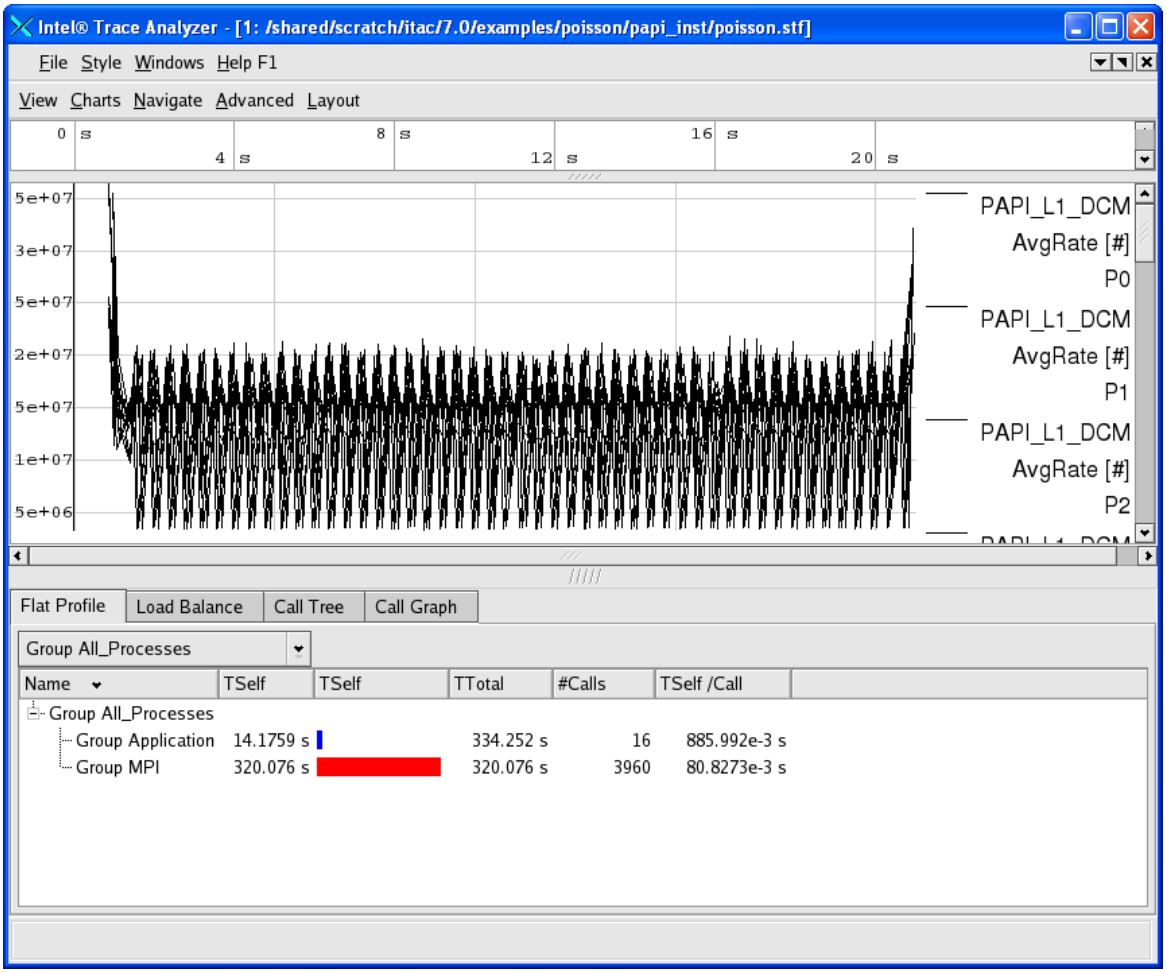

Figure 6.6 – A maximized view for the Counter Timeline Chart and the Function Profile Chart

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${VT_LIB_DIR} -lVTsample -lVT –L${PAPI_ROOT}/papi/lib -lpapi
${VT_ADD_LIBS}
```

The compilation commands are:

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

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

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

mpiifort test.f90 -o testf90 -L${VT_LIB_DIR} -lVTsample -lVT -
L${PAPI_ROOT}/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: http://premier.intel.com.

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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_CHECK_TRACING on -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}

mpiexec -genv VT_CHECK_TRACING on -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:

```
mpiicc deadlock.c -o deadlock.exe –g

mpiexec -genv VT_CHECK_TRACING on -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:

```
mpiicc deadlock.c -o deadlock.exe –g

mpiexec -genv VT_CHECK_TRACING on -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:

```
global/collective/datatype_mismatch/
```

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
43     MPI_Init( &argc, &argv );
44     MPI_Comm_size( MPI_COMM_WORLD, &size );
45     MPI_Comm_rank( MPI_COMM_WORLD, &rank );
46
47     /* error: types do not match */
48     if( !rank ) {
49         int send = 0;
50         MPI_Bcast( &send, 1, MPI_INT, 0, MPI_COMM_WORLD );
51     } else {
52         char recv[4];
53         MPI_Bcast( &recv, 4, MPI_CHAR, 0, MPI_COMM_WORLD );
54     }
55
56     MPI_Finalize( );
57
58     return 0;
59 }
```

At lines 52 and 53, adjustments can be made to the source which would look something like the following:

```
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:

```
                                    …

[0 Thu Mar 26 19:53:34 2009] INFO: Error checking completed without
finding any problems.

                                    …
```

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 VT_CHECK_TRACING on -genv VT_LOGFILE_PREFIX
/shared/scratch/test_correctness_checking/inst -genv LD_PRELOAD
libVTmc.so -genv VT_DEADLOCK_TIMEOUT 20s -genv VT_DEADLOCK_WARNING 25s
-n 2 ./deadlock.exe 0 80000
```

diagnostic messages that look something like the following 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` which for the example command-line:

```
mpiexec -genv VT_CHECK_TRACING on -genv VT_LOGFILE_PREFIX
/shared/scratch/test_correctness_checking/inst -genv LD_PRELOAD
libVTmc.so -genv VT_DEADLOCK_TIMEOUT 20s -genv VT_DEADLOCK_WARNING 25s
-n 2 ./deadlock.exe 0 80000
```

is `/shared/scratch/test_correctness_checking/inst`.

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):

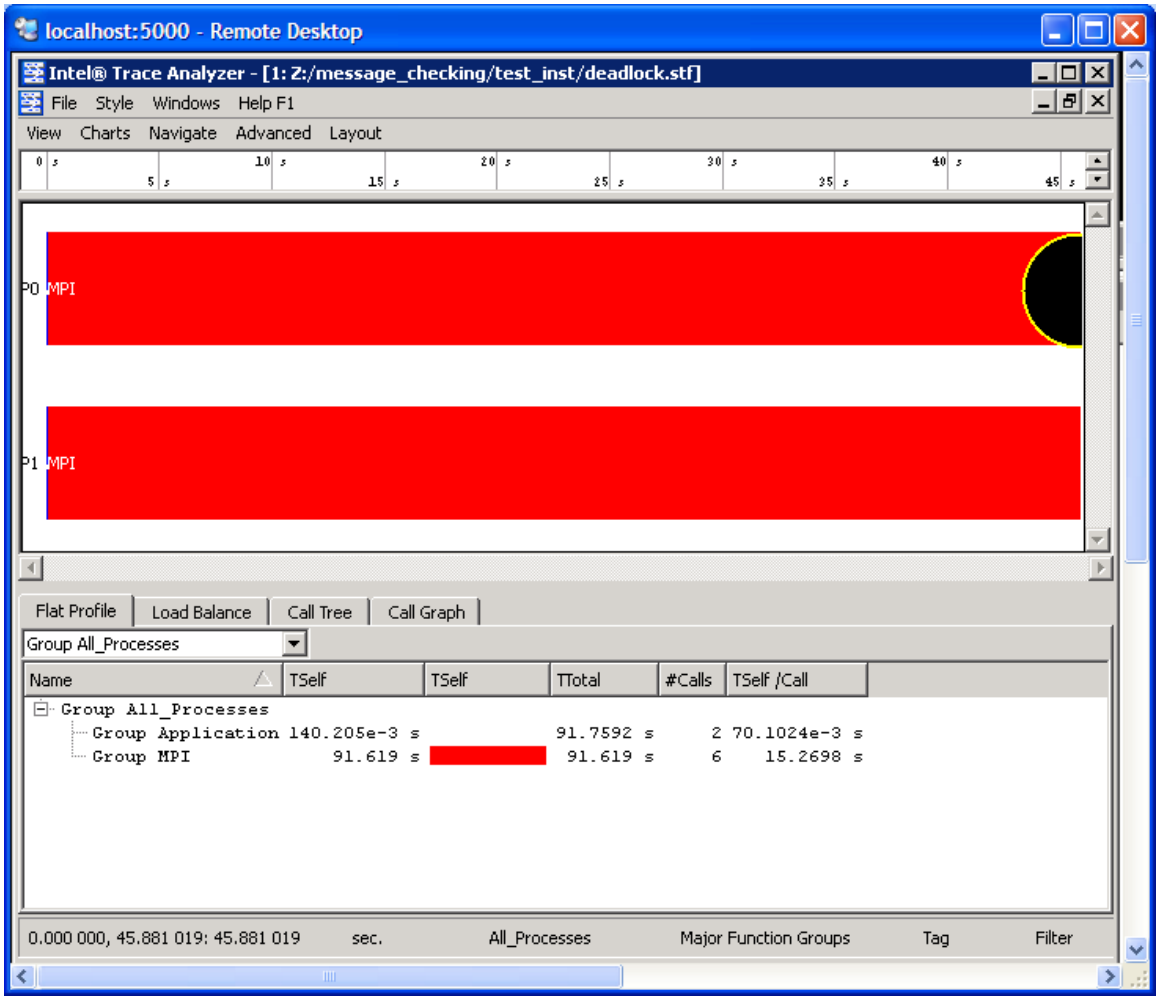

Figure 6.7 – Event Timeline illustrating an error as signified by the black circle

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.

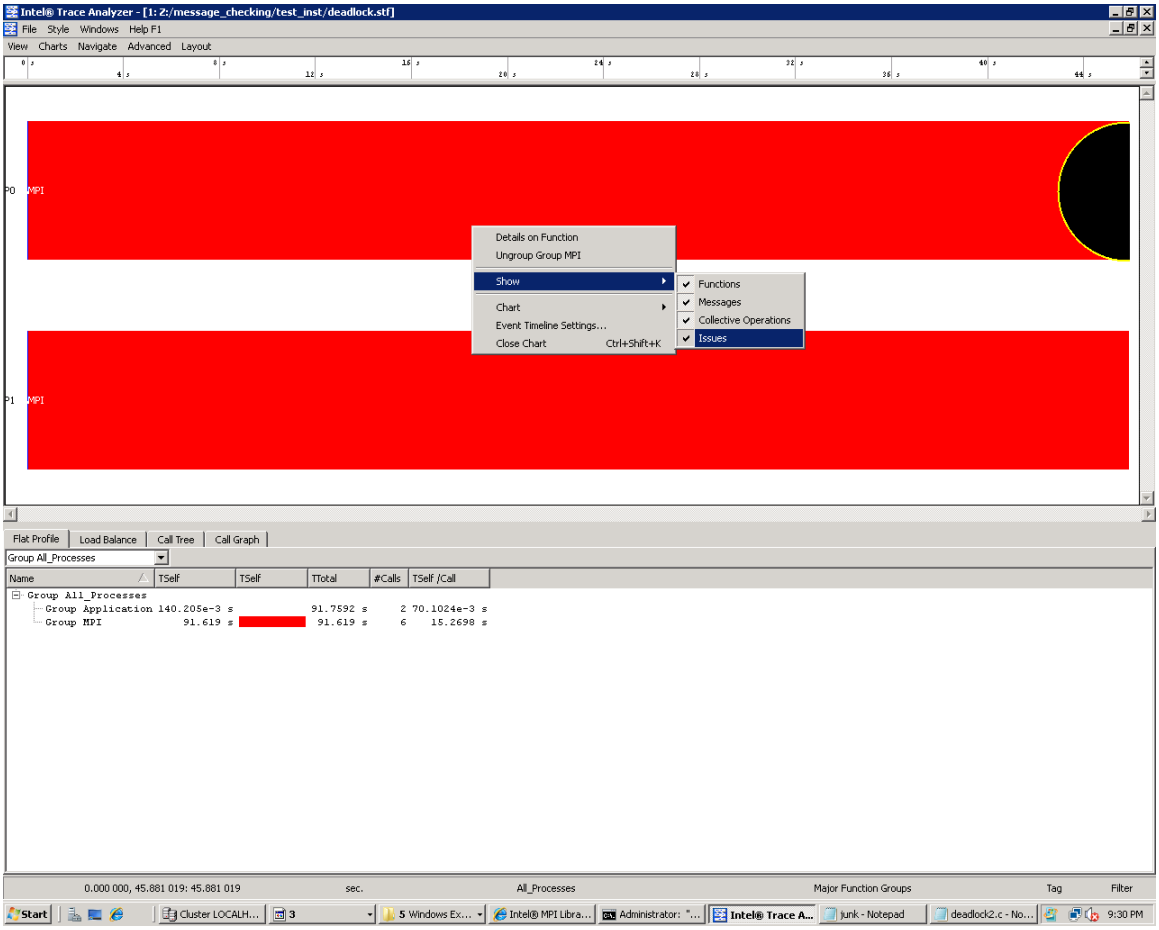

Figure 6.8 – Context menu that can be used to suppress "Issues". This is done by un-checking the "Issues" item

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):

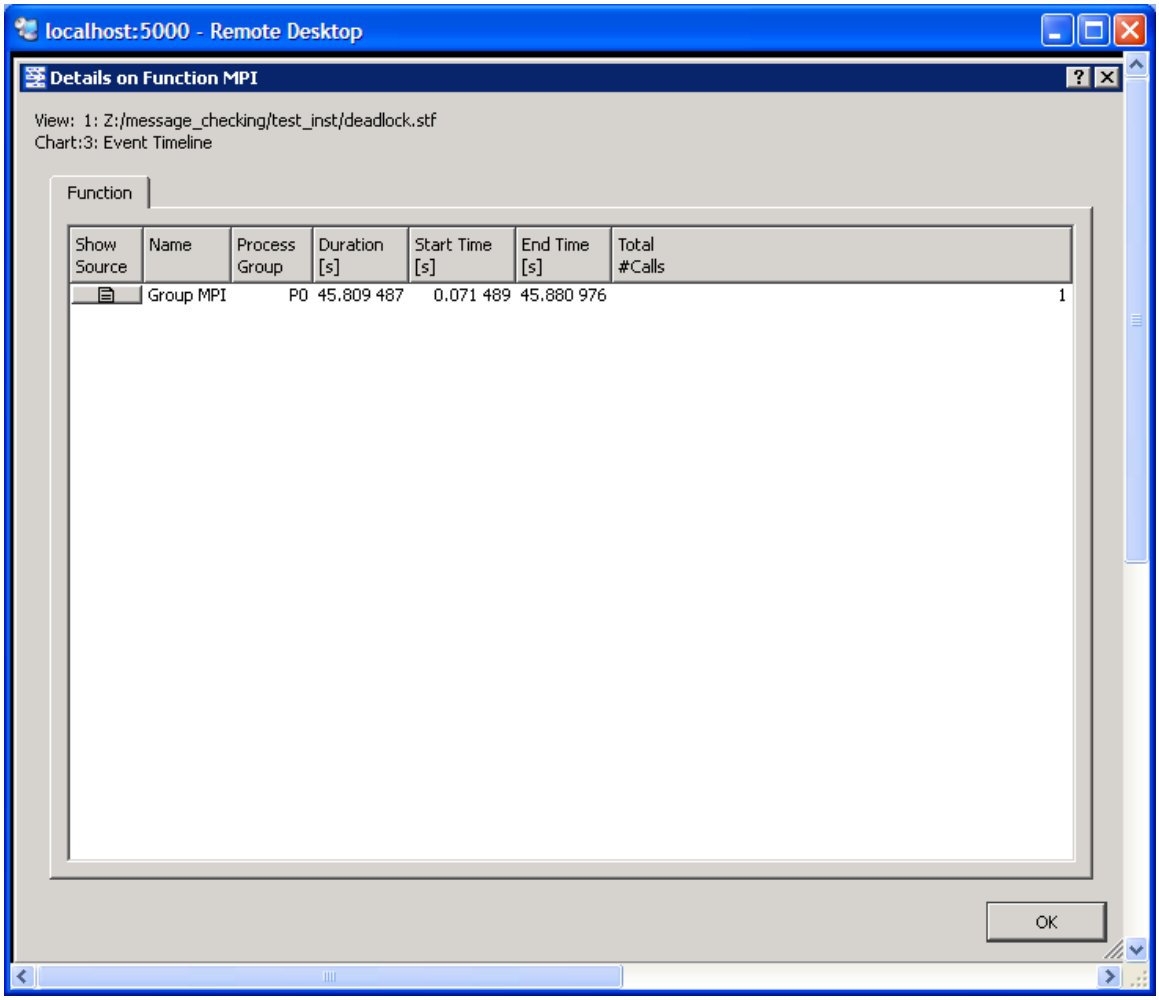

Figure 6.9 – Illustration of the Detail on Function panel. The Show Source tab is the first item on the left

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:

```
                                    ...
     49       MPI_Recv (buffer_in, MAX_ARRAY_LENGTH, MPI_INT, other,
999,
     50                 MPI_COMM_WORLD, &status);
     51       MPI_Send (buffer_out, messagelength, MPI_INT, other, 999,
     52                 MPI_COMM_WORLD);
                                    ...
```

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

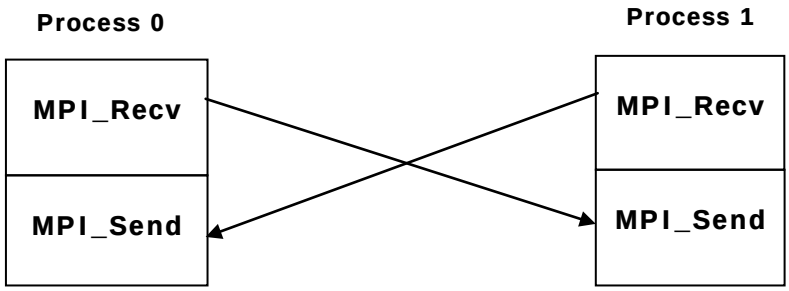

Figure 6.11 – Cycle illustration for processes 0 and 1 when executing source lines 49 and 43 within application `deadlock.c`

1. Use a different ordering of MPI communication 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:

```
                                    ...
41   if (sendfirst) {
42       printf ("\n%d/%d: sending %d\n", rank, size, messagelength);
43       MPI_Send (buffer_out, messagelength, MPI_INT, other, 999, MPI_COMM_WORLD);
44       MPI_Recv (buffer_in, MAX_ARRAY_LENGTH, MPI_INT, other, 999,
45                 MPI_COMM_WORLD, &status);
46       printf ("\n%d/%d: received %d\n", rank, size, messagelength);
47     } else {
48       printf ("\n%d/%d: receiving %d\n", rank, size, messagelength);
49       MPI_Recv (buffer_in, MAX_ARRAY_LENGTH, MPI_INT, other, 999,
50                 MPI_COMM_WORLD, &status);
51       MPI_Send (buffer_out, messagelength, MPI_INT, other, 999,
52                 MPI_COMM_WORLD);
33       printf ("\n%d/%d: sendt %d\n", rank, size, messagelength);
54     }
                                    ...
```

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 VT_CHECK_TRACING on -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: sent 80000

1/2: sent 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).

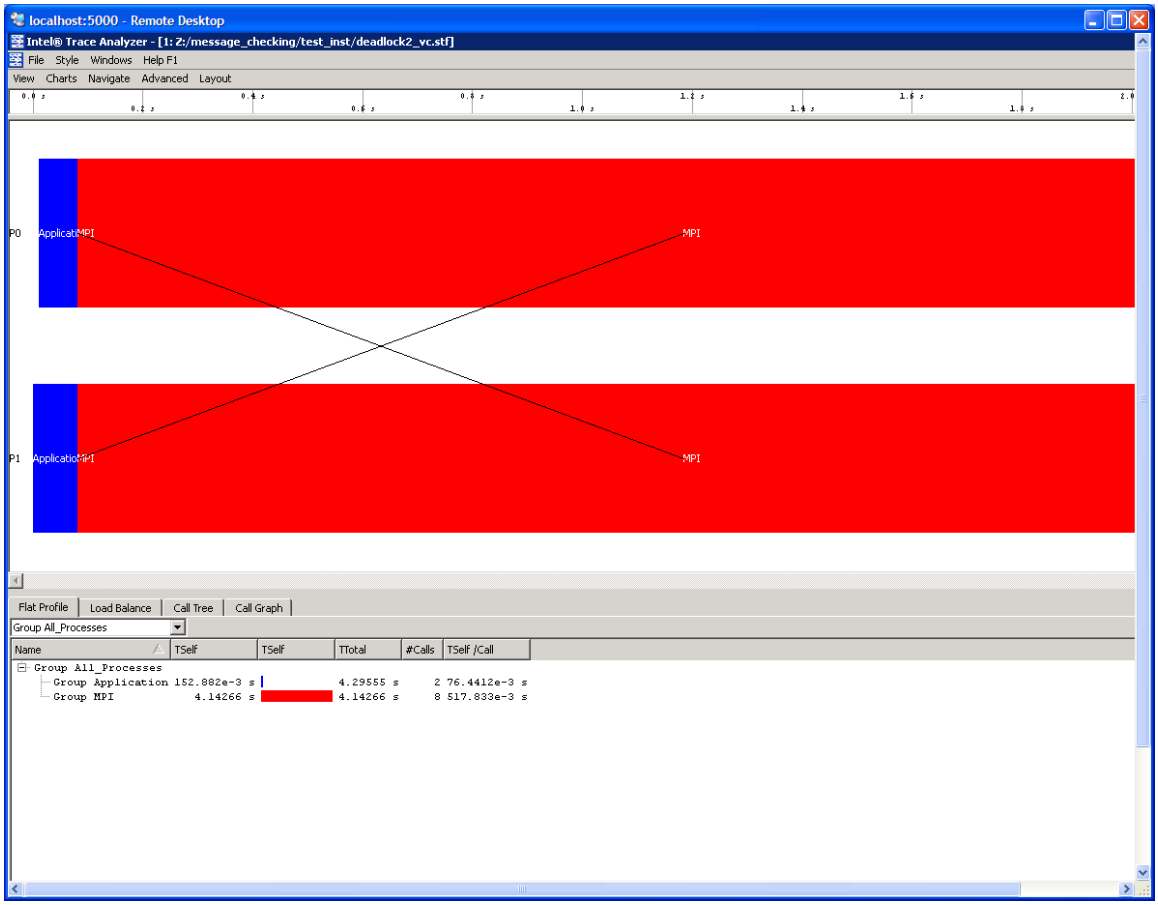

Figure 6.12 – Illustration of deadlock removal by using `MPI_Sendrecv` in the original source file called `deadlock.c`

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6.6 Saving a Working Environment through a Project File

There may be situations where you are in the middle of an inspection with Intel® Trace Analyzer and you need to be away. For example, suppose you initially typed the command:

```
traceanalyzer test_inst/testcpp.stf
```

and you need to temporarily stop the analysis, and you are looking at the following panel:

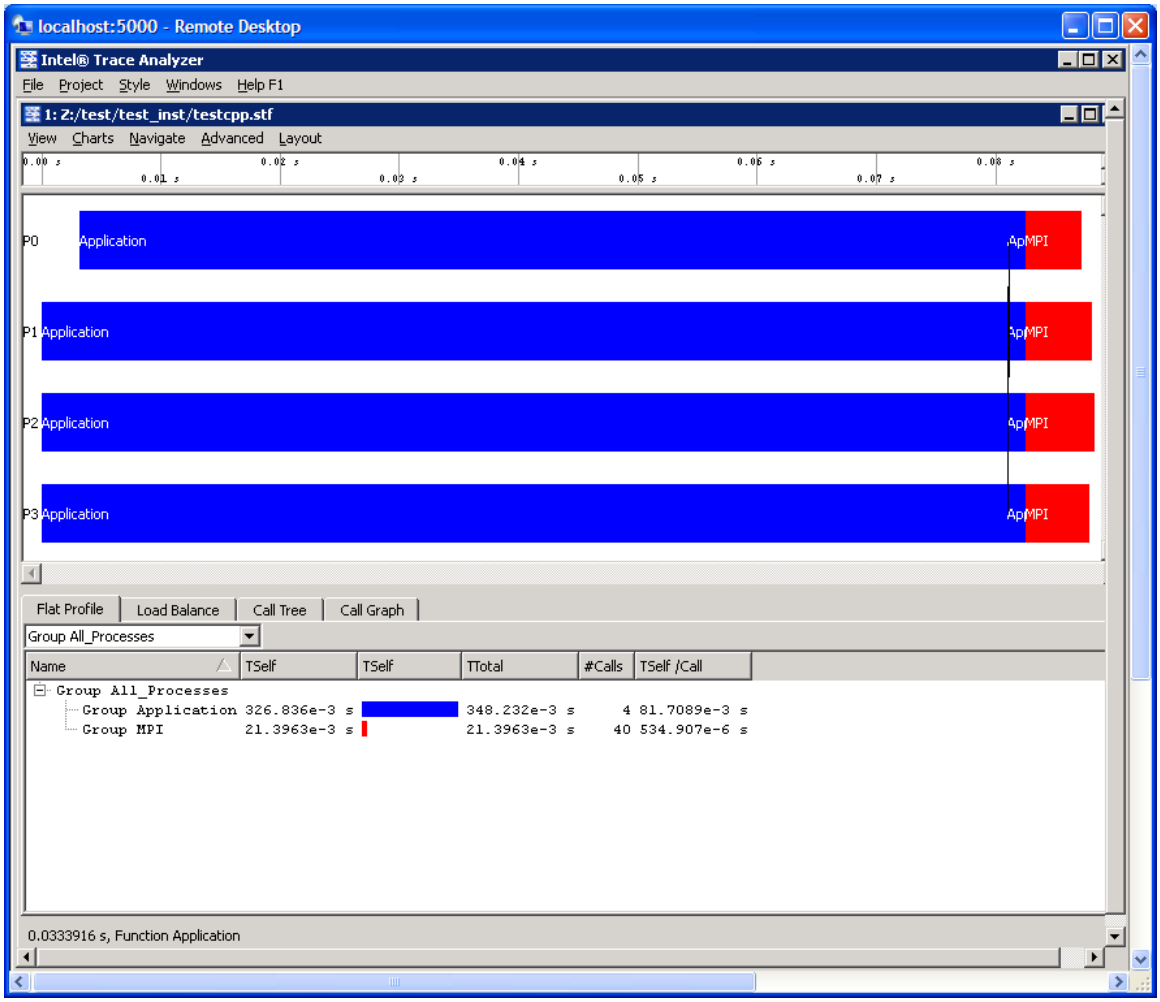

Figure 6.13 – Event timeline for running 4 MPI processes for the executable generated from `test.cpp`

For the panel rendering above, if you selection Project->Save Project or Project->Save Project As…, you will generate a subpanel that allows you to save the state of your session. This is project file has a suffix of "`.itapr`", which is an acronym for Intel® Trace Analyzer project. Figure 6.14 shows the process of saving the state of your session through a project file.

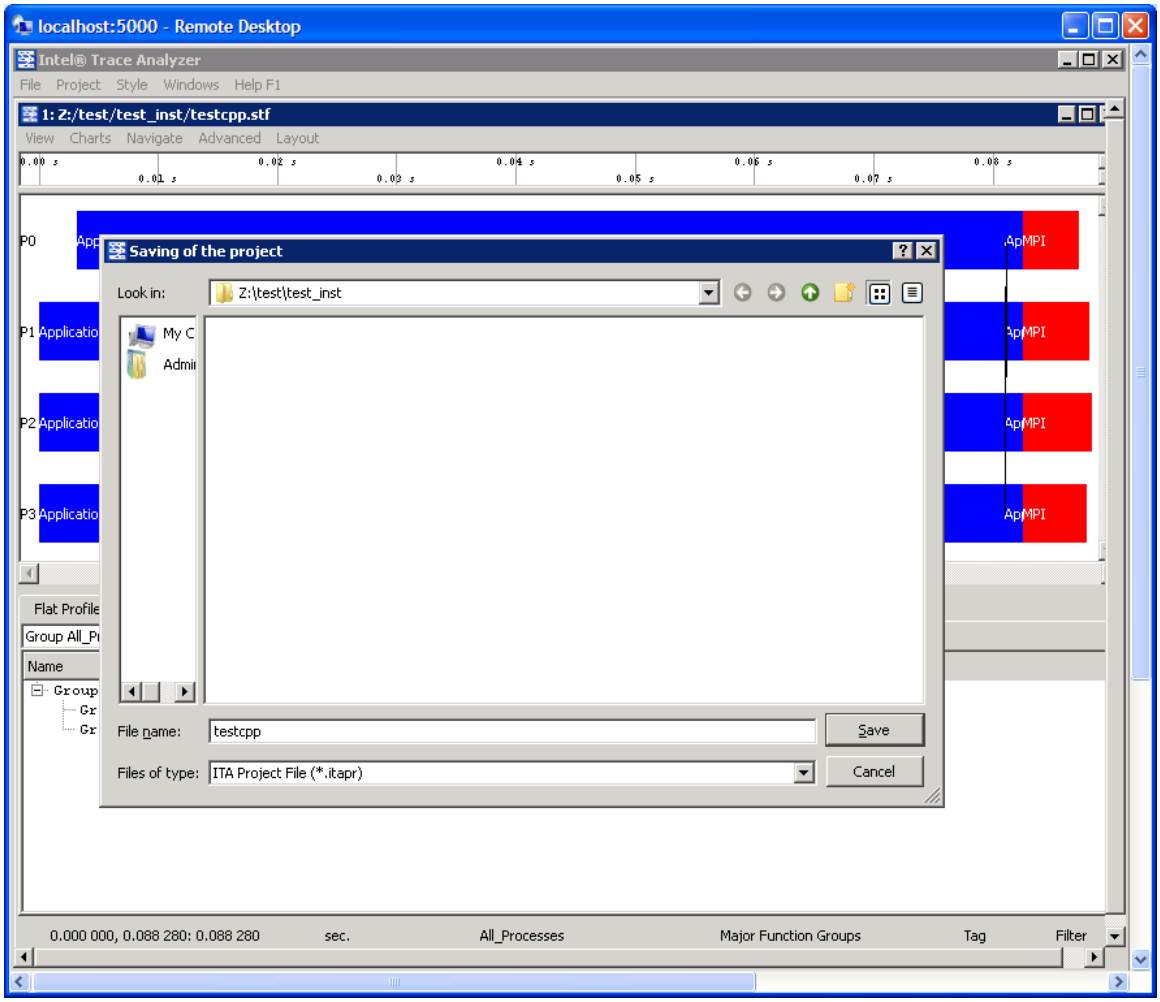

Figure 6.14 – Saving a Project File called `testcpp.itapr`

Suppose at a later time you wish to continue the analysis with Intel® Trace Analyzer. You can type the command:

```
traceanalyzer
```

You can then select Project->Load Project… and the following subpanel will appear (Figure 6.15):

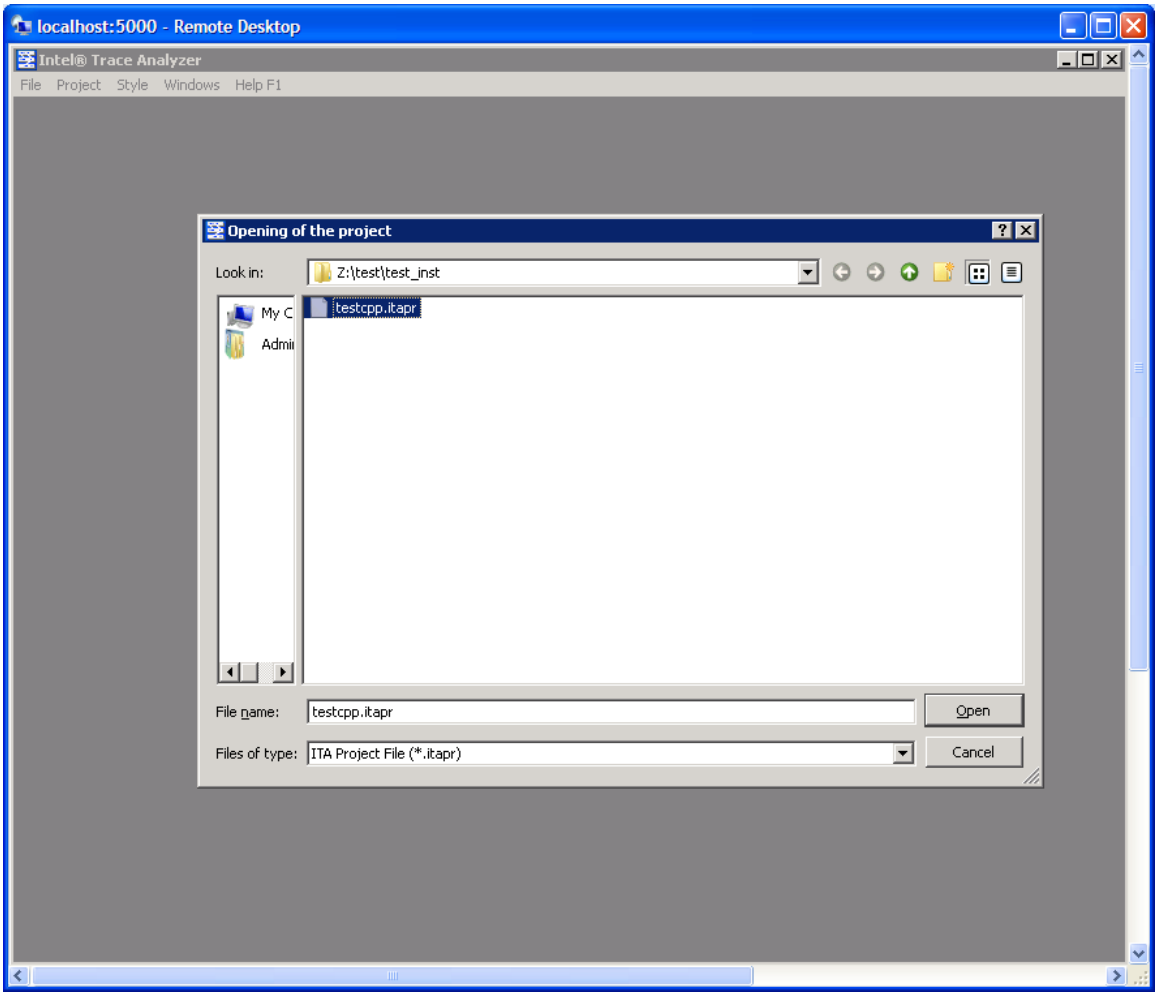

Figure 6.15 – Loading a Project File called `testcpp.itapr`

With regards to Figure 6.15, simply mouse over the Open button and you will immediately go back to point where you last left off (Figure 6.13). For complete details on saving and loading a project file, please see Section 2.2 of the Intel® Trace Analyzer Reference Guide, which is titled “Project Menu”. The path to this file is:

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

on the system where the Intel® Trace Analyzer and Collector is installed.

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6.7 Analysis of Application Imbalance

With respect to Figure 6.13, a developer may want to know a summary of process imbalance for the executable. One can do this by selecting the menu path Advanced-

>Application Imbalance Diagram. Figure 6.16 shows the result of making this selection.

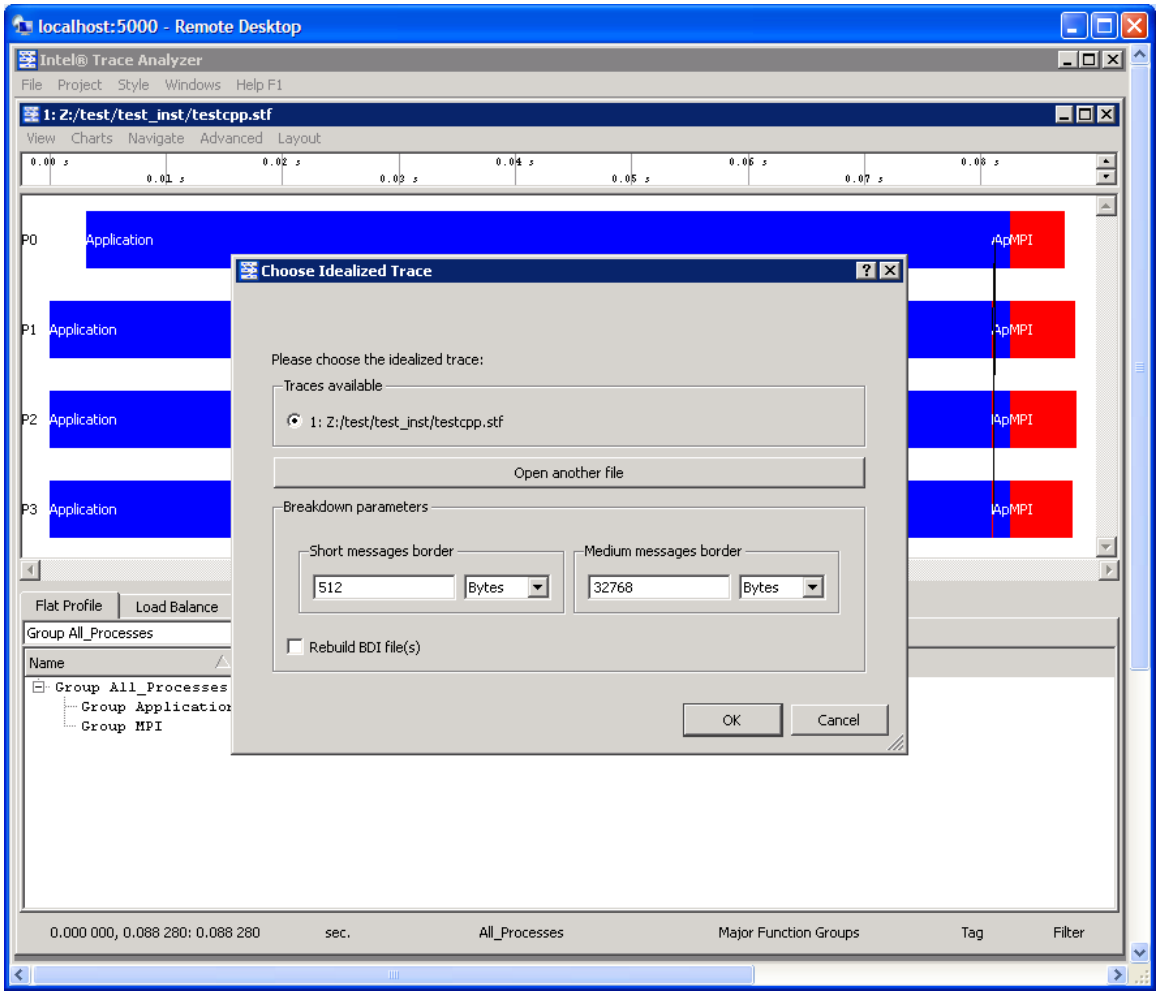

Figure 6.16 – Selecting Application Imbalance for the menu selection Advanced->Application Imbalance Diagram

Pressing the OK button in the subpanel will generate the following (Figure 6.17). You can verify the meaning of the histogram subcomponents by pressing on the Colors… button in Figure 6.17. This will generate the panel shown in Figure 6.18.

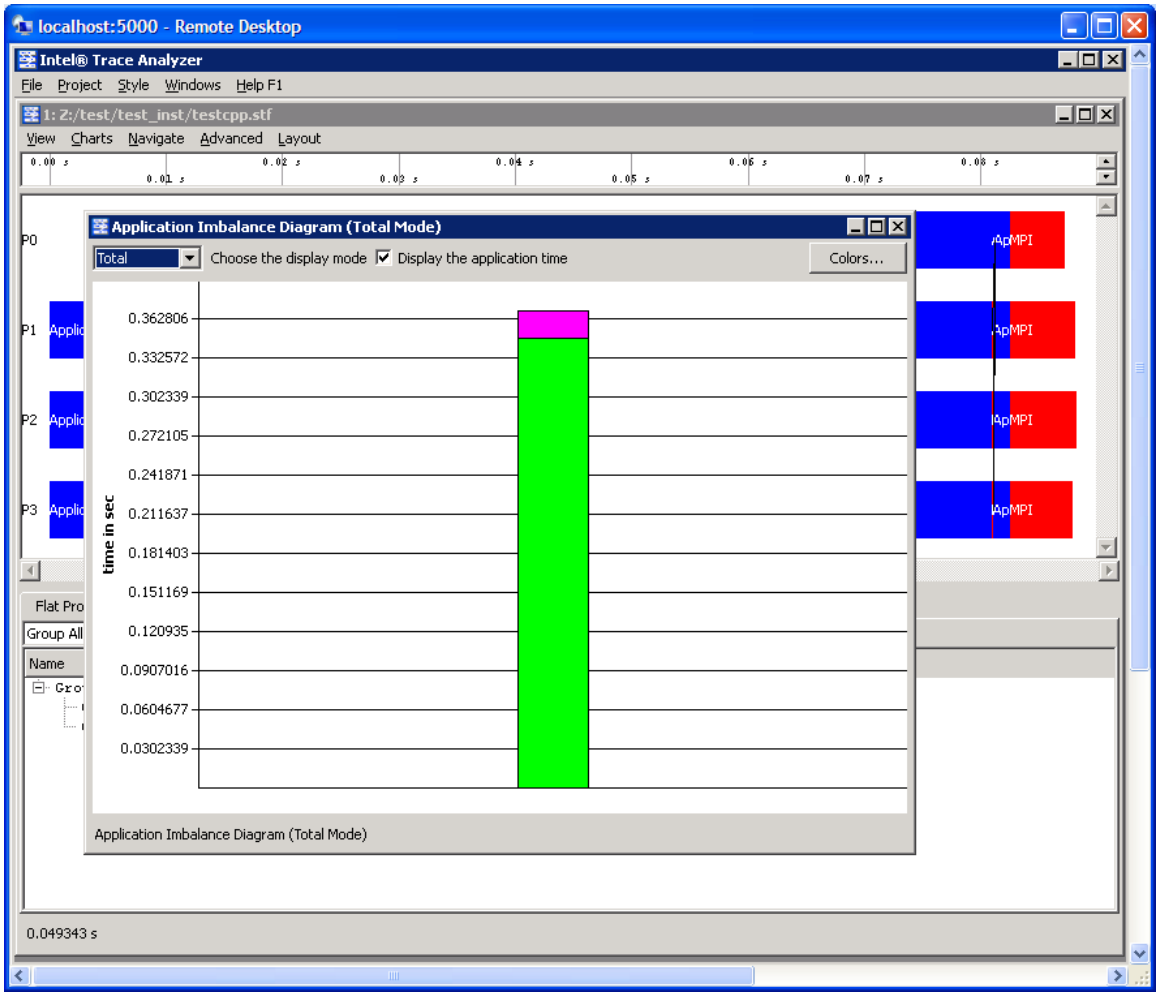

Figure 6.17 – Histogram subpanel as a result of pressing the OK button shown in Figure 6.16

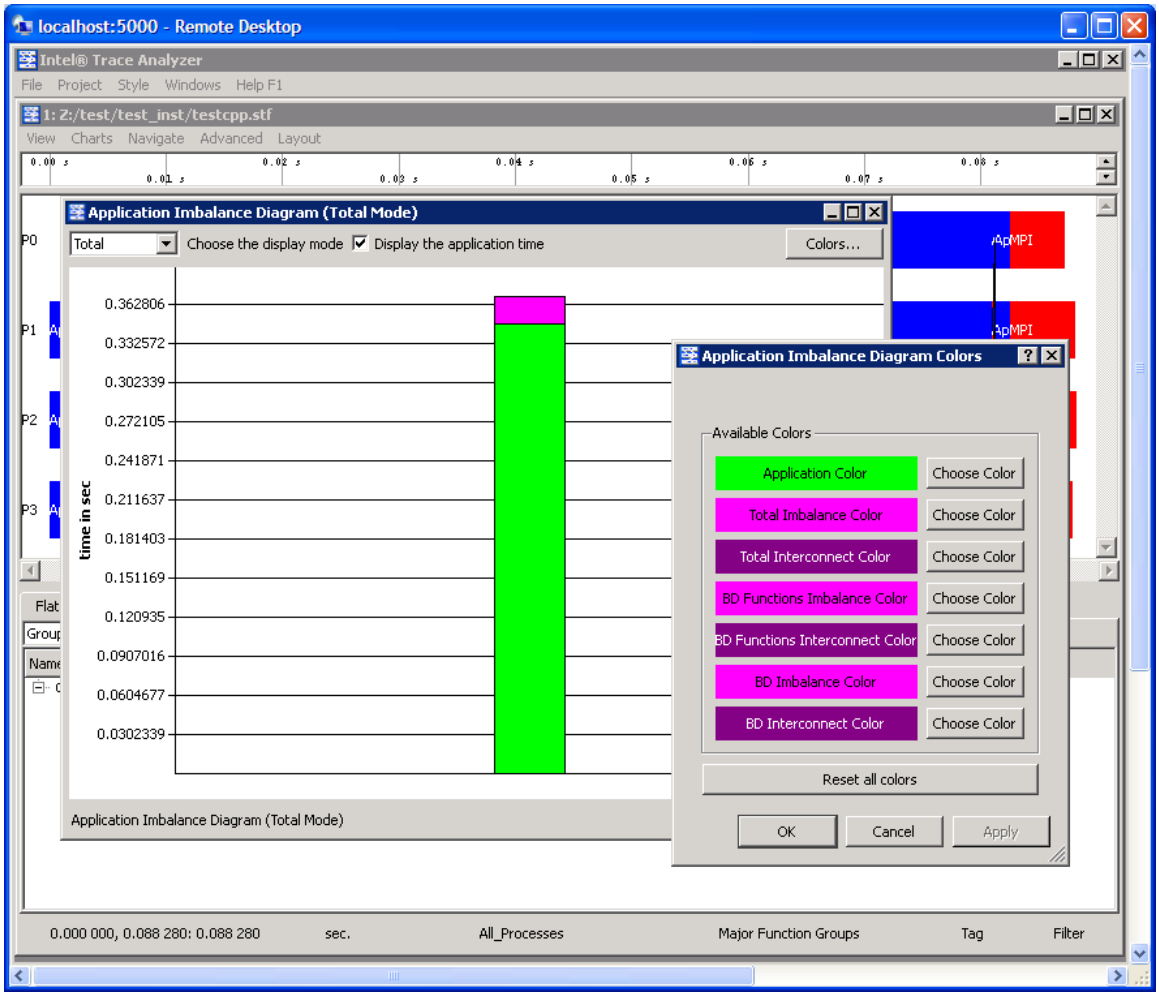

Figure 6.18 – Legend for interpreting the histogram contributions for the Application Imbalance Diagram

For complete details on application imbalance, please see Section 5.4 of the Intel® Trace Analyzer Reference Guide, which is titled “Application Imbalance Diagram Dialog Box”. The path to this file is:

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

on the system where the Intel® Trace Analyzer and Collector is installed.

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6.8 Analysis with the Ideal Interconnect Simulator

In analyzing the performance of your executable, you can compare your instrumentation trace with an ideal trace for the executable. To do this, make the

menu selection Advanced->Idealized. As a result of this, a dialog subpanel will appear which will allow you to create an idealized trace of execution (Figure 6.19):

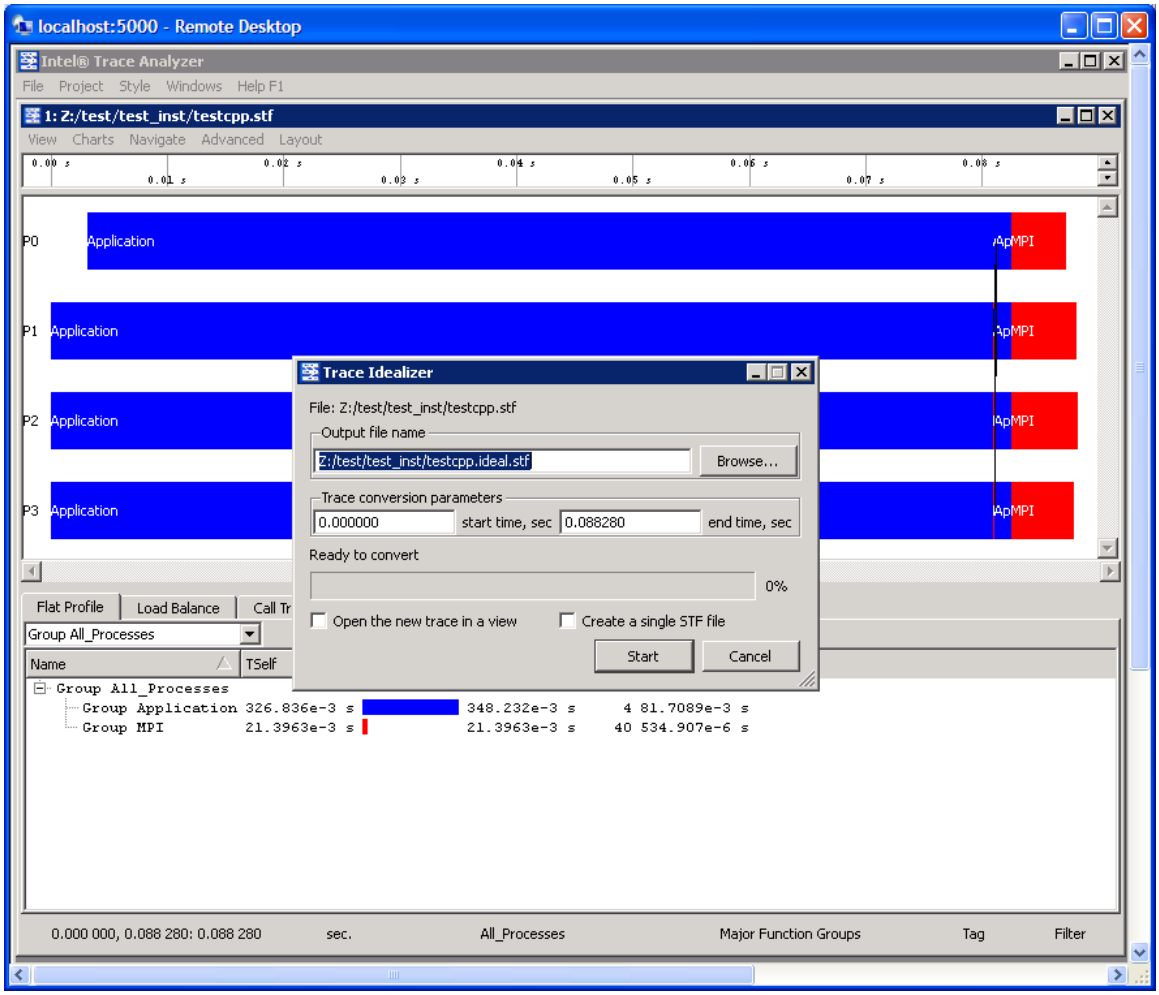

Figure 6.19 – Trace Idealizer dialog box generated as a result of the menu selection Advanced->Idealization

By pressing the Start button in the dialog panel for Figure 6.19, a trace file will be generated called "`testcpp.ideal.stf`". After creating this file, you can then make the menu selection File->Open for the given Intel® Trace Analyzer panel and open the trace file "`testcpp.ideal.stf`" for comparative analysis. Figure 6.20 shows the side-by-side results of the actual execution trace and the ideal trace for the application "`test.cpp`".

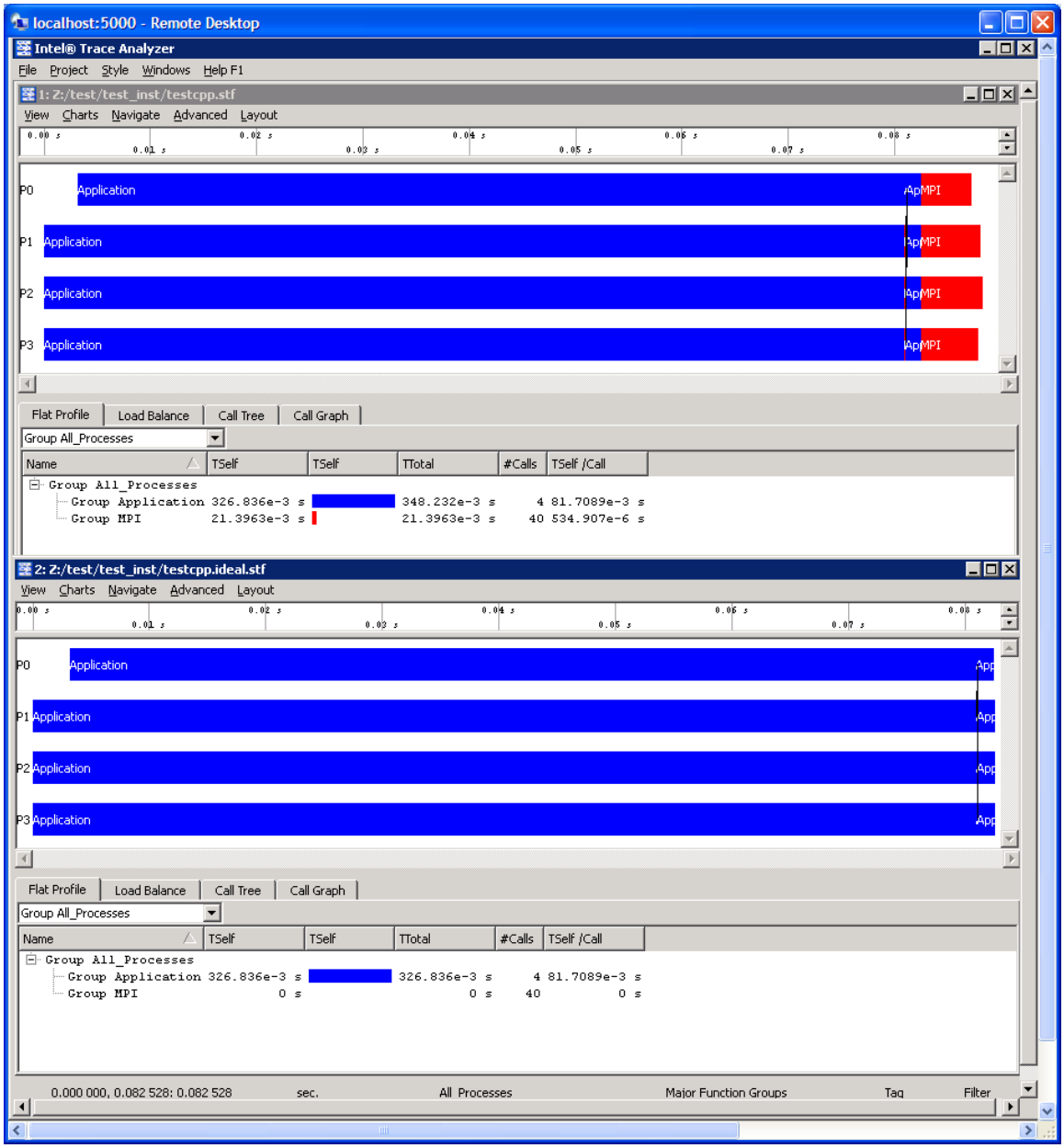

Figure 6.20 – Comparison of the actual execution trace versus the idealized trace for the application `test.cpp`

Notice in Figure 6.20 that the cost of doing message passing in the ideal case is negligible. You can use the data from the ideal case to help gauge the type of tuning performance that should be pursued.

For complete details on application imbalance, please see Section 5.3 of the Intel® Trace Analyzer Reference Guide, which is titled “Trace Idealizer Dialog Box”. The path to this file is:

<*directory-path-to-ITAC*>/doc/ITA_Reference_Guide.pdf

on the system where the Intel® Trace Analyzer and Collector is installed.

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6.9 Building a Simulator with the Custom Plug-in Framework

The Intel® Trace Analyzer and Collector provides you with a custom plug-in API that allows you to write your own simulator. The simulator API can be find in the folder path:

<*directory-path-to-ITAC*>/examples/icpf/

on the system where the Intel® Trace Analyzer and Collector is installed. The API source file within the subfolder `icpf` is called `h_devsim.cpp`. For background on building a customer simulator for trace files, please see Chapter 9 of the Intel® Trace Analyzer Reference Guide, which is titled “Custom Plug-in Framework”. The path to this file is:

<*directory-path-to-ITAC*>/doc/ITA_Reference_Guide.pdf

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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 `017` may vary. The default directory path for the library installation process is:

```
/opt/intel/ictce/4.0.0.017/mkl
```

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

```
benchmarks/
doc/
examples/
include/
interfaces/
lib/
licenses/
man/
tests/
tools/
uninstall.sh
```

Complete user documentation for Intel Math Kernel Library 10.2 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.

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

Note that the gmake command above is applicable to Intel® 64 processor-based systems. This makefile creates and runs executables for the ScaLAPACK (SCAlable LAPACK) examples.

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

Finally, for IA-32 architectures, the gmake command might be:

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

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 Intel® 64 architecture, using Intel MPI Library 4.0, 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.

```
SCALAPACK banded linear systems.
'MPI machine'

Tests of the parallel complex single precision band matrix solve
The following scaled residual checks will be computed:
 Solve residual         = ||Ax - b|| / (||x|| * ||A|| * eps * N)
 Factorization residual = ||A - LU|| / (||A|| * 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:
  N    :             3     5    17
  bwl  :             1
  bwu  :             1
  NB   :            -1
  NRHS :             4
  NBRHS:             1
  P    :             1     1     1     1
  Q    :             1     2     3     4

Relative machine precision (eps) is taken to be       0.596046E-07
Routines pass computational tests if scaled residual is less than   3.0000

TIME TR      N  BWL BWU    NB  NRHS    P    Q L*U Time Slv Time   MFLOPS   MFLOP2  CHECK
---- -- ------  --- ---  ---- ----- ---- ---- -------- -------- -------- -------- ------

WALL N       3   1   1    3     4    1    1     0.000   0.0001     1.06     1.00 PASSED
WALL N       5   1   1    5     4    1    1     0.000   0.0001     1.75     1.66 PASSED
WALL N      17   1   1   17     4    1    1     0.000   0.0001     6.10     5.77 PASSED
WALL N       3   1   1    2     4    1    2     0.000   0.0003     0.36     0.53 PASSED
WALL N       5   1   1    3     4    1    2     0.000   0.0002     0.90     1.35 PASSED
WALL N      17   1   1    9     4    1    2     0.000   0.0002     3.03     4.59 PASSED
WALL N       3   1   1    2     4    1    3     0.001   0.0006     0.19     0.27 PASSED
WALL N       5   1   1    2     4    1    3     0.001   0.0010     0.17     0.30 PASSED
WALL N      17   1   1    6     4    1    3     0.001   0.0010     0.75     1.16 PASSED
WALL N       3   1   1    2     4    1    4     0.001   0.0007     0.17     0.24 PASSED
WALL N       5   1   1    2     4    1    4     0.002   0.0026     0.08     0.13 PASSED
WALL N      17   1   1    5     4    1    4     0.001   0.0011     0.66     1.00 PASSED

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.

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):

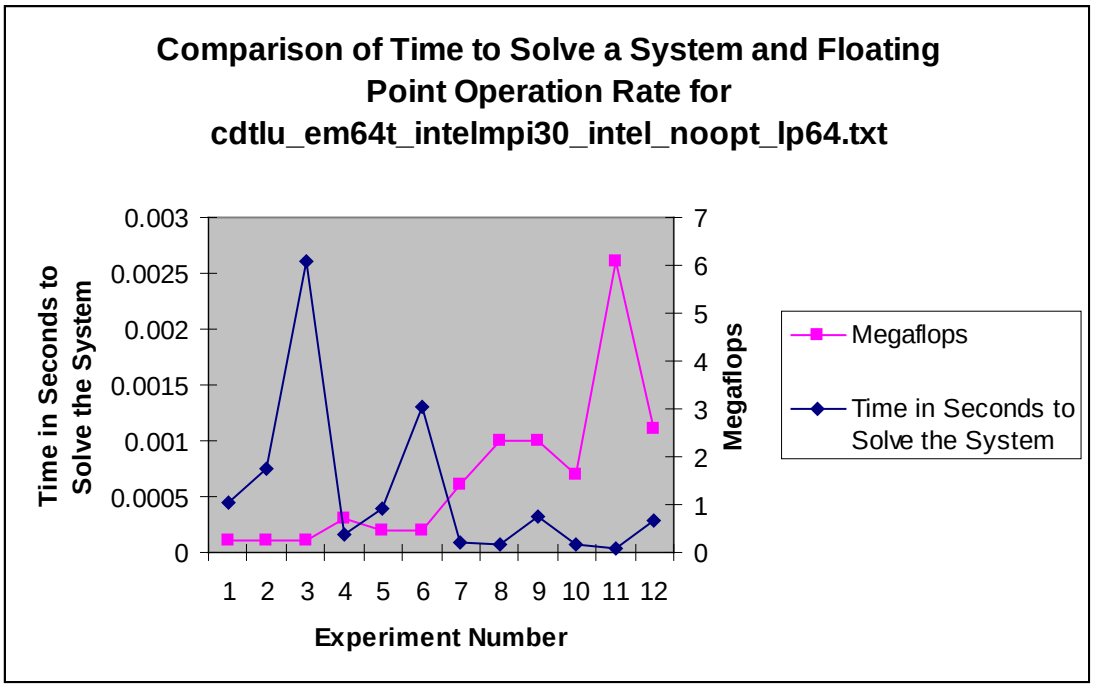

Figure 7.1 – Display of ScaLAPACK DATA from the executable `xcdtlu_em64t_intelmpi30_intel_noopt_lp64`

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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-32 cluster that is running Linux, you could use the following gmake command:

```
gmake lib32 mpi=intelmpi30 LIBdir=/opt/intel/ictce/4.0.0.017/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:

```
gmake libem64t mpi=intelmpi30
LIBdir=/opt/intel/ictce/4.0.0.017/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:

```
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:

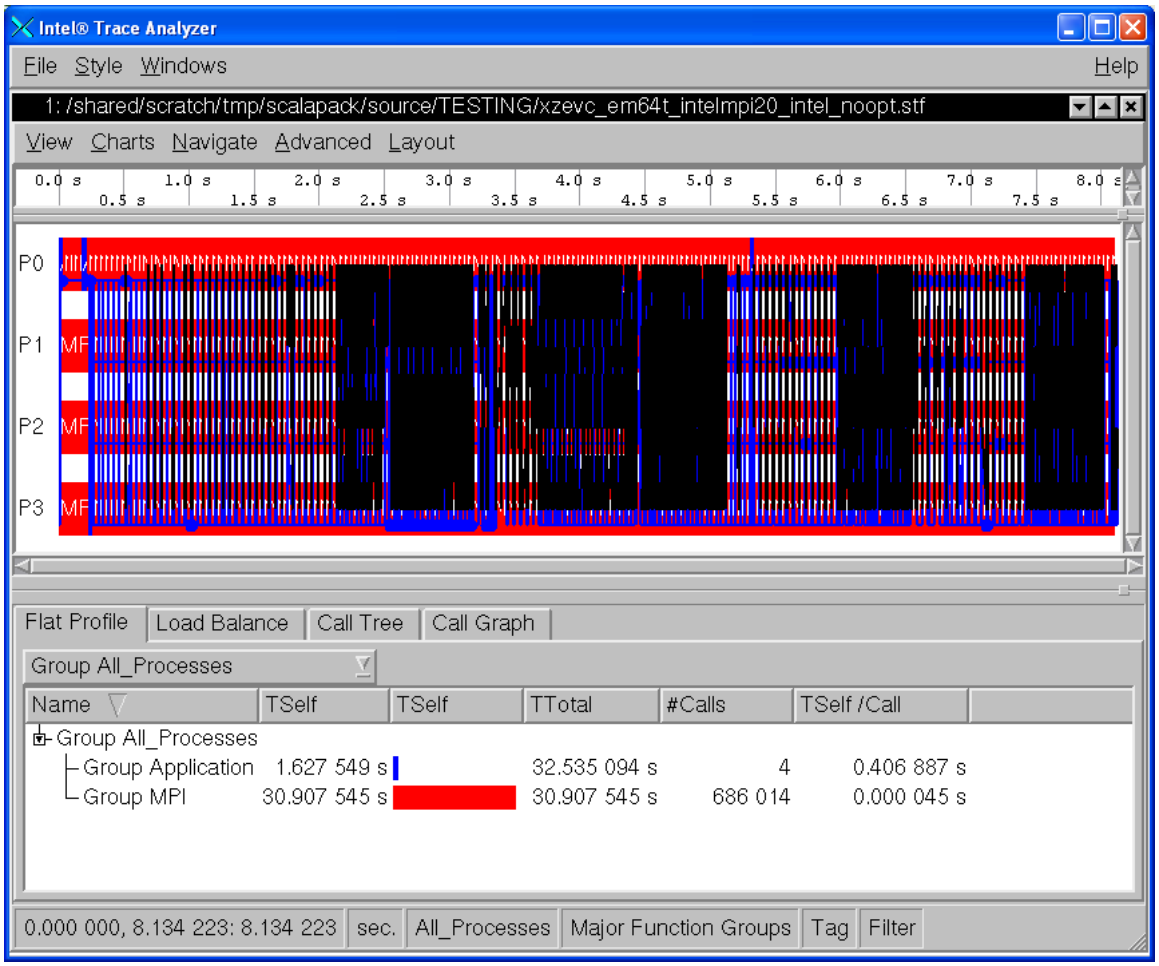

Figure 7.2 – Event Timeline Chart and the Function Profile Chart for the executable `xzevc_em64t_intelmpi30_intel_noopt_lp64`

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/4.0.0.017/mkl/lib/em64t MPILIB="-L${VT_LIB_DIR}
-lVT ${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.

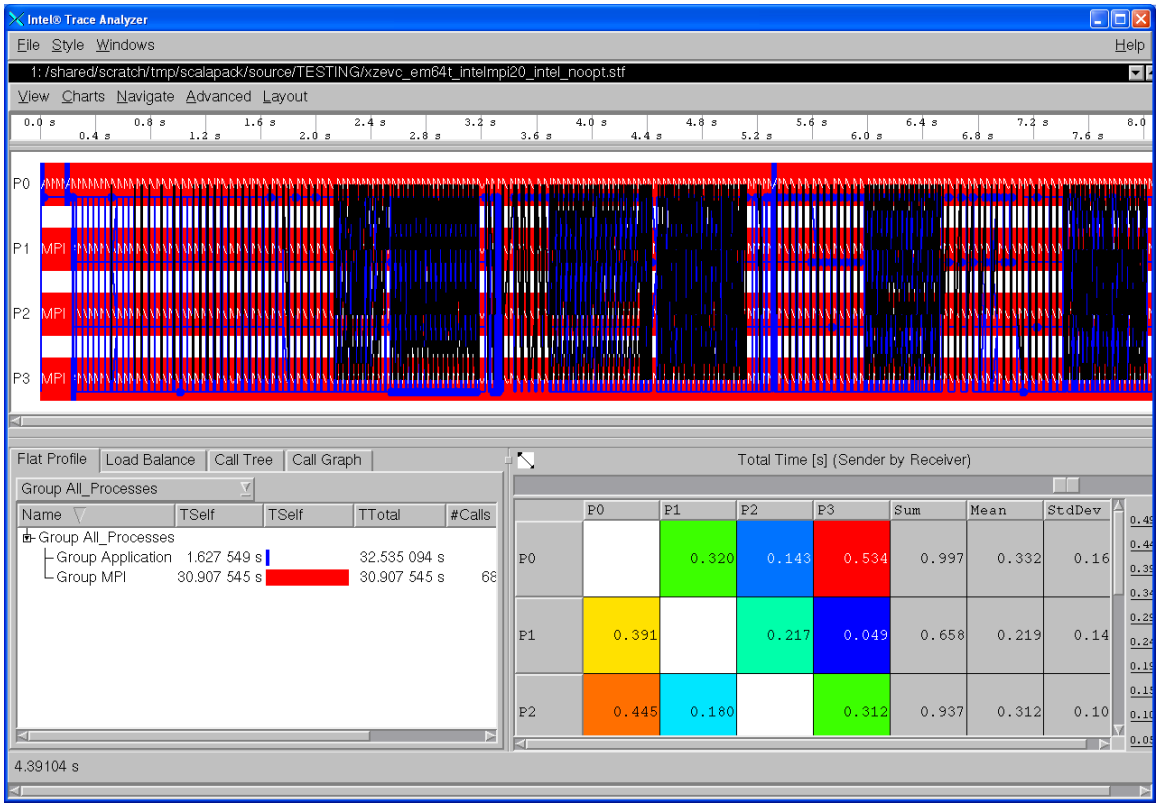

Figure 7.3 – The Message Profile Chart (lower right) for the executable `xzevc_em64t_intelmpi30_intel_noopt_lp64`

If you proceed to select **Charts->Message Profile**, you will generate the Message Profile Chart shown in Figure 7.3. Subsequently, if **Charts->Collective Operations Profile** is selected, then the chart shown in Figure 7.4 will be produced.

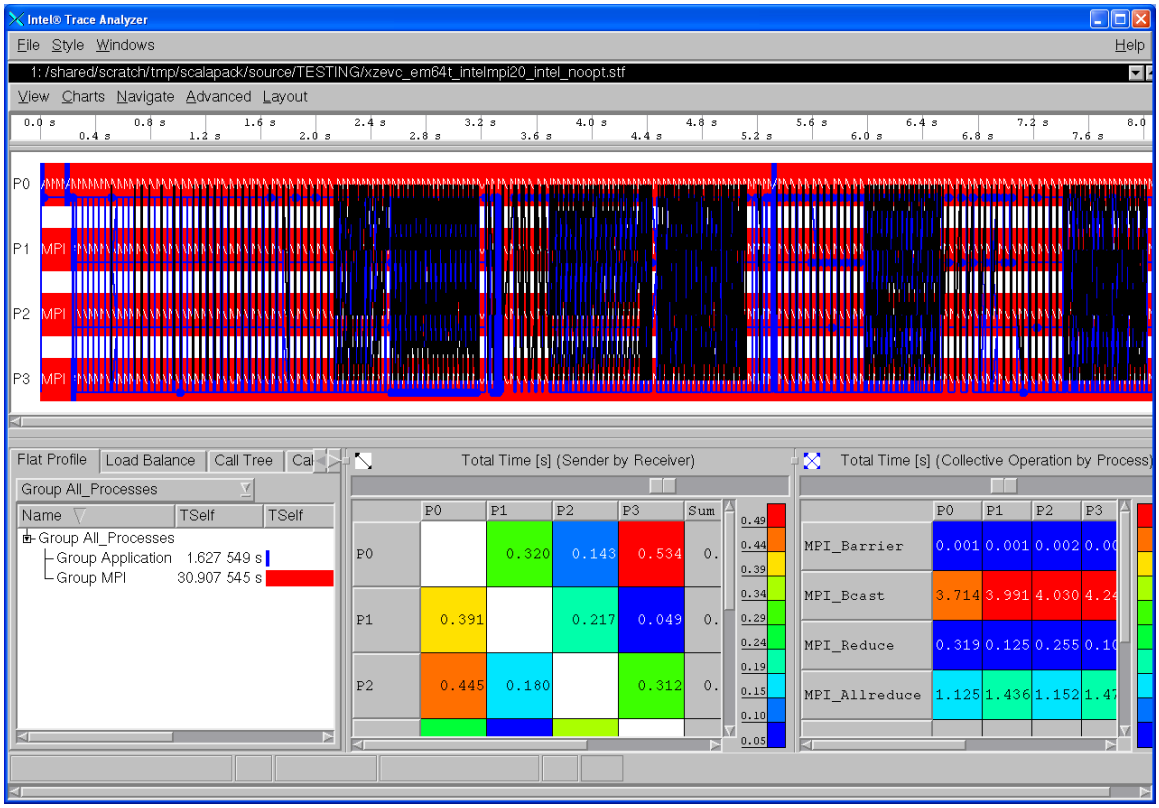

Figure 7.4 – Display of the Collective Operations Profile Chart (lower right) for `xzevc_em64t_intelmpi30_intel_noopt_lp64`

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.

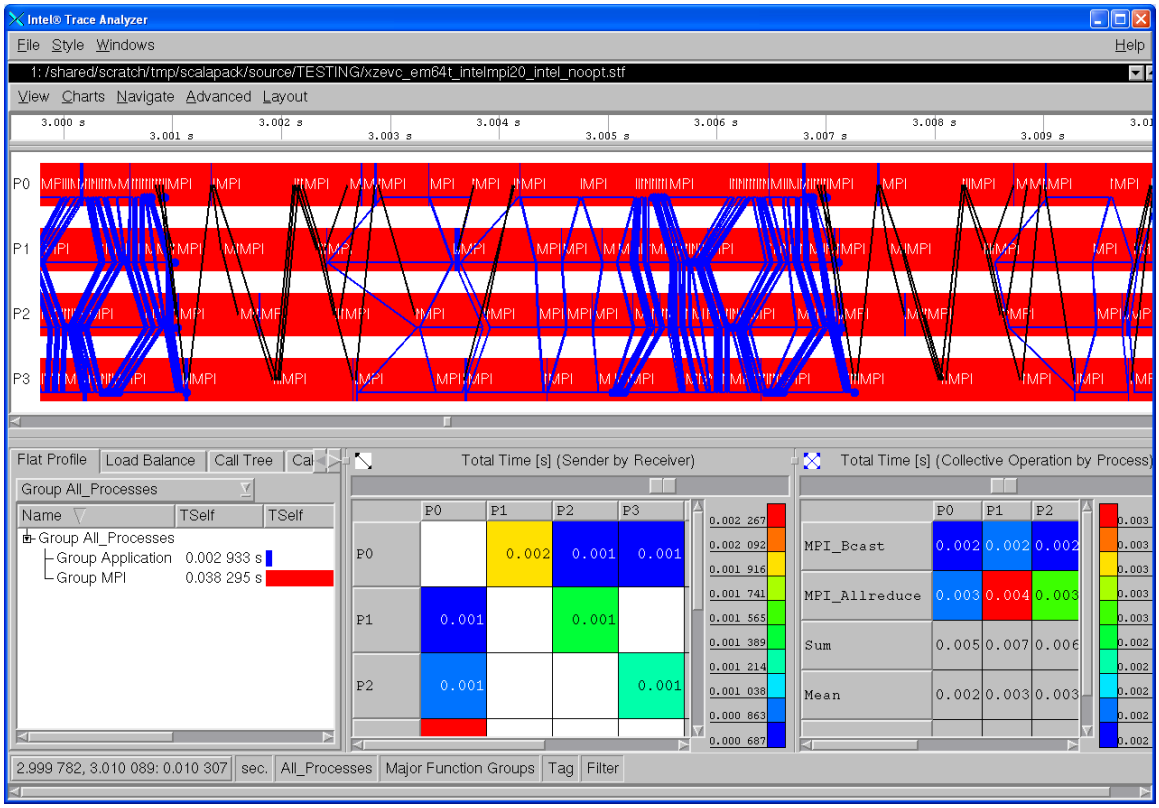

Figure 7.5 – Zooming in on the Event Timeline Chart for example `xzevc_em64t_intelmpi30_intel_noopt_lp64`

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.

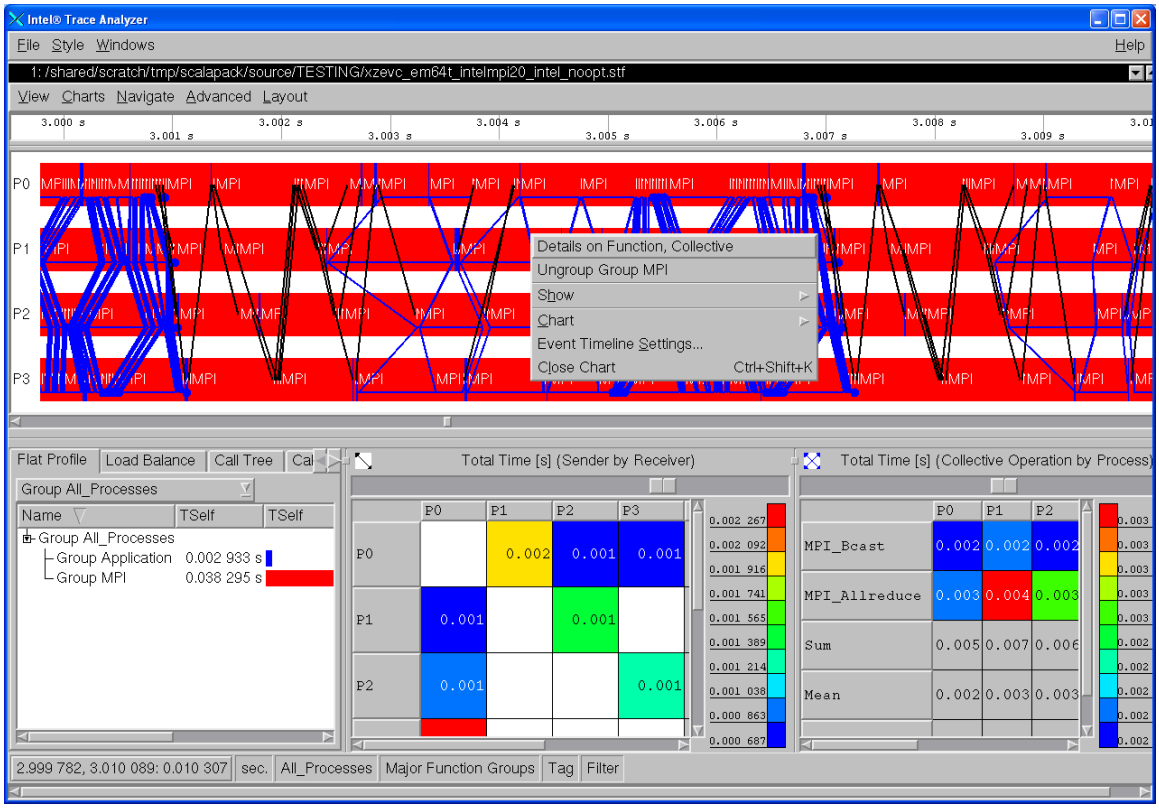

Figure 7.6 – Context Menu Selection for starting the process of drilling down to what the particular collective operation was executing (e.g. MPI_Allreduce) within the executable xzevc_em64t_intelmpi30_intel_noopt_lp64

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 –g option, and the Intel Trace Collector VT_PCTRACE environment variable would have to be set. For the ScaLAPACK gmake command, you might set the –g option with the following makefile variable:

```
OPTS="-O0 -g"
```

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7.2 Experimenting with the Cluster DFT Software

On Linux OS, in the directory path:

```
<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/         pdettc/       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:

Intel Processor Architecture	Command-line Sequence for Linux	Trace Results are Located In	Execution Results are Located In

IA-32	`#!/bin/sh`
	`export CWD=${PWD}`
	`export VT_LOGFILE_PREFIX=${CWD}/cdftc_inst`
	`rm -rf ${VT_LOGFILE_PREFIX}`
	`mkdir ${VT_LOGFILE_PREFIX}`
	`export VT_PCTRACE=5`
	`export VT_DETAILED_STATES=5`
	`cd`
	`/usr/local/opt/intel/ictce/4.0.0.017/mkl/examples/cdftc`
	`gmake lib32 mpi=intel3`
	`workdir=${VT_LOGFILE_PREFIX} CS="mpiicc -t=log" RS="mpiexec -n 4"`
	`RES_DIR=${VT_LOGFILE_PREFIX}`
		`${CWD}/cdftc_inst`	`${CWD}/cdftc_inst`

Intel® 64 (formerly Intel EM64T)	`#!/bin/sh`
	`export CWD=${PWD}`
	`export VT_LOGFILE_PREFIX=${CWD}/cdftc_inst`
	`rm -rf ${VT_LOGFILE_PREFIX}`
	`mkdir ${VT_LOGFILE_PREFIX}`
	`export VT_PCTRACE=5`
	`export VT_DETAILED_STATES=5`
	`cd`
	`/usr/local/opt/intel/ictce/4.0.0.017/mkl/examples/cdftc`
	`gmake libem64t mpi=intel3`
	`workdir=${VT_LOGFILE_PREFIX} CS="mpiicc -t=log" RS="mpiexec -n 4"`
	`RES_DIR=${VT_LOGFILE_PREFIX}`
		`${CWD}/cdftc_inst`	`${CWD}/cdftc_inst`

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

```
/usr/local/opt/intel/ictce/4.0.0.017/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:

```
/usr/local/opt/intel/ictce/4.0.0.017/mkl/examples/cdftc
```

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. The other target of this type is libem64t. 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:

Intel Processor Architecture	Command-line Sequence for Linux	Trace Results are Located In	Execution Results are Located In
IA-32	export VT_LOGFILE_PREFIX=${CWD}/cdftf_inst rm -rf ${VT_LOGFILE_PREFIX} mkdir ${VT_LOGFILE_PREFIX} export VT_PCTRACE=5 export VT_DETAILED_STATES=5 cd /usr/local/opt/intel/ict/4.0.0.017/mkl/examples/cdftf gmake lib32 mpi=intel3 workdir=${VT_LOGFILE_PREFIX} CS="mpiifort -t=log -DMPI_KIND_=4" RS="mpiexec -n 4" RES_DIR=${VT_LOGFILE_PREFIX}"	${CWD}/cdftf_inst	${CWD}/cdftf_inst
Intel® 64 (formerly Intel EM64T)	export VT_LOGFILE_PREFIX=${CWD}/cdftf_inst rm -rf ${VT_LOGFILE_PREFIX} mkdir ${VT_LOGFILE_PREFIX} export VT_PCTRACE=5 export VT_DETAILED_STATES=5 cd /usr/local/opt/intel/ict/4.0.0.017/mkl/examples/cdftf gmake libem64t mpi=intel3 workdir=${VT_LOGFILE_PREFIX} CS="mpiifort -	${CWD}/cdftf_inst	${CWD}/cdftf_inst

	t=log -DMPI_KIND_=4" RS="mpiexec -n 4" RES_DIR=${VT_LOGFILE_PREFIX}		

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:

```
#!/bin/sh
export CWD=${PWD}
export VT_LOGFILE_PREFIX=${CWD}/cdftc_inst
rm -rf ${VT_LOGFILE_PREFIX}
mkdir ${VT_LOGFILE_PREFIX}
export VT_PCTRACE=5
export VT_DETAILED_STATES=5
cd /usr/local/opt/intel/ict/4.0.0.017/mkl/examples/cdftc
gmake libem64t mpi=intel3 workdir=${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 ${VT_LOGFILE_PREFIX}
export VT_PCTRACE=5
export VT_DETAILED_STATES=5
cd /usr/local/opt/intel/ict/4.0.0.017/mkl/examples/cdftf
gmake libem64t mpi=intel3 workdir=${VT_LOGFILE_PREFIX} CS="mpiifort -
t=log -DMPI_KIND_=4" RS="mpiexec -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

 Row 0:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
 Row 1:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
 Row 2:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
 Row 3:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
 Row 4:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
 Row 5:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
 Row 6:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
 Row 7:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
 Row 8:
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)
(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)(   1.000,   0.000)

                                          …
```

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.

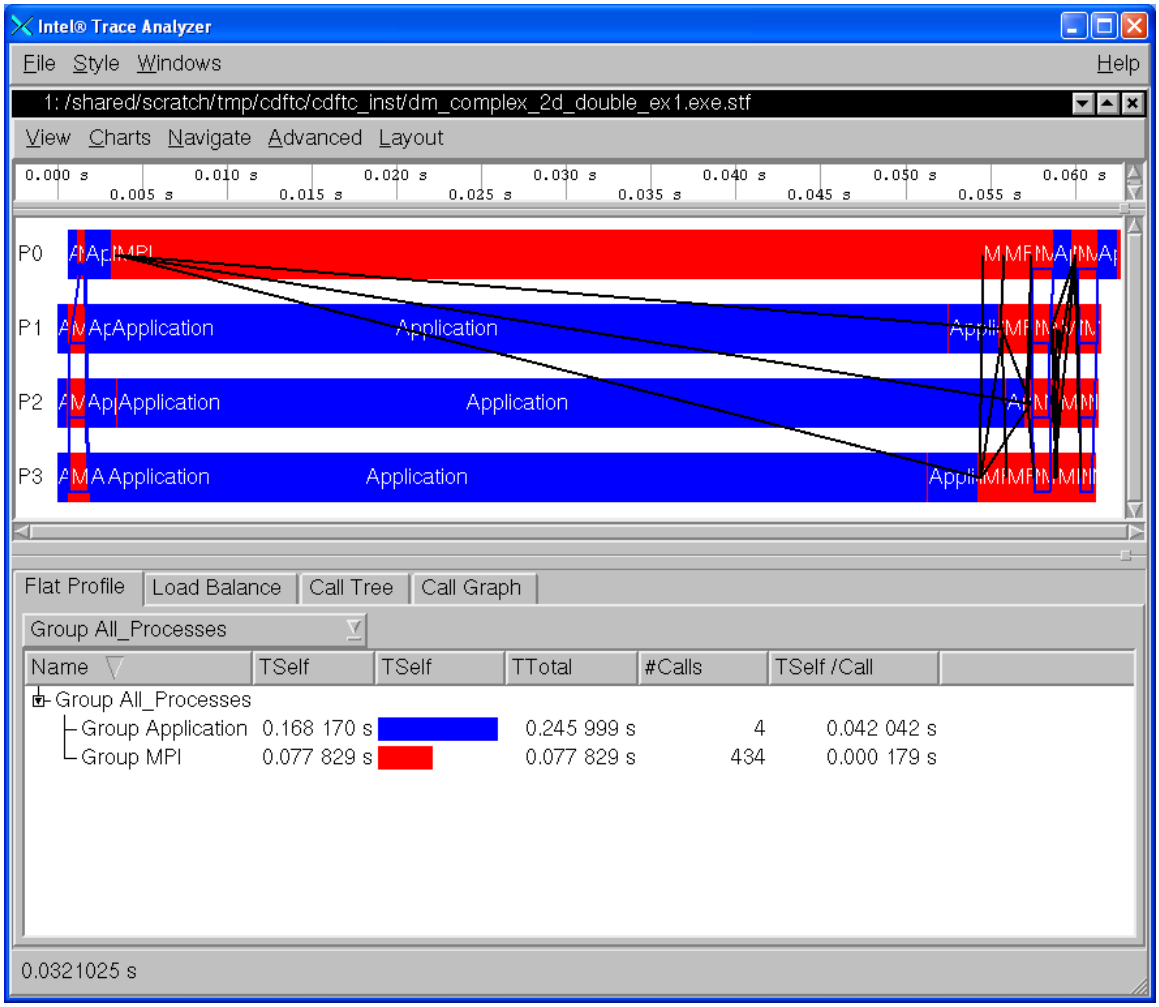

Figure 7.7 – The Event Timeline Chart and the Function Profile Chart for a Cluster Discrete Fourier Transform Example

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7.3 Experimenting with the High Performance Linpack Benchmark*

On Linux, in the directory path:

<directory-path-to-mkl>/benchmarks/mp_linpack

you will find a set of files and subdirectories that look something like the following:

```
./          COPYRIGHT*                  INSTALL*    Make.ia32* man/        src/     www/
../         HISTORY*                    lib_hybrid/ Make.ipf*  nodeperf.c* testing/
bin_intel/  HPL.build.log.220120040613* Make.em64t* makes/     README*     TODO*
```

```
BUGS*       include/                    Makefile*   Make.top*  setup/      TUNING*
```

If you make a scratch directory, say:

```
test_mp_linpack
```

on a file share for your cluster, and copy the contents of <*directory-path-to-mkl*>/benchmarks/mp_linpack into that scratch directory you can then proceed to build a High Performance Linpack executable. To create an executable for Intel® 64 architecture, you might issue the following gmake command:

```
gmake arch=em64t
LAdir=/usr/local/opt/intel/ictce/4.0.0.010/mkl/lib/em64t
LAinc=/usr/local/opt/intel/ictce/4.0.0.010/mkl/include
```

where the command sequence above is one continuous line. The macros LAdir and LAinc describe the directory path to the Intel® 64 Math Kernel library and the Intel® MKL include directory, respectively. The partial directory path /usr/local/opt/intel/ictce/4.0.0.010 for the macros LAdir and LAinc should be considered an *example* of where an Intel® Math Kernel Library might reside. Note that on your system, the path and a version number value such as 4.0.0.010 may vary depending on *your* software release.

The High Performance Linpack executable for the gmake command above will be placed into …/test_mp_linpack/bin/em64t and will be called xhpl. The table below summarizes makefile and associated mpiexec commands that might be used to create xhpl executables for IA-32, and Intel® 64 architectures, respectively. The command-line syntax in the table is that of Bourne* Shell or Korn* Shell. The mpiexec commands use 4 MPI processes to do the domain decomposition.

Intel Processor Architecture	Command-line Sequence for Linux	Executable is Located In	Execution Results are Located In
IA-32	#!/bin/sh export CWD=${PWD} gmake clean_arch_all arch=ia32 gmake arch=ia32 LAdir=/usr/local/opt/intel/ictce/4.0.0.010/mkl/lib/32 LAinc=/usr/local/opt/intel/ictce/4.0.0.010/mkl/include cd ${CWD}/bin/ia32 mpiexec –n 4 ./xhpl > results.ia32.out	${CWD}/bin/ia32	${CWD}/bin/ia32
Intel® 64 (formerly Intel EM64T)	#!/bin/sh export CWD=${PWD} gmake clean_arch_all arch=em64t gmake arch=em64t LAdir=/usr/local/opt/intel/ictce/4.0.0.010/mkl/lib/em64t LAinc=/usr/local/opt/intel/ictce/4.0.0.010/mkl/include cd ${CWD}/bin/em64t mpiexec –n 4 ./xhpl > results.em64t.out	${CWD}/bin/em64t	${CWD}/bin/em64t

The output results *might* look something like the following for Intel® 64 architecture:

```
================================================================================
HPLinpack 2.0  --  High-Performance Linpack benchmark  --   September 10, 2008
Written by A. Petitet and R. Clint Whaley,  Innovative Computing Laboratory, UTK
Modified by Piotr Luszczek, Innovative Computing Laboratory, UTK
Modified by Julien Langou, University of Colorado Denver
================================================================================

An explanation of the input/output parameters follows:
T/V    : Wall time / encoded variant.
N      : The order of the coefficient matrix A.
NB     : The partitioning blocking factor.
P      : The number of process rows.
Q      : The number of process columns.
Time   : Time in seconds to solve the linear system.
Gflops : Rate of execution for solving the linear system.

The following parameter values will be used:

N      :    1000
NB     :     112      120
PMAP   : Row-major process mapping
P      :       1        2        1        4
Q      :       1        2        4        1
PFACT  :    Left
NBMIN  :       4        2
NDIV   :       2
```

```
RFACT  :   Crout
BCAST  :   1ring
DEPTH  :       0
SWAP   : Mix (threshold = 256)
L1     : no-transposed form
U      : no-transposed form
EQUIL  : no
ALIGN  : 8 double precision words

--------------------------------------------------------------------------------

                                       ...

================================================================================
T/V                N    NB     P     Q               Time                 Gflops
--------------------------------------------------------------------------------
WR00C2L2        1000   120     4     1               0.35             1.894e+00
--------------------------------------------------------------------------------
||Ax-b||_oo/(eps*(||A||_oo*||x||_oo+||b||_oo)*N)=        0.0052671 ..... PASSED
================================================================================

Finished     16 tests with the following results:
             16 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 file <*directory-path-to-mkl*>/doc/mkl_documentation.htm contains a landing page linking various documentation files associated with Intel MKL 10.2. To make inquiries about Intel Math Kernel Library 10.2, visit the URL: http://premier.intel.com.

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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_Users_Guide.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

mpiexec -n 4 IMB-IO >&! IMB-IO.report

mpiexec -n 4 IMB-MPI1 >&! IMB-MPI1.report
```

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9. Uninstalling the Intel® Cluster Toolkit Compiler Edition on Linux* OS

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-Compiler-Edition>/uninstall.sh`

An example folder might be:

`/usr/local/opt/intel/ictce/4.0.0.017/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
    uninstall.sh - Uninstall Intel(R) Cluster Toolkit Compiler Edition
for Linux* 4.0.

SYNOPSIS
    uninstall.sh [options]

Copyright(C) 1999-2010, Intel Corporation. All Rights Reserved.
```

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10. Hardware Recommendations for Installation on Linux* OS

Processor System Requirements

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

NOTE: It is assumed that the processors listed above are configured into homogeneous clusters.

Disk-Space Requirements

20 GBs of disk space (minimum)

NOTE: 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* OS

OS Distributions	IA-32 Architecture	Intel® 64 Architecture	
		32-Bit Applications	64-Bit Applications
Red Hat Enterprise Linux* 4.0	S	S	S
Red Hat Enterprise Linux* 5.0	S	S	S
SUSE Linux Enterprise Server* 10	S	S	S
SUSE Linux Enterprise Server* 11	S	S	S

S = Supported

Memory Requirements

2 GB of RAM (minimum)

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11. System Administrator Checklist for Linux* OS

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
```

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12. User Checklist for Linux* OS

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 export
   ```

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/4.0.0.017/ictvars.sh
   ```

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

   ```
   setenv INTEL_LICENSE_FILE /opt/intel/licenses
   source /opt/intel/ictce/4.0.0.017/ictvars.csh
   ```

3. For Bourne* Shell on Linux*, once the Intel® Cluster Toolkit Compiler Edition environment variables referenced within "ictvars.sh" file have been sourced via a .bashrc file, users for a given Bourne* Shell login session can simply type:

   ```
   . ictvars.sh ia32
   ```

   for creating IA-32 executables. Alternatively, to restore the default Intel® Cluster Toolkit environment variable settings so as to build executables with Intel® 64 address extensions, simply type:

   ```
   . ictvars.sh
   ```

   within the Bourne* Shell login session.

   Note that the full path to ictvars.sh can be omitted once it has been sourced in the .bashrc file.

   For a C Shell login session on Linux*, IA-32 executables can be created with a login session command such as:

   ```
   source /opt/intel/ict/4.0.0.035/ictvars.csh ia32
   ```

Within a C Shell login session, to restore the default Intel® Cluster Toolkit Compiler Edition environment variable settings so as to build executables with Intel® 64 address extensions, simply type:

```
source /opt/intel/ict/4.0.0.035/ictvars.csh
```

4. 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
   ```

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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.

Library Selection	Meaning	How to Request
libVT.a	Default library	`-tcollect`
libVTcs.a	Client-server trace collection library	`-tcollect=VTcs`
libVTfs.a	Fail-safe trace collection library	`-tcollect=Vtfs`

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.

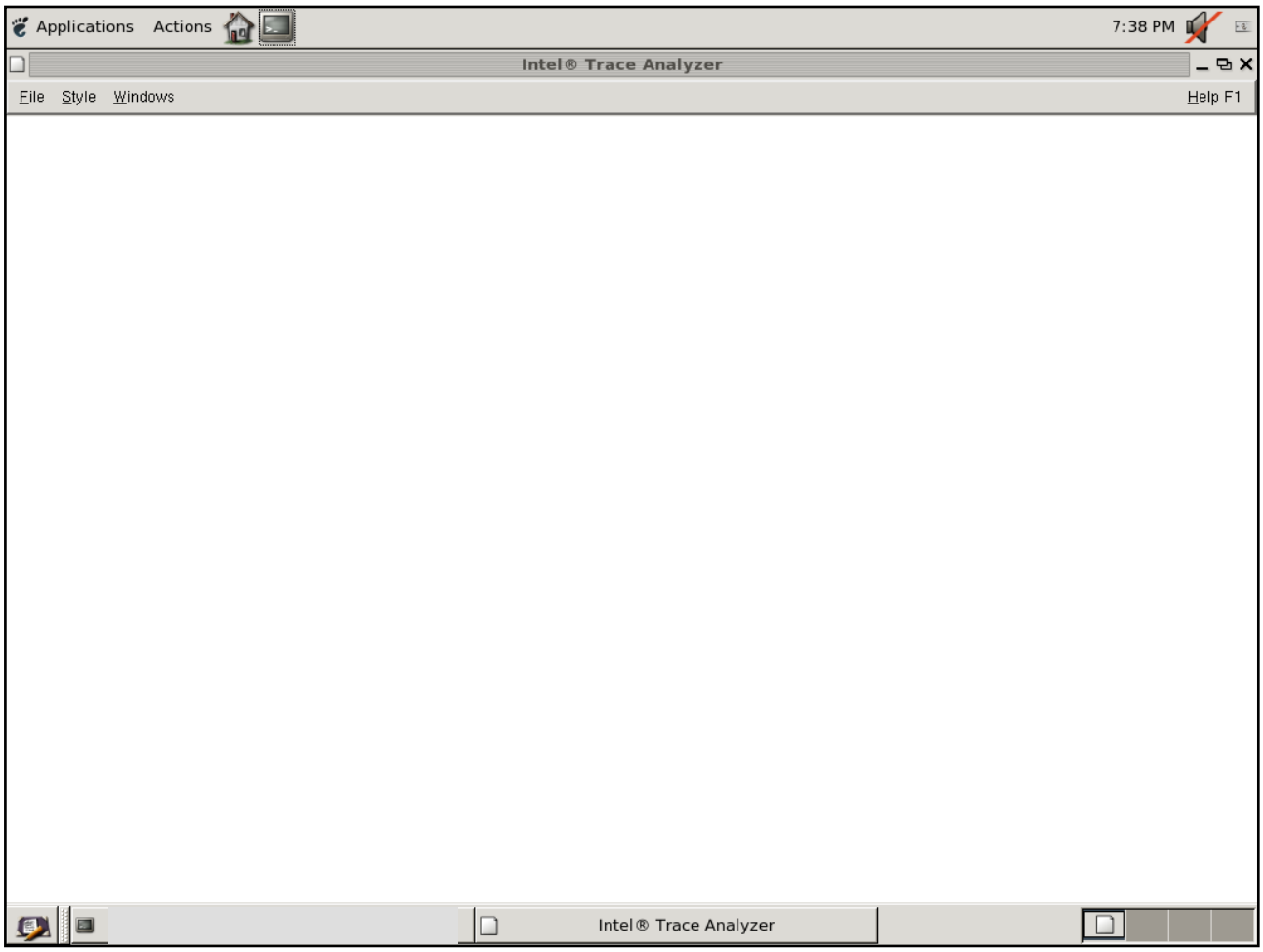

Figure 13.1 – Base panel for the Intel Trace Analyzer when invoking a Linux Shell Command: `traceanalyzer` without any arguments

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

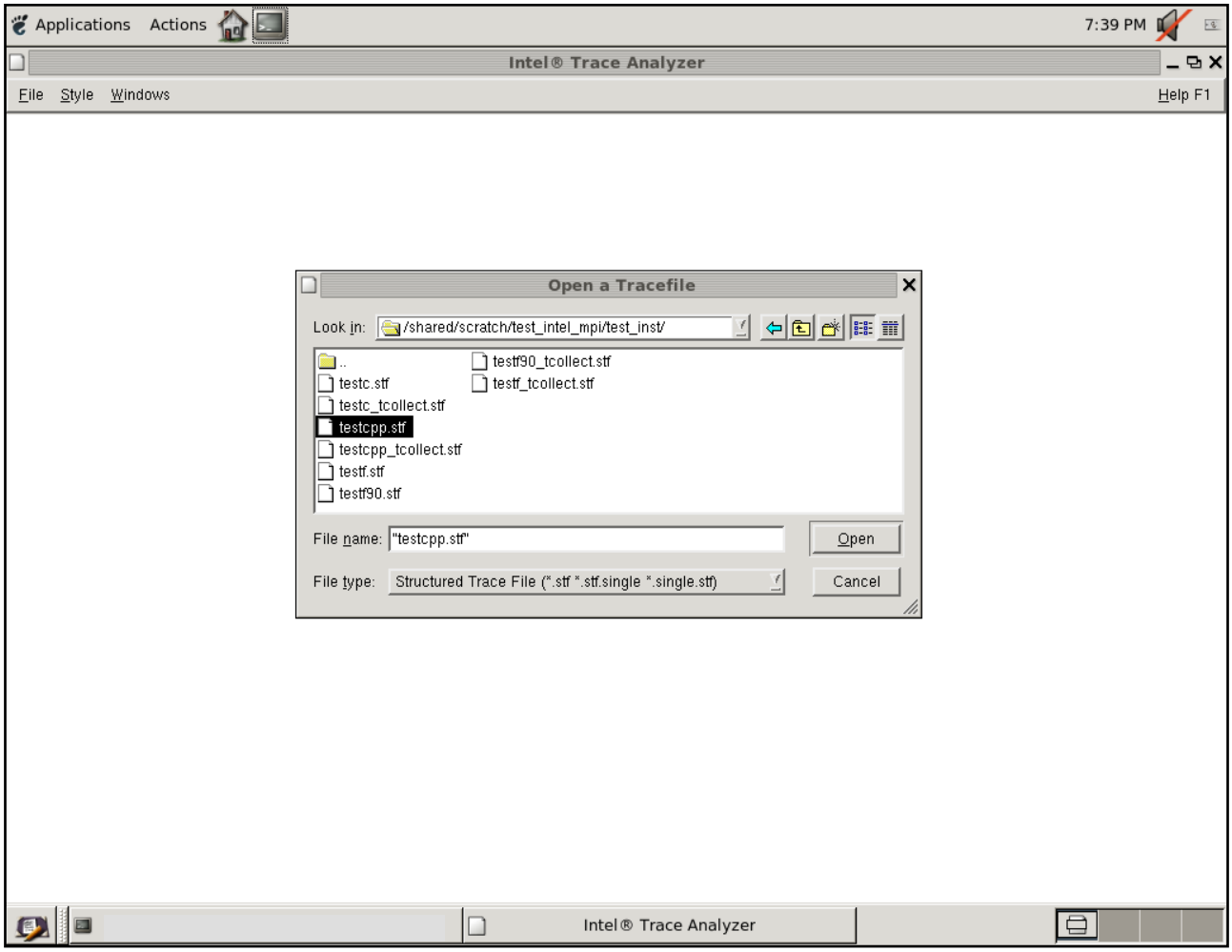

Figure 13.2 – Open a Tracefile Rendering for the `test_inst` Folder where `testcpp.stf` has been Highlighted

Selecting `testcpp.stf` will generate a Flat Profile panel within the Intel Trace Analyzer session that might look something like the following.

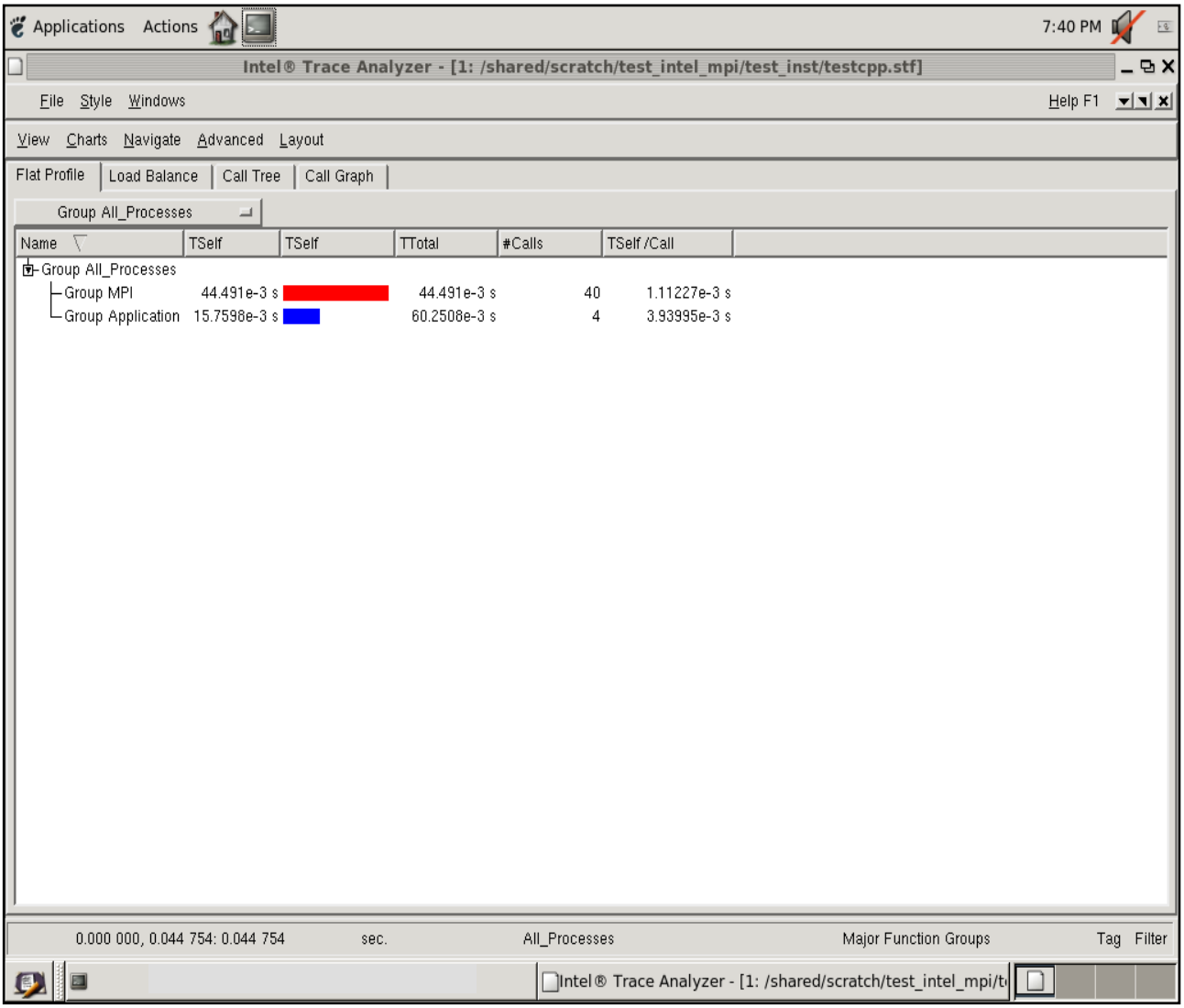

Figure 13.3 – Flat Panel Display for test_inst\testcpp.stf

For the Flat Panel Display, if you select `File->Compare` the following sub-panel will appear.

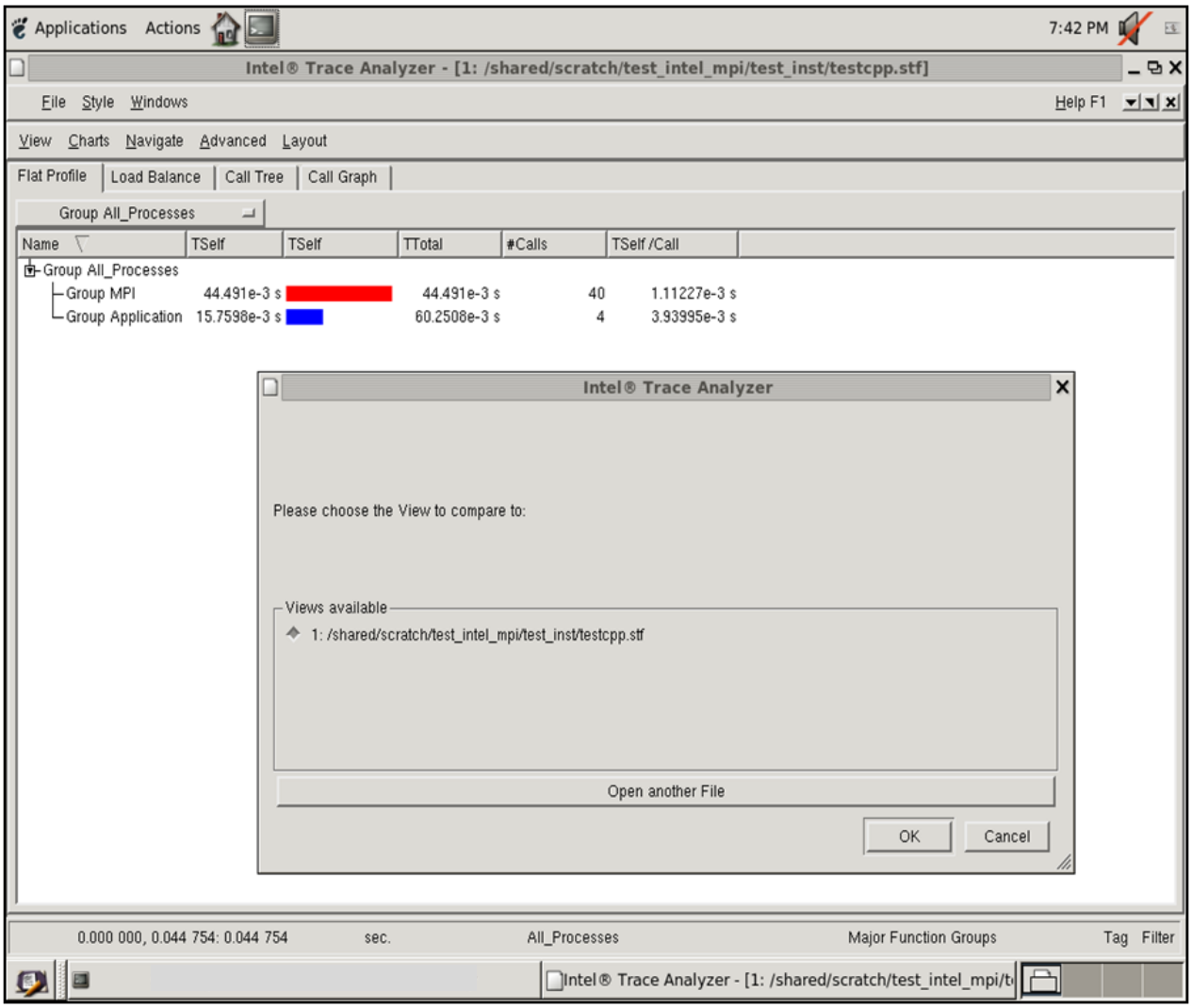

Figure 13.4 – Sub-panel Display for Adding a Comparison STF File

Click on the “Open another file” button and select `testcpp_tcollect.stf` and then proceed to push on the Open button with your mouse.

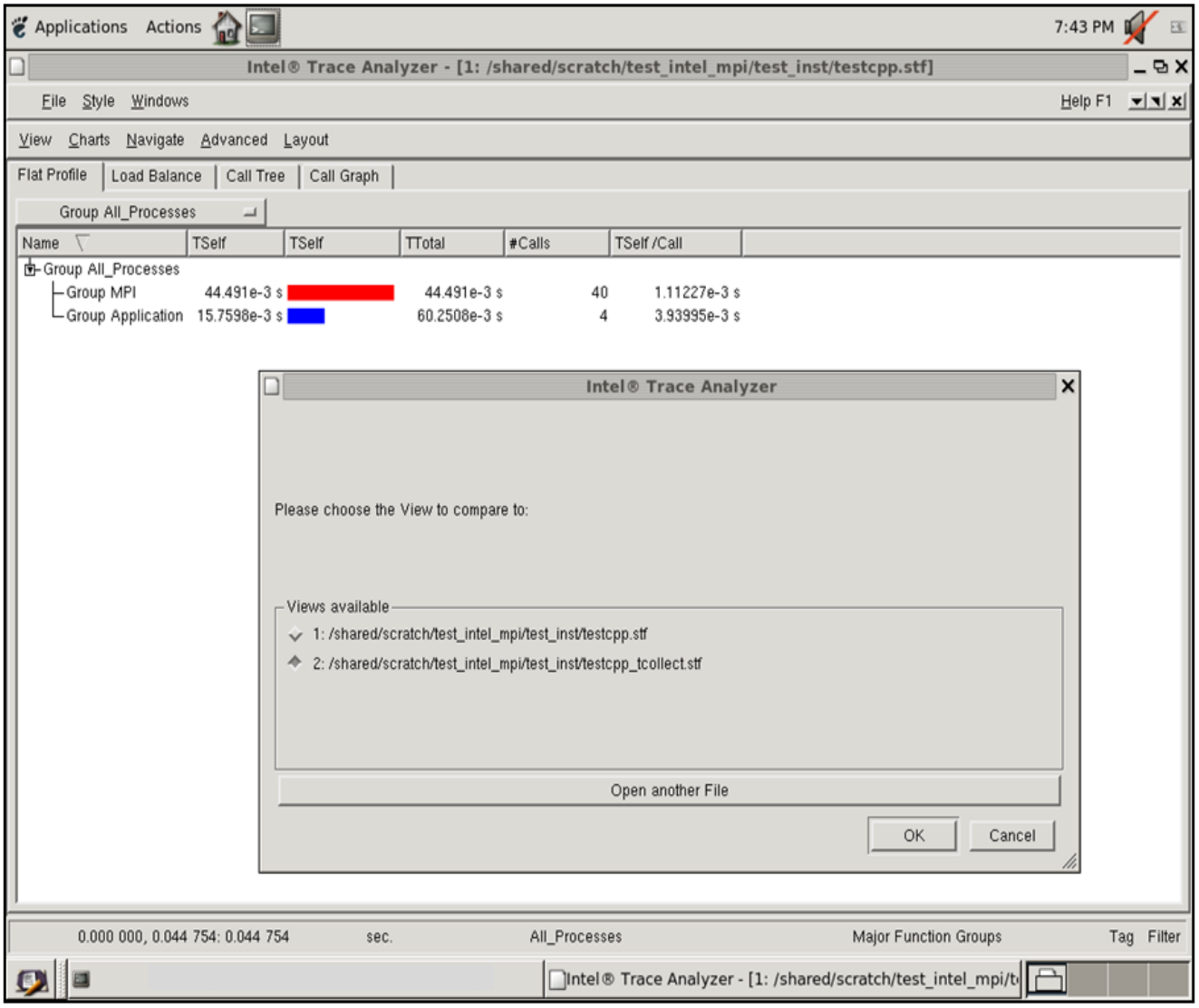

Figure 13.5 – Sub-panel Activating the Second STF File for Comparison

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`).

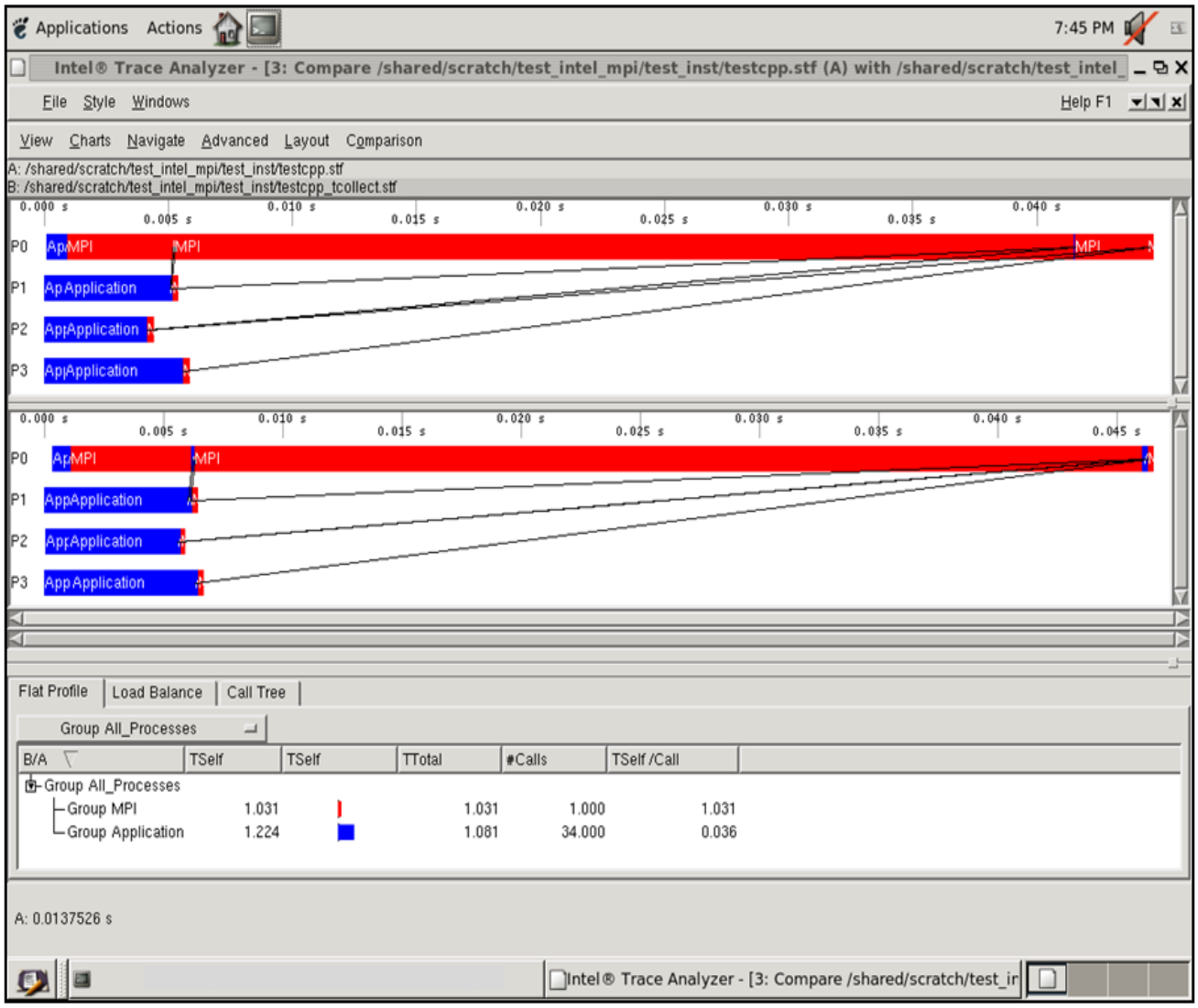

Figure 13.6 – Comparison of `testcpp.stf` and `testcpp_tcollect.stf`

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:

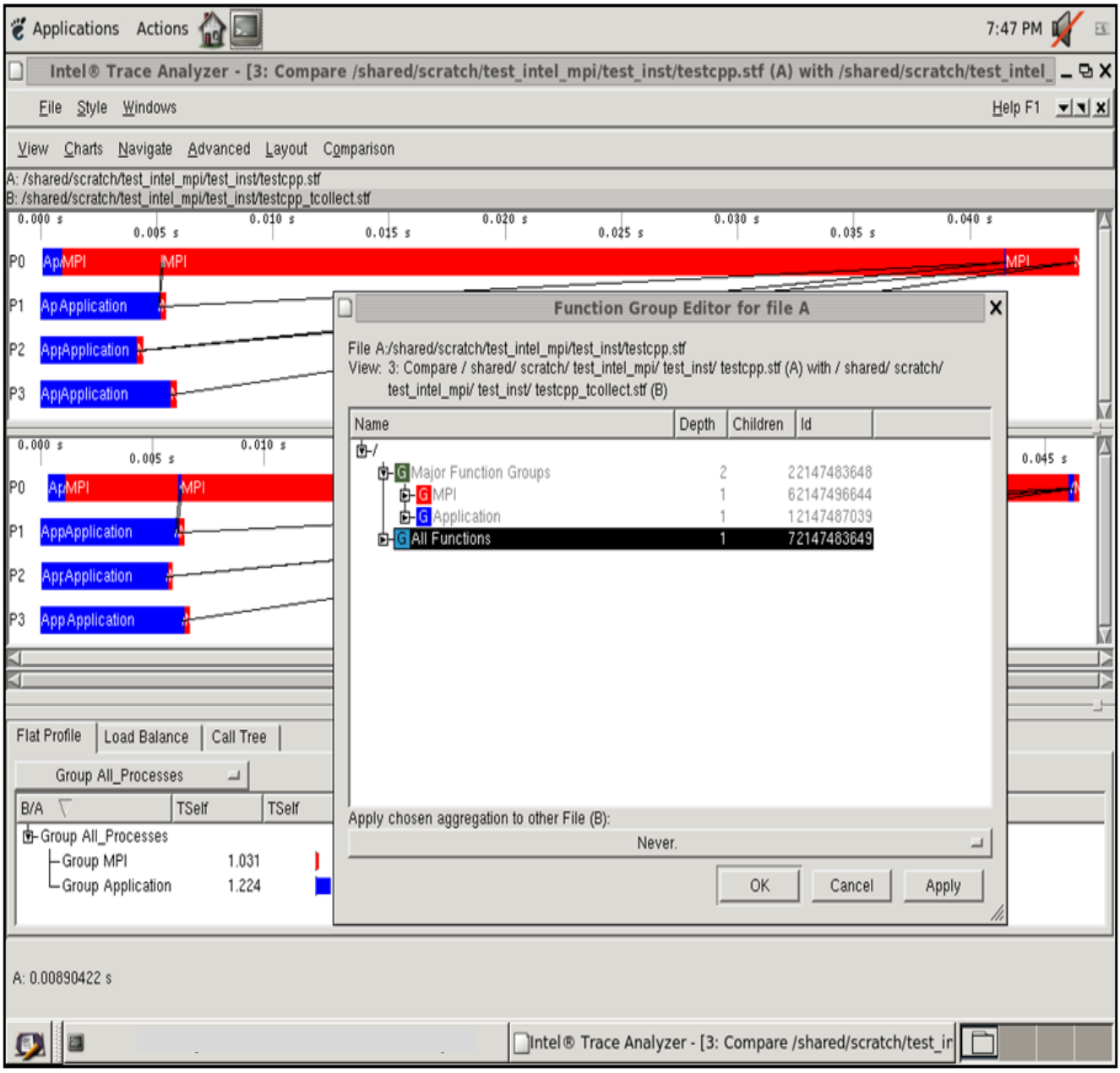

Figure 13.7 – "Function Group Editor for file A" Display (i.e, for file `testcpp.stf`)

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:

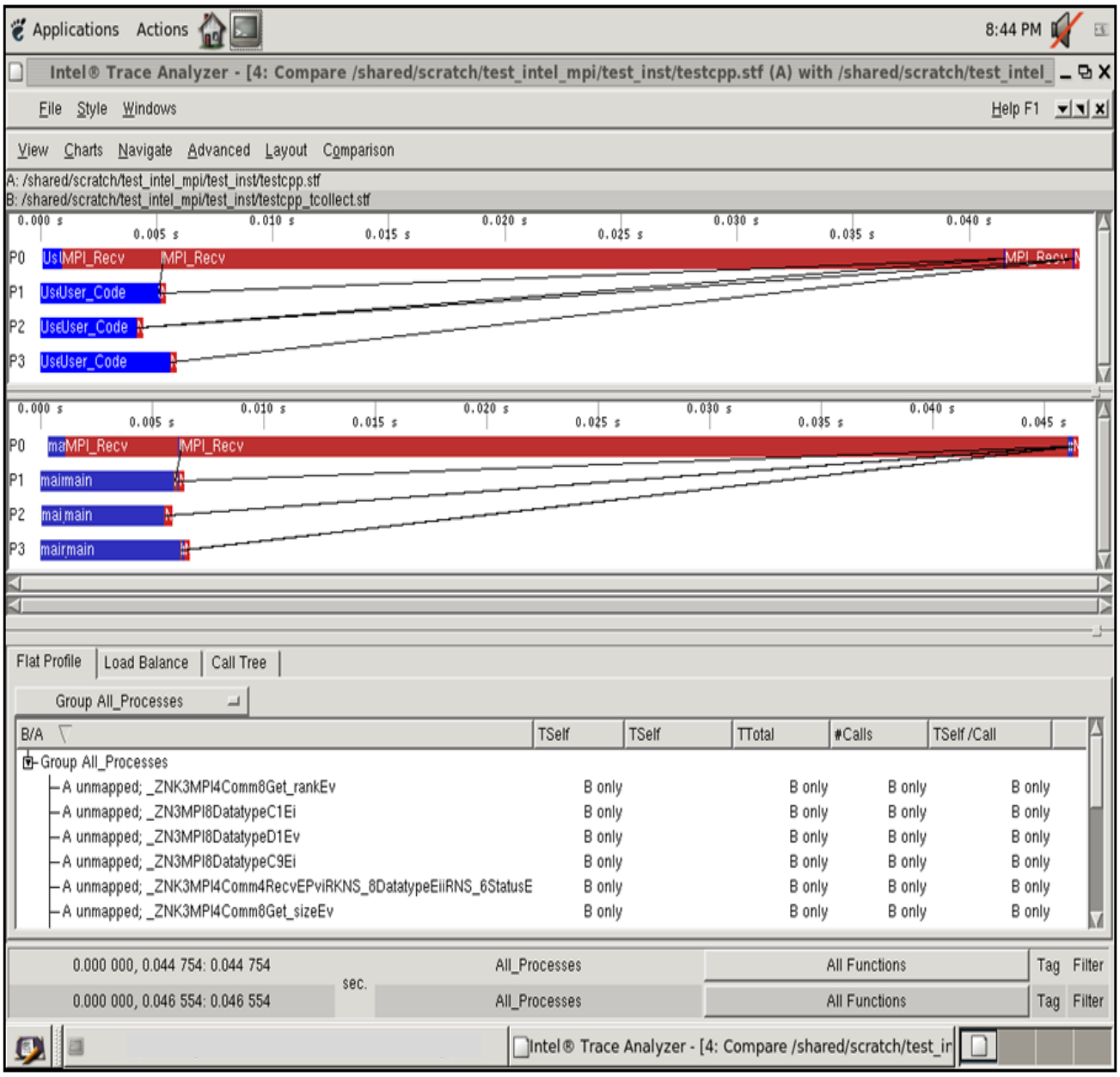

Figure 13.8 – Comparison of STF Files `testcpp.stf` and `testcpp_tcollect.stf` after making the All Functions Selection

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:

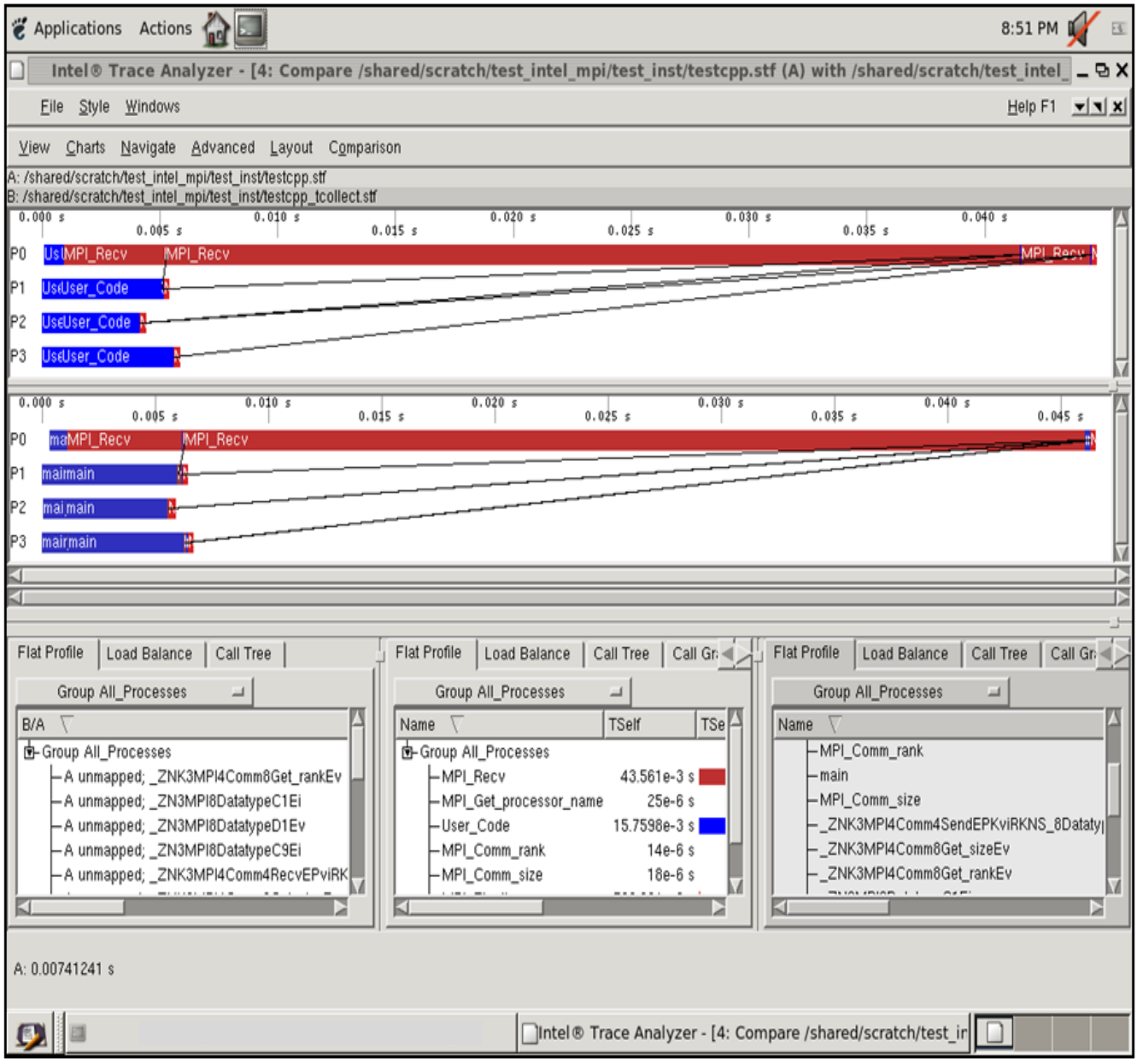

Figure 13.9 – Function Profile Sub-panels in the Lower Middle and Lower Right Sections of the Display for `testcpp.stf` and `testcpp_tcollect.stf`

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

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14. Using Cluster OpenMP*

Cluster OpenMP is only available on Linux platforms. The Intel® architecture must be Intel® 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:

   Speedup = Time(1 thread) / Time(*n* threads) = ~*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:

Speedup = Time(serial) / 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
```

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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
```

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`.

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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
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.

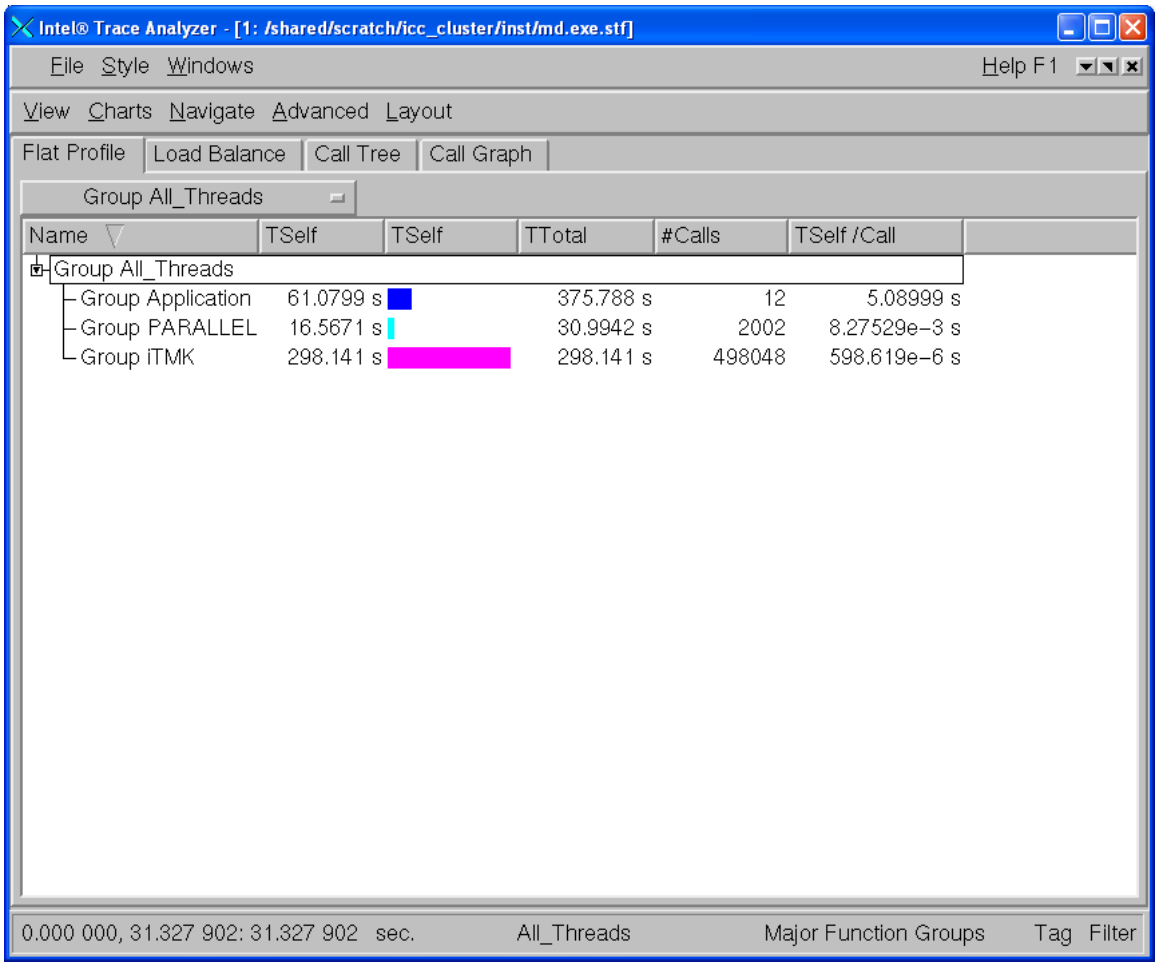

Figure 14.1 – Profile Display for trace file `md.ex.stf`

Figure 14.2 shows the result of opening up the Event Timeline display through the menu selection Charts->Event Timeline:

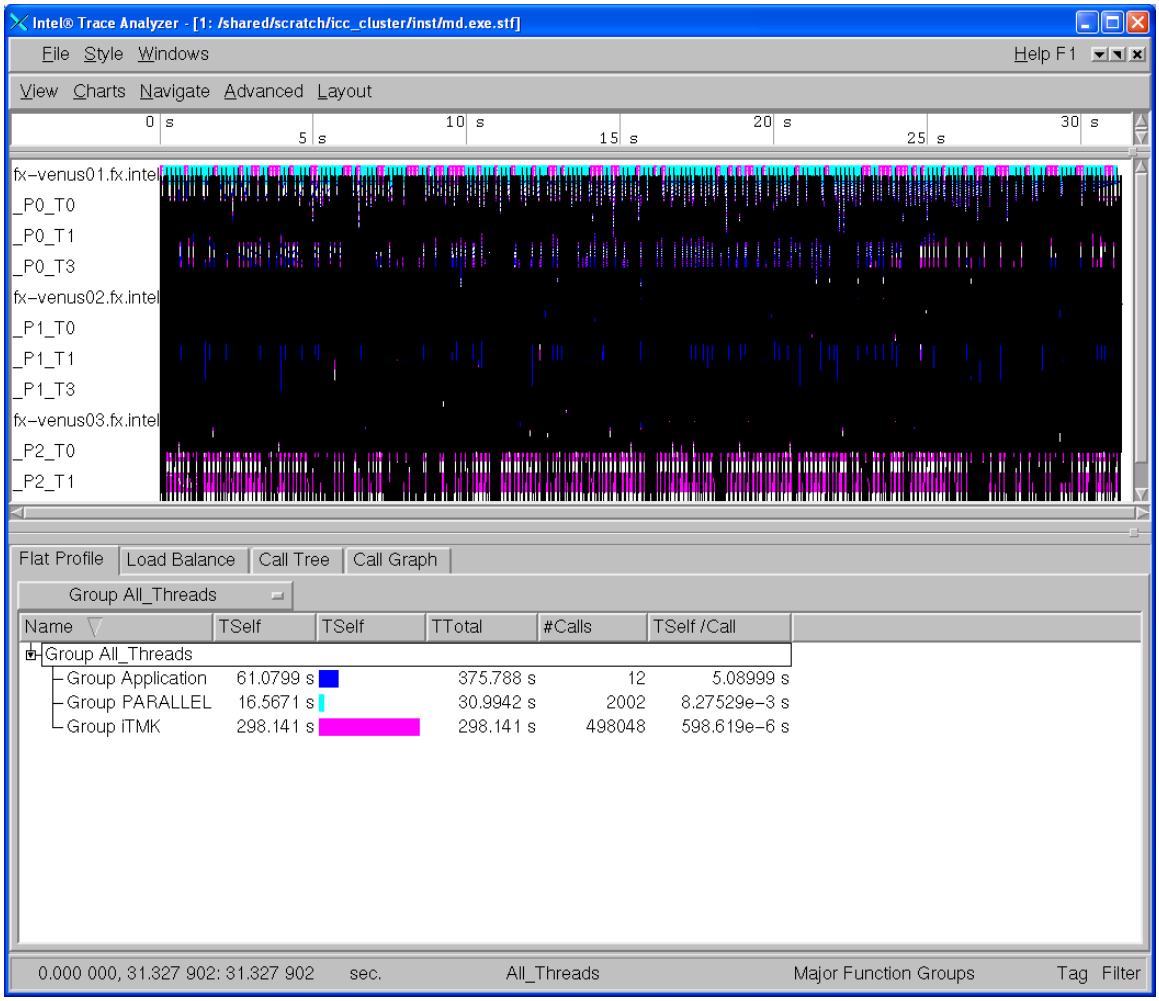

Figure 14.2 – Intel® Trace Analyzer display showing the Event Timeline and Function profile display for `md.exe`

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).

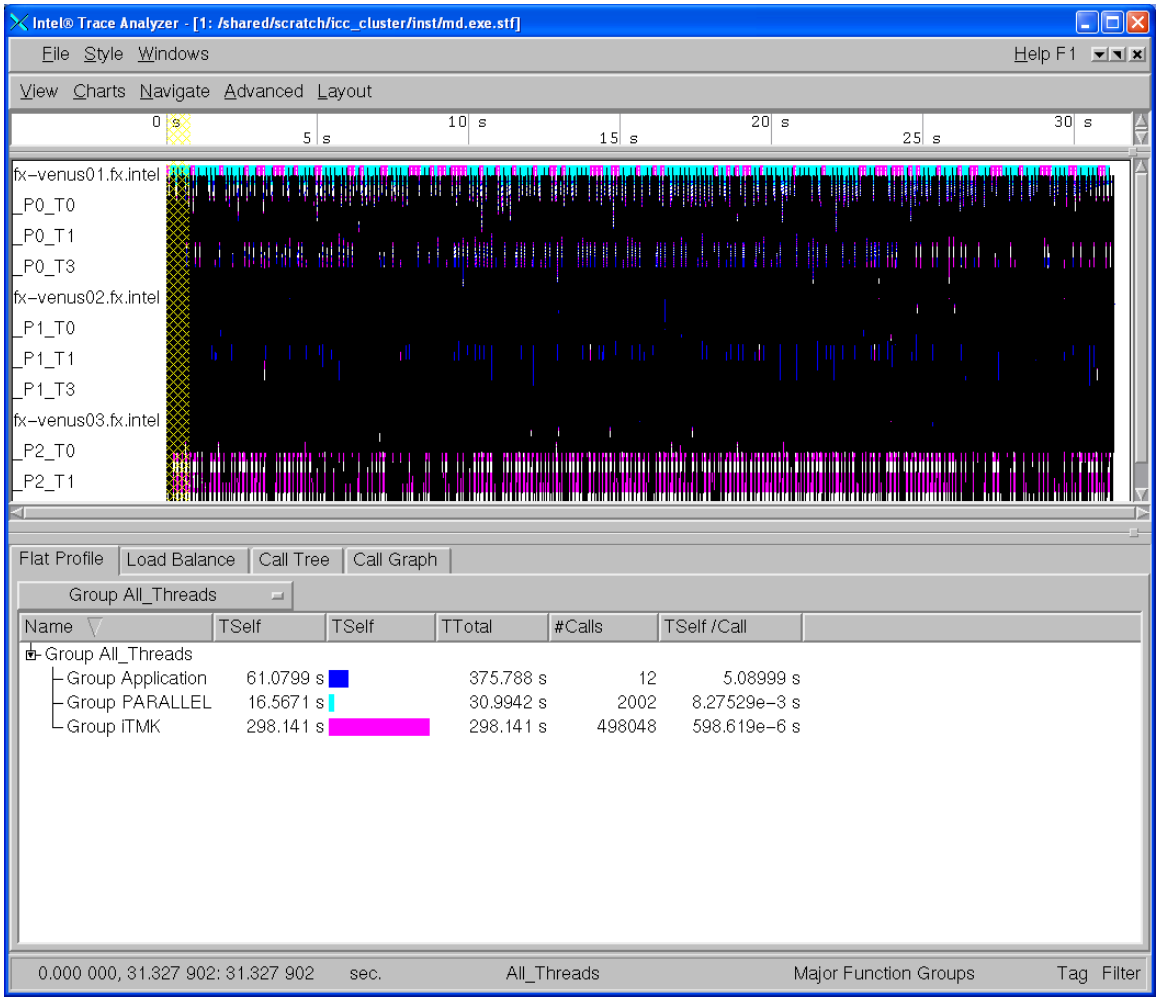

Figure 14.3 – Highlighting a time interval (shown in yellow) with the leftmost mouse button

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.

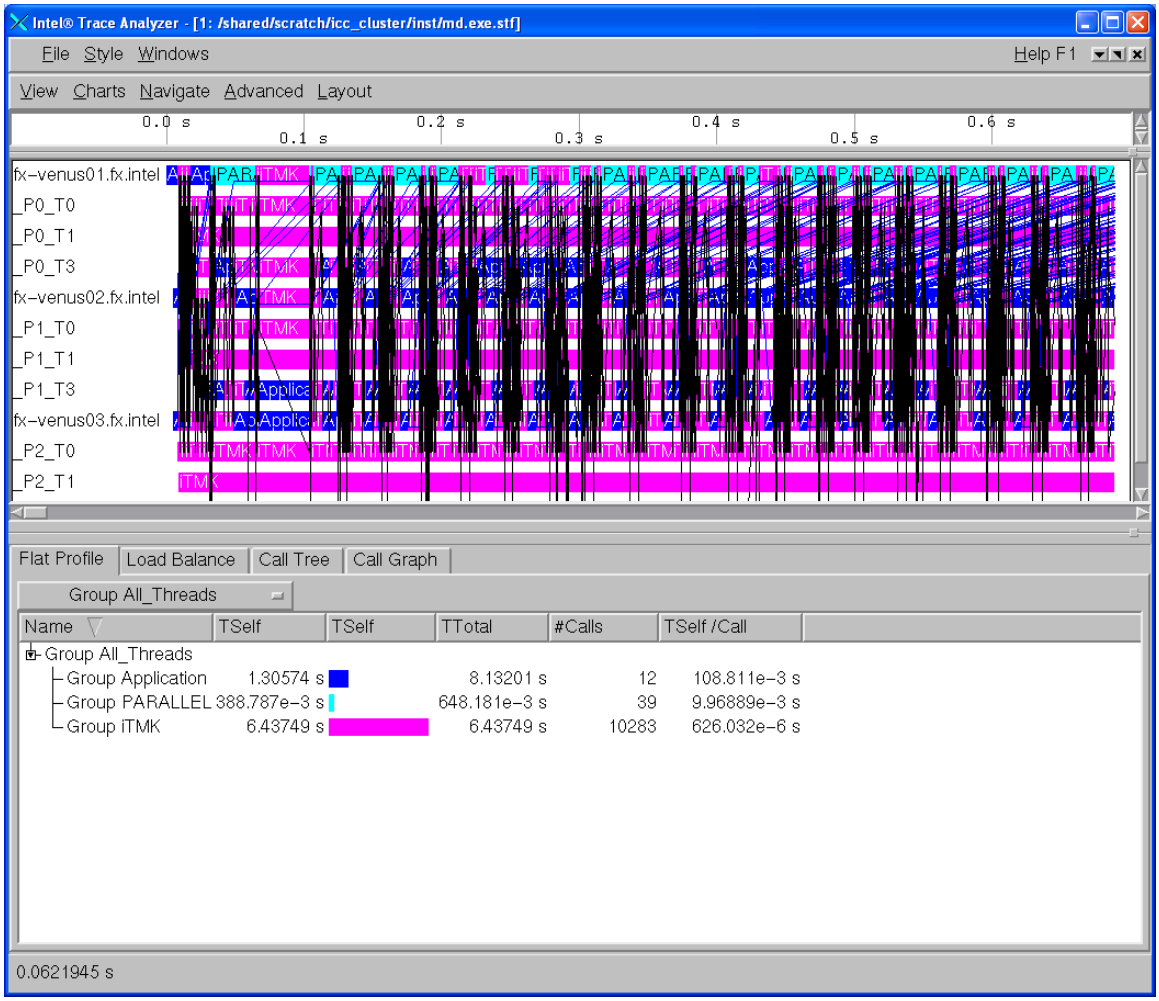

Figure 14.4 – The result of zooming on the particular time line segment that was highlighted in Figure 14.3

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.

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