# Red Hat Enterprise Linux 6

# Developer Guide

An introduction to application development tools in Red Hat Enterprise Linux 6

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# Red Hat Enterprise Linux 6 Developer Guide
# An introduction to application development tools in Red Hat Enterprise Linux 6
# Edition 0

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This document describes the different features and utilities that make Red Hat Enterprise Linux 6 an ideal enterprise platform for application development. It focuses on Eclipse as an end-to-end integrated development environment (IDE), but also includes command-line tools and other utilities outside Eclipse.

# Preface

This book describes the some of the more commonly-used programming resources in Red Hat Enterprise Linux 6. Each phase of the application development process is described as a separate chapter, enumerating tools that accomplish different tasks for that particular phase.

Note that this is not a comprehensive listing of all available development tools in Red Hat Enterprise Linux 6. In addition, each section herein does not contain detailed documentation of each tool. Rather, this book provides a brief overview of each tool, with a short description of updates to the tool in Red Hat Enterprise Linux 6 along with (more importantly) references to more detailed information.

In addition, this book focuses on Eclipse as an end-to-end integrated development platform. This was done to highlight the Red Hat Enterprise Linux 6 version of Eclipse and several Eclipse plug-ins.

## 1. Document Conventions

This manual uses several conventions to highlight certain words and phrases and draw attention to specific pieces of information.

In PDF and paper editions, this manual uses typefaces drawn from the *Liberation Fonts*[1] set. The Liberation Fonts set is also used in HTML editions if the set is installed on your system. If not, alternative but equivalent typefaces are displayed. Note: Red Hat Enterprise Linux 5 and later includes the Liberation Fonts set by default.

### 1.1. Typographic Conventions

Four typographic conventions are used to call attention to specific words and phrases. These conventions, and the circumstances they apply to, are as follows.

**`Mono-spaced Bold`**

Used to highlight system input, including shell commands, file names and paths. Also used to highlight keycaps and key combinations. For example:

> To see the contents of the file **`my_next_bestselling_novel`** in your current working directory, enter the **`cat my_next_bestselling_novel`** command at the shell prompt and press **`Enter`** to execute the command.

The above includes a file name, a shell command and a keycap, all presented in mono-spaced bold and all distinguishable thanks to context.

Key combinations can be distinguished from keycaps by the hyphen connecting each part of a key combination. For example:

> Press **`Enter`** to execute the command.
>
> Press **`Ctrl`**+**`Alt`**+**`F2`** to switch to the first virtual terminal. Press **`Ctrl`**+**`Alt`**+**`F1`** to return to your X-Windows session.

The first paragraph highlights the particular keycap to press. The second highlights two key combinations (each a set of three keycaps with each set pressed simultaneously).

If source code is discussed, class names, methods, functions, variable names and returned values mentioned within a paragraph will be presented as above, in **`mono-spaced bold`**. For example:

[1] https://fedorahosted.org/liberation-fonts/

> File-related classes include **`filesystem`** for file systems, **`file`** for files, and **`dir`** for directories. Each class has its own associated set of permissions.

**Proportional Bold**

This denotes words or phrases encountered on a system, including application names; dialog box text; labeled buttons; check-box and radio button labels; menu titles and sub-menu titles. For example:

> Choose **System** → **Preferences** → **Mouse** from the main menu bar to launch **Mouse Preferences**. In the **Buttons** tab, click the **Left-handed mouse** check box and click **Close** to switch the primary mouse button from the left to the right (making the mouse suitable for use in the left hand).
>
> To insert a special character into a **gedit** file, choose **Applications** → **Accessories** → **Character Map** from the main menu bar. Next, choose **Search** → **Find…** from the **Character Map** menu bar, type the name of the character in the **Search** field and click **Next**. The character you sought will be highlighted in the **Character Table**. Double-click this highlighted character to place it in the **Text to copy** field and then click the **Copy** button. Now switch back to your document and choose **Edit** → **Paste** from the **gedit** menu bar.

The above text includes application names; system-wide menu names and items; application-specific menu names; and buttons and text found within a GUI interface, all presented in proportional bold and all distinguishable by context.

***`Mono-spaced Bold Italic`*** or ***`Proportional Bold Italic`***

Whether mono-spaced bold or proportional bold, the addition of italics indicates replaceable or variable text. Italics denotes text you do not input literally or displayed text that changes depending on circumstance. For example:

> To connect to a remote machine using ssh, type **`ssh`** ***`username@domain.name`*** at a shell prompt. If the remote machine is **`example.com`** and your username on that machine is john, type **`ssh john@example.com`**.
>
> The **`mount -o remount`** ***`file-system`*** command remounts the named file system. For example, to remount the **`/home`** file system, the command is **`mount -o remount /home`**.
>
> To see the version of a currently installed package, use the **`rpm -q`** ***`package`*** command. It will return a result as follows: ***`package-version-release`***.

Note the words in bold italics above — username, domain.name, file-system, package, version and release. Each word is a placeholder, either for text you enter when issuing a command or for text displayed by the system.

Aside from standard usage for presenting the title of a work, italics denotes the first use of a new and important term. For example:

> Publican is a *DocBook* publishing system.

## 1.2. Pull-quote Conventions

Terminal output and source code listings are set off visually from the surrounding text.

Output sent to a terminal is set in **`mono-spaced roman`** and presented thus:

```
books        Desktop   documentation  drafts  mss    photos   stuff  svn
books_tests  Desktop1  downloads      images  notes  scripts  svgs
```

Source-code listings are also set in **`mono-spaced roman`** but add syntax highlighting as follows:

```
package org.jboss.book.jca.ex1;

import javax.naming.InitialContext;

public class ExClient
{
   public static void main(String args[])
       throws Exception
   {
      InitialContext iniCtx = new InitialContext();
      Object         ref    = iniCtx.lookup("EchoBean");
      EchoHome       home   = (EchoHome) ref;
      Echo           echo   = home.create();

      System.out.println("Created Echo");

      System.out.println("Echo.echo('Hello') = " + echo.echo("Hello"));
   }
}
```

### 1.3. Notes and Warnings

Finally, we use three visual styles to draw attention to information that might otherwise be overlooked.

**Note**

Notes are tips, shortcuts or alternative approaches to the task at hand. Ignoring a note should have no negative consequences, but you might miss out on a trick that makes your life easier.

**Important**

Important boxes detail things that are easily missed: configuration changes that only apply to the current session, or services that need restarting before an update will apply. Ignoring a box labeled 'Important' will not cause data loss but may cause irritation and frustration.

**Warning**

Warnings should not be ignored. Ignoring warnings will most likely cause data loss.

## 2. Getting Help and Giving Feedback

### 2.1. Do You Need Help?

If you experience difficulty with a procedure described in this documentation, visit the Red Hat Customer Portal at *http://access.redhat.com*. Through the customer portal, you can:

- search or browse through a knowledgebase of technical support articles about Red Hat products.
- submit a support case to Red Hat Global Support Services (GSS).
- access other product documentation.

Red Hat also hosts a large number of electronic mailing lists for discussion of Red Hat software and technology. You can find a list of publicly available mailing lists at *https://www.redhat.com/mailman/listinfo*. Click on the name of any mailing list to subscribe to that list or to access the list archives.

## 2.2. We Need Feedback!

If you find a typographical error in this manual, or if you have thought of a way to make this manual better, we would love to hear from you! Please submit a report in Bugzilla: *http://bugzilla.redhat.com/* against the product **Red_Hat_Enterprise_Linux.**

When submitting a bug report, be sure to mention the manual's identifier: *doc-Developer_Guide*

If you have a suggestion for improving the documentation, try to be as specific as possible when describing it. If you have found an error, please include the section number and some of the surrounding text so we can find it easily.

# Introduction to Eclipse

Eclipse is a powerful development environment that provides tools for each phase of the development process. It is integrated into a single, fully configurable user interface for ease of use, featuring a pluggable architecture which allows for extension in a variety of ways.

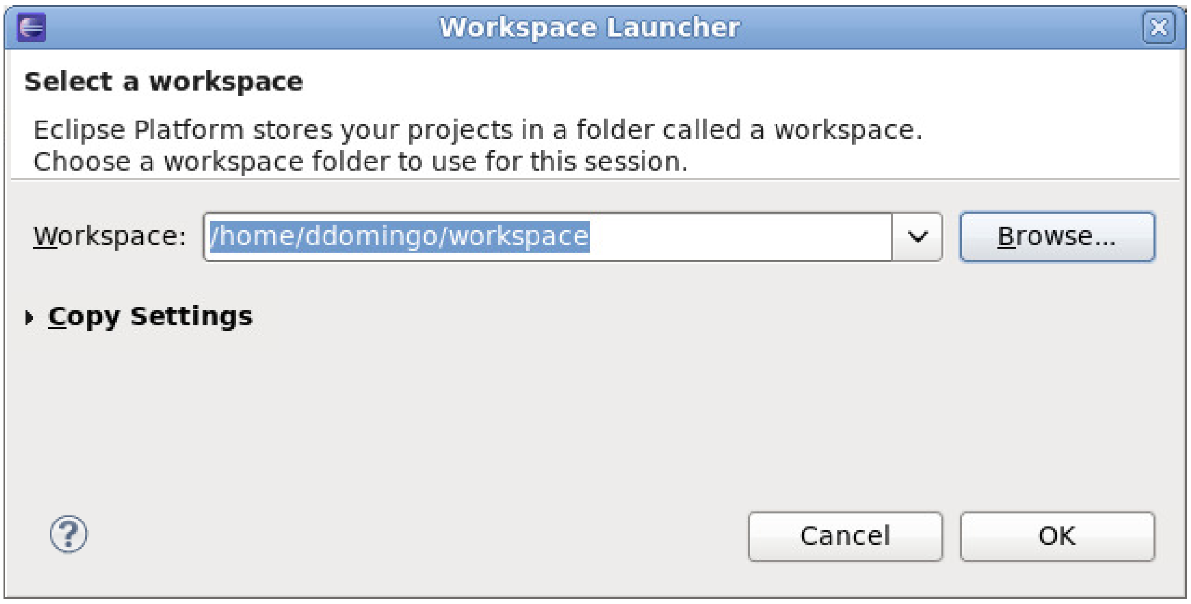
Eclipse integrates a variety of disparate tools into a unified environment to create a rich development experience. The Valgrind plug-in, for example, allows programmers to perform memory profiling (normally done through the command line) through the Eclipse user interface. This functionality is not exclusive only to Eclipse.

Being a graphical application, Eclipse is a welcome alternative to developers who find the command line interface intimidating or difficult. In addition, Eclipse's built-in **Help** system provides extensive documentation for each integrated feature and tool. This greatly decreases the initial time investment required for new developers to become fluent in its use.

The traditional (i.e. mostly command-line based) Linux tools suite (**`gcc`**, **`gdb`**, etc) and Eclipse offer two distinct approaches to programming. Most traditional Linux tools are far more flexible, subtle, and (in aggregate) more powerful than their Eclipse-based counterparts. These traditional Linux tools, on the other hand, are more difficult to master, and offer more capabilities than are required by most programmers or projects. Eclipse, by contrast, sacrifices some of these benefits in favor of an integrated environment, which in turn is suitable for users who prefer their tools accessible in a single, graphical interface.

## 1.1. Understanding Eclipse Projects

Eclipse stores all project and user files in a designated *workspace*. You can have multiple workspaces and can switch between each one on the fly. However, Eclipse will only be able to load projects from the current active workspace. To switch between active workspaces, navigate to **File** > **Switch Workspace** > ***`/path/to/workspace`***. You can also add a new workspace through the **Workspace Launcher** wizard; to open this wizard, navigate to **File** > **Switch Workspace** > **Other**.



Workspace Launcher

Select a workspace

Eclipse Platform stores your projects in a folder called a workspace.
Choose a workspace folder to use for this session.

Workspace: /home/ddomingo/workspace

Figure 1.1. Workspace Launcher

For information about configuring workspaces, refer to *Reference* > *Preferences* > *Workspace* in the *Workbench User Guide* (**Help Contents**).

A project can be imported directly into Eclipse if it contains the necessary Eclipse metafiles. Eclipse uses these files to determine what kind of perspectives, tools, and other user interface configurations to implement.

As such, when attempting to import a project that has never been used on Eclipse, it may be necessary to do so through the **New Project** wizard instead of the **Import** wizard. Doing so will create the necessary Eclipse metafiles for the project, which you can also include when you commit the project.

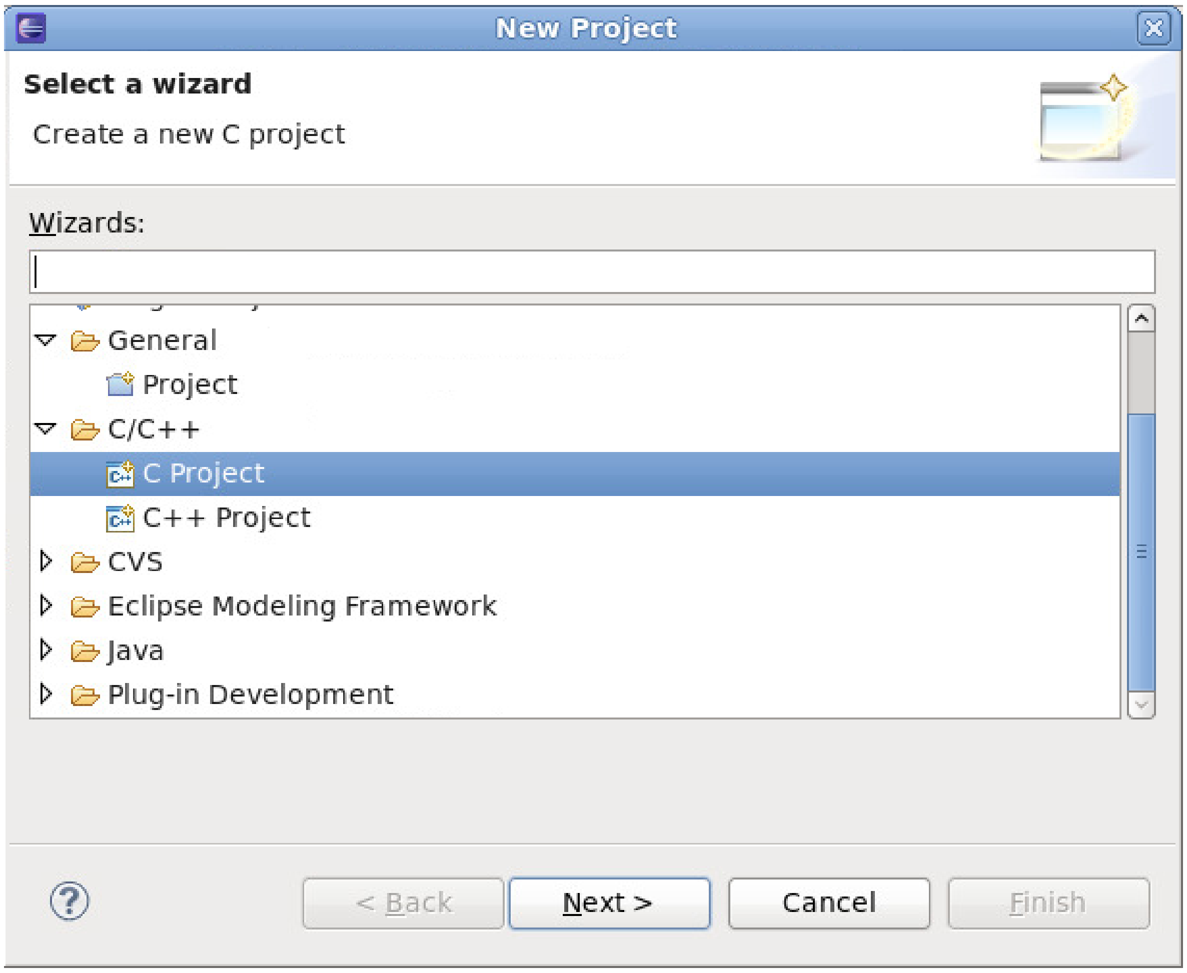


Figure 1.2. New Project Wizard

The **Import** wizard is suitable mostly for projects that were created or previously edited in Eclipse, i.e. projects that contain the necessary Eclipse metafiles.

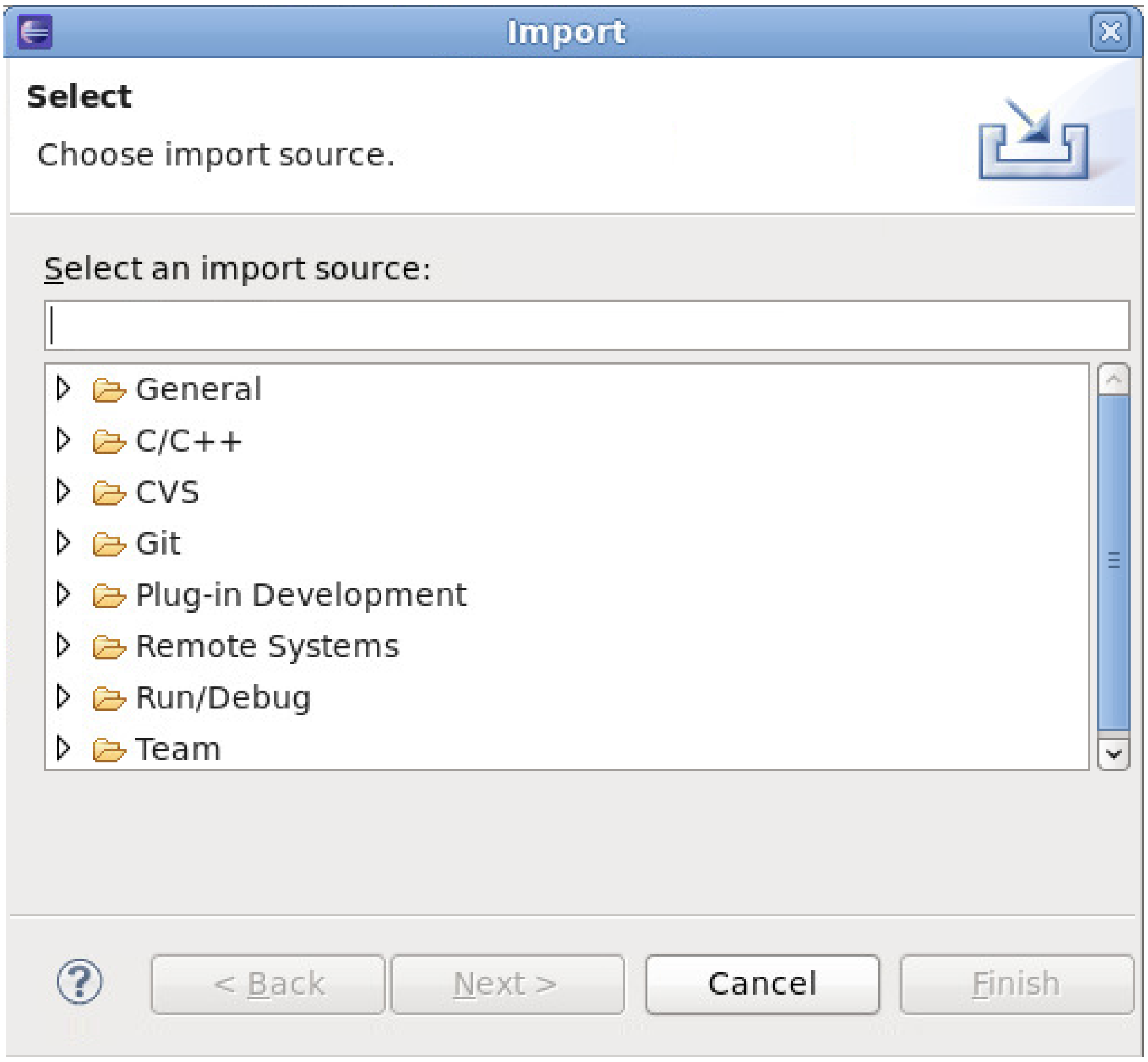


Figure 1.3. Import Wizard

## 1.2. Help In Eclipse

Eclipse features a comprehensive internal help library that covers nearly every facet of the Integrated Development Environment (IDE). Every Eclipse documentation plug-in installs its content to this library, where it is indexed accordingly. To access this library, use the **Help** menu.

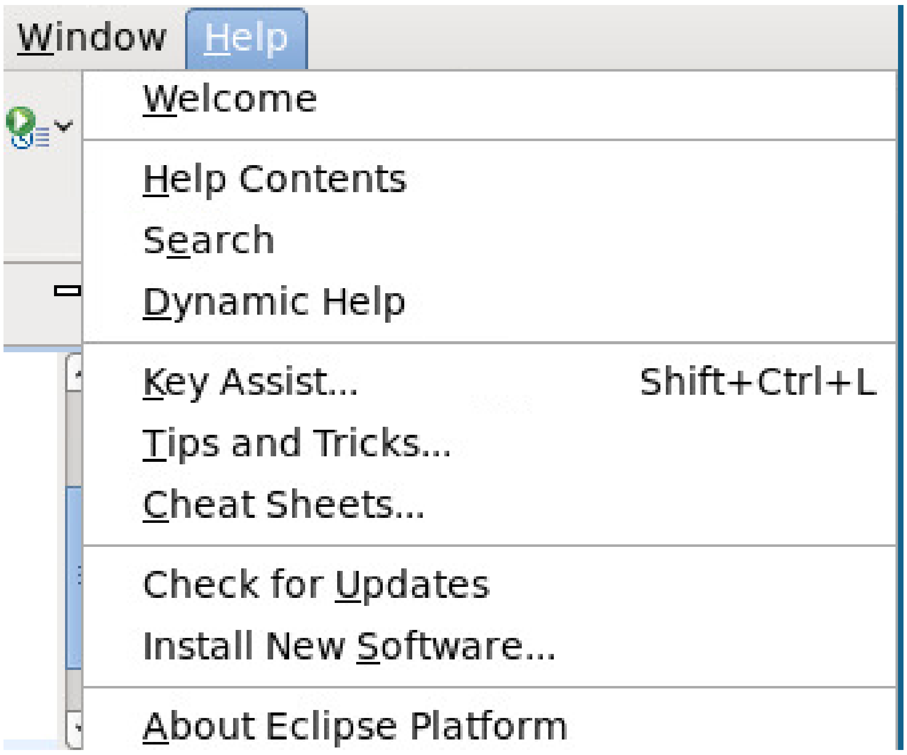
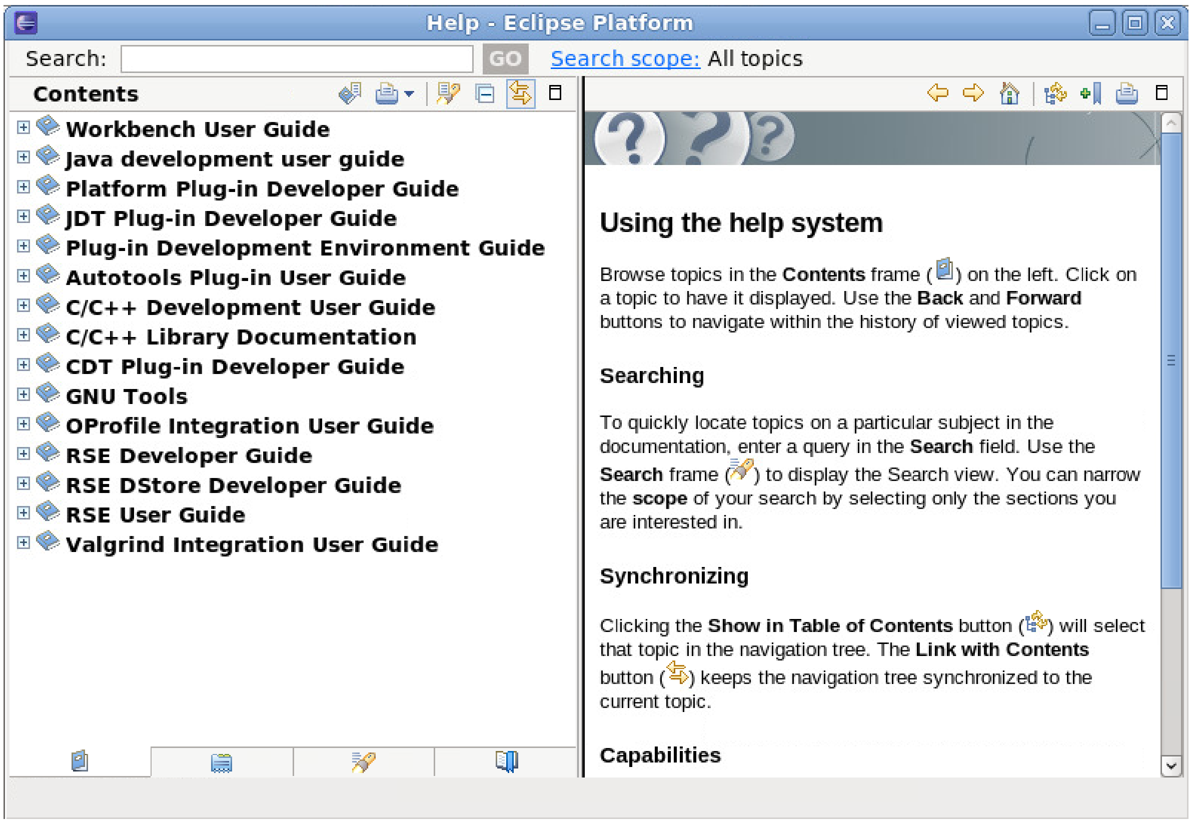


Figure 1.4. Help

To open the main **Help** menu, navigate to **Help** > **Help Contents**. The **Help** menu displays all the available content provided by installed documentation plug-ins in the **Contents** field.


Help - Eclipse Platform
Search:
GO
Search scope: All topics
Contents
Workbench User Guide
Java development user guide
Platform Plug-in Developer Guide
JDT Plug-in Developer Guide
Plug-in Development Environment Guide
Autotools Plug-in User Guide
C/C++ Development User Guide
C/C++ Library Documentation
CDT Plug-in Developer Guide
GNU Tools
OProfile Integration User Guide
RSE Developer Guide
RSE DStore Developer Guide
RSE User Guide
Valgrind Integration User Guide

Using the help system

Browse topics in the **Contents** frame ( ) on the left. Click on a topic to have it displayed. Use the **Back** and **Forward** buttons to navigate within the history of viewed topics.

Searching

To quickly locate topics on a particular subject in the documentation, enter a query in the **Search** field. Use the **Search** frame ( ) to display the Search view. You can narrow the **scope** of your search by selecting only the sections you are interested in.

Synchronizing

Clicking the **Show in Table of Contents** button ( ) will select that topic in the navigation tree. The **Link with Contents** button ( ) keeps the navigation tree synchronized to the current topic.

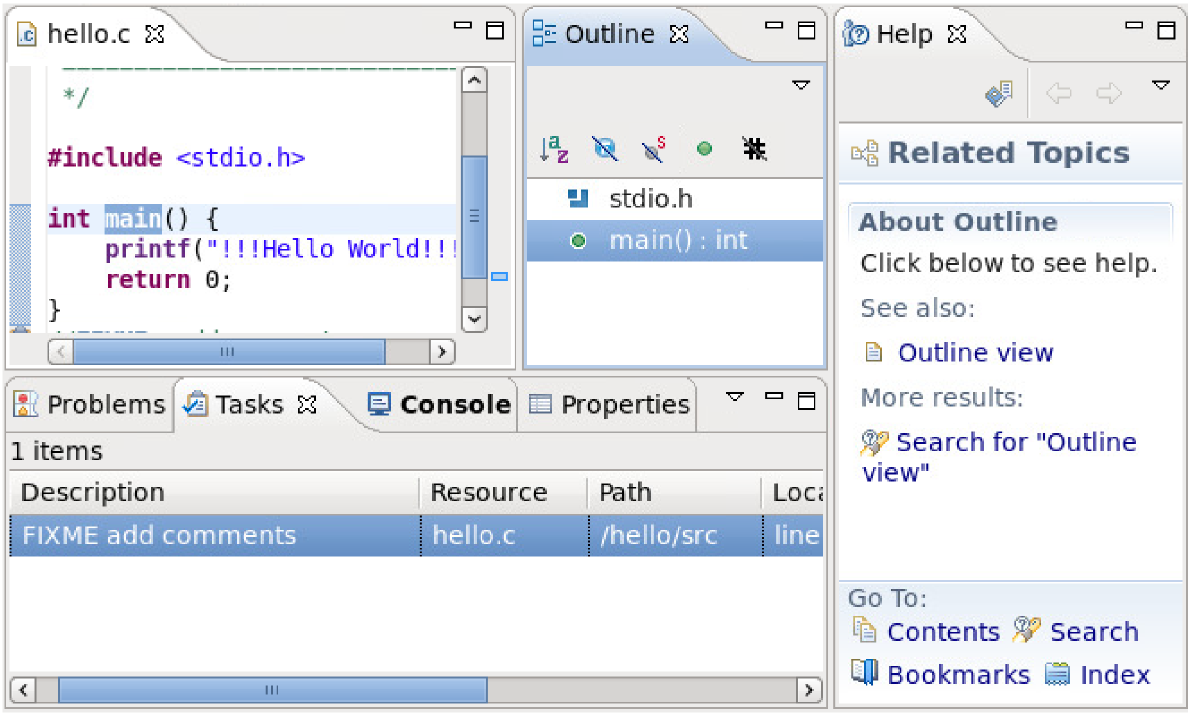
Capabilities

Figure 1.5. Help Menu

The tabs at the bottom of the **Contents** field provides different options for accessing Eclipse documentation. You can navigate through each "book" by section/header or by simply searching via the **Search** field. You can also bookmark sections in each book and access them through the **Bookmarks** tab.

The *Workbench User Guide* documents all facets of the Eclipse user interface extensively. It contains very low-level information on the Eclipse workbench, perspectives, and different concepts useful in understanding how Eclipse works. The *Workbench User Guide* is an ideal resource for users with little to intermediate experience with Eclipse or IDEs in general. This documentation plug-in is installed by default.

The Eclipse help system also includes a *dynamic help* feature. This feature opens a new window in the workbench that displays documentation relating to a selected interface element. To activate dynamic help, navigate to **Help** > **Dynamic Help**.



```
*/

#include <stdio.h>

int main() {
    printf("!!!Hello World!!!
    return 0;
}
```

stdio.h
main() : int

1 items

| Description | Resource | Path | Loc |
|---|---|---|---|
| FIXME add comments | hello.c | /hello/src | line |

Related Topics

About Outline

Click below to see help.

See also:

Outline view

More results:

Search for "Outline view"

Go To:

Contents Search Bookmarks Index

Figure 1.6. Dynamic Help

The rightmost window in *Figure 1.6, “Dynamic Help”* displays help topics related to the **Outline** view, which is the selected user interface element.

## 1.3. Development Toolkits

Red Hat Enterprise Linux 6 supports the primary Eclipse development toolkits for C/C++ (**`CDT`**) and Java (**`JDT`**). These toolkits provide a set of integrated tools specific to their respective languages. Both toolkits supply Eclipse GUI interfaces with the required tools for editing, building, running, and debugging source code.

Each toolkit provides custom editors for their respective language. Both **`CDT`** and **`JDT`** also provide multiple editors for a variety of file types used in a project. For example, the **`CDT`** supplies different editors specific for C/C++ header files and source files, along with a **`Makefile`** editor.

Toolkit-supplied editors provide error parsing for some file types (without requiring a build), although this may not be available on projects where cross-file dependencies exist. The **`CDT`** source file editor, for example, provides error parsing in the context of a single file, but some errors may only be visible when a complete project is built. Other common features among toolkit-supplied editors are colorization, code folding, and automatic indentation. In some cases, other plug-ins provide advanced editor features such as automatic code completion, hover help, and contextual search; a good example of such a plug-in is **`libhover`**, which adds these extended features to C/C++ editors (refer to *Section 2.2.2, “libhover Plug-in”* for more information).

User interfaces for most (if not all) steps in creating a project's target (inary, file, library, etc) are provided by the build functionalities of each toolkit. Each toolkit also provides Eclipse with the means to automate as much of the build process as possible, helping you concentrate more on writing code than building it. Both toolkits also add useful UI elements for finding problems in code preventing a build; for example, Eclipse sends compile errors to the **Problems** view. For most error types, Eclipse allows you to navigate directly to an error's cause (file and code segment) by simply clicking on its entry in the **Problems** view.

As is with editors, other plug-ins can also provide extended capabilities for building a project — the **`Autotools`** plug-in, for example, allows you to add portability to a C/C++ project, allowing other developers to build the project in a wide variety of environments (for more information, refer to *Section 4.3, “Autotools”*).

For projects with executable/binary targets, each toolkit also supplies run/debug functionalities to Eclipse. In most projects, "run" is simply executed as a "debug" action without interruptions. Both toolkits tie the **Debug** view to the Eclipse editor, allowing breakpoints to be set. Conversely, triggered breakpoints open their corresponding functions in code in the editor. Variable values can also be explored by clicking their names in the code.

For some projects, *build integration* is also possible. With this, Eclipse automatically rebuilds a project or installs a "hot patch" if you edit code in the middle of a debugging session. This allows a more streamlined debug-and-correct process, which some developers prefer.

The Eclipse **Help** menu provides extensive documentation on both **`CDT`** and **`JDT`**. For more information on either toolkit, refer to the *Java Development User Guide* or *C/C++ Development User Guide* in the Eclipse **Help Contents**.

# The Eclipse Integrated Development Environment (IDE)

The entire user interface in *Figure 2.1, “Eclipse User Interface (default)”* is referred to as the Eclipse *workbench*. It is generally composed of a code **Editor**, **Project Explorer** window, and several views. All elements in the Eclipse workbench are configurable, and fully documented in the *Workbench User Guide* (**Help Contents**). Refer to *Section 2.2, “Useful Hints”* for a brief overview on customizing the user interface.

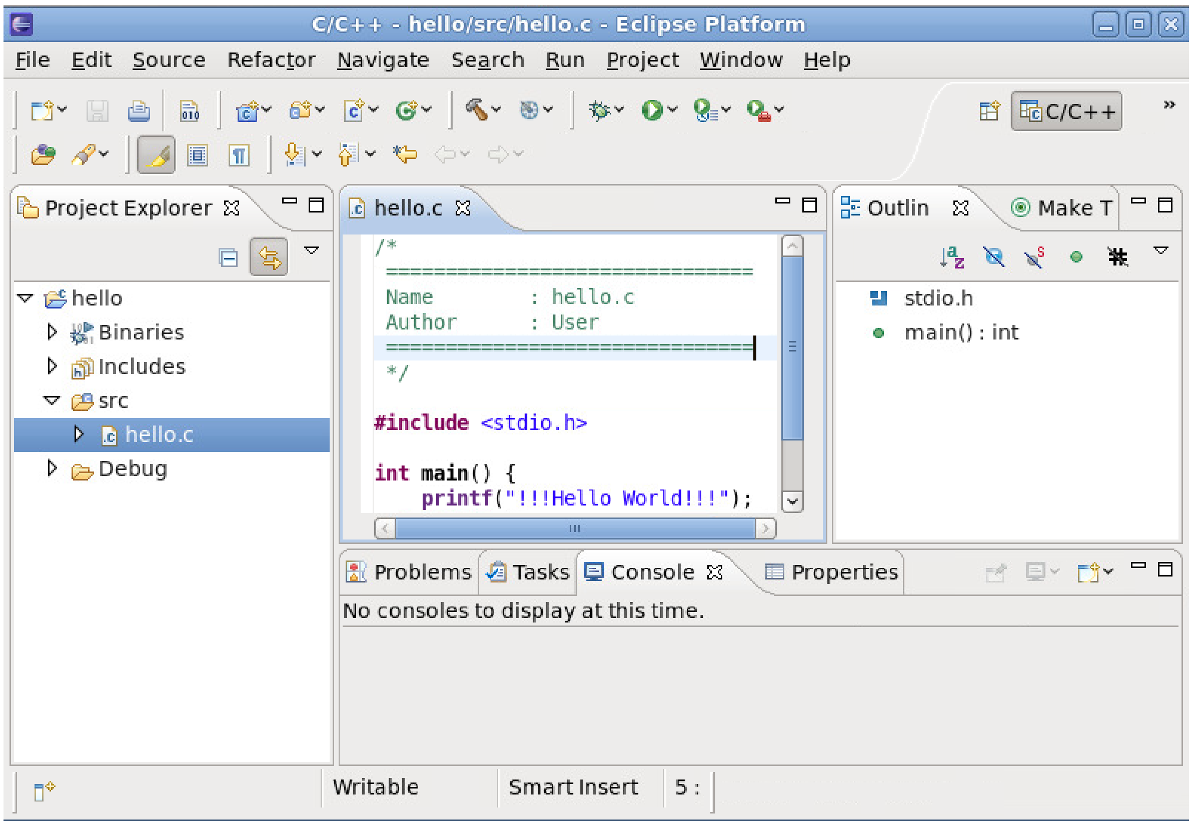
Eclipse features different *perspectives*. A perspective is a set of views and editors most useful to a specific type of task or project; the Eclipse workbench can contain one or more perspectives. *Figure 2.1, “Eclipse User Interface (default)”* features the default perspective for C/C++.

Eclipse also divides many functions into several classes, housed inside distinct *menu items*. For example, the **Project** menu houses functions relating to compiling/building a project. The **Window** menu contains options for creating and customizing perspectives, menu items, and other user interface elements. For a brief overview of each main menu item, refer to *Reference > C/C++ Menubar* in the *C/C++ Development User Guide* or *Reference > Menus and Actions* in the *Java Development User Guide*.

The following sections provide a high-level overview of the different elements visible in the default user interface of the Eclipse *integrated development environment* (IDE).

## 2.1. User Interface

The Eclipse workbench provides a user interface for many features and tools essential for every phase of the development process. This section provides an overview of Eclipse's primary user interface.

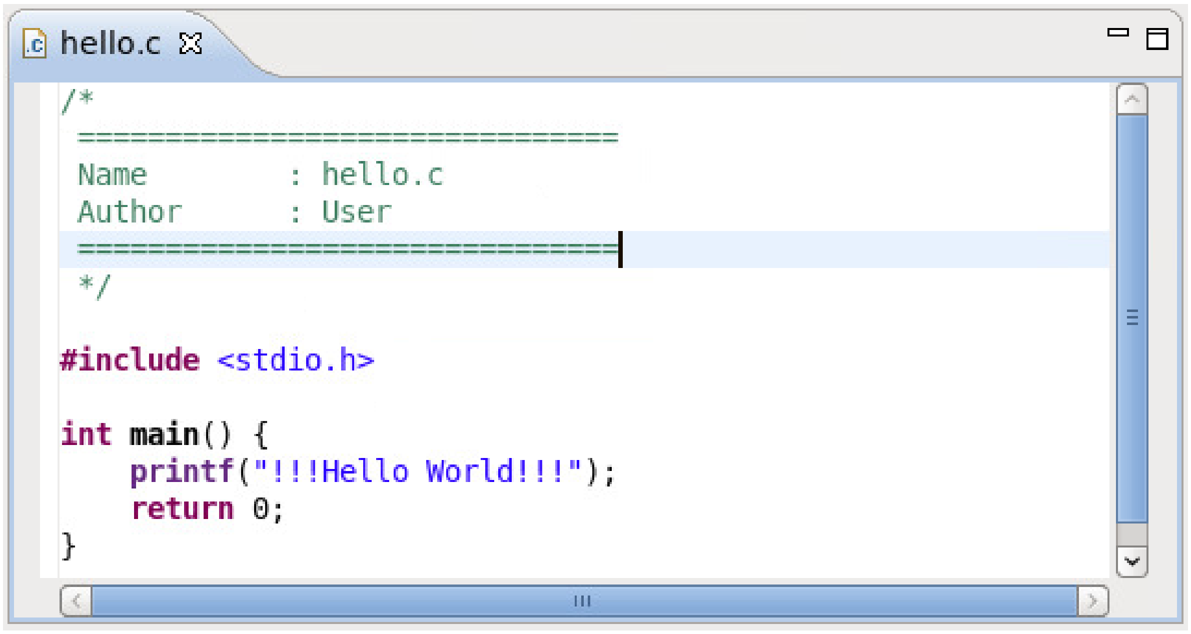


```
/*
 ================================
 Name        : hello.c
 Author      : User
 ================================
 */

#include <stdio.h>

int main() {
    printf("!!!Hello World!!!");
```

No consoles to display at this time.

Figure 2.1. Eclipse User Interface (default)

*Figure 2.1, “Eclipse User Interface (default)”* displays the default workbench for C/C++ projects. To switch between available perspectives in a workbench, press **`Ctrl`**+**`F8`**. For some hints on perspective customization, refer to *Section 2.2, “Useful Hints”*. The figures that follow describe each basic element visible in the default C/C++ perspective.



```
/*
 ==============================
 Name        : hello.c
 Author      : User
 ==============================
 */

#include <stdio.h>

int main() {
    printf("!!!Hello World!!!");
    return 0;
}
```

Figure 2.2. Eclipse Editor

The **Editor** is used to write and edit source files. Eclipse can autodetect and load an appropriate language editor (e.g. C Editor for files ending in **`.c`**) for most types of source files. To configure the settings for the **`Editor`**, navigate to **Window** > **Preferences** > ***`language (e.g. Java, C++)`*** > **Code Style**.

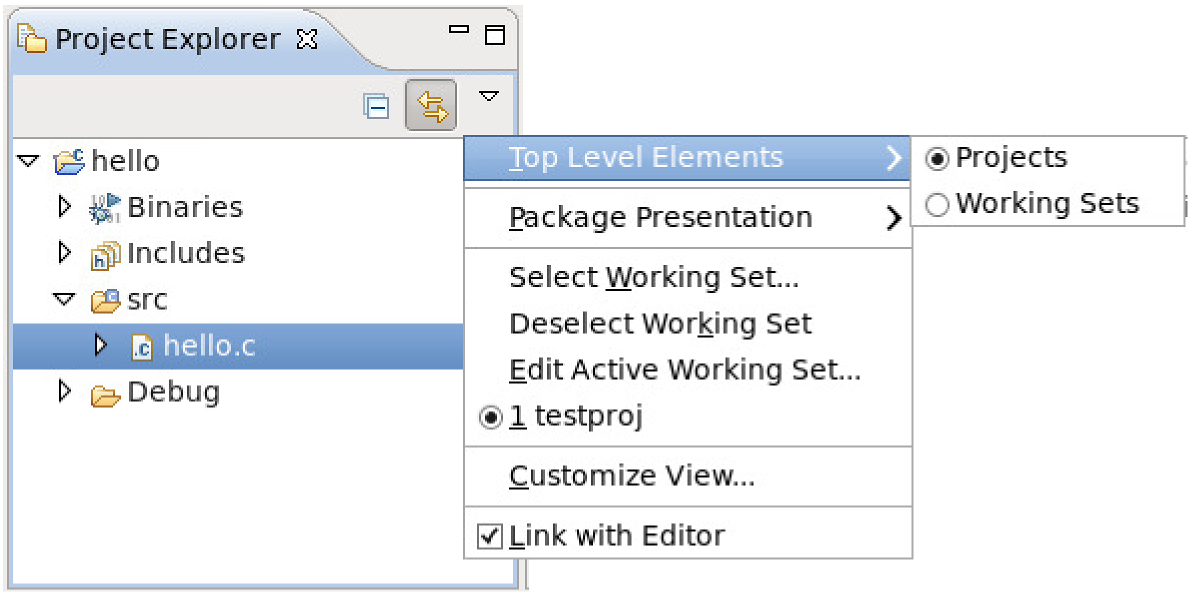


Figure 2.3. Project Explorer

The **Project Explorer View** provides a hierarchical view of all project resources (binaries, source files, etc.). You can open, delete, or otherwise edit any files from this view.

The **View Menu** button in the **Project Explorer View** allows you to configure whether projects or *working sets* are the top-level items in the **Project Explorer View**. A working set is a group of projects arbitrarily classified as a single set; working sets are handy in organizing related or linked projects.

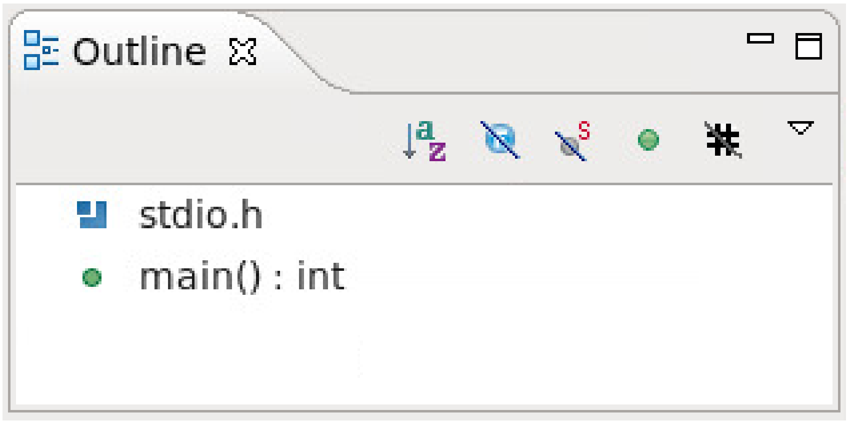
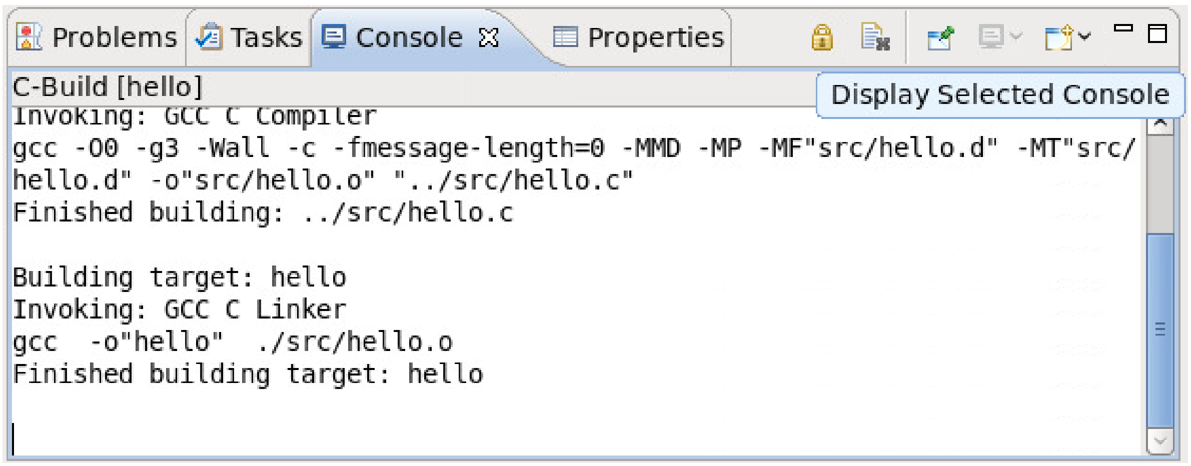


Figure 2.4. Outline Window

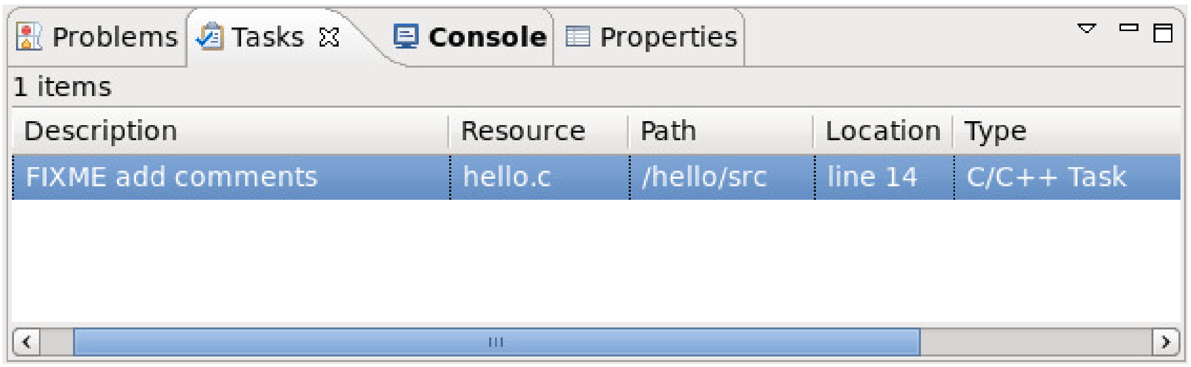
The **Outline** window provides a condensed view of the code in a source file. It details different variables, functions, libraries, and other structural elements from the selected file in the Editor, all of which are editor-specific.



```
Invoking: GCC C Compiler
gcc -O0 -g3 -Wall -c -fmessage-length=0 -MMD -MP -MF"src/hello.d" -MT"src/
hello.d" -o"src/hello.o" "../src/hello.c"
Finished building: ../src/hello.c

Building target: hello
Invoking: GCC C Linker
gcc  -o"hello"  ./src/hello.o
Finished building target: hello
```

Figure 2.5. Console View

Some functions and plugged-in programs in Eclipse send their output to the **Console** view. This view's **Display Selected Console** button allows you to switch between different consoles.

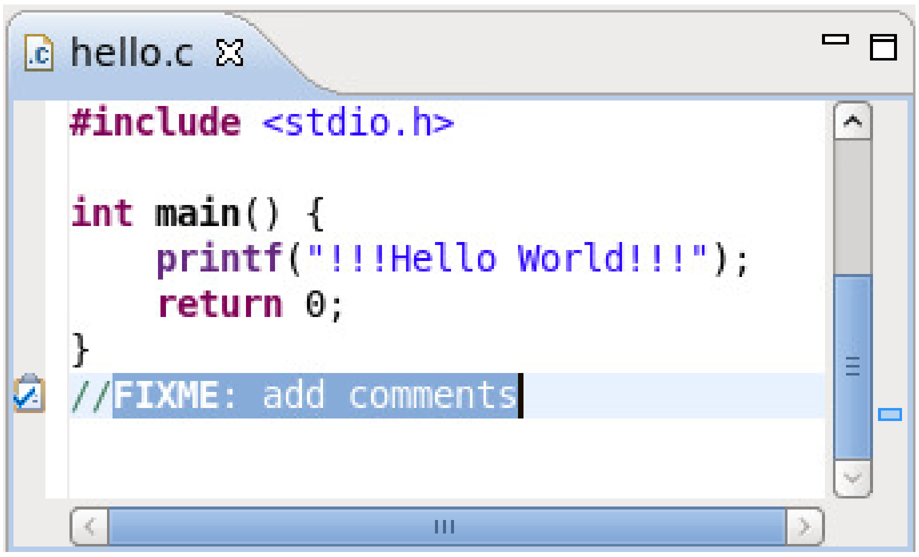


1 items

| Description | Resource | Path | Location | Type |
|---|---|---|---|---|
| FIXME add comments | hello.c | /hello/src | line 14 | C/C++ Task |

Figure 2.6. Tasks View

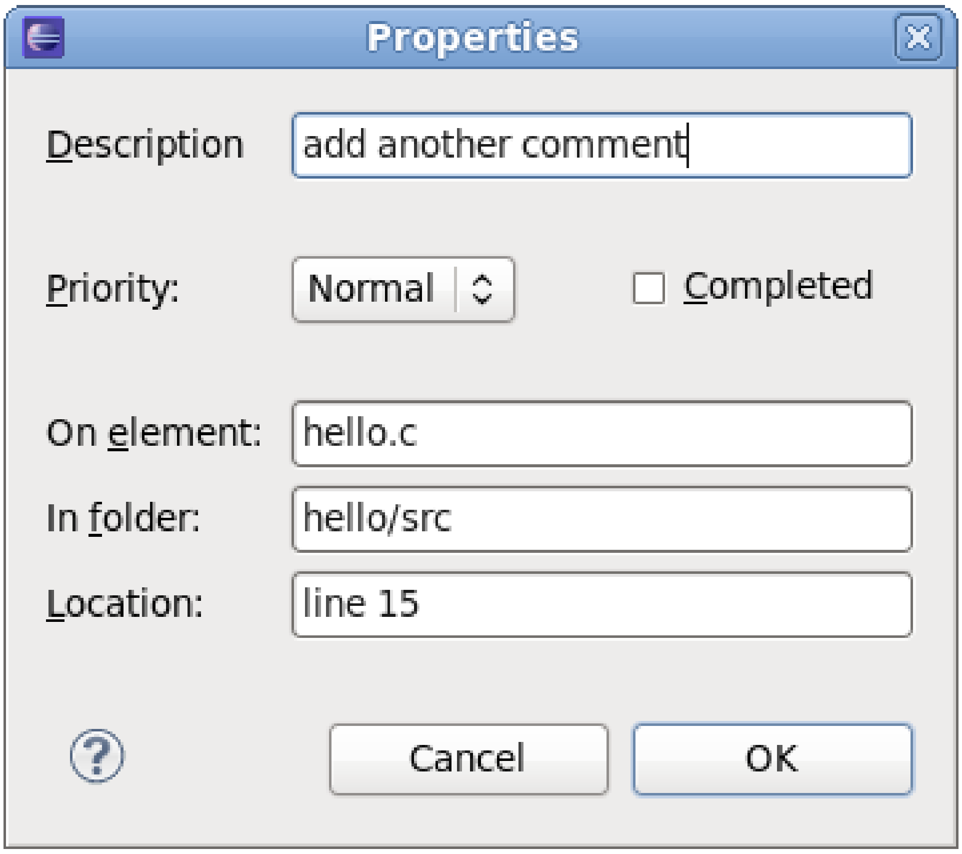
The **Tasks** view allows you to track specially-marked reminder comments in the code. This view shows the location of each task comment and allows you to sort them in several ways.



```
#include <stdio.h>

int main() {
	printf("!!!Hello World!!!");
	return 0;
}
//FIXME: add comments
```

Figure 2.7. Sample of Tracked Comment

Most Eclipse editors track comments marked with `//FIXME` or `//TODO` tags. Tracked comments —i.e. *task tags*—are different for source files written in other languages. To add or configure task tags, navigate to **Window** > **Preferences** and use the keyword `task tags` to display the task tag configuration menus for specific editors/languages.



Description: add another comment

Priority: Normal ☐ Completed

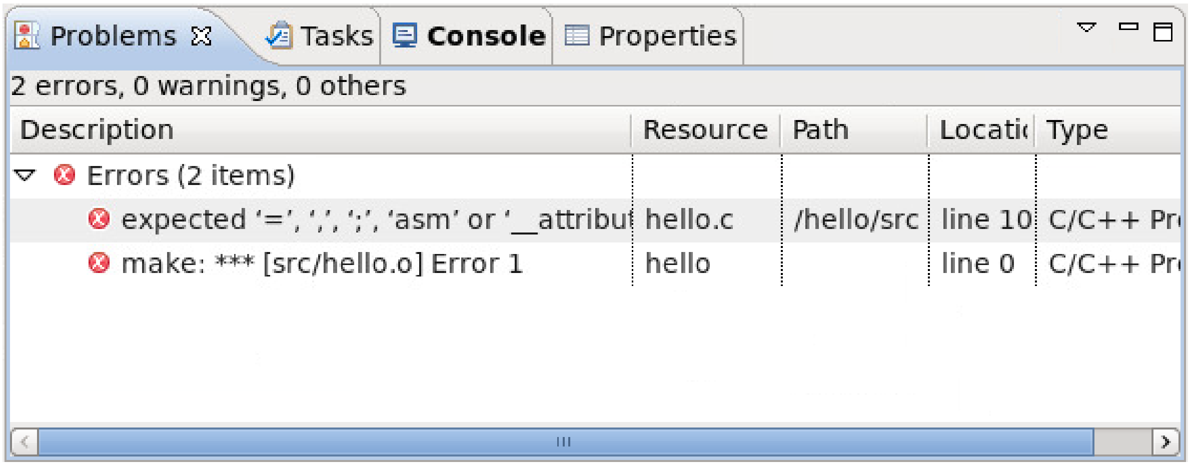
On element: hello.c

In folder: hello/src

Location: line 15

Figure 2.8. Task Properties

Alternatively, you can also use **Edit** > **Add Task** to open the task **Properties** menu (*Figure 2.8, “Task Properties”*). This will allow you to add a task to a specific location in a source file without using a task tag.



2 errors, 0 warnings, 0 others

| Description | Resource | Path | Locati | Type |
|---|---|---|---|---|
| Errors (2 items) | | | | |
| expected '=', ',', ';', 'asm' or '__attribut | hello.c | /hello/src | line 10 | C/C++ Pr |
| make: *** [src/hello.o] Error 1 | hello | | line 0 | C/C++ Pr |

Figure 2.9. Problems View

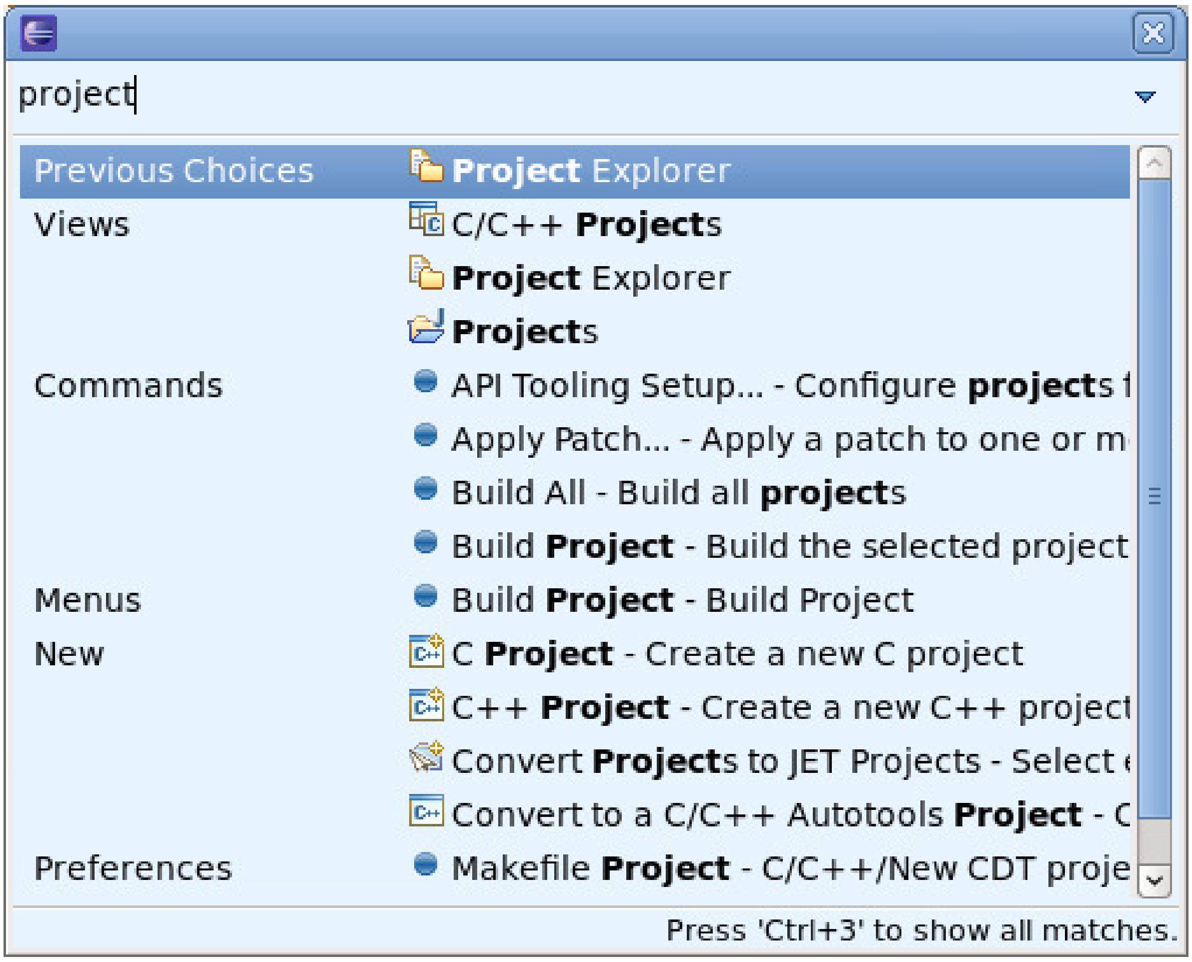
The **Problems** view displays any errors or warnings that occurred during the execution of specific actions such as builds, cleans, or profile runs. To display a suggested "quick fix" to a specific problem, select it and press **`Ctrl`+`1`**.

## 2.2. Useful Hints

Many Eclipse users learn useful tricks and troubleshooting techniques throughout their experience with the Eclipse user interface. This section highlights some of the more useful hints that users new to Eclipse may be interested in learning. The *Tips and Tricks* section of the *Workbench User Guide* contains a more extensive list of Eclipse tips.

### 2.2.1. The quick access menu

One of the most useful Eclipse tips is to use the **quick access** menu. Typing a word in the **quick access** menu will present a list of Views, Commands, Help files and other actions related to that word. To open this menu, press **`Ctrl`+`3`**.



project

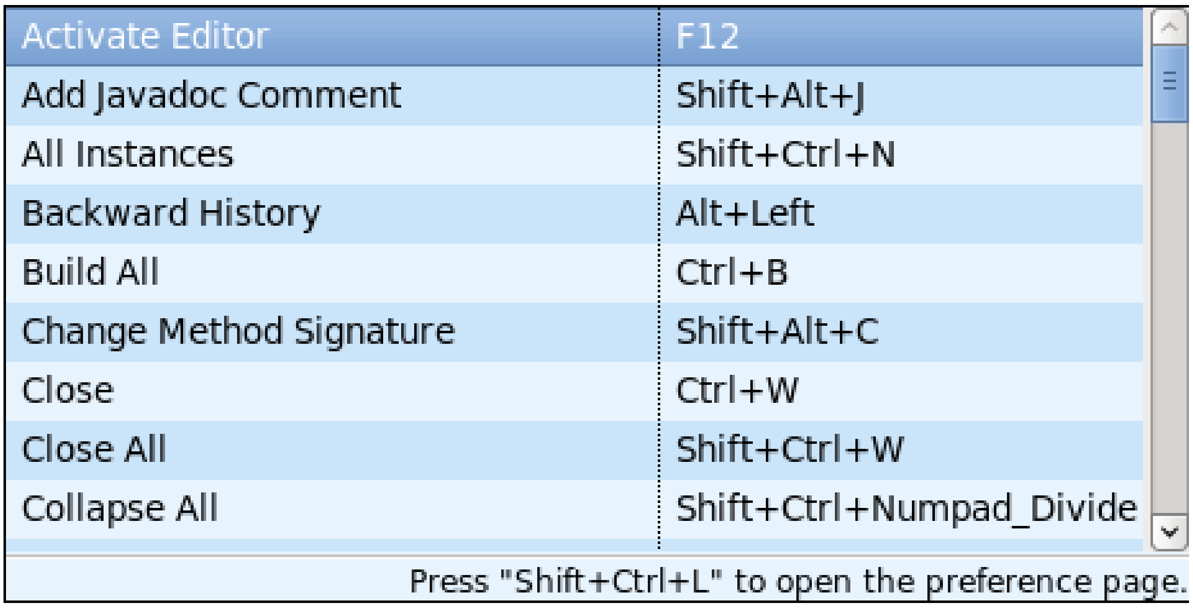
| | |
|---|---|
| Previous Choices | **Project** Explorer |
| Views | C/C++ **Project**s |
| | **Project** Explorer |
| | **Project**s |
| Commands | API Tooling Setup... - Configure **project**s f |
| | Apply Patch... - Apply a patch to one or m |
| | Build All - Build all **project**s |
| | Build **Project** - Build the selected project |
| Menus | Build **Project** - Build Project |
| New | C **Project** - Create a new C project |
| | C++ **Project** - Create a new C++ project |
| | Convert **Project**s to JET Projects - Select |
| | Convert to a C/C++ Autotools **Project** - C |
| Preferences | Makefile **Project** - C/C++/New CDT proje |

Press 'Ctrl+3' to show all matches.

Figure 2.10. Quick Access Menu

In *Figure 2.10, “Quick Access Menu”*, clicking **Views** > **Project Explorer** will select the **Project Explorer** window. Clicking any item from the **Commands**, **Menus**, **New**, or **Preferences** categories to run the selected item. This is similar to navigating to or clicking the respective menu options or taskbar icons. You can also navigate through the **quick access** menu using the arrow keys.

It is also possible to view a complete list of all keyboard shortcut commands; to do so, press **`Shift`**+**`Ctrl`**+**`L`**.

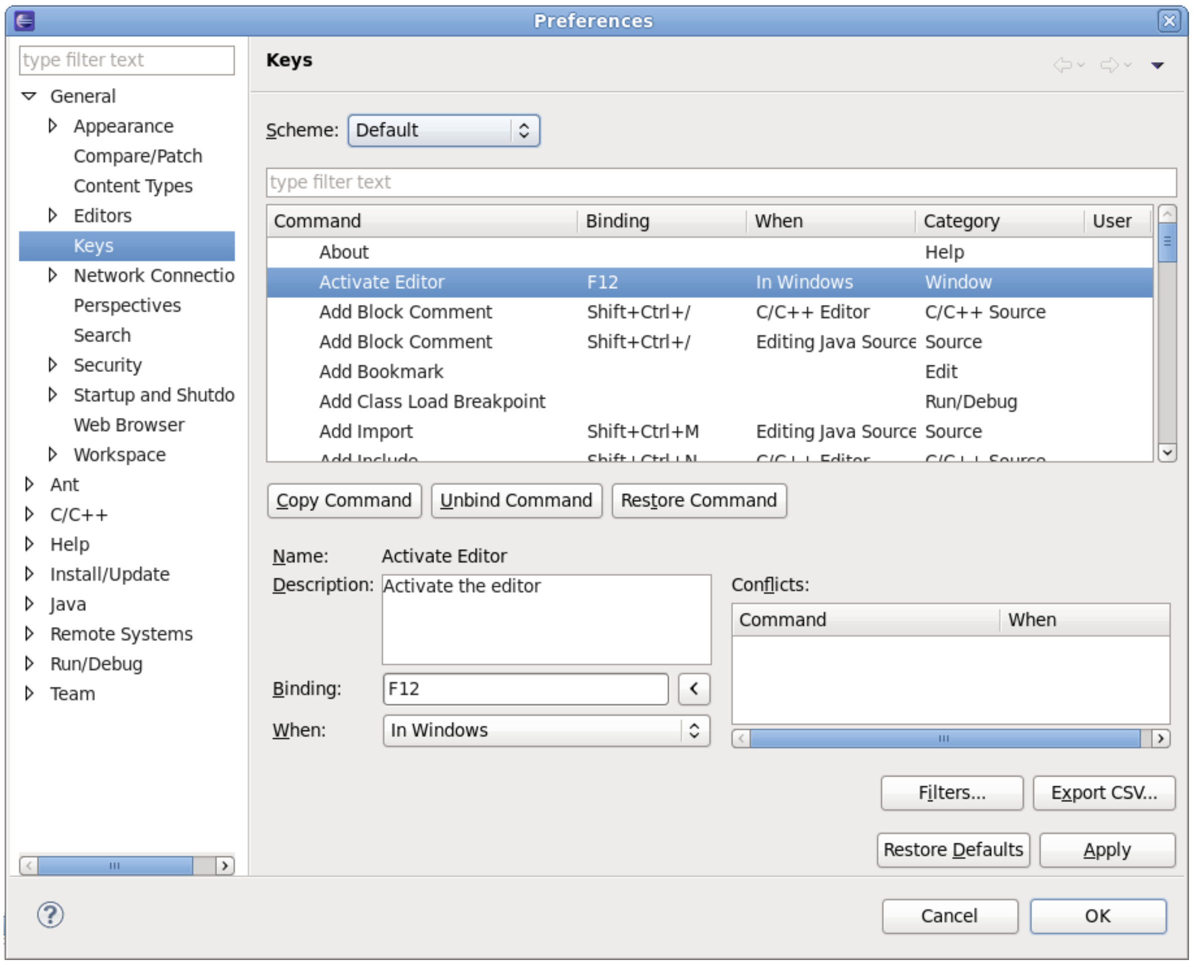


| | |
|---|---|
| Activate Editor | F12 |
| Add Javadoc Comment | Shift+Alt+J |
| All Instances | Shift+Ctrl+N |
| Backward History | Alt+Left |
| Build All | Ctrl+B |
| Change Method Signature | Shift+Alt+C |
| Close | Ctrl+W |
| Close All | Shift+Ctrl+W |
| Collapse All | Shift+Ctrl+Numpad_Divide |

Press "Shift+Ctrl+L" to open the preference page.

Figure 2.11. Keyboard Shortcuts

To configure Eclipse keyboard shortcuts, press **`Shift`+`Ctrl`+`L`** again while the **Keyboard Shortcuts** list is open.



Keys

Scheme: Default

type filter text

| Command | Binding | When | Category | User |
|---|---|---|---|---|
| About | | | Help | |
| Activate Editor | F12 | In Windows | Window | |
| Add Block Comment | Shift+Ctrl+/ | C/C++ Editor | C/C++ Source | |
| Add Block Comment | Shift+Ctrl+/ | Editing Java Source | Source | |
| Add Bookmark | | | Edit | |
| Add Class Load Breakpoint | | | Run/Debug | |
| Add Import | Shift+Ctrl+M | Editing Java Source | Source | |

Name: Activate Editor

Description: Activate the editor

Binding: F12

When: In Windows

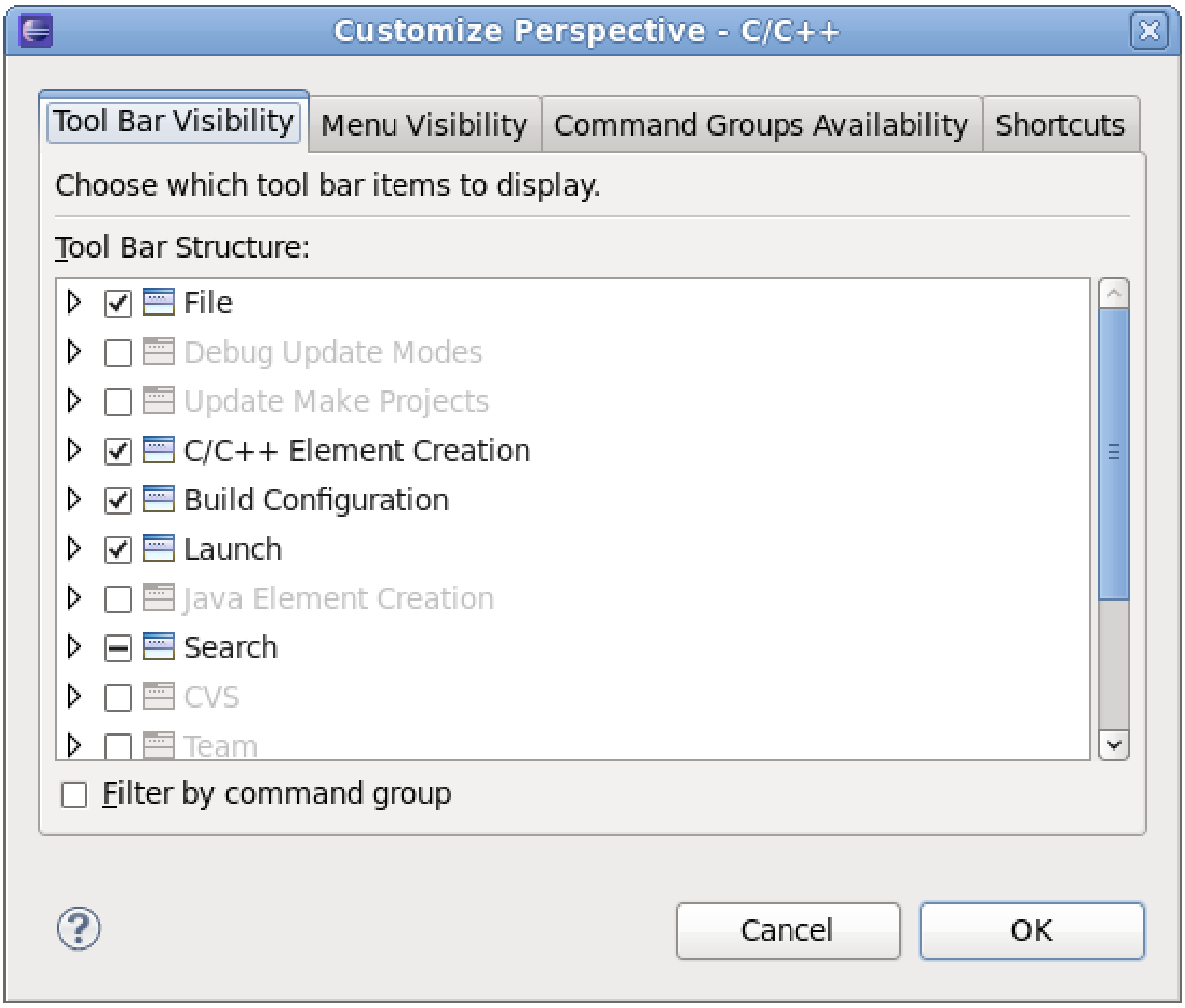
Conflicts:

| Command | When |
|---|---|

Figure 2.12. Configuring Keyboard Shortcuts

To customize the current perspective, navigate to **Window** > **Customize Perspective**. This opens the **Customize Perspective** menu, allowing the visible tool bars, main menu items, command groups, and short cuts to be configured.

The location of each view within the workbench can be customized by clicking on a view's title and dragging it to a desired location.


Customize Perspective - C/C++

Tool Bar Visibility | Menu Visibility | Command Groups Availability | Shortcuts

Choose which tool bar items to display.

Tool Bar Structure:

- [✓] File
- [ ] Debug Update Modes
- [ ] Update Make Projects
- [✓] C/C++ Element Creation
- [✓] Build Configuration
- [✓] Launch
- [ ] Java Element Creation
- [–] Search
- [ ] CVS
- [ ] Team

[ ] Filter by command group

Cancel | OK

Figure 2.13. Customize Perspective Menu

*Figure 2.13, “Customize Perspective Menu”* displays the **Tool Bar Visibility** tab. As the name suggests, this tab allows you to toggle the visibility of the tool bars (*Figure 2.14, “Toolbar”*).

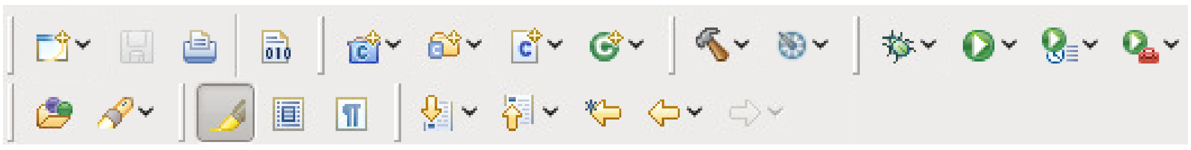


Figure 2.14. Toolbar

The following figures display the other tabs in the **Customize Perspective Menu**:

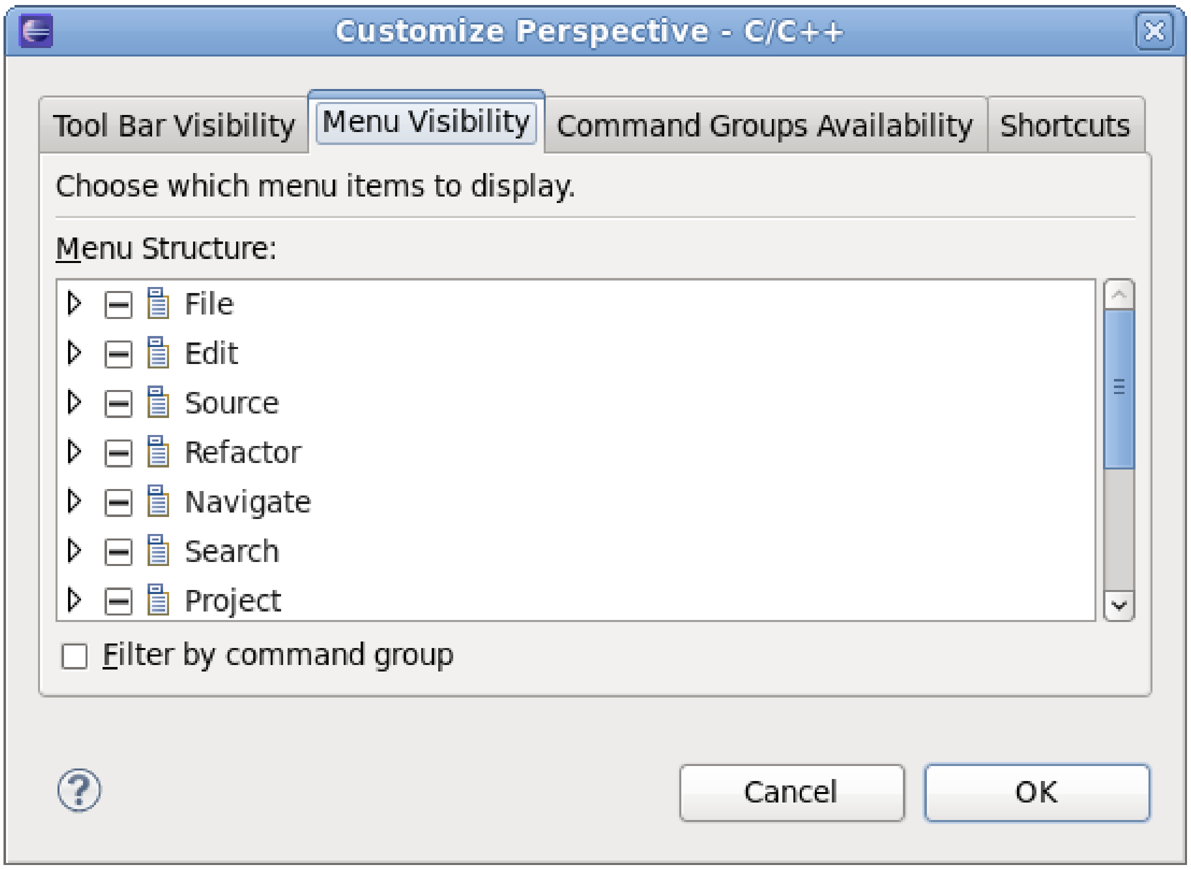
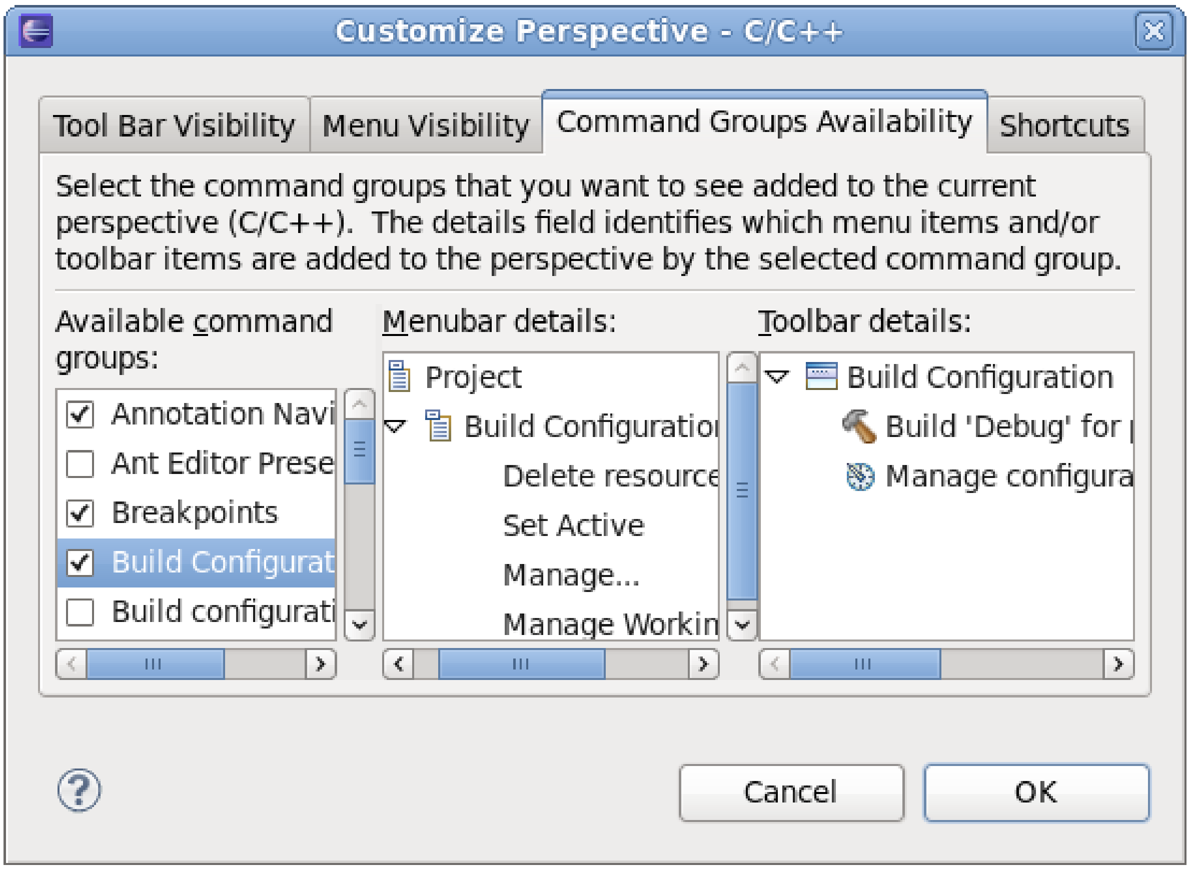


Figure 2.15. Menu Visibility Tab

The **Menu Visibility** tab configures what functions are visible in each main menu item. For a brief overview of each main menu item, refer to *Reference* > *C/C++ Menubar* in the *C/C++ Development User Guide* or *Reference* > *Menus and Actions* in the *Java Development User Guide*.


Customize Perspective - C/C++

Tool Bar Visibility | Menu Visibility | Command Groups Availability | Shortcuts

Select the command groups that you want to see added to the current perspective (C/C++). The details field identifies which menu items and/or toolbar items are added to the perspective by the selected command group.

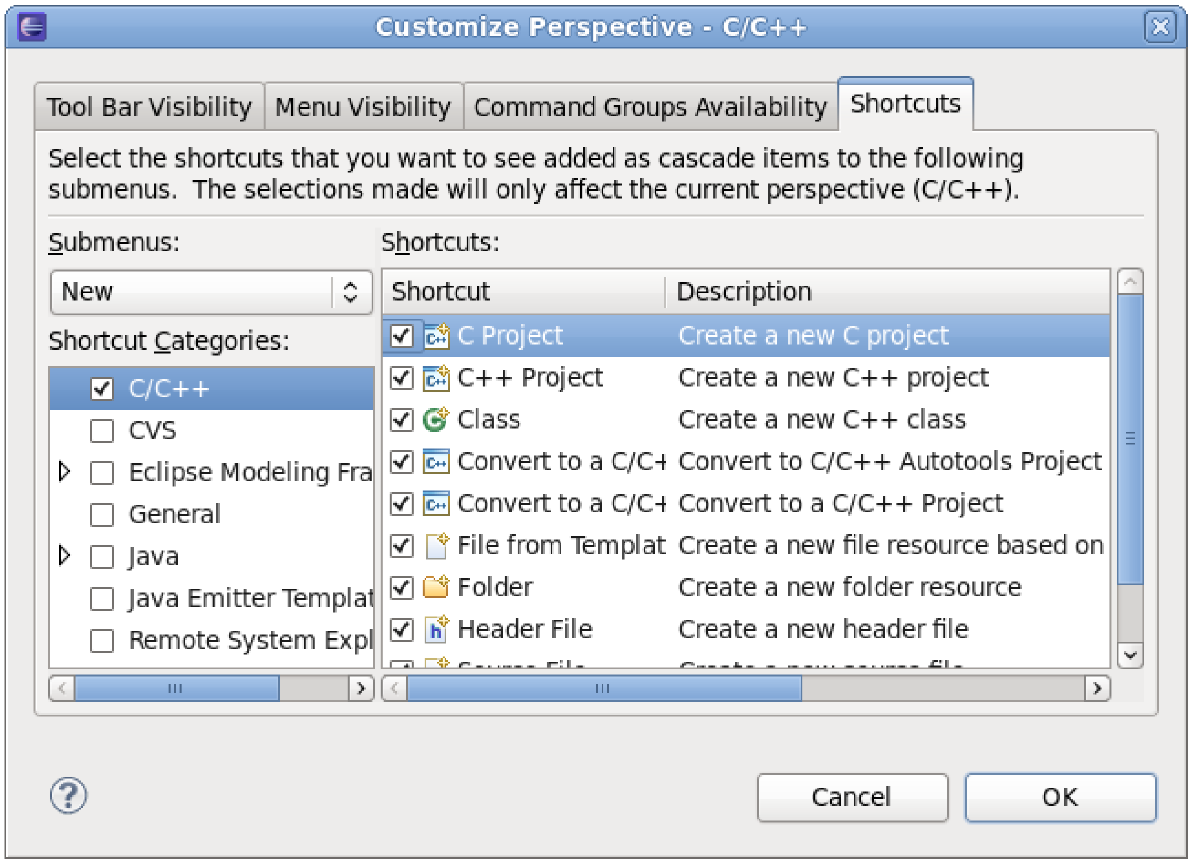
Available command groups:
- [✓] Annotation Navi
- [ ] Ant Editor Prese
- [✓] Breakpoints
- [✓] Build Configurat
- [ ] Build configurati

Menubar details:
- Project
  - Build Configuratio
    - Delete resource
    - Set Active
    - Manage...
    - Manage Workin

Toolbar details:
- Build Configuration
  - Build 'Debug' for
  - Manage configura

Figure 2.16. Command Group Availability Tab

Command groups add functions or options to the main menu or tool bar area. Use the **Command Group Availability** tab to add or remove a Command group. The **Menubar details** and **Toolbar details** fields display the functions or options added by the Command group to either Main Menu or Toolbar Area, respectively.



Select the shortcuts that you want to see added as cascade items to the following submenus. The selections made will only affect the current perspective (C/C++).

Submenus: New

Shortcut Categories:

- [✓] C/C++
- [ ] CVS
- [ ] Eclipse Modeling Fra
- [ ] General
- [ ] Java
- [ ] Java Emitter Templat
- [ ] Remote System Expl

Shortcuts:

| Shortcut | Description |
|---|---|
| [✓] C Project | Create a new C project |
| [✓] C++ Project | Create a new C++ project |
| [✓] Class | Create a new C++ class |
| [✓] Convert to a C/C+ | Convert to C/C++ Autotools Project |
| [✓] Convert to a C/C+ | Convert to a C/C++ Project |
| [✓] File from Templat | Create a new file resource based on |
| [✓] Folder | Create a new folder resource |
| [✓] Header File | Create a new header file |

Figure 2.17. Shortcuts Tab

The **Shortcuts** tab configures what menu items are available under the following submenus:

- **File** > **New**
- **Window** > **Open Perspective**
- **Window** > **Show View**

## 2.2.2. libhover Plug-in

The **`libhover`** plug-in for Eclipse provides plug-and-play hover help support for the GNU C Library and GNU C++ Standard Library. This allows developers to refer to existing documentation on **`glibc`** and **`libstdc++`** libraries within the Eclipse IDE in a more seamless and convenient manner via *hover help* and *code completion*.

For C++ library resources, **`libhover`** needs to *index* the file using the CDT indexer. Indexing parses the given file in context of a build; the build context determines where header files come from and how types, macros, and similar items are resolved. To be able to index a C++ source file, **`libhover`** usually requires you to perform an actual build first, although in some cases it may already know where the header files are located.

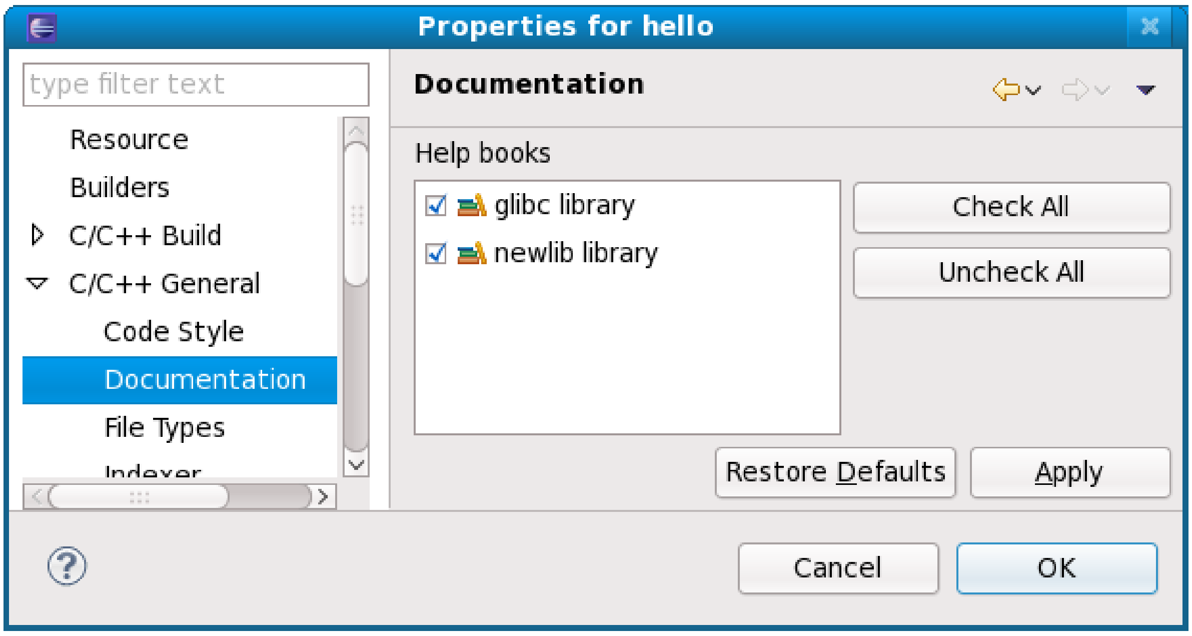
The **`libhover`** plug-in may need indexing for C++ sources because a C++ member function name is not enough information to look up its documentation. For C++, the class name and parameter signature of the function is also required to determine exactly which member is being referenced. This is because C++ allows different classes to have members of the same name, and even within a class, members may have the same name but with different method signatures.

In addition, C++ also has type definitions and templated classes to deal with. Such information requires parsing an entire file and its associated **`include`** files; **`libhover`** can only do this via indexing.

C functions, on the other hand, can be referenced in their documentation by name alone. As such, **`libhover`** does not need to index C source files in order to provide hover help or code completion. Simply choose an appropriate C header file to be included for a selection.

### 2.2.2.1. Setup and Usage

Hover help for all installed **`libhover`** libraries is enabled by default, and it can be disabled per project. To disable or enable hover help for a particular project, right-click the project name and click **Properties**. On the menu that appears, navigate to **C/C++ General** > **Documentation**. Check or uncheck a library in the **Help books** section to enable or disable hover help for that particular library.



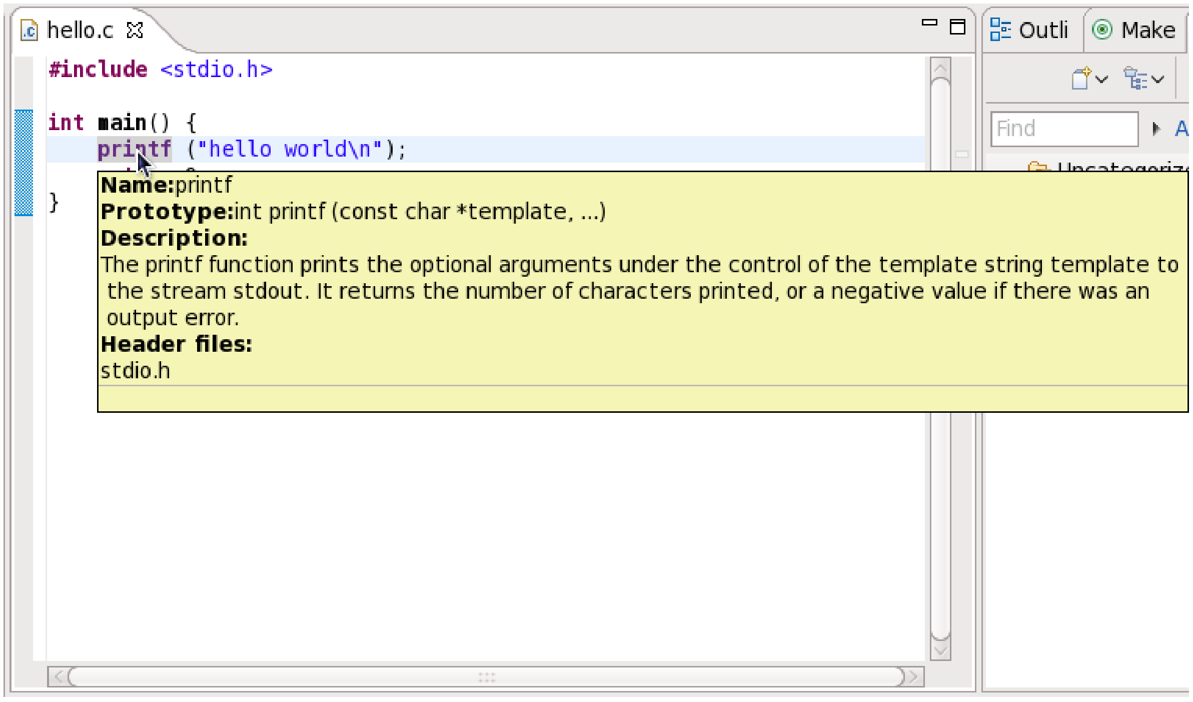
☑ glibc library
☑ newlib library

Figure 2.18. Enabling/Disabling Hover Help

Disabling hover help from a particular library may be preferable, particularly if multiple **`libhover`** libraries overlap in functionality. For example, the **`newlib`** library (whose **`libhover`** library plug-in is supported in Red Hat Enterprise Linux 6) contains functions whose names overlap with those in the GNU C library (provided by default); having **`libhover`** plugins for both **`newlib`** and **`glibc`** installed would mean having to disable one.

When multiple **`libhover`** libraries libraries are enabled and there exists a functional overlap between libraries, the Help content for the function from the *first* listed library in the **Help books** section will appear in hover help (i.e. in *Figure 2.18, "Enabling/Disabling Hover Help"*, **`glibc`**). For code completion, **`libhover`** will offer all possible alternatives from all enabled **`libhover`** libraries.

To use hover help, simply hover the mouse over a function name or member function name in the **C/C++ Editor**. After a few seconds, **`libhover`** will display library documentation on the selected C function or C++ member function.

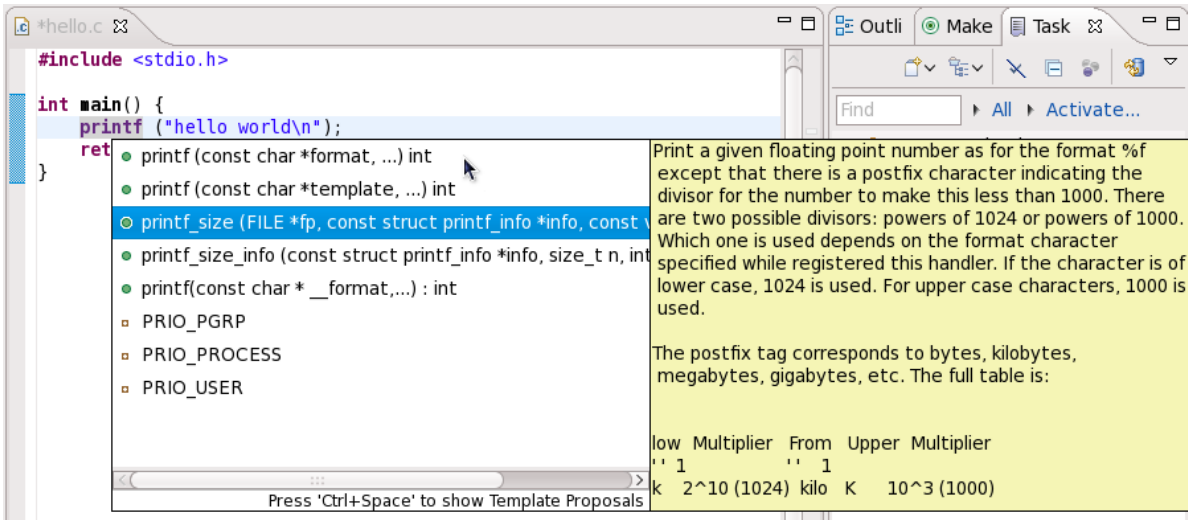


```
#include <stdio.h>

int main() {
    printf ("hello world\n");
}
```

**Name:**printf
**Prototype:**int printf (const char *template, ...)
**Description:**
The printf function prints the optional arguments under the control of the template string template to the stream stdout. It returns the number of characters printed, or a negative value if there was an output error.
**Header files:**
stdio.h

Figure 2.19. Using Hover Help

To use code completion, select a string in the code and press **`Ctrl`**+**`Space`**. This will display all possible functions given the selected string; click on a possible function to view its description.



```
#include <stdio.h>

int main() {
    printf ("hello world\n");
    ret
}
```

- printf (const char *format, ...) int
- printf (const char *template, ...) int
- printf_size (FILE *fp, const struct printf_info *info, const
- printf_size_info (const struct printf_info *info, size_t n, int
- printf(const char * __format,...) : int
- PRIO_PGRP
- PRIO_PROCESS
- PRIO_USER

Press 'Ctrl+Space' to show Template Proposals

Print a given floating point number as for the format %f except that there is a postfix character indicating the divisor for the number to make this less than 1000. There are two possible divisors: powers of 1024 or powers of 1000. Which one is used depends on the format character specified while registered this handler. If the character is of lower case, 1024 is used. For upper case characters, 1000 is used.

The postfix tag corresponds to bytes, kilobytes, megabytes, gigabytes, etc. The full table is:

```
low  Multiplier  From  Upper  Multiplier
' '  1                 ' '    1
k    2^10 (1024)  kilo  K      10^3 (1000)
```

Figure 2.20. Using Code Completion

# Libraries and Runtime Support

Red Hat Enterprise Linux 6 supports the development of custom applications in a wide variety of programming languages using proven, industrial-strength tools. This chapter describes the runtime support libraries provided in Red Hat Enterprise Linux 6.

## 3.1. Version Information

The following table compares the version information for runtime support packages in supported programming languages between Red Hat Enterprise Linux 6, Red Hat Enterprise Linux 5, and Red Hat Enterprise Linux 4.

This is not an exhaustive list. Instead, this is a survey of standard language runtimes, and key dependencies for software developed on Red Hat Enterprise Linux 6.

Table 3.1. Language and Runtime Library Versions

| Package Name | 6 | 5 | 4 |
|---|---|---|---|
| *glibc* | 2.12 | 2.5 | 2.3 |
| *libstdc++* | 4.4 | 4.1 | 3.4 |
| *boost* | 1.41 | 1.33 | 1.32 |
| *java* | 1.5 (IBM), 1.6 (IBM, OpenJDK, Oracle Java) | 1.4, 1.5, and 1.6 | 1.4 |
| *python* | 2.6 | 2.4 | 2.3 |
| *php* | 5.3 | 5.1 | 4.3 |
| *ruby* | 1.8 | 1.8 | 1.8 |
| *httpd* | 2.2 | 2.2 | 2.0 |
| *postgresql* | 8.4 | 8.1 | 7.4 |
| *mysql* | 5.1 | 5.0 | 4.1 |
| *nss* | 3.12 | 3.12 | 3.12 |
| *openssl* | 1.0.0 | 0.9.8e | 0.9.7a |
| *libX11* | 1.3 | 1.0 | |
| *firefox* | 3.6 | 3.6 | 3.6 |
| *kdebase* | 4.3 | 3.5 | 3.3 |
| *gtk2* | 2.18 | 2.10 | 2.04 |

## 3.2. Compatibility

Compatibility specifies the portability of binary objects and source code across different instances of a computer operating environment. Officially, Red Hat supports current release and two consecutive prior versions. This means that applications built on Red Hat Enterprise Linux 4 and Red Hat Enterprise Linux 5 will continue to run on Red Hat Enterprise Linux 6 as long as they comply with Red Hat guidelines (using the symbols that have been white-listed, for example).

Red Hat understands that as an enterprise platform, customers rely on long-term deployment of their applications. For this reason, applications built against C/C++ libraries with the help of compatibility libraries for Red Hat Enterprise Linux 2 and Red Hat Enterprise Linux 3 continue to be supported.

For further information regarding this, refer to Red Hat Enterprise Linux supported releases accessed at *https://access.redhat.com/support/policy/updates/errata/* and the general Red Hat Enterprise Linux compatibility policy, accessed at *https://www.redhat.com/f/pdf/rhel/RHEL6_App_Compatibility_WP.pdf*.

There are two types of compatibility:

Source Compatibility
: Source compatibility specifies that code will compile and execute in a consistent and predictable way across different instances of the operating environment. This type of compatibility is defined by conformance with specified Application Programming Interfaces (APIs).

Binary Compatibility
: Binary Compatibility specifies that compiled binaries in the form of executables and *Dynamic Shared Objects* (DSOs) will run correctly across different instances of the operating environment. This type of compatibility is defined by conformance with specified Application Binary Interfaces (ABIs).

### 3.2.1. API Compatibility

Source compatibility enables a body of application source code to be compiled and operate correctly on multiple instances of an operating environment, across one or more hardware architectures, as long as the source code is compiled individually for each specific hardware architecture.

Source compatibility is defined by an Application Programming Interface (API), which is a set of programming interfaces and data structures provided to application developers. The programming syntax of APIs in the C programming language are defined in header files. These header files specify data types and programmatic functions. They are available to programmers for use in their applications, and are implemented by the operating system or libraries. The syntax of APIs are enforced at compile time, or when the application source code is compiled to produce executable binary objectcode.

APIs are classified as:

- *De facto standards* not formally specified but implied by a particular implementation.
- *De jure standards* formally specified in standards documentation.

In all cases, application developers should seek to ensure that any behavior they depend on is described in formal API documentation, so as to avoid introducing dependencies on unspecified implementation specific semantics or even introducing dependencies on bugs in a particular implementation of an API. For example, new releases of the GNU C library are not guaranteed to be compatible with older releases if the old behavior violated a specification.

Red Hat Enterprise Linux by and large seeks to implement source compatibility with a variety of de jure industry standards developed for Unix operating environments. While Red Hat Enterprise Linux does not fully conform to all aspects of these standards, the standards documents do provide a defined set of interfaces, and many components of Red Hat Enterprise Linux track compliance with them (particularly glibc, the GNU C Library, and gcc, the GNU C/C++/Java/Fortran Compiler). There are and will be certain aspects of the standards which are not implemented as required on Linux.

### 3.2.2. ABI Compatibility

Binary compatibility enables a single compiled binary to operate correctly on multiple instances of an operating environment that share a common hardware architecture (whether that architecture support is implemented in native hardware or a virtualization layer), but a different underlying software architecture.

Binary compatibility is defined by an Application Binary Interface (ABI). The ABI is a set of runtime conventions adhered to by all tools which deal with a compiled binary representation of a program. Examples of such tools include compilers, linkers, runtime libraries, and the operating system itself. The ABI includes not only the binary file formats, but also the semantics of library functions which are used by applications.

### 3.2.3. Policy

Ideally, rebuild and repackage applications for each major release. This allows full advantage of new optimizations in the compiler, as well as new features available in the latest tools, to be taken.

However, there are times when it is useful to build one set of binaries that can be deployed on multiple major releases at once. This is especially useful with old code bases that are not compliant to the latest revision of the language standards available in more recent Red Hat Enterprise Linux releases.

Therefore it is advised to refer to the Red Hat Enterprise Linux 6 *Application Compatibility Specification*[4] for guidance. This document outlines Red Hat policy and recommendations regarding backwards compatibility, particularly for specific packages.

### 3.2.4. Static Linking

Static linking is emphatically discouraged for all Red Hat Enterprise Linux releases. Static linking causes far more problems than it solves, and should be avoided at all costs.

The main drawback of static linking is that it is only guaranteed to work on the system on which it was built, and even then only until the next release of glibc or libstdc++ (in the case of C++). There is no forward or backward compatibility with a static build. Furthermore, any security fixes (or general-purpose fixes) in subsequent updates to the libraries will not be available unless the affected statically linked executables are re-linked.

A few more reasons why static linking should be avoided are:

- Larger memory footprint.
- Slower application startup time.
- Reduced glibc features with static linking.
- Security measures like load address randomization cannot be used.
- Dynamic loading of shared objects outside of glibc is not supported.

For aditional reasons to avoid static linking, see: *Static Linking Considered Harmful*[5].

## 3.3. Library and Runtime Details

### 3.3.1. The GNU C Library

The **`glibc`** package contains the GNU C Library. This defines all functions specified by the ISO C standard, POSIX specific features, some Unix derivatives, and GNU-specific extensions. The most important set of shared libraries in the GNU C Library are the standard C and math libraries.

[4] https://www.redhat.com/f/pdf/rhel/RHEL6_App_Compatibility_WP.pdf
[5] http://www.akkadia.org/drepper/no_static_linking.html

The GNU C Library defines its functions through specific *header* files, which you can declare in source code. Each header file contains definitions of a group of related facilities; for example, the **`stdio.h`** header file defines I/O-specific facilities, while **`math.h`** defines functions for computing mathematical operations.

#### 3.3.1.1. GNU C Library Updates

The Red Hat Enterprise Linux 6 version of the GNU C Library features the following improvements over its Red Hat Enterprise Linux 5 version:

- Added locales, including:
  - bo_CN
  - bo_IN
  - shs_CA
  - ber_DZ
  - ber_MA
  - en_NG
  - fil_PH
  - fur_IT
  - fy_DE
  - ha_NG
  - ig_NG
  - ik_CA
  - iu_CA
  - li_BE
  - li_NL
  - nds_DE
  - nds_NL
  - pap_AN
  - sc_IT
  - tk_TM
- Added new interfaces, namely:
  - **`preadv`**
  - **`preadv64`**
  - **`pwritev`**

  - **pwritev64**
  - **malloc_info**
  - **mkostemp**
  - **mkostemp64**
- Added new Linux-specific interfaces, namely:
  - **epoll_pwait**
  - **sched_getcpu**
  - **accept4**
  - **fallocate**
  - **fallocate64**
  - **inotify_init1**
  - **dup3**
  - **epoll_create1**
  - **pipe2**
  - **signalfd**
  - **eventfd**
  - **eventfd_read**
  - **eventfd_write**
- Added new checking functions, namely:
  - **asprintf**
  - **dprintf**
  - **obstack_printf**
  - **vasprintf**
  - **vdprintf**
  - **obstack_vprintf**
  - **fread**
  - **fread_unlocked**
  - **open***
  - **mq_open**

For a more detailed list of updates to the GNU C Library, refer to **`/usr/share/doc/glibc-`*`version`*`/NEWS`** . All changes as of version 2.12 apply to the GNU C Library in Red Hat Enterprise Linux 6. Some of these changes have also been backported to Red Hat Enterprise Linux 5 versions of **`glibc`**.

#### 3.3.1.2. GNU C Library Documentation

The GNU C Library is fully documented in the *GNU C Library* manual; to access this manual locally, install **`glibc-devel`** and run **`info libc`**. An upstream version of this book is also available here:

*http://www.gnu.org/software/libc/manual/html_mono/libc.html*

### 3.3.2. The GNU C++ Standard Library

The **`libstdc++`** package contains the GNU C++ Standard Library, which is an ongoing project to implement the ISO 14882 Standard C++ library.

Installing the **`libstdc++`** package will provide just enough to satisfy link dependencies (i.e. only shared library files). To make full use of all available libraries and header files for C++ development, you must install **`libstdc++-devel`** as well. The **`libstdc++-devel`** package also contains a GNU-specific implementation of the Standard Template Library (STL).

For Red Hat Enterprise Linux 4, 5, and 6, the C++ language and runtime implementation has remained stable and as such no compatibility libraries are needed for **`libstdc++`**. However, this is not the case for Red Hat Enterprise Linux 2 and 3. For Red Hat Enterprise Linux 2 **`compat-libstdc++-296`** needs to be installed. For Red Hat Enterprise Linux 3 **`compat-libstdc++-33`** needs to be installed. Neither of these are installed by default so need to be added separately.

#### 3.3.2.1. GNU C++ Standard Library Updates

The Red Hat Enterprise Linux 6 version of the GNU C++ Standard Library features the following improvements over its Red Hat Enterprise Linux 5 version:

- Added support for elements of ISO C++ TR1, namely:
  - **`<tr1/array>`**
  - **`<tr1/complex>`**
  - **`<tr1/memory>`**
  - **`<tr1/functional>`**
  - **`<tr1/random>`**
  - **`<tr1/regex>`**
  - **`<tr1/tuple>`**
  - **`<tr1/type_traits>`**
  - **`<tr1/unordered_map>`**
  - **`<tr1/unordered_set>`**
  - **`<tr1/utility>`**
  - **`<tr1/cmath>`**

- Added support for elements of the upcoming ISO C++ standard, C++0x. These elements include:
  - **`<array>`**
  - **`<chrono>`**
  - **`<condition_variable>`**
  - **`<forward_list>`**
  - **`<functional>`**
  - **`<initalizer_list>`**
  - **`<mutex>`**
  - **`<random>`**
  - **`<ratio>`**
  - **`<regex>`**
  - **`<system_error>`**
  - **`<thread>`**
  - **`<tuple>`**
  - **`<type_traits>`**
  - **`<unordered_map>`**
  - **`<unordered_set>`**
- Added support for the **`-fvisibility`** command.
- Added the following extensions:
  - **`__gnu_cxx::typelist`**
  - **`__gnu_cxx::throw_allocator`**

For more information about updates to **`libstdc++`** in Red Hat Enterprise Linux 6, refer to the *C++ Runtime Library* section of the following documents:

- *GCC 4.2 Release Series Changes, New Features, and Fixes*: *http://gcc.gnu.org/gcc-4.2/changes.html*
- *GCC 4.3 Release Series Changes, New Features, and Fixes*: *http://gcc.gnu.org/gcc-4.3/changes.html*
- *GCC 4.4 Release Series Changes, New Features, and Fixes*: *http://gcc.gnu.org/gcc-4.4/changes.html*

#### 3.3.2.2. GNU C++ Standard Library Documentation

To use the **`man`** pages for library components, install the **`libstdc++-docs`** package. This will provide **`man`** page information for nearly all resources provided by the library; for example, to view information about the **`vector`** container, use its fully-qualified component name:

**`man std::vector`**

This will display the following information (abbreviated):

```
std::vector(3)                                                std::vector(3)

NAME
       std::vector -

       A standard container which offers fixed time access to individual
       elements in any order.

SYNOPSIS
       Inherits std::_Vector_base< _Tp, _Alloc >.

   Public Types
       typedef _Alloc allocator_type
       typedef __gnu_cxx::__normal_iterator< const_pointer, vector >
           const_iterator
       typedef _Tp_alloc_type::const_pointer const_pointer
       typedef _Tp_alloc_type::const_reference const_reference
       typedef std::reverse_iterator< const_iterator >
```

The **`libstdc++-docs`** package also provides manuals and reference information in HTML form at the following directory:

**`file:///usr/share/doc/libstdc++-docs-`*`version`*`/html/spine.html`**

The main site for the development of libstdc++ is hosted on *gcc.gnu.org*[8].

### 3.3.3. Boost

The **`boost`** package contains a large number of free peer-reviewed portable C++ source libraries. These libraries are suitable for tasks such as portable file-systems and time/date abstraction, serialization, unit testing, thread creation and multi-process synchronization, parsing, graphing, regular expression manipulation, and many others.

Installing the **`boost`** package will provide just enough libraries to satisfy link dependencies (i.e. only shared library files). To make full use of all available libraries and header files for C++ development, you must install **`boost-devel`** as well.

The **`boost`** package is actually a meta-package, containing many library sub-packages. These sub-packages can also be installed in an *a la carte* fashion to provide finer inter-package dependency tracking. The meta-package includes all of the following sub-packages:

- **`boost-date-time`**
- **`boost-filesystem`**
- **`boost-graph`**
- **`boost-iostreams`**
- **`boost-math`**

[8] http://gcc.gnu.org/libstdc++

- **`boost-program-options`**
- **`boost-python`**
- **`boost-regex`**
- **`boost-serialization`**
- **`boost-signals`**
- **`boost-system`**
- **`boost-test`**
- **`boost-thread`**
- **`boost-wave`**

Not included in the meta-package are packages for static linking or packages that depend on the underlying Message Passing Interface (MPI) support.

MPI support is provided in two forms: one for the default Open MPI implementation [10] , and another for the alternate MPICH2 implementation. The selection of the underlying MPI library in use is up to the user and depends on specific hardware details and user preferences. Please note that these packages can be installed in parallel, as installed files have unique directory locations.

For Open MPI:

- **`boost-openmpi`**
- **`boost-openmpi-devel`**
- **`boost-graph-openmpi`**
- **`boost-openmpi-python`**

For MPICH2:

- **`boost-mpich2`**
- **`boost-mpich2-devel`**
- **`boost-graph-mpich2`**
- **`boost-mpich2-python`**

If static linkage cannot be avoided, the **`boost-static`** package will install the necessary static libraries. Both thread-enabled and single-threaded libraries are provided.

#### 3.3.3.1. Boost Updates

The Red Hat Enterprise Linux 6 version of Boost features many packaging improvements and new features.

Several aspects of the **`boost`** package have changed. As noted above, the monolithic **`boost`** package has been augmented by smaller, more discrete sub-packages. This allows for more control

[10] MPI support is not available on IBM System Z machines (where Open MPI is not available).

of dependencies by users, and for smaller binary packages when packaging a custom application that uses Boost.

In addition, both single-threaded and multi-threaded versions of all libraries are packaged. The multi-threaded versions include the `mt` suffix, as per the usual Boost convention.

Boost also features the following new libraries:

- Foreach
- Statechart
- TR1
- Typeof
- Xpressive
- Asio
- Bitmap
- Circular Buffer
- Function Types
- Fusion
- GIL
- Interprocess
- Intrusive
- Math/Special Functions
- Math/Statistical Distributions
- MPI
- System
- Accumulators
- Exception
- Units
- Unordered
- Proto
- Flyweight
- Scope Exit
- Swap
- Signals2
- Property Tree

Many of the existing libraries have been improved, bug-fixed, and otherwise enhanced.

#### 3.3.3.2. Boost Documentation

The **`boost-doc`** package provides manuals and reference information in HTML form located in the following directory:

```
file:///usr/share/doc/boost-doc-version/index.html
```

The main site for the development of Boost is hosted on *boost.org*[11].

### 3.3.4. Qt

The **`qt`** package provides the Qt (pronounced "cute") cross-platform application development framework used in the development of GUI programs. Aside from being a popular "widget toolkit", Qt is also used for developing non-GUI programs such as console tools and servers. Qt was used in the development of notable projects such as Google Earth, KDE, Opera, OPIE, VoxOx, Skype, VLC media player and VirtualBox. It is produced by Nokia's Qt Development Frameworks division, which came into being after Nokia's acquisition of the Norwegian company Trolltech, the original producer of Qt, on June 17, 2008.

Qt uses standard C++ but makes extensive use of a special pre-processor called the *Meta Object Compiler* (MOC) to enrich the language. Qt can also be used in other programming languages via language bindings. It runs on all major platforms and has extensive internationalization support. Non-GUI Qt features include SQL database access, XML parsing, thread management, network support, and a unified cross-platform API for file handling.

Distributed under the terms of the GNU Lesser General Public License (among others), Qt is free and open source software. The Red Hat Enterprise Linux 6 version of Qt supports a wide range of compilers, including the GCC C++ compiler and the Visual Studio suite.

#### 3.3.4.1. Qt Updates

Some of the improvements the Red Hat Enterprise Linux 6 version of Qt include:

- Advanced user experience
  - **Advanced Graphics Effects:** options for opacity, drop-shadows, blur, colorization, and other similar effects
  - **Animation and State Machine:** create simple or complex animations without the hassle of managing complex code
  - Gesture and multi-touch support
- Support for new platforms
  - Windows 7, Mac OSX 10.6, and other desktop platforms are now supported
  - Added support for mobile development; Qt is optimized for the upcoming Maemo 6 platform, and will soon be ported to Maemo 5. In addition, Qt now supports the Symbian platform, with integration for the S60 framework.

[11] http://boost.org

    - Added support for Real-Time Operating Systems such as QNX and VxWorks

- Improved performance, featuring added support for hardware-accelerated rendering (along with other rendering updates)

- Updated cross-platform IDE

For more details on updates to Qt included in Red Hat Enterprise Linux 6, refer to the following links:

- *http://doc.qt.nokia.com/4.6/qt4-6-intro.html*

- *http://doc.qt.nokia.com/4.6/qt4-intro.html*

### 3.3.4.2. Qt Creator

**Qt Creator** is a cross-platform IDE tailored to the needs of Qt developers. It includes the following graphical tools:

- An advanced C++ code editor

- Integrated GUI layout and forms designer

- Project and build management tools

- Integrated, context-sensitive help system

- Visual debugger

- Rapid code navigation tools

For more information about **Qt Creator**, refer to the following link:

*http://qt.nokia.com/products/appdev/developer-tools/developer-tools#qt-tools-at-a*

### 3.3.4.3. Qt Library Documentation

The **`qt-doc`** package provides HTML manuals and references located in **`/usr/share/doc/qt4/html/`**. This package also provides the *Qt Reference Documentation*, which is an excellent starting point for development within the Qt framework.

You can also install further demos and examples from **`qt-demos`** and **`qt-examples`**. To get an overview of the capabilities of the Qt framework, refer to **`/usr/bin/qtdemo-qt4`** (provided by **`qt-demos`**).

For more information on the development of Qt, refer to the following online resources:

- *Qt Developer Blogs*: *http://labs.trolltech.com/blogs/*

- *Qt Developer Zone*: *http://qt.nokia.com/developer/developer-zone*

- *Qt Mailing List*: *http://lists.trolltech.com/*

## 3.3.5. KDE Development Framework

The **`kdelibs-devel`** package provides the KDE libraries, which build on Qt to provide a framework for making application development easier. The KDE development framework also helps provide consistency across the KDE desktop environment.

#### 3.3.5.1. KDE4 Architecture

The KDE development framework's architecture in Red Hat Enterprise Linux 6 uses KDE4, which is built on the following technologies:

Plasma

> **Plasma** replaces KDesktop in KDE4. Its implementation is based on the **Qt Graphics View Framework**, which was introduced in Qt 4.2. For more information about **Plasma**, refer to *http://techbase.kde.org/Development/Architecture/KDE4/Plasma*.

Sonnet

> **Sonnet** is a multilingual spell-checking application that supports automatic language detection, primary/backup dictionaries, and other useful features. It replaces **`kspell2`** in KDE4.

KIO

> The KIO library provides a framework for network-transparent file handling, allowing users to easily access files through network-transparent protocols. It also helps provides standard file dialogs.

KJS/KHTML

> KJS and KHTML are fully-fledged JavaScript and HTML engines used by different applications native to KDE4 (such as **konqueror**).

Solid

> **Solid** is a hardware and network awareness framework that allows you to develop applications with hardware interaction features. Its comprehensive API provides the necessary abstraction to support cross-platform application development. For more information, refer to *http://techbase.kde.org/Development/Architecture/KDE4/Solid*.

Phonon

> **Phonon** is a multimedia framework that helps you develop applications with multimedia functionalities. It facilitates the usage of media capabilities within KDE. For more information, refer to *http://techbase.kde.org/Development/Architecture/KDE4/Phonon*.

Telepathy

> **Telepathy** provides a real-time communication and collaboration framework within KDE4. Its primary function is to tighten integration between different components within KDE. For a brief overview on the project, refer to *http://community.kde.org/Real-Time_Communication_and_Collaboration*.

Akonadi

> **Akonadi** provides a framework for centralizing storage of *Parallel Infrastructure Management* (PIM) components. For more information, refer to *http://techbase.kde.org/Development/Architecture/KDE4/Akonadi*.

Online Help within KDE4

> KDE4 also features an easy-to-use Qt-based framework for adding online help capabilities to applications. Such capabilities include tooltips, hover-help information, and **khelpcenter** manuals. For a brief overview on online help within KDE4, refer to *http://techbase.kde.org/Development/Architecture/KDE4/Providing_Online_Help*.

KXMLGUI

> **KXMLGUI** is a framework for designing user interfaces using XML. This framework allows you to design UI elements based on "actions" (defined by the developer) without having to revise

source code. For more information, refer to *http://developer.kde.org/documentation/library/kdeqt/kde3arch/xmlgui.html*.

Strigi

**Strigi** is a desktop search daemon compatible with many desktop environments and operating systems. It uses its own **jstream** system which allows for deep indexing of files. For more information on the development of **Strigi**, refer to *http://www.vandenoever.info/software/strigi/*.

KNewStuff2

**KNewStuff2** is a collaborative data sharing library used by many KDE4 applications. For more information, refer to *http://techbase.kde.org/Projects/KNS2*.

### 3.3.5.2. kdelibs Documentation

The **`kdelibs-apidocs`** package provides HTML documentation for the KDE development framework in **`/usr/share/doc/HTML/en/kdelibs4-apidocs/`**. The following links also provide details on KDE-related programming tasks:

- *http://techbase.kde.org/*
- *http://techbase.kde.org/Development/Tutorials*
- *http://techbase.kde.org/Development/FAQs*
- *http://api.kde.org*

## 3.3.6. NSS Shared Databases

The NSS shared database format, introduced on NSS 3.12, is now available in Red Hat Enterprise 6. This encompasses a number of new features and components to improve access and usability.

Included, is the NSS certificate and key database which are now sqlite-based and allow for concurrent access. The legacy **`key3.db`** and **`cert8.db`** are also replaced with new SQL databases called **`key4.db`** and **`cert9.db`**. These new databases will store PKCS #11 token objects, which are the same as what is currently stored in **`cert8.db`** and **`key3.db`**.

Having support for shared databases enables a system-wide NSS database. It resides in **`/etc/pki/nssdb`** where globally trusted CA certificates become accessible to all applications. The command **`rv = NSS_InitReadWrite("sql:/etc/pki/nssdb");`** initializes NSS for applications. If the application is run with root privileges, then the system-wide database is available on a read and write basis. However, if it is run with normal user privileges it becomes read only.

Additionally, a PEM PKCS #11 module for NSS allows applications to load into memory certificates and keys stored in PEM-formatted files (for example, those produced by openssl).

### 3.3.6.1. Backwards Compatibility

The binary compatibility guarantees made by NSS upstream are preserved in NSS for Red Hat Enterprise Linux 6. This guarantee states that the NSS 3.12 is backwards compatible with all older NSS 3.x shared libraries. Therefore, a program linked with an older NSS 3.x shared library will work without recompiling or relinking, and any applications that restrict the use of NSS APIs to the NSS Public Functions remain compatible with future versions of the NSS shared libraries.

Red Hat Enterprise Linux 5 and 4 run on the same version of NSS as Red Hat Enterprise Linux 6 so there are no ABI or API changes. However, there are still differences as NSS's internal cryptographic module in Red Hat Enterprise Linux 6 is the one from NSS 3.12, whereas Red Hat Enterprise Linux 5 and 4 still use the older one from NSS 3.15. This means that new functionality that had been introduced with NSS 3.12, such as the shared database, is now available with Red Hat Enterprise Linux 6's version of NSS.

#### 3.3.6.2. NSS Shared Databases Documentation

Mozilla's wiki page explains the system-wide database rationale in great detail and can be accessed *here*[12].

### 3.3.7. Python

The **`python`** package adds support for the Python programming language. This package provides the object and cached bytecode files needed to enable runtime support for basic Python programs. It also contains the **`python`** interpreter and the **`pydoc`** documentation tool. The **`python-devel`** package contains the libraries and header files needed for developing Python extensions.

Red Hat Enterprise Linux also ships with numerous **`python`**-related packages. By convention, the names of these packages have a **`python`** prefix or suffix. Such packages are either library extensions or python bindings to an existing library. For instance, **`dbus-python`** is a Python language binding for D-Bus.

Note that both cached bytecode (**`*.pyc`**/**`*.pyo`** files) and compiled extension modules (**`*.so`** files) are incompatible between Python 2.4 (used in Red Hat Enterprise Linux 5) and Python 2.6 (used in Red Hat Enterprise Linux 6). As such, you will need to rebuild any extension modules you use that are not part of Red Hat Enterprise Linux.

#### 3.3.7.1. Python Updates

The Red Hat Enterprise Linux 6 version of Python features various language changes. For information about these changes, refer to the following project resources:

- What's New in Python 2.5: *http://docs.python.org/whatsnew/2.5.html*
- What's New in Python 2.6: *http://docs.python.org/whatsnew/2.6.html*

Both resources also contain advice on porting code developed using previous Python versions.

#### 3.3.7.2. Python Documentation

For more information about Python, refer to **`man python`**. You can also install **`python-docs`**, which provides HTML manuals and references in the following location:

**`file:///usr/share/doc/python-docs-`*`version`*`/html/index.html`**

For details on library and language components, use **`pydoc`** ***`component_name`***. For example, **`pydoc math`** will display the following information about the **`math`** Python module:

```
Help on module math:

NAME
 math

FILE
 /usr/lib64/python2.6/lib-dynload/mathmodule.so
```

[12] http://wiki.mozilla.org/NSS_Shared_DB_And_LINUX

```
DESCRIPTION
 This module is always available.  It provides access to the
 mathematical functions defined by the C standard.

FUNCTIONS
 acos[...]
  acos(x)

  Return the arc cosine (measured in radians) of x.

 acosh[...]
  acosh(x)

  Return the hyperbolic arc cosine (measured in radians) of x.

 asin(...)
  asin(x)

  Return the arc sine (measured in radians) of x.

 asinh[...]
  asinh(x)

  Return the hyperbolic arc sine (measured in radians) of x.
```

The main site for the Python development project is hosted on *python.org*[14].

## 3.3.8. Java

The **java-1.6.0-openjdk** package adds support for the Java programming language. This package provides the **java** interpreter. The **java-1.6.0-openjdk-devel** package contains the **javac** compiler, as well as the libraries and header files needed for developing Java extensions.

Red Hat Enterprise Linux also ships with numerous **java**-related packages. By convention, the names of these packages have a **java** prefix or suffix.

### 3.3.8.1. Java Documentation

For more information about Java, refer to **man java**. Some associated utilities also have their own respective **man** pages.

You can also install other Java documentation packages for more details about specific Java utilities. By convention, such documentation packages have the **javadoc** suffix (e.g. **dbus-java-javadoc**).

The main site for the development of Java is hosted on *http://openjdk.java.net/*. The main site for the library runtime of Java is hosted on *http://icedtea.classpath.org*.

## 3.3.9. Ruby

The **ruby** package provides the Ruby interpreter and adds support for the Ruby programming language. The **ruby-devel** package contains the libraries and header files needed for developing Ruby extensions.

Red Hat Enterprise Linux also ships with numerous **ruby**-related packages. By convention, the names of these packages have a **ruby** or **rubygem** prefix or suffix. Such packages are either library extensions or Ruby bindings to an existing library.

[14] http://python.org

Examples of **`ruby`**-related packages include:

- ruby-flexmock
- rubygem-flexmock
- rubygems
- ruby-irb
- ruby-libguestfs
- ruby-libs
- ruby-qpid
- ruby-rdoc
- ruby-ri
- ruby-saslwrapper
- ruby-static
- ruby-tcltk

For information about updates to the Ruby language in Red Hat Enterprise Linux 6, refer to the following resources:

- **`file:///usr/share/doc/ruby-`*`version`*`/NEWS`**
- **`file:///usr/share/doc/ruby-`*`version`*`/NEWS-`*`version`***

### 3.3.9.1. Ruby Documentation

For more information about Ruby, refer to **`man ruby`**. You can also install **`ruby-docs`**, which provides HTML manuals and references in the following location:

**`file:///usr/share/doc/ruby-docs-`*`version/`***

The main site for the development of Ruby is hosted on *http://www.ruby-lang.org*. The *http://www.ruby-doc.org* site also contains Ruby documentation.

## 3.3.10. Perl

The **`perl`** package adds support for the Perl programming language. This package provides Perl core modules, the Perl Language Interpreter, and the PerlDoc tool.

Red Hat also provides various perl modules in package form; these packages are named with the **`perl-*`** prefix. These modules provide stand-alone applications, language extensions, Perl libraries, and external library bindings.

### 3.3.10.1. Perl Updates

Red Hat Enterprise Linux 6.0 ships with **`perl-5.10.1`**. If you are running an older system, rebuild or alter external modules and applications accordingly in order to ensure optimum performance.

For a full list of the differences between the Perl versions refer to the following documents:

- Perl 5.10 delta: *http://perldoc.perl.org/perl5100delta.html*
- Perl 5.10.1 delta: *http://perldoc.perl.org/perl5101delta.html*

### 3.3.10.2. Installation

Perl's capabilities can be extended by installing additional modules. These modules come in the following forms:

Official Red Hat RPM
: The official module packages can be installed with **`yum`** or **`rpm`** from the Red Hat Enterprise Linux repositories. They are installed to **`/usr/share/perl5`** and either **`/usr/lib/perl5`** for 32bit architectures or **`/usr/lib64/perl5`** for 64bit architectures.

Modules from CPAN
: Use the **`cpan`** tool provided by the perl-CPAN package to install modules directly from the CPAN website. They are installed to **`/usr/local/share/perl5`** and either **`/usr/local/lib/perl5`** for 32bit architectures or **`/usr/local/lib64/perl5`** for 64bit architectures.

Third party module package
: Third party modules are installed to **`/usr/share/perl5/vendor_perl`** and either **`/usr/lib/perl5/vendor_perl`** for 32bit architectures or **`/usr/lib64/perl5/vendor_perl`** for 64bit architectures.

Custom module package / manually installed module
: These should be placed in the same directories as third party modules. That is, **`/usr/share/perl5/vendor_perl`** and either **`/usr/lib/perl5/vendor_perl`** for 32bit architectures or **`/usr/lib64/perl5/vendor_perl`** for 64bit architectures.

**Warning**

If an official version of a module is already installed, installing its non-official version can create conflicts in the **`/usr/share/man`** directory.

### 3.3.10.3. Perl Documentation

The **`perldoc`** tool provides documentation on language and core modules. To learn more about a module, use perldoc module_name. For example, **`perldoc CGI`** will display the following information about the CGI core module:

```
NAME
 CGI - Handle Common Gateway Interface requests and responses

SYNOPSIS
 use CGI;

 my $q = CGI->new;

[...]

DESCRIPTION
 CGI.pm is a stable, complete and mature solution for processing and preparing HTTP requests
 and responses.  Major features including processing form submissions, file uploads, reading
 and writing cookies, query string generation and manipulation, and processing and preparing
 HTTP headers. Some HTML generation utilities are included as well.
```

```
[...]

PROGRAMMING STYLE
  There are two styles of programming with CGI.pm, an object-oriented style and a function-
oriented style.  In the object-oriented style you create one or more CGI objects and then use
 object methods to create the various elements of the page.  Each CGI object starts out with
 the list of named parameters that were passed to your CGI script by the server.

[...]
```

For details on Perl functions, use **`perldoc -f`** ***`function_name`***. For example, perldoc -f split wil display the following information about the split function:

```

split /PATTERN/,EXPR,LIMIT
split /PATTERN/,EXPR
split /PATTERN/
split   Splits the string EXPR into a list of strings and returns that list.  By default,
 empty leading fields are preserved, and empty trailing ones are deleted.  (If all fields are
 empty, they are considered to be trailing.)

In scalar context, returns the number of fields found. In scalar and void context it splits
 into the @_ array.  Use of split in scalar and void context is deprecated, however, because
 it clobbers your subroutine arguments.

If EXPR is omitted, splits the $_ string.  If PATTERN is also omitted, splits on whitespace
 (after skipping any leading whitespace).  Anything matching PATTERN is taken to be
 a delimiter separating the fields.  (Note that the delimiter may be longer than one
 character.)

[...]
```

Current PerlDoc documentation can be found on *perldoc.perl.org*[20].

Core and external modules are documented on the *Comprehensive Perl Archive Network*[21].

[20] http://perldoc.perl.org/
[21] http://www.cpan.org/

# Compiling and Building

Red Hat Enterprise Linux 6 includes many packages used for software development, including tools for compiling and building source code. This chapter discusses several of these packages and tools used to compile source code.

## 4.1. GNU Compiler Collection (GCC)

The GNU Compiler Collection (GCC) is a set of tools for compiling a variety of programming languages (including C, C++, ObjectiveC, ObjectiveC++, Fortran, and Ada) into highly optimized machine code. These tools include various compilers (like **`gcc`** and **`g++`**), run-time libraries (like **`libgcc`**, **`libstdc++`**, **`libgfortran`**, and **`libgomp`**), and miscellaneous other utilities.

### 4.1.1. GCC Status and Features

GCC for Red Hat Enterprise Linux 6 is based on the 4.4.x release series and includes several bug fixes, enhancements, and backports from upcoming releases (including the GCC 4.5). However, GCC 4.5 was not considered sufficiently mature for an enterprise distribution when RHEL6 features were frozen.

This standardization means that as updates to the 4.4 series become available (4.4.1, 4.4.2, ect), they will be incorporated into the compiler included with RHEL6 as updates. Red Hat may import additional backports and enhancements from upcoming releases outside the 4.4 series that won't break compatibility within the Enterprise Linux release. Occasionally, code that was not compliant to standards may fail to compile or its functionality may change in the process of fixing bugs or maintaining standards compliant behavior.

Since the previous release of Red Hat Enterprise Linux, GCC has had three major releases: 4.2.x, 4.3.x, and 4.4.x. A selective summary of the expansive list of changes follows.

- The inliner, dead code elimination routines, compile time, and memory usage codes are now improved. This release also features a new register allocator, instruction scheduler, and software pipeliner.
- Version 3.0 of the OpenMP specification is now supported for the C, C++, and Fortran compilers.
- Experimental support for the upcoming ISO C++ standard (C++0x) is included. This has support for auto/inline namespaces, character types, and scoped enumerations. To enable this, use the compiler options **`-std=c++0x`** (which disables GNU extensions) or **`-std=gnu++0x`**.

  For a more detailed list of the status of C++0x improvements, refer to:

  *http://gcc.gnu.org/gcc-4.4/cxx0x_status.html*
- GCC now incorporates the *Variable Tracking at Assignments* (VTA) infrastructure. This allows GCC to better track variables during optimizations so that it can produce improved debugging information (i.e. DWARF) for the GNU Project Debugger, SystemTap, and other tools. For a brief overview of VTA, refer to *Section 5.3, “Variable Tracking at Assignments”*.

  With VTA you can debug optimized code drastically better than with previous GCC releases, and you do not have to compile with -O0 to provide a better debugging experience.
- Fortran 2008 is now supported, while support for Fortran 2003 is extended.

For a more detailed list of improvements in GCC, refer to:

- *Updates in the 4.2 Series*: *http://gcc.gnu.org/gcc-4.2/changes.html*
- *Updates in the 4.3 Series*: *http://gcc.gnu.org/gcc-4.3/changes.html*
- *Updates in the 4.4 Series*: *http://gcc.gnu.org/gcc-4.4/changes.html*

In addition to the changes introduced via the GCC 4.4 rebase, the Red Hat Enterprise Linux 6 version of GCC also features several fixes and enhancements backported from upstream sources (i.e. version 4.5 and beyond). These improvements include the following (among others):

- Improved DWARF3 debugging for debugging optimized C++ code.
- Fortran optimization improvements.
- More accurate instruction length information for ix86, Intel 64 and AMD64, and s390.
- Intel Atom support
- POWER7 support
- C++ raw string support, u/U/u8 string literal support

### 4.1.2. Language Compatibility

Application Binary Interfaces specified by the GNU C, C++, Fortran and Java Compiler include:

- Calling conventions. These specify how arguments are passed to functions and how results are returned from functions.
- Register usage conventions. These specify how processor registers are allocated and used.
- Object file formats. These specify the representation of binary object code.
- Size, layout, and alignment of data types. These specify how data is laid out in memory.
- Interfaces provided by the runtime environment. Where the documented semantics do not change from one version to another they must be kept available and use the same name at all times.

The default system C compiler included with Red Hat Enterprise Linux 6 is largely compatible with the C99 ABI standard. Deviations from the C99 standard in GCC 4.4 are tracked *online*[3].

In addition to the C ABI, the Application Binary Interface for the GNU C++ Compiler specifies the binary interfaces needed to support the C++ language, such as:

- Name mangling and demangling
- Creation and propagation of exceptions
- Formatting of run-time type information
- Constructors and destructors
- Layout, alignment, and padding of classes and derived classes
- Virtual function implementation details, such as the layout and alignment of virtual tables

[3] http://gcc.gnu.org/gcc-4.4/c99status.html

The default system C++ compiler included with Red Hat Enterprise Linux 6 conforms to the C++ ABI defined by the *Itanium C++ ABI (1.86)*[4].

Although every effort has been made to keep each version of GCC compatible with previous releases, some incompatibilities do exist.

## ABI incompatibilities between RHEL6 and RHEL5

The following is a list of known incompatibilities between the Red Hat Enterprise Linux 6 and 5 toolchains.

- Passing/returning structs with flexible array members by value changed in some cases on Intel 64 and AMD64.
- Passing/returning of unions with long double members by value changed in some cases on Intel 64 and AMD64.
- Passing/returning structs with complex float member by value changed in some cases on Intel 64 and AMD64.
- Passing of 256-bit vectors on x86, Intel 64 and AMD64 platforms changed when **`-mavx`** is used.
- There have been multiple changes in passing of _Decimal{32,64,128} types and aggregates containing those by value on several targets.
- Packing of packed char bitfields changed in some cases.

## ABI incompatibilities between RHEL5 and RHEL4

The following is a list of known incompatibilities between the Red Hat Enterprise Linux 5 and 4 toolchains.

- There have been changes in the library interface specified by the C++ ABI for thread-safe initialization of function-scope static variables.
- On Intel 64 and AMD64, the medium model for building applications where data segment exceeds 4GB, was redesigned to match the latest ABI draft at the time. The ABI change results in incompatibility among medium model objects.

The compiler flag **`-Wabi`** can be used to get diagnostics indicating where these constructs appear in source code, though it will not catch every single case. This flag is especially useful for C++ code to warn whenever the compiler generates code that is known to be incompatible with the vendor-neutral C++ ABI.

Excluding the incompatibilities listed above, the GCC C and C++ language ABIs are *mostly* ABI compatible. The vast majority of source code will not encounter any of the known issues, and can be considered compatible.

Compatible ABIs allow the objects created by compiling source code to be portable to other systems. In particular, for Red Hat Enterprise Linux, this allows for *upward* compatibility. Upward compatibility is defined as the ability to link shared libraries and objects, created using a version of the compilers in a particular RHEL release, with no problems. This includes new objects compiled on subsequent RHEL releases.

[4] http://www.codesourcery.com/cxx-abi/

The C ABI is considered to be stable, and has been so since at least RHEL3 (again, barring any incompatibilities mentioned in the above lists). Libraries built on RHEL3 and later can be linked to objects created on a subsequent environment (RHEL4, RHEL5, and RHEL6).

The C++ ABI is considered to be stable, but less stable than the C ABI, and only as of RHEL4 (corresponding to GCC version 3.4 and above.). As with C, this is only an upward compatibility. Libraries built on RHEL4 and above can be linked to objects created on a subsequent environment (RHEL5, and RHEL6).

To force GCC to generate code compatible with the C++ ABI in RHEL releases prior to RHEL4, some developers have used the **`-fabi-version=1`** option. This practice is not recommended. Objects created this way are indistinguishable from objects conforming to the current stable ABI, and can be linked (incorrectly) amongst the different ABIs, especially when using new compilers to generate code to be linked with old libraries that were built with tools prior to RHEL4.

**Warning**

The above incompatibilities make it incredibly difficult to maintain ABI shared library sanity between releases, especially if when developing custom libraries with multiple dependencies outside of the core libraries. Therefore, if shared libraries are developed, it is *highly* recommend that a new version is built for each Red Hat Enterprise Linux release.

### 4.1.3. Object Compatibility and Interoperability

Two items that are important are the changes and enhancements in the underlying tools used by the compiler, and the compatibility between the different versions of a language's compiler.

Changes and new features in tools like **`ld`** (distributed as part of the **`binutils`** package) or in the dynamic loader (**`ld.so`**, distributed as part of the **`glibc`** package) can subtly change the object files that the compiler produces. These changes mean that object files moving to the current release of Red Hat Enterprise Linux from previous releases may loose functionality, behave differently at runtime, or otherwise interoperate in a diminished capacity. Known problem areas include:

- **`ld --build-id`**

  In RHEL6 this is passed to **`ld`** by default, whereas RHEL5 **`ld`** doesn't recognize it.

- **`as .cfi_sections`** support

  In RHEL6 this directive allows **`.debug_frame`**, **`.eh_frame`** or both to be emitted from **`.cfi*`** directives. In RHEL5 only **`.eh_frame`** is emitted.

- **`as`**, **`ld`**, **`ld.so`**, and **`gdb`** **`STB_GNU_UNIQUE`** and **`%gnu_unique_symbol`** support

  In RHEL6 more debug information is generated and stored in object files. This information relies on new features detailed in the **`DWARF`** standard, and also on new extensions not yet standardized. In RHEL5, tools like **`as`**, **`ld`**, **`gdb`**, **`objdump`**, and **`readelf`** may not be prepared for this new information and may fail to interoperate with objects created with the newer tools. In addition, RHEL5 produced object files do not support these new features; these object files may be handled by RHEL6 tools in a sub-optimal manner.

  An outgrowth of this enhanced debug information is that the debuginfo packages that ship with system libraries allow you to do useful source level debugging into system libraries if they are installed. Refer to *Section 5.1, “Installing Debuginfo Packages”* for more information on debuginfo packages.

Object file changes, such as the ones listed above, may interfere with the portable use of **`prelink`**.

### 4.1.4. Backwards Compatibility Packages

Several packages are provided to serve as an aid for those moving source code or executables from older versions of Red Hat Enterprise Linux to the current release. These packages are intended to be used as a temporary aid in transitioning sources to newer compilers with changed behavior, or as a convenient way to otherwise isolate differences in the system environment from the compile environment.

**Note**

Please be advised that Red Hat may remove these packages in future Red Hat Enterprise Linux releases.

The following packages provide compatibility tools for compiling Fortran or C++ source code on the current release of Red Hat Enterprise Linux 6 *as if one was using the older compilers on Red Hat Enterprise Linux 4*:

- **`compat-gcc-34`**
- **`compat-gcc-34-c++`**
- **`compat-gcc-34-g77`**

The following package provides a compatibility runtime library for Fortran executables *compiled on Red Hat Enterprise Linux 5* to run without recompilation on the current release of Red Hat Enterprise Linux 6:

- **`compat-libgfortran-41`**

Please note that backwards compatibility library packages are not provided for all supported system libraries, just the system libraries pertaining to the compiler and the C/C++ standard libraries.

For more information about backwards compatibility library packages, refer to the *Application Compatibility* section of the Red Hat Enterprise Linux 6 *Migration Guide*.

### 4.1.5. Previewing RHEL6 compiler features on RHEL5

On Red Hat Enterprise Linux 5, we have included the package **`gcc44`** as an update. This is a backport of the RHEL6 compiler to allow users running RHEL5 to compile their code with the RHEL6 compiler and experiment with new features and optimizations before upgrading their systems to the next major release. The resulting binary will be forward compatible with RHEL6, so one can compile on RHEL5 with **`gcc44`** and run on RHEL5, RHEL6, and above.

The RHEL5 **`gcc44`** compiler will be kept reasonably in step with the GCC 4.4.x that we ship with RHEL6 to ease transition. Though, to get the latest features, it is recommended RHEL6 is used for development. The **`gcc44`** is only provided as an aid in the conversion process.

### 4.1.6. Running GCC

To compile using GCC tools, first install **`binutils`** and **`gcc`**; doing so will also install several dependencies.

In brief, the tools work via the **gcc** command. This is the main driver for the compiler. It can be used from the command line to pre-process or compile a source file, link object files and libraries, or perform a combination thereof. By default, **gcc** takes care of the details and links in the provided **libgcc** library.

The compiler functions provided by GCC are also integrated into the Eclipse IDE as part of the **CDT**. This presents many advantages, particularly for developers who prefer a graphical interface and fully integrated environment. For more information about compiling in Eclipse, refer to *Section 1.3, " Development Toolkits"*.

Conversely, using GCC tools from the command-line interface consumes less system resources. This also allows finer-grained control over compilers; GCC's command-line tools can even be used outside of the graphical mode (runlevel 5).

### 4.1.6.1. Simple C Usage

Basic compilation of a C language program using GCC is easy. Start with the following simple program:

#### hello.c

```
#include <stdio.h>

int main ()
{
  printf ("Hello world!\n");
  return 0;
}
```

The following procedure illustrates the compilation process for C in its most basic form.

Procedure 4.1. Compiling a 'Hello World' C Program

1. Compile *hello.c* into an executable with:

   ```
   gcc hello.c -o hello
   ```

   Ensure that the resulting binary **hello** is in the same directory as **hello.c**.

2. Run the **hello** binary, i.e. **hello**.

### 4.1.6.2. Simple C++ Usage

Basic compilation of a C++ language program using GCC is similar. Start with the following simple program:

#### hello.cc

```
#include <iostream>

using namespace std;
```

```
int main(void)
{
  cout << "Hello World!" << endl;
  return 0;
}
```

The following procedure illustrates the compilation process for C++ in its most basic form.

### Procedure 4.2. Compiling a 'Hello World' C++ Program

1. Compile *hello.cc* into an executable with:

   ```
   g++ hello.cc -o hello
   ```

   Ensure that the resulting binary **`hello`** is in the same directory as **`hello.cc`**.

2. Run the **`hello`** binary, i.e. **`hello`**.

### 4.1.6.3. Simple Multi-File Usage

To use basic compilation involving multiple files or object files, start with the following two source files:

#### one.c

```
#include <stdio.h>
void hello()
{
  printf("Hello world!\n");
}
```

#### two.c

```
extern void hello();

int main()
{
  hello();
  return 0;
}
```

The following procedure illustrates a simple, multi-file compilation process in its most basic form.

### Procedure 4.3. Compiling a Program with Multiple Source Files

1. Compile *one.c* into an executable with:

   ```
   gcc -c one.c -o one.o
   ```

   Ensure that the resulting binary **`one.o`** is in the same directory as **`one.c`**.

2. Compile *two.c* into an executable with:

   ```
   gcc -c two.c -o two.o
   ```

   Ensure that the resulting binary **`two.o`** is in the same directory as **`two.c`**.

3. Compile the two object files **`one.o`** and **`two.o`** into a single executable with:

```
gcc one.o two.o -o hello
```

Ensure that the resulting binary **`hello`** is in the same directory as **`one.o`** and **`two.o`**.

4. Run the **`hello`** binary, i.e. **`hello`**.

### 4.1.6.4. Recommended Optimization Options

Different projects require different optimization options. There is no one-size-fits-all approach when it comes to optimization, but here are a few guidelines to keep in mind.

#### Instruction selection and tuning

It is very important to chose the correct architecture for instruction scheduling. By default GCC produces code is optimized for the most common processors, but if the CPU on which your code will run is known, the corresponding **`-mtune=`** option to optimize the instruction scheduling, and **`-march=`** option to optimize the instruction selection should be used.

The option **`-mtune=`** optimizes instruction scheduling to fit your architecture by tuning everything except the ABI and the available instruction set. This option will not chose particular instructions, but instead will tune your program in such a way that executing on a particular architecture will be optimized. For example, if an Intel Core2 CPU will predominantly be used, choose **`-mtune=core2`**. If the wrong choice is made, the program will still run, but not optimally on the given architecture. The architecture on which the program will most likely run should always be chosen.

The option **`-march=`** optimizes instruction selection. As such, it is important to choose correctly as choosing incorrectly will cause your program to fail. This option selects the instruction set used when generating code. For example, if the program will be run on an AMD K8 core based CPU, choose **`-march=k8`**. Specifying the architecture with this option will imply **`-mtune=`**.

The **`-mtune=`** and **`-march=`** commands should only be used for tuning and selecting instructions within a given architecture, not to generate code for a different architecture (also known as cross-compiling). For example, this is not to be used to generate PowerPC code from an Intel 64 and AMD64 platform.

For a complete list of the available options for both **`-march=`** and **`-mtune=`**, refer to the GCC documentation available here: *GCC 4.4.4 Manual: Hardware Models and Configurations*[5]

#### General purpose optimization flags

The compiler flag **`-O2`** is a good middle of the road option to generate fast code. It produces the best optimized code when the resulting code size is not large. Use this when unsure what would best suit.

When code size is not an issue, **`-O3`** is preferable. This option produces code that is slightly larger but runs faster because of a more frequent inline of functions. This is ideal for floating point intensive code.

The other general purpose optimization flag is **`-Os`**. This flag also optimizes for size, and produces faster code in situations where a smaller footprint will increase code locality, thereby reducing cache misses.

Use **`-frecord-gcc-switches`** when compiling objects. This records the options used to build objects into objects themselves. After an object is built, it determines which set of options were used

[5] http://gcc.gnu.org/onlinedocs/gcc-4.4.4/gcc/Submodel-Options.html#Submodel-Options

to build it. The set of options are then recorded in a section called **`.GCC.command.line`** within the object and can be examined with the following:

```
$ gcc -frecord-gcc-switches -O3 -Wall hello.c -o hello
$ readelf --string-dump=.GCC.command.line hello

String dump of section '.GCC.command.line':
  [     0]  hello.c
  [     8]  -mtune=generic
  [    17]  -O3
  [    1b]  -Wall
  [    21]  -frecord-gcc-switches
```

It is very important to test and try different options with a representative data set. Often, different modules or objects can be compiled with different optimization flags in order to produce optimal results. Refer to *Section 4.1.6.5, “Using Profile Feedback to Tune Optimization Heuristics.”* for additional optimization tuning.

### 4.1.6.5. Using Profile Feedback to Tune Optimization Heuristics.

During the transformation of a typical set of source code into an executable, tens of hundreds of choices must be made about the importance of speed in one part of code over another, or code size as opposed to code speed. By default, these choices are made by the compiler using reasonable heuristics, tuned over time to produce the optimum runtime performance. However, GCC also has a way to teach the compiler to optimize executables for a specific machine in a specific production environment. This feature is called profile feedback.

Profile feedback is used to tune optimizations such as:

- Inlining
- Branch prediction
- Instruction scheduling
- Inter-procedural constant propagation
- determining of hot or cold functions

Profile feedback compiles a program first to generate a program that is run and analyzed and then a second time to optimize with the gathered data.

Procedure 4.4. Using Profile Feedback

1. **Step One**
   The application must be instrumented to produce profiling information by compiling it with **`-fprofile-generate`**.

2. **Step Two**
   Run the application to accumulate and save the profiling information.

3. **Step Three**
   Recompile the application with **`-fprofile-use`**.

Step three will use the profile information gathered in step one to tune the compiler's heuristics while optimizing the code into a final executable.

Procedure 4.5. Compiling a Program with Profiling Feedback

1. Compile **`source.c`** to include profiling instrumentation:

```
gcc source.c -fprofile-generate -O2 -o executable
```

2. Run **`executable`** to gather profiling information:

   ```
   ./executable
   ```

3. Recompile and optimize **`source.c`** with profiling information gathered in step one:

   ```
   gcc source.c -fprofile-use -O2 -o executable
   ```

Multiple data collection runs, as seen in step two, will accumulate data into the profiling file instead of replacing it. This allows the executable in step two to be run multiple times with additional representative data in order to collect even more information.

The executable must run with representative levels of both the machine being used and a respective data set large enough for the input needed. This ensures optimal results are achieved.

By default, GCC will generate the profile data into the directory where step one was performed. To generate this information elsewhere, compile with **`-fprofile-dir=DIR`** where **`DIR`** is the preferred output directory.

**Warning**

The format of the compiler feedback data file changes between compiler versions. It is imperative that the program compilation is repeated with every new version of the compiler.

### 4.1.6.6. Using 32-bit compilers on a 64-bit host

On a 64-bit host, GCC will build executables that can only run on 64-bit hosts. However, GCC can be used to build executables that will run both on 64-bit hosts and on 32-bit hosts.

To build 32-bit binaries on a 64-bit host, first install 32-bit versions of any supporting libraries the executable may need. This must at least include supporting libraries for **`glibc`** and **`libgcc`**, and possibly for **`libstdc++`** if the program is a C++ program. On Intel 64 and AMD64, this can be done with:

```
yum install glibc-devel.i686 libgcc.i686 libstdc++-devel.i686
```

There may be cases where it is useful to to install additional 32-bit libraries that a program may need. For example, if a program uses the **`db4-devel`** libraries to build, the 32-bit version of these libraries can be installed with:

```
yum install db4-devel.i686
```

**Note**

The **`.i686`** suffix on the x86 platform (as opposed to **`x86-64`**) specifies a 32-bit version of the given package. For PowerPC architectures, the suffix is **`ppc`** (as opposed to **`ppc64`**).

After the 32-bit libraries have been installed, the **`-m32`** option can be passed to the compiler and linker to produce 32-bit executables. Provided the supporting 32-bit libraries are installed on the 64-bit system, this executable will be able to run on both 32-bit systems and 64-bit systems.

Procedure 4.6. Compiling a 32-bit Program on a 64-bit Host

1. On a 64-bit system, compile **`hello.c`** into a 64-bit executable with:

   **`gcc hello.c -o hello64`**

2. Ensure that the resulting executable is a 64-bit binary:

```
$ file hello64
hello64: ELF 64-bit LSB executable, x86-64, version 1 (GNU/Linux), dynamically linked
 (uses shared libs), for GNU/Linux 2.6.18, not stripped
$ ldd hello64
linux-vdso.so.1 =>  (0x00007fff242dd000)
libc.so.6 => /lib64/libc.so.6 (0x00007f0721514000)
/lib64/ld-linux-x86-64.so.2 (0x00007f0721893000)
```

   The command **`file`** on a 64-bit executable will include **`ELF 64-bit`** in its output, and **`ldd`** will list **`/lib64/libc.so.6`** as the main C library linked.

3. On a 64-bit system, compile **`hello.c`** into a 32-bit executable with:

   **`gcc -m32 hello.c -o hello32`**

4. Ensure that the resulting executable is a 32-bit binary:

```
$ file hello32
hello32: ELF 32-bit LSB executable, Intel 80386, version 1 (GNU/Linux), dynamically
 linked (uses shared libs), for GNU/Linux 2.6.18, not stripped
$ ldd hello32
linux-gate.so.1 =>  (0x007eb000)
libc.so.6 => /lib/libc.so.6 (0x00b13000)
/lib/ld-linux.so.2 (0x00cd7000)
```

   The command **`file`** on a 32-bit executable will include **`ELF 32-bit`** in its output, and **`ldd`** will list **`/lib/libc.so.6`** as the main C library linked.

If you have not installed the 32-bit supporting libraries you will get an error similar to this for C code:

```
$ gcc -m32 hello32.c -o hello32
/usr/bin/ld: crt1.o: No such file: No such file or directory
collect2: ld returned 1 exit status
```

A similar error would be triggered on C++ code:

```
$ g++ -m32 hello32.cc -o hello32-c++
In file included from /usr/include/features.h:385,
     from /usr/lib/gcc/x86_64-redhat-linux/4.4.4/../../../../include/c++/4.4.4/x86_64-redhat-
linux/32/bits/os_defines.h:39,
     from /usr/lib/gcc/x86_64-redhat-linux/4.4.4/../../../../include/c++/4.4.4/x86_64-redhat-
linux/32/bits/c++config.h:243,
     from /usr/lib/gcc/x86_64-redhat-linux/4.4.4/../../../../include/c++/4.4.4/iostream:39,
     from hello32.cc:1:
/usr/include/gnu/stubs.h:7:27: error: gnu/stubs-32.h: No such file or directory
```

These errors indicate that the supporting 32-bit libraries have not been properly installed as explained at the beginning of this section.

Also important is to note that building with **`-m32`** will in not adapt or convert a program to resolve any issues arising from 32/64-bit incompatibilities. For tips on writing portable code and converting from 32-bits to 64-bits, see the paper entitled *Porting to 64-bit GNU/Linux Systems* in the *Proceedings of the 2003 GCC Developers Summit*[6].

### 4.1.7. GCC Documentation

For more information about GCC compilers, refer to the **`man`** pages for **`cpp`**, **`gcc`**, **`g++`**, **`gcj`**, and **`gfortran`**.

the following online user manuals are also available:

- *GCC 4.4.4 Manual*[7]
- *GCC 4.4.4 GNU Fortran Manual*[8]
- *GCC 4.4.4 GCJ Manual*[9]
- *GCC 4.4.4 CPP Manual*[10]
- *GCC 4.4.4 GNAT Reference Manual*[11]
- *GCC 4.4.4 GNAT User's Guide*[12]
- *GCC 4.4.4 GNU OpenMP Manual*[13]

The main site for the development of GCC is *gcc.gnu.org*[14].

## 4.2. Distributed Compiling

Red Hat Enterprise Linux 6 also supports *distributed compiling*. This involves transforming one compile job into many smaller jobs; these jobs are distributed over a cluster of machines, which speeds up build time (particularly for programs with large codebases). The **`distcc`** package provides this capability.

To set up distributed compiling, install the following packages:

- **`distcc`**
- **`distcc-server`**

For more information about distributed compiling, refer to the **`man`** pages for **`distcc`** and **`distccd`**. The following link also provides detailed information about the development of **`distcc`**:

*http://code.google.com/p/distcc*

## 4.3. Autotools

GNU Autotools is a suite of command-line tools that allow developers to build applications on different systems, regardless of the installed packages or even Linux distribution. These tools aid developers in creating a **`configure`** script. This script runs prior to builds and creates the top-level **`Makefile`**s

[6] http://www.linux.org.uk/~ajh/gcc/gccsummit-2003-proceedings.pdf
[14] http://gcc.gnu.org

needed to build the application. The **`configure`** script may perform tests on the current system, create additional files, or run other directives as per parameters provided by the builder.

The Autotools suite's most commonly-used tools are:

autoconf
: Generates the **`configure`** script from an input file (e.g. **`configure.ac`**)

automake
: Creates the **`Makefile`** for a project on a specific system

autoscan
: Generates a preliminary input file (i.e. **`configure.scan`**), which can be edited to create a final **`configure.ac`** to be used by **`autoconf`**

All tools in the Autotools suite are part of the **`Development Tools`** group package. You can install this package group to install the entire Autotools suite, or simply use **`yum`** to install any tools in the suite as you wish.

## 4.3.1. Autotools Plug-in for Eclipse

The Autotools suite is also integrated into the Eclipse IDE via the Autotools plug-in. This plug-in provides an Eclipse graphical user interface for Autotools, which is suitable for most C/C++ projects.

As of Red Hat Enterprise Linux 6, this plug-in only supports two templates for new C/C++ projects:

- An empty project
- A "hello world" application

The empty project template is used when importing projects into the C/C++ Development Toolkit that already support Autotools. Future updates to the Autotools plug-in will include additional graphical user interfaces (e.g. wizards) for creating shared libraries and other complex scenarios.

The Red Hat Enterprise Linux 6 version of the Autotools plug-in also does not integrate **`git`** or **`mercurial`** into Eclipse. As such, Autotools projects that use **`git`** repositories will need to be checked out *outside* the Eclipse workspace. Afterwards, you can specify the source location for such projects in Eclipse. Any repository manipulation (e.g. commits, updates) will need to be done via the command line.

## 4.3.2. Configuration Script

The most crucial function of Autotools is the creation of the **`configure`** script. This script tests systems for tools, input files, and other features it can use in order to build the project [15]. The **`configure`** script generates a **`Makefile`** which allows the **`make`** tool to build the project based on the system configuration.

To create the **`configure`** script, first create an input file. Then feed it to an Autotools utility in order to create the **`configure`** script. This input file is typically **`configure.ac`** or **`Makefile.am`**; the former is usually processed by **`autoconf`**, while the latter is fed to **`automake`**.

If a **`Makefile.am`** input file is available, the **`automake`** utility creates a **`Makefile`** template (i.e. **`Makefile. in`**), which may refer to information collected at configuration time. For example, the

[15] For information about tests that **`configure`** can perform, refer to the following link: *http://www.gnu.org/software/autoconf/manual/autoconf.html#Existing-Tests*

**`Makefile`** may need to link to a particular library *if and only if* that library is already installed. When the **`configure`** script runs, **`automake`** will use the **`Makefile. in`** templates to create a **`Makefile`**.

If a **`configure.ac`** file is available instead, then **`autoconf`** will automatically create the **`configure`** script based on the macros invoked by **`configure.ac`**. To create a preliminary **`configure.ac`**, use the **`autoscan`** utility and edit the file accordingly.

### 4.3.3. Autotools Documentation

Red Hat Enterprise Linux 6 includes **`man`** pages for **`autoconf`**, **`automake`**, **`autoscan`** and most tools included in the Autotools suite. In addition, the Autotools community provides extensive documentation on **`autoconf`** and **`automake`** on the following websites:

- *http://www.gnu.org/software/autoconf/manual/autoconf.html*
- *http://www.gnu.org/software/autoconf/manual/automake.html*

The following is an online book describing the use of Autotools. Although the above online documentation is the recommended and most up to date information on Autotools, this book is a good alternative and introduction.

- *http://sourceware.org/autobook/*

For information on how to create Autotools input files, refer to:

- *http://www.gnu.org/software/autoconf/manual/autoconf.html#Making-configure-Scripts*
- *http://www.gnu.org/software/autoconf/manual/automake.html#Invoking-Automake*

The following upstream example also illustrates the use of Autotools in a simple **`hello`** program:

- *http://www.gnu.org/software/hello/manual/hello.html*

The *Autotools Plug-in For Eclipse* whitepaper also provides more detail on the Red Hat Enterprise Linux 6 release of the Autotools plug-in. This whitepaper also includes a "by example" case study to walk you through a typical use-case for the plug-in. Refer to the following link for more information:

*http://docs.redhat.com/docs/en-US/Red_Hat_Enterprise_Linux/6/html/Autotools_Plug-In_for_Eclipse/index.html*

## 4.4. Eclipse Built-in Specfile Editor

The Specfile Editor Plug-in for Eclipse provides useful features to help developers manage **`.spec`** files. This plug-in allows users to leverage several Eclipse GUI features in editing **`.spec`** files, such as auto-completion, highlighting, file hyperlinks, and folding.

In addition, the Specfile Editor Plug-in also integrates the **`rpmlint`** tool into the Eclipse interface. **`rpmlint`** is a command-line tool that helps developers detect common RPM package errors. The richer visualization offered by the Eclipse interface helps developers quickly detect, view, and correct mistakes reported by **`rpmlint`**.

The Specfile Editor for Eclipse is provided by the **`eclipse-rpm-editor`** package. For more information about this plug-in, refer to *Specfile Editor User Guide* in the Eclipse **Help Contents**.

# Debugging

Useful, well-written software generally goes through several different phases of application development, allowing ample opportunity for mistakes to be made. Some phases come with their own set of mechanisms to detect errors. For example, during compilation an elementary semantic analysis is often performed to make sure objects, such as variables and functions, are adequately described.

The error-checking mechanisms performed during each application development phase aims to catch simple and obvious mistakes in code. The debugging phase helps to bring more subtle errors to light that fell through the cracks during routine code inspection.

## 5.1. Installing Debuginfo Packages

Red Hat Enterprise Linux also provides **`-debuginfo`** packages for all architecture-dependent RPMs included in the operating system. A **`-debuginfo`** package contains accurate debugging information for its corresponding package. To install the **`-debuginfo`** package of a package (i.e. typically ***`packagename`*`-debuginfo`**), use the following command:

```
debuginfo-install packagename
```

**Note**

Attempting to debug a package without having its **`-debuginfo`** equivalent installed may fail, although GDB will try to provide any helpful diagnostics it can.

## 5.2. GDB

Fundamentally, like most debuggers, GDB manages the execution of compiled code in a very closely controlled environment. This environment makes possible the following fundamental mechanisms necessary to the operation of GDB:

- Inspect and modify memory within the code being debugged (e.g. reading and setting variables).
- Control the execution state of the code being debugged, principally whether it's running or stopped.
- Detect the execution of particular sections of code (e.g. stop running code when it reaches a specified area of interest to the programmer).
- Detect access to particular areas of memory (e.g. stop running code when it accesses a specified variable).
- Execute portions of code (from an otherwise stopped program) in a controlled manner.
- Detect various programmatic asynchronous events such as signals.

The operation of these mechanisms rely mostly on information produced by a compiler. For example, to view the value of a variable, GDB has to know:

- The location of the variable in memory
- The nature of the variable

This means that displaying a double-precision floating point value requires a very different process from displaying a string of characters. For something complex like a structure, GDB has to know not only the characteristics of each individual elements in the structure, but the morphology of the structure as well.

GDB requires the following items in order to fully function:

Debug Information
: Much of GDB's operations rely on a program's *debug information*. While this information generally comes from compilers, much of it is necessary only while debugging a program, i.e. it is not used during the program's normal execution. For this reason, compilers do not always make that information available by default — GCC, for instance, must be explicitly instructed to provide this debugging information with the **`-g`** flag.

  To make full use of GDB's capabilities, it is *highly advisable* to make the debug information available first to GDB. GDB can only be of *very limited* use when run against code with no available debug information.

Source Code
: One of the most useful features of GDB (or any other debugger) is the ability to associate events and circumstances in program execution with their corresponding location in source code. This location normally refers to a specific line or series of lines in a source file. This, of course, would require that a program's source code be available to GDB at debug time.

### 5.2.1. Simple GDB

GDB literally contains dozens of commands. This section describes the most fundamental ones.

**`br`** (breakpoint)
: The breakpoint command instructs GDB to halt execution upon reaching a specified point in the execution. That point can be specified a number of ways, but the most common are just as the line number in the source file, or the name of a function. Any number of breakpoints can be in effect simultaneously. This is frequently the first command issued after starting GDB.

**`r`** (run)
: The **`run`** command starts the execution of the program. If **`run`** is executed with any arguments, those arguments are passed on to the executable as if the program has been started normally. Users normally issue this command after setting breakpoints.

Before an executable is started, or once the executable stops at, for example, a breakpoint, the state of many aspects of the program can be inspected. The following commands are a few of the more common ways things can be examined.

**`p`** (print)
: The **`print`** command displays the value of the argument given, and that argument can be almost anything relevant to the program. Usually, the argument is simply the name of a variable of any complexity, from a simple single value to a structure. An argument can also be an expression valid in the current language, including the use of program variables and library functions, or functions defined in the program being tested.

**`bt`** (backtrace)
: The **`backtrace`** displays the chain of function calls used up until the execution was terminated. This is useful for investigating serious bugs (such as segmentation faults) with elusive causes.

**`l`** (list)
: When execution is stopped, the **`list`** command shows the line in the source code corresponding to where the program stopped.

The execution of a stopped program can be resumed in a number of ways. The following are the most common.

**c** (continue)
: The **`continue`** command simply restarts the execution of the program, which will continue to execute until it encounters a breakpoint, runs into a specified or emergent condition (e.g. an error), or terminates.

**n** (next)
: Like **`continue`**, the **`next`** command also restarts execution; however, in addition to the stopping conditions implicit in the **`continue`** command, **`next`** will also halt execution at the next sequential line of code in the current source file.

**s** (step)
: Like **`next`**, the **`step`** command also halts execution at each sequential line of code in the current source file. However, if execution is currently stopped at a source line containing a *function call*, GDB stops execution after entering the function call (rather than executing it).

**`fini`** (finish)
: Like the aforementioned commands, the **`finish`** command resumes executions, but halts when execution returns from a function.

Finally, two essential commands:

**q** (quit)
: This terminates the execution.

**h** (help)
: The **`help`** command provides access to its extensive internal documentation. The command takes arguments: **`help breakpoint`** (or **`h br`**), for example, shows a detailed description of the **`breakpoint`** command. Refer to the **`help`** output of each command for more detailed information.

## 5.2.2. Running GDB

This section will describe a basic execution of GDB, using the following simple program:

### hello.c

```
#include <stdio.h>

char hello[] = { "Hello, World!" };

int
main()
{
  fprintf (stdout, "%s\n", hello);
  return (0);
}
```

The following procedure illustrates the debugging process in its most basic form.

**Procedure 5.1. Debugging a 'Hello World' Program**

1. Compile *hello.c* into an executable with the debug flag set, as in:

```
gcc -g -o hello hello.c
```

Ensure that the resulting binary **`hello`** is in the same directory as **`hello.c`**.

2. Run **gdb** on the **`hello`** binary, i.e. **`gdb hello`**.

3. After several introductory comments, **gdb** will display the default GDB prompt:

```
(gdb)
```

4. Some things can be done even before execution is started. The variable **`hello`** is global, so it can be seen even before the **`main`** procedure starts:

```
gdb) p hello
$1 = "Hello, World!"
(gdb) p hello[0]
$2 = 72 'H'
(gdb) p *hello
$3 = 72 'H'
(gdb)
```

Note that the **`print`** targets **`hello[0]`** and **`*hello`** require the evaluation of an expression, as does, for example, **`*(hello + 1)`**:

```
(gdb) p *(hello + 1)
$4 = 101 'e'
```

5. Next, list the source:

```
(gdb) l
1       #include <stdio.h>
2
3       char hello[] = { "Hello, World!" };
4
5       int
6       main()
7       {
8         fprintf (stdout, "%s\n", hello);
9         return (0);
10      }
```

The **`list`** reveals that the **`fprintf`** call is on line 8. Apply a breakpoint on that line and resume the code:

```
(gdb) br 8
Breakpoint 1 at 0x80483ed: file hello.c, line 8.
(gdb) r
Starting program: /home/moller/tinkering/gdb-manual/hello

Breakpoint 1, main () at hello.c:8
8         fprintf (stdout, "%s\n", hello);
```

6. Finally, use the “next” command to step past the **`fprintf`** call, executing it:

```
(gdb) n
Hello, World!
9         return (0);
```

The following sections describe more complex applications of GDB.

### 5.2.3. Conditional Breakpoints

In many real-world cases, a program may perform its task well during the first few thousand times; it may then start crashing or encountering errors during its eight thousandth iteration of the task. Debugging programs like this can be difficult, as it is hard to imagine a programmer with the patience to issue a **`continue`** command thousands of times just to get to the iteration that crashed.

Situations like this are common in real life, which is why GDB allows programmers to attach conditions to a breakpoint. For example, consider the following program:

#### simple.c

```
#include <stdio.h>

main()
{
  int i;

  for (i = 0;; i++) {
fprintf (stdout, "i = %d\n", i);
  }
}
```

To set a conditional breakpoint at the GDB prompt:

```
(gdb) br 8 if i == 8936
Breakpoint 1 at 0x80483f5: file iterations.c, line 8.
(gdb) r
```

With this condition, the program execution will eventually stop with the following output:

```
i = 8931
i = 8932
i = 8933
i = 8934
i = 8935

Breakpoint 1, main () at iterations.c:8
8           fprintf (stdout, "i = %d\n", i);
```

Inspect the breakpoint information (using **`info br`**) to review the breakpoint status:

```
(gdb) info br
Num     Type           Disp Enb Address    What
```

```
1       breakpoint     keep y   0x080483f5 in main at iterations.c:8
        stop only if i == 8936
        breakpoint already hit 1 time
```

### 5.2.4. Forked Execution

Among the more challenging bugs confronting programmers is where one program (the *parent*) makes an independent copy of itself (a *fork*). That fork then creates a *child* process which, in turn, fails. Debugging the parent process may or may not be useful. Often the only way to get to the bug may be by debugging the child process, but this is not always possible.

The **`set follow-fork-mode`** feature is used to overcome this barrier allowing programmers to follow a a child process instead of the parent process.

**`set follow-fork-mode parent`**
: The original process is debugged after a fork. The child process runs unimpeded. This is the default.

**`set follow-fork-mode child`**
: The new process is debugged after a fork. The parent process runs unimpeded.

**`show follow-fork-mode`**
: Display the current debugger response to a fork call.

Use the **`set detach-on-fork`** command to debug both the parent and the child processes after a fork, or retain debugger control over them both.

**`set detach-on-fork on`**
: The child process (or parent process, depending on the value of **`follow-fork-mode`** will be detached and allowed to run independently. This is the default.

**`set detach-on-fork off`**
: Both processes will be held under the control of GDB. One process (child or parent, depending on the value of **`follow-fork-mode`**) is debugged as usual, while the other is suspended.

**`show detach-on-fork`**
: Show whether **`detach-on-fork`** mode is on or off.

Consider the following program:

```
fork.c

#include <unistd.h>

int main()
{
  pid_t  pid;
  const char *name;

  pid = fork();
  if (pid == 0)
    {
      name = "I am the child";
    }
  else
    {
      name = "I am the parent";
    }
  return 0;
}
```

This program, compiled with the command **`gcc -g fork.c -o fork -lpthread`** and examined under GDB will show:

```
gdb ./fork
[...]
(gdb) run
[...]
Breakpoint 1, main () at fork.c:8
8   pid = fork();
(gdb) next
Detaching after fork from child process 3840.
9   if (pid == 0)
(gdb) next
15        name = "I am the parent";
(gdb) next
17    return 0;
(gdb) print name
$1 = 0x400717 "I am the parent"
```

GDB followed the parent process and allowed the child process (process 3840) to continue execution.

The following is the same test using **`set follow-fork-mode child`**.

```
(gdb) set follow-fork-mode child
(gdb) break main
Breakpoint 1 at 0x4005dc: file fork.c, line 8.
(gdb) run
[...]
Breakpoint 1, main () at fork.c:8
8   pid = fork();
(gdb) next
[New process 3875]
[Thread debugging using libthread_db enabled]
[Switching to Thread 0x7ffff7fd5720 (LWP 3875)]
9   if (pid == 0)
(gdb) next
11        name = "I am the child";
(gdb) next
17    return 0;
(gdb) print name
$2 = 0x400708 "I am the child"
(gdb)
```

GDB switched to the child process here.

This can be permanent by adding the setting to the appropriate **`.gdbinit`**.

For example, if **`set follow-fork-mode ask`** is added to **`~/.gdbinit`**, then ask mode becomes the default mode.

### 5.2.5. Debugging Individual Threads

GDB has the ability to debug individual threads, and to manipulate and examine them independently. This functionality is not enabled by default. To do so use **`set non-stop on`** and **`set target-async on`**. These can be added to **`.gdbinit`**. Once that functionality is turned on, GDB is ready to conduct thread debugging.

For example, the following program creates two threads. These two threads, along with the original thread executing main makes a total of three threads.

```
three-threads.c

#include <stdio.h>
#include <pthread.h>
#include <unistd.h>

pthread_t thread;

void* thread3 (void* d)
{
  int count3 = 0;

  while(count3 < 1000){
    sleep(10);
    printf("Thread 3: %d\n", count3++);
  }
  return NULL;
}

void* thread2 (void* d)
{
  int count2 = 0;

  while(count2 < 1000){
    printf("Thread 2: %d\n", count2++);
  }
  return NULL;
}

int main (){

  pthread_create (&thread, NULL, thread2, NULL);
  pthread_create (&thread, NULL, thread3, NULL);

  //Thread 1
  int count1 = 0;

  while(count1 < 1000){
    printf("Thread 1: %d\n", count1++);
  }

  pthread_join(thread,NULL);
  return 0;
}
```

Compile this program in order to examine it under GDB.

```
gcc -g three-threads.c -o three-threads  -lpthread
gdb ./three-threads
```

First set breakpoints on all thread functions; thread1, thread2, and main.

```
(gdb) break thread3
Breakpoint 1 at 0x4006c0: file three-threads.c, line 9.
(gdb) break thread2
Breakpoint 2 at 0x40070c: file three-threads.c, line 20.
(gdb) break main
Breakpoint 3 at 0x40074a: file three-threads.c, line 30.
```

Then run the program.

```
(gdb) run
[...]
```

```
Breakpoint 3, main () at three-threads.c:30
30   pthread_create (&thread, NULL, thread2, NULL);
[...]
(gdb) info threads
* 1 Thread 0x7ffff7fd5720 (LWP 4620)  main () at three-threads.c:30
(gdb)
```

Note that the command **`info threads`** provides a summary of the program's threads and some details about their current state. In this case there is only one thread that has been created so far.

Continue execution some more.

```
(gdb) next
[New Thread 0x7ffff7fd3710 (LWP 4687)]
31   pthread_create (&thread, NULL, thread3, NULL);
(gdb)
Breakpoint 2, thread2 (d=0x0) at three-threads.c:20
20   int count2 = 0;
next
[New Thread 0x7ffff75d2710 (LWP 4688)]
34   int count1 = 0;
(gdb)
Breakpoint 1, thread3 (d=0x0) at three-threads.c:9
9   int count3 = 0;
info threads
  3 Thread 0x7ffff75d2710 (LWP 4688)  thread3 (d=0x0) at three-threads.c:9
  2 Thread 0x7ffff7fd3710 (LWP 4687)  thread2 (d=0x0) at three-threads.c:20
* 1 Thread 0x7ffff7fd5720 (LWP 4620)  main () at three-threads.c:34
```

Here, two more threads are created. The star indicates the thread currently under focus. Also, the newly created threads have hit the breakpoint set for them in their initialization functions. Namely, thread2() and thread3().

To begin real thread debugging, use the **`thread <thread number>`** command to switch the focus to another thread.

```
(gdb) thread 2
[Switching to thread 2 (Thread 0x7ffff7fd3710 (LWP 4687))]#0  thread2 (d=0x0)
    at three-threads.c:20
20   int count2 = 0;
(gdb) list
15   return NULL;
16 }
17
18 void* thread2 (void* d)
19 {
20   int count2 = 0;
21
22   while(count2 < 1000){
23     printf("Thread 2: %d\n", count2++);
24   }
```

Thread 2 stopped at line 20 in its function thread2().

```
(gdb) next
22   while(count2 < 1000){
(gdb) print count2
$1 = 0
(gdb) next
23     printf("Thread 2: %d\n", count2++);
```

```
(gdb) next
Thread 2: 0
22   while(count2 < 1000){
(gdb) next
23     printf("Thread 2: %d\n", count2++);
(gdb) print count2
$2 = 1
(gdb) info threads
  3 Thread 0x7ffff75d2710 (LWP 4688)  thread3 (d=0x0) at three-threads.c:9
* 2 Thread 0x7ffff7fd3710 (LWP 4687)  thread2 (d=0x0) at three-threads.c:23
  1 Thread 0x7ffff7fd5720 (LWP 4620)  main () at three-threads.c:34
(gdb)
```

Above, a few lines of thread2 printed the counter count2 and left thread 2 at line 23 as is seen by the output of 'info threads'.

Now thread3.

```
(gdb) thread 3
[Switching to thread 3 (Thread 0x7ffff75d2710 (LWP 4688))]#0  thread3 (d=0x0)
    at three-threads.c:9
9   int count3 = 0;
(gdb) list
4
5 pthread_t thread;
6
7 void* thread3 (void* d)
8 {
9   int count3 = 0;
10
11   while(count3 < 1000){
12     sleep(10);
13     printf("Thread 3: %d\n", count3++);
(gdb)
```

Thread three is a little different in that it has a sleep statement and executes slowly. Think of it as a representation of an uninteresting IO thread. Since this thread is uninteresting, continue its execution uninterrupted, using the **`continue`**.

```
(gdb) continue &
(gdb) Thread 3: 0
Thread 3: 1
Thread 3: 2
Thread 3: 3
```

Take note of the *&* at the end of the **`continue`**. This allows the GDB prompt to return so other commands can be executed. Using the **`interrupt`**, execution can be stopped should thread 3 become interesting again.

```
(gdb) interrupt
[Thread 0x7ffff75d2710 (LWP 4688)] #3 stopped.
0x000000343f4a6a6d in nanosleep () at ../sysdeps/unix/syscall-template.S:82
82 T_PSEUDO (SYSCALL_SYMBOL, SYSCALL_NAME, SYSCALL_NARGS)
```

It is also possible to go back to the original main thread and examine it some more.

```
(gdb) thread 1
[Switching to thread 1 (Thread 0x7ffff7fd5720 (LWP 4620))]#0  main ()
    at three-threads.c:34
34   int count1 = 0;
(gdb) next
```

```
36    while(count1 < 1000){
(gdb) next
37      printf("Thread 1: %d\n", count1++);
(gdb) next
Thread 1: 0
36    while(count1 < 1000){
(gdb) next
37      printf("Thread 1: %d\n", count1++);
(gdb) next
Thread 1: 1
36    while(count1 < 1000){
(gdb) next
37      printf("Thread 1: %d\n", count1++);
(gdb) next
Thread 1: 2
36    while(count1 < 1000){
(gdb) print count1
$3 = 3
(gdb) info threads
  3 Thread 0x7ffff75d2710 (LWP 4688)  0x000000343f4a6a6d in nanosleep ()
    at ../sysdeps/unix/syscall-template.S:82
  2 Thread 0x7ffff7fd3710 (LWP 4687)  thread2 (d=0x0) at three-threads.c:23
* 1 Thread 0x7ffff7fd5720 (LWP 4620)  main () at three-threads.c:36
(gdb)
```

As can be seen from the output of info threads, the other threads are where they were left, unaffected by the debugging of thread 1.

### 5.2.6. Alternative User Interfaces for GDB

GDB uses the command line as its default interface. However, it also has an API called *machine interface* (MI). MI allows IDE developers to create other user interfaces to GDB.

Some examples of these interfaces are:

Eclipse (CDT)
: A graphical debugger interface integrated with the Eclipse development environment. More information can be found at the *Eclipse website*[2].

Nemiver
: A graphical debugger interface which is well suited to the GNOME Desktop Environment. More information can be found at the *Nemiver website*[3]

Emacs
: A GDB interface which is integrated with the emacs. More information can be found at the *Emacs website*[4]

### 5.2.7. GDB Documentation

For more detailed information about GDB, refer to the GDB manual:

*http://sources.redhat.com/gdb/current/onlinedocs/gdb.html*

Also, the commands **`info gdb`** and **`man gdb`** will provide more concise information that is up to date with the installed version of gdb.

[2] http://www.eclipse.org/cdt/
[3] http://projects.gnome.org/nemiver/
[4] http://www.gnu.org/software/emacs/manual/hutml_node/emacs/GDB-Graphical-Interface.html

## 5.3. Variable Tracking at Assignments

*Variable Tracking at Assignments* (VTA) is a new infrastructure included in GCC used to improve variable tracking during optimizations. This allows GCC to produce more precise, meaningful, and useful debugging information for GDB, SystemTap, and other debugging tools.

When GCC compiles code with optimizations enabled, variables are renamed, moved around, or even removed altogether. As such, optimized compiling can cause a debugger to report that some variables have been "optimized out". With VTA enabled, optimized code is internally annotated to ensure that optimization passes to transparently keep track of each variable's value, regardless of whether the variable is moved or removed.

VTA's benefits are more pronounced when debugging applications with inlined functions. Without VTA, optimization could completely remove some arguments of an inlined function, preventing the debugger from inspecting its value. With VTA, optimization will still happen, and appropriate debugging information will be generated for any missing arguments.

VTA is enabled by default when compiling code with optimizations and debugging information enabled. To disable VTA during such builds, add the **`-fno-var-tracking-assignments`**. In addition, the VTA infrastructure includes the new **`gcc`** option **`-fcompare-debug`**. This option tests code compiled by GCC with debug information and without debug information: the test passes if the two binaries are identical. This test ensures that executable code is not affected by any debugging options, which further ensures that there are no hidden bugs in the debug code. Note that **`-fcompare-debug`** adds significant cost in compilation time. Refer to **`man gcc`** for details about this option.

For more information about the infrastructure and development of VTA, refer to *A Plan to Fix Local Variable Debug Information in GCC*, available at the following link:

*http://gcc.gnu.org/wiki/Var_Tracking_Assignments*

A slide deck version of this whitepaper is also available at *http://people.redhat.com/aoliva/papers/vta/slides.pdf*.

## 5.4. Python Pretty-Printers

The GDB command **`print`** outputs comprehensive debugging information for a target application. GDB aims to provide as much debugging data as it can to users; however, this means that for highly complex programs the amount of data can become very cryptic.

In addition, GDB does not provide any tools that help decipher GDB **`print`** output. GDB does not even empower users to easily create tools that can help decipher program data. This makes the practice of reading and understanding debugging data quite arcane, particularly for large, complex projects.

For most developers, the only way to customize GDB **`print`** output (and make it more meaningful) is to revise and recompile GDB. However, very few developers can actually do this. Further, this practice will not scale well, particularly if the developer needs to also debug other programs that are heterogeneous and contain equally complex debugging data.

To address this, the Red Hat Enterprise Linux 6 version of GDB is now compatible with Python *pretty-printers*. This allows the retrieval of more meaningful debugging data by leaving the introspection, printing, and formatting logic to a *third-party* Python script.

Compatibility with Python pretty-printers gives you the chance to truly customize GDB output as you see fit. This makes GDB a more viable debugging solution to a wider range of projects, since you now have the flexibility to *adapt* GDB output as needed, and with greater ease. Further, developers with intimate knowledge of a project and a specific programming language are best qualified in deciding what kind of output is meaningful, allowing them to improve the usefulness of that output.

The Python pretty-printers implementation allows users to automatically inspect, format, and print program data according to specification. These specifications are written as rules implemented via Python scripts. This offers the following benefits:

### Safe

To pass program data to a set of registered Python pretty-printers, the GDB development team added *hooks* to the GDB printing code. These hooks were implemented with safety in mind: the built-in GDB printing code is still intact, allowing it to serve as a default fallback printing logic. As such, if no specialized printers are available, GDB will still print debugging data the way it always did. This ensures that GDB is backwards-compatible; users who have no need of pretty-printers can still continue using GDB.

### Highly Customizable

This new "Python-scripted" approach allows users to distill as much knowledge as required into specific printers. As such, a project can have an entire library of printer scripts that parses program data in a unique manner specific to its user's needs. There is no limit to the number of printers a user can build for a specific project; what's more, being able to customize debugging data script by script offers users an easier way to re-use and re-purpose printer scripts — or even a whole library of them.

### Easy to Learn

The best part about this approach is its lower barrier to entry. Python scripting is quite easy to learn (in comparison, at least) and has a large library of free documentation available online. In addition, most programmers already have basic to intermediate experience in Python scripting, or in scripting in general.

Here is a small example of a pretty printer. Consider the following C++ program:

```
fruit.cc

enum Fruits {Orange, Apple, Banana};

class Fruit
{
  int fruit;

 public:
  Fruit (int f)
    {
      fruit = f;
    }
};

int main()
{
  Fruit myFruit(Apple);
  return 0;             // line 17
}
```

This is compiled with the command **`g++ -g fruit.cc -o fruit`**. Now, examine this program with GDB.

```
gdb ./fruit
```

```
[...]
(gdb) break 17
Breakpoint 1 at 0x40056d: file fruit.cc, line 17.
(gdb) run

Breakpoint 1, main () at fruit.cc:17
17    return 0;             // line 17
(gdb) print myFruit
$1 = {fruit = 1}
```

The output of **`{fruit = 1}`** is correct because that is the internal representation of 'fruit' in the data structure 'Fruit'. However, this is not easily read by humans as it is difficult to tell which fruit the integer 1 represents.

To solve this problem, write the following pretty printer:

```
fruit.py

class FruitPrinter:
    def __init__(self, val):
        self.val = val

    def to_string (self):
        fruit = self.val['fruit']

        if (fruit == 0):
            name = "Orange"
        elif (fruit == 1):
            name = "Apple"
        elif (fruit == 2):
            name = "Banana"
        else:
            name = "unknown"
        return "Our fruit is " + name

def lookup_type (val):
    if str(val.type) == 'Fruit':
        return FruitPrinter(val)
    return None

gdb.pretty_printers.append (lookup_type)
```

Examine this printer from the bottom up.

The line **`gdb.pretty_printers.append (lookup_type)`** adds the function `lookup_type` to GDB's list of printer lookup functions.

The function `lookup_type` is responsible for examining the type of object to be printed, and returning an appropriate pretty printer. The object is passed by GDB in the parameter *`val`*. `val.type` is an attribute which represents the type of the pretty printer.

**`FruitPrinter`** is where the actual work is done. More specifically in the `to_string` function of that Class. In this function, the integer **`fruit`** is retrieved using the python dictionary syntax **`self.val['fruit']`**. Then the name is determined using that value. The string returned by this function is the string that will be printed to the user.

The *GDB and Python Pretty-Printers* whitepaper provides more details on this feature. This whitepaper also includes details and examples on how to write your own Python pretty-printer as well as how to import it into GDB. Refer to the following link for more information:

*http://docs.redhat.com/docs/en-US/Red_Hat_Enterprise_Linux/6/html/GDB_and_Python_Pretty_Printers/*

# Profiling

Developers profile programs to focus attention on the areas of the program that have the largest impact on performance. The types of data collected include what section of the program consumes the most processor time, and where memory is allocated. Profiling collects data from the actual program execution. Thus, the quality of the data collect is influenced by the actual tasks being performed by the program. The tasks performed during profiling should be representative of actual use; this ensures that problems arising from realistic use of the program are addressed during development.

Red Hat Enterprise Linux 6 includes a number of different tools (Valgrind, OProfile, **`perf`**, and SystemTap) to collect profiling data. Each tool is suitable for performing specific types of profile runs, as described in the following sections.

## 6.1. Profiling In Eclipse

To launch a profile run, navigate to **Run** > **Profile**. This will open the **Profile As** dialogue, from which you can select a tool for a profile run.

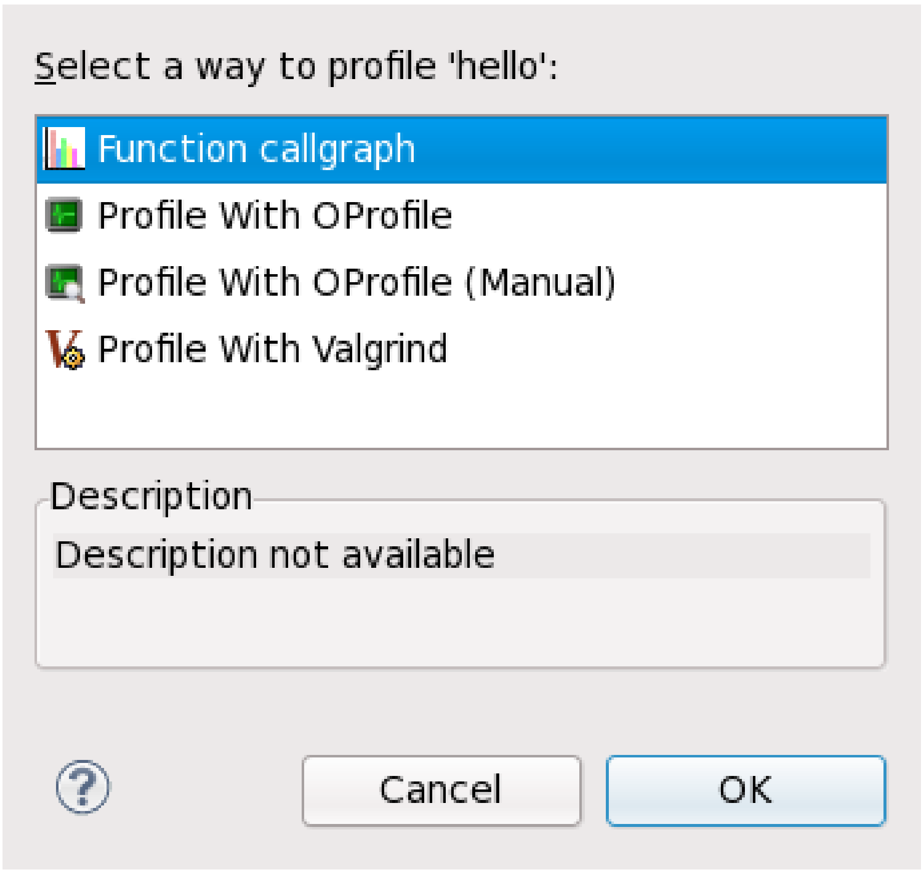
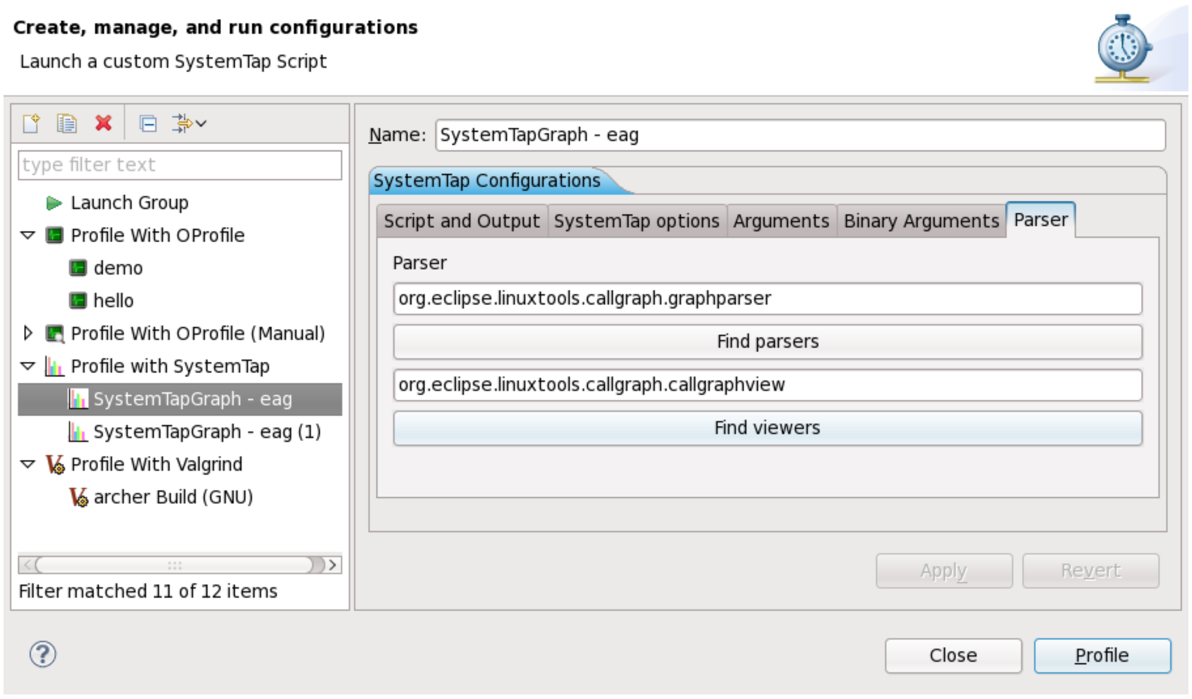

Select a way to profile 'hello':
Function callgraph
Profile With OProfile
Profile With OProfile (Manual)
Profile With Valgrind
Description
Description not available
Cancel
OK

Figure 6.1. Profile As

To configure each tool for a profile run, navigate to **Run** > **Profile Configuration**. This will open the **Profile Configuration** menu.


Create, manage, and run configurations

Launch a custom SystemTap Script

Name: SystemTapGraph - eag

SystemTap Configurations

Script and Output | SystemTap options | Arguments | Binary Arguments | Parser

Parser

org.eclipse.linuxtools.callgraph.graphparser

org.eclipse.linuxtools.callgraph.callgraphview

- Launch Group
- Profile With OProfile
  - demo
  - hello
- Profile With OProfile (Manual)
- Profile with SystemTap
  - SystemTapGraph - eag
  - SystemTapGraph - eag (1)
- Profile With Valgrind
  - archer Build (GNU)

Filter matched 11 of 12 items

Figure 6.2. Profile Configuration

For more information on configuring and performing a profile run with each tool in Eclipse, refer to *Section 6.2.3, “Valgrind Plug-in for Eclipse ”*, *Section 6.3.3, “OProfile Plug-in For Eclipse ”*, and *Section 6.5, “ Eclipse-Callgraph”*.

## 6.2. Valgrind

**Valgrind** is an instrumentation framework for building dynamic analysis tools that can be used to profile applications in detail. Valgrind tools are generally used to automatically detect many memory management and threading problems. The Valgrind suite also includes tools that allow the building of new profiling tools as needed.

Valgrind provides instrumentation for user-space binaries to check for errors, such as the use of uninitialized memory, improper allocation/freeing of memory, and improper arguments for systemcalls. Its profiling tools can be used by normal users on most binaries; however, compared to other profilers, Valgrind profile runs are significantly slower. To profile a binary, Valgrind rewrites its executable and instruments the rewritten binary. Valgrind's tools are most useful for looking for memory-related issues in user-space programs; it is not suitable for debugging time-specific issues or kernel-space instrumentation/debugging.

Previously, Valgrind did not support IBM System z architecture. However, as of 6.1, this support has been added, meaning Valgrind now supports all hardware architectures that are supported by Red Hat Enterprise Linux 6.x.

### 6.2.1. Valgrind Tools

The Valgrind suite is composed of the following tools:

memcheck

This tool detects memory management problems in programs by checking all reads from and writes to memory and intercepting all system calls to **`malloc`**, **`new`**, **`free`**, and **`delete`**. **Memcheck** is perhaps the most used Valgrind tool, as memory management problems can be difficult to detect using other means. Such problems often remain undetected for long periods, eventually causing crashes that are difficult to diagnose.

cachegrind

**Cachegrind** is a cache profiler that accurately pinpoints sources of cache misses in code by performing a detailed simulation of the I1, D1 and L2 caches in the CPU. It shows the number of cache misses, memory references, and instructions accruing to each line of source code; **Cachegrind** also provides per-function, per-module, and whole-program summaries, and can even show counts for each individual machine instructions.

callgrind

Like **`cachegrind`**, **`callgrind`** can model cache behavior. However, the main purpose of **`callgrind`** is to record callgraphs data for the executed code.

massif

**Massif** is a heap profiler; it measures how much heap memory a program uses, providing information on heap blocks, heap administration overheads, and stack sizes. Heap profilers are useful in finding ways to reduce heap memory usage. On systems that use virtual memory, programs with optimized heap memory usage are less likely to run out of memory, and may be faster as they require less paging.

helgrind

In programs that use the POSIX pthreads threading primitives, **Helgrind** detects synchronisation errors. Such errors are:

- Misuses of the POSIX pthreads API
- Potential deadlocks arising from lock ordering problems
- Data races (i.e. accessing memory without adequate locking)

Valgrind also allows you to develop your own profiling tools. In line with this, Valgrind includes the **`lackey`** tool, which is a sample that can be used as a template for generating your own tools.

## 6.2.2. Using Valgrind

The **`valgrind`** package and its dependencies install all the necessary tools for performing a Valgrind profile run. To profile a program with Valgrind, use:

```
valgrind --tool=toolname program
```

Refer to *Section 6.2.1, "Valgrind Tools"* for a list of arguments for ***`toolname`***. In addition to the suite of Valgrind tools, **none** is also a valid argument for ***`toolname`***; this argument allows you to run a program under Valgrind without performing any profiling. This is useful for debugging or benchmarking Valgrind itself.

You can also instruct Valgrind to send all of its information to a specific file. To do so, use the option **`--log-file=`*`filename`***. For example, to check the memory usage of the executable file **`hello`** and send profile information to **`output`**, use:

```
valgrind --tool=memcheck --log-file=output hello
```

Refer to *Section 6.2.4, "Valgrind Documentation"* for more information on Valgrind, along with other available documentation on the Valgrind suite of tools.

### 6.2.3. Valgrind Plug-in for Eclipse

The **Valgrind** plug-in for Eclipse (documented herein) integrates several **Valgrind** tools into Eclipse. This allows Eclipse users to seamlessly include profiling capabilities into their workflow. At present, the **Valgrind** plug-in for Eclipse supports three **Valgrind** tools:

- Memcheck
- Massif
- Cachegrind

The Valgrind plug-in for Eclipse is provided by the **`eclipse-valgrind`** package. For more information about this plug-in, refer to *Valgrind Integration User Guide* in the Eclipse **Help Contents**.

### 6.2.4. Valgrind Documentation

For more extensive information on Valgrind, refer to **`man valgrind`**. Red Hat Enterprise Linux 6 also provides a comprehensive *Valgrind Documentation* book, available as PDF and HTML in:

- **`file:///usr/share/doc/valgrind-`*`version`*`/valgrind_manual.pdf`**
- **`file:///usr/share/doc/valgrind-`*`version`*`/html/index.html`**

The *Valgrind Integration User Guide* in the Eclipse **Help Contents** also also provides detailed information on the setup and usage of the Valgrind plug-in for Eclipse. This guide is provided by the **`eclipse-valgrind`** package.

## 6.3. OProfile

OProfile is a system-wide Linux profiler, capable of running at low overhead. It consists of a kernel driver and a daemon for collecting raw sample data, along with a suite of tools for parsing that data into meaningful information. OProfile is generally used by developers to determine which sections of code consume the most amount of CPU time, and why.

During a profile run, OProfile uses the processor's performance monitoring hardware. Valgrind rewrites the binary of an application, and in turn instruments it. OProfile, on the other hand,simply profiles a running application as-is. It sets up the performance monitoring hardware to take a sample every *x* number of events (e.g. cache misses or branch instructions). Each sample also contains information on where it occurred in the program.

OProfile's profiling methods consume less resources than Valgrind. However, OProfile requires root privileges. OProfile is useful for finding "hot-spots" in code, and looking for their causes (e.g. poor cache performance, branch mispredictions).

Using OProfile involves starting the OProfile daemon (**`oprofiled`**), running the program to be profiled, collecting the system profile data, and parsing it into a more understandable format. OProfile provides several tools for every step of this process.

### 6.3.1. OProfile Tools

The most useful OProfile commands include the following:

opcontrol
: This tool is used to start/stop the OProfile daemon and configure a profile session.

opreport
: The **`opreport`** command outputs binary image summaries, or per-symbol data, from OProfile profiling sessions.

opannotate
: The **`opannotate`** command outputs annotated source and/or assembly from the profile data of an OProfile session.

oparchive
: The **`oparchive`** command generates a directory populated with executable, debug, and OProfile sample files. This directory can be moved to another machine (via **`tar`**), where it can be analyzed offline.

opgprof
: Like **`opreport`**, the **`opgprof`** command outputs profile data for a given binary image from an OProfile session. The output of **`opgprof`** is in **`gprof`** format.

For a complete list of OProfile commands, refer to **`man oprofile`**. For detailed information on each OProfile command, refer to its corresponding **`man`** page. Refer to *Section 6.3.4, “OProfile Documentation”* for other available documentation on OProfile.

### 6.3.2. Using OProfile

The **`oprofile`** package and its dependencies install all the necessary utilities for performing an OProfile profile run. To instruct the OProfile to profile all the application running on the system and to group the samples for the shared libraries with the application using the library, run the following command as root:

```
opcontrol --no-vmlinux --separate=library --start
```

You can also start the OProfile daemon without collecting system data. To do so, use the option **`--start-daemon`** instead. The **`--stop`** option halts data collection, while the **`--shutdown`** terminates the OProfile daemon.

Use **`opreport`**, **`opannotate`**, or **`opgprof`** to display the collected profiling data. By default, the data collected by the OProfile daemon is stored in **`/var/lib/oprofile/samples/`**.

### 6.3.3. OProfile Plug-in For Eclipse

The **OProfile** suite of tools provide powerful call profiling capabilities; as a plug-in, these capabilities are well ported into the Eclipse user interface. The **OProfile Plug-in** provides the following benefits:

#### Targeted Profiling

The **OProfile Plug-in** will allow Eclipse users to profile a specific binary, include related shared libraries/kernel modules, and even exclude binaries. This produces very targeted, detailed usage results on each binary, function, and symbol, down to individual line numbers in the source code.

#### User Interface Fully Integrated into CDT

The plug-in displays enriched **OProfile** results through Eclipse, just like any other plug-in. Double-clicking on a source line in the results brings users directly to the corresponding line in the Eclipse editor. This allows users to build, profile, and edit code through a single interface, making profiling a convenient experience for Eclipse users. In addition, profile runs are launched and configured the same way as C/C++ applications within Eclipse.

### Fully Customizable Profiling Options

The Eclipse interface allows users to configure their profile run using all options available in the **OProfile** command-line utility. The plug-in supports event configuration based on processor debugging registers (i.e. counters), as well as interrupt-based profiling for kernels or processors that don't support hardware counters.

### Ease of Use

The **OProfile Plug-in** provides generally useful defaults for all options, usable for a majority of profiling runs. In addition, it also features a "one-click profile" that executes a profile run using these defaults. Users can profile applications from start to finish, or select specific areas of code through a manual control dialog.

The OProfile plug-in for Eclipse is provided by the **`eclipse-oprofile`** package. For more information about this plug-in, refer to *OProfile Integration User Guide* in the Eclipse **Help Contents** (also provided by **`eclipse-profile`**).

## 6.3.4. OProfile Documentation

For a more extensive information on OProfile, refer to **`man oprofile`**. Red Hat Enterprise Linux 6 also provides two comprehensive guides to OProfile in **`file:///usr/share/doc/oprofile-`*`version`*`/`**:

OProfile Manual

A comprehensive manual with detailed instructions on the setup and use of OProfile is found at **`file:///usr/share/doc/oprofile-`*`version`*`/oprofile.html`**

OProfile Internals

Documentation on the internal workings of OProfile, useful for programmers interested in contributing to the OProfile upstream, can be found at **`file:///usr/share/doc/oprofile-`*`version`*`/internals.html`**

The *OProfile Integration User Guide* in the Eclipse **Help Contents** also provides detailed information on the setup and usage of the OProfile plug-in for Eclipse. This guide is provided by the **`eclipse-oprofile`** package.

## 6.4. SystemTap

SystemTap is a useful instrumentation platform for probing running processes and kernel activity on the Linux system. To execute a probe:

1. Write *SystemTap scripts* that specify which system events (e.g. virtual file system reads, packet transmissions) should trigger specified actions (e.g. print, parse, or otherwise manipulate data).

2. SystemTap translates the script into a C program, which it compiles into a kernel module.

3. SystemTap loads the kernel module to perform the actual probe.

SystemTap scripts are useful for monitoring system operation and diagnosing system issues with minimal intrusion into the normal operation of the system. You can quickly instrument running system test hypotheses without having to recompile and re-install instrumented code. To compile a SystemTap script that probes *kernel-space*, SystemTap uses information from three different *kernel information packages*:

- ***`kernel-variant`*`-devel-`*`version`***

- ***kernel-variant*-debuginfo-*version***
- ***kernel-variant*-debuginfo-common-*arch*-*version***

**Difference between Red Hat Enterprise Linux 5 and 6**

The kernel information package in Red Hat Enterprise Linux 6 is now named ***kernel-variant*-debuginfo-common-*arch*-*version***. It was originally ***kernel-variant*-debuginfo-common-*version*** in Red Hat Enterprise Linux 5.

These kernel information packages must match the kernel to be probed. In addition, to compile SystemTap scripts for multiple kernels, the kernel information packages of each kernel must also be installed.

An important new feature has been added as of Red Hat Enterprise Linux 6.1: the **--remote** option. This allows users to build the SystemTap module locally, and then execute it remotely via SSH. The syntax to use this is **--remote [USER@]HOSTNAME**; set the execution target to the specified SSH host, optionally using a different username. This option may be repeated to target multiple execution targets. Passes 1-4 are completed locally as normal to build the scrip, and then pass 5 copies the module to the target and runs it.

The following sections describe other new SystemTap features available in the Red Hat Enterprise Linux 6 release.

### 6.4.1. SystemTap Compile Server

SystemTap in Red Hat Enterprise Linux 6 supports a *compile server and client* deployment. With this setup, the kernel information packages of *all* client systems in the network are installed on just one compile server host (or a few). When a client system attempts to compile a kernel module from a SystemTap script, it remotely accesses the kernel information it needs from the centralized compile server host.

A properly configured and maintained SystemTap compile server host offers the following benefits:

- The system administrator can verify the integrity of kernel information packages before making the packages available to users.
- The identity of a compile server can be authenticated using the *Secure Socket Layer* (SSL). SSL provides an encrypted network connection that prevents eavesdropping or tampering during transmission.
- Individual users can run their own servers and authorize them for their own use as trusted.
- System administrators can authorize one or more servers on the network as trusted for use by all users.
- A server that has not been explicitly authorized is ignored, preventing any server impersonations and similar attacks.

### 6.4.2. SystemTap Support for Unprivileged Users

For security purposes, users in an enterprise setting are rarely given privileged (i.e. root or **sudo**) access to their own machines. In addition, full SystemTap functionality should also be restricted to privileged users, as this can provide the ability to completely take control of a system.

SystemTap in Red Hat Enterprise Linux 6 features a new option to the SystemTap client: **`--unprivileged`**. This option allows an unprivileged user to run **`stap`**. Of course, several restrictions apply to unprivileged users that attempt to run **`stap`**.

> **Note**
>
> An unprivileged user is a member of the group **`stapusr`** but is not a member of the group **`stapdev`** (and is not root).

Before loading any kernel modules created by unprivileged users, SystemTap verifies the integrity of the module using standard digital (cryptographic) signing techniques. Each time the **`--unprivileged`** option is used, the server checks the script against the constraints imposed for unprivileged users. If the checks are successful, the server compiles the script and signs the resulting module using a self-generated certificate. When the client attempts to load the module, **`staprun`** first verifies the signature of the module by checking it against a database of trusted signing certificates maintained and authorized by root.

Once a signed kernel module is successfully verified, **`staprun`** is assured that:

- The module was created using a trusted systemtap server implementation.
- The module was compiled using the **`--unprivileged`** option.
- The module meets the restrictions required for use by an unprivileged user.
- The module has not been tampered with since it was created.

## 6.4.3. SSL and Certificate Management

SystemTap in Red Hat Enterprise Linux 6 implements authentication and security via certificates and public/private key pairs. It is the responsibility of the system administrator to add the credentials (i.e. certificates) of compile servers to a database of trusted servers. SystemTap uses this database to verify the identity of a compile server that the client attempts to access. Likewise, SystemTap also uses this method to verify kernel modules created by compile servers using the **`--unprivileged`** option.

### 6.4.3.1. Authorizing Compile Servers for Connection

The first time a compile server is started on a server host, the compile server automatically generates a certificate. This certificate verifies the compile server's identity during SSL authentication and module signing.

In order for clients to access the compile server (whether on the same server host or from a client machine), the system administrator must add the compile server's certificate to a database of trusted servers. Each client host intending to use compile servers maintains such a database. This allows individual users to customize their database of trusted servers, which can include a list of compile servers authorized for their own use only.

### 6.4.3.2. Authorizing Compile Servers for Module Signing (for Unprivileged Users)

Unprivileged users can only load signed, authorized SystemTap kernel modules. For modules to be recognized as such, they have to be created by a compile server whose certificate appears in a database of trusted signers; this database must be maintained on each host where the module will be loaded.

#### 6.4.3.3. Automatic Authorization

Servers started using the **`stap-server`** initscript are automatically authorized to receive connections from all clients on the same host.

Servers started by other means are automatically authorized to receive connections from clients on the same host run by the user who started the server. This was implemented with convenience in mind; users are automatically authorized to connect to a server they started themselves, provided that both client and server are running on the same host.

Whenever root starts a compile server, *all* clients running on the same host automatically recognize the server as authorized. However, Red Hat advises that you refrain from doing so.

Similarly, a compile server initiated through **`stap-server`** is automatically authorized as a trusted signer on the host in which it runs. If the compile server was initiated through other means, it is not automatically authorized as such.

### 6.4.4. SystemTap Documentation

For more detailed information about SystemTap, refer to the following books (also provided by Red Hat):

- *SystemTap Beginner's Guide*
- *SystemTap Tapset Reference*
- *SystemTap Language Reference* (documentation supplied by IBM)

The *SystemTap Beginner's Guide* and *SystemTap Tapset Reference* are also available locally when you install the **`systemtap`** package:

- **`file:///usr/share/doc/systemtap-`*`version`*`/SystemTap_Beginners_Guide/index.html`**
- **`file:///usr/share/doc/systemtap-`*`version`*`/SystemTap_Beginners_Guide.pdf`**
- **`file:///usr/share/doc/systemtap-`*`version`*`/tapsets/index.html`**
- **`file:///usr/share/doc/systemtap-`*`version`*`/tapsets.pdf`**

The *Section 6.4.1, “SystemTap Compile Server”*, *Section 6.4.2, “SystemTap Support for Unprivileged Users”*, and *Section 6.4.3, “ SSL and Certificate Management”* sections are excerpts from the *SystemTap Support for Unprivileged Users and Server Client Deployment* whitepaper. This whitepaper also provides more details on each feature, along with a case study to help illustrate their application in a real-world environment.

## 6.5. Eclipse-Callgraph

Red Hat Enterprise Linux 6 also includes the Eclipse-Callgraph plug-in, which provides a visual function trace of a program. This allows you to view a visualization of selected (or even all) functions used by the profiled application.

Eclipse-Callgraph uses SystemTap to perform a comprehensive function trace within a program. As such, you will need to install SystemTap along with the required kernel information packages.

For more information about SystemTap, refer to *Section 6.4, “SystemTap ”* and other SystemTap documentation provided by Red Hat.

This plug-in allows you to profile C/C++ projects directly within the Eclipse IDE, providing various runtime details such as:

- The relationship between function calls
- Number of times each function was called
- Time taken by each instance of a function (relative to the program's execution time)
- Time taken by all instances of a function (relative to program's execution time)

### 6.5.1. Launching a Profile With Eclipse-Callgraph

To profile an application with Eclipse-Callgraph, simply right-click on a project and navigate to **Profile As** > **Function callgraph**. This will open a dialogue from which you can select an executable to profile.

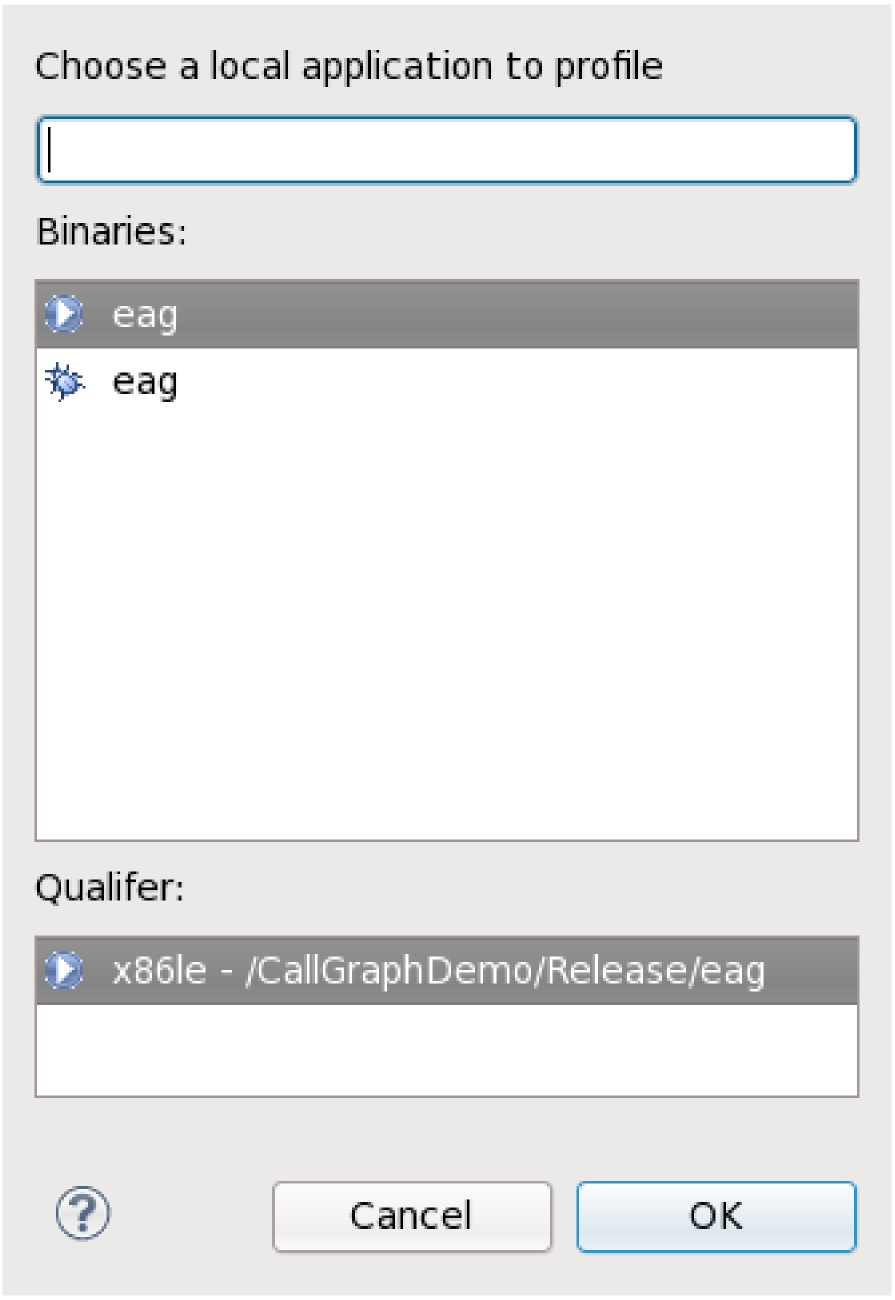

Choose a local application to profile
Binaries:
eag
eag
Qualifer:
x86le - /CallGraphDemo/Release/eag
Cancel
OK

Figure 6.3. Eclipse-Callgraph Profile

After selecting an executable to profile, Eclipse-Callgraph will ask which files to probe. By default, all source files in the project will be selected.

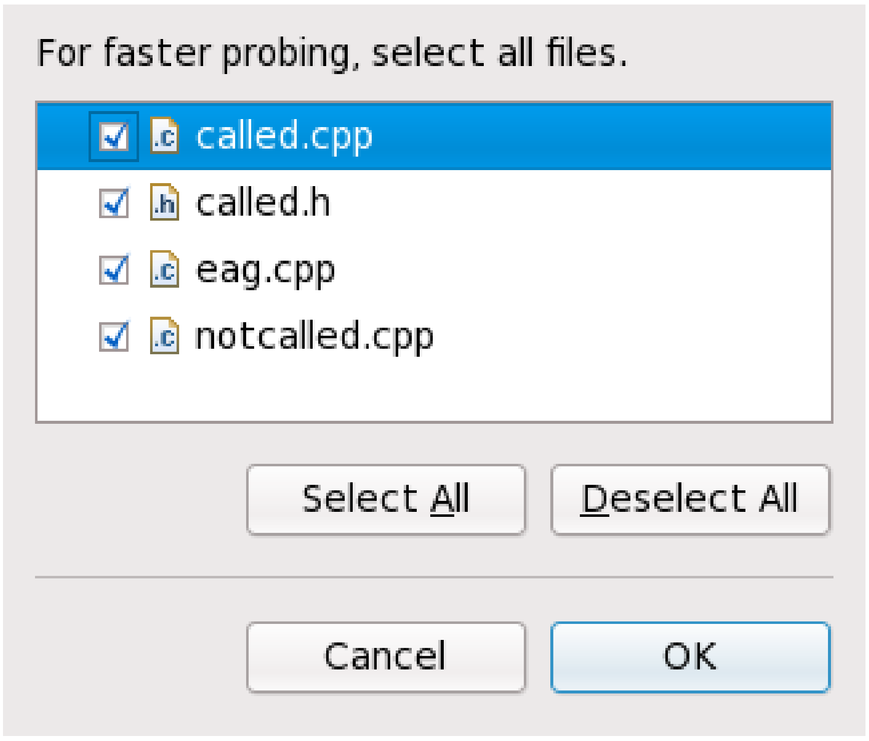


Figure 6.4. Selecting Files to Probe

## 6.5.2. The Callgraph View

The **Callgraph** view's toolbar allows you to select a perspective and perform other functions. To play a visual representation of a function trace, click the **View Menu** button then navigate to **Goto**. This menu will allow you to pause, step through, or mark each function as it executes.

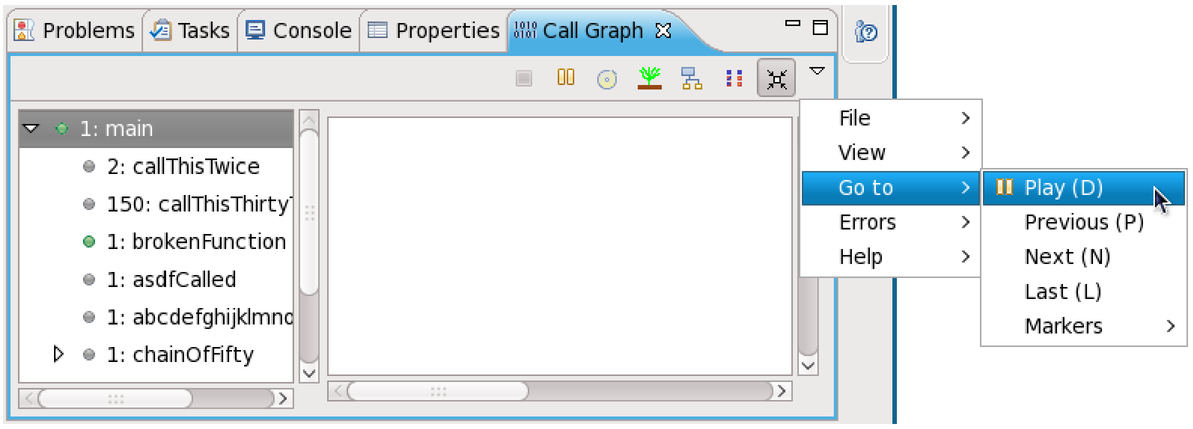


Figure 6.5. View > Goto

You can also save or load a profile run through the **View Menu**. To do either, navigate to **File** under the **View Menu**; this will display different options relating to saving and loading profile runs.

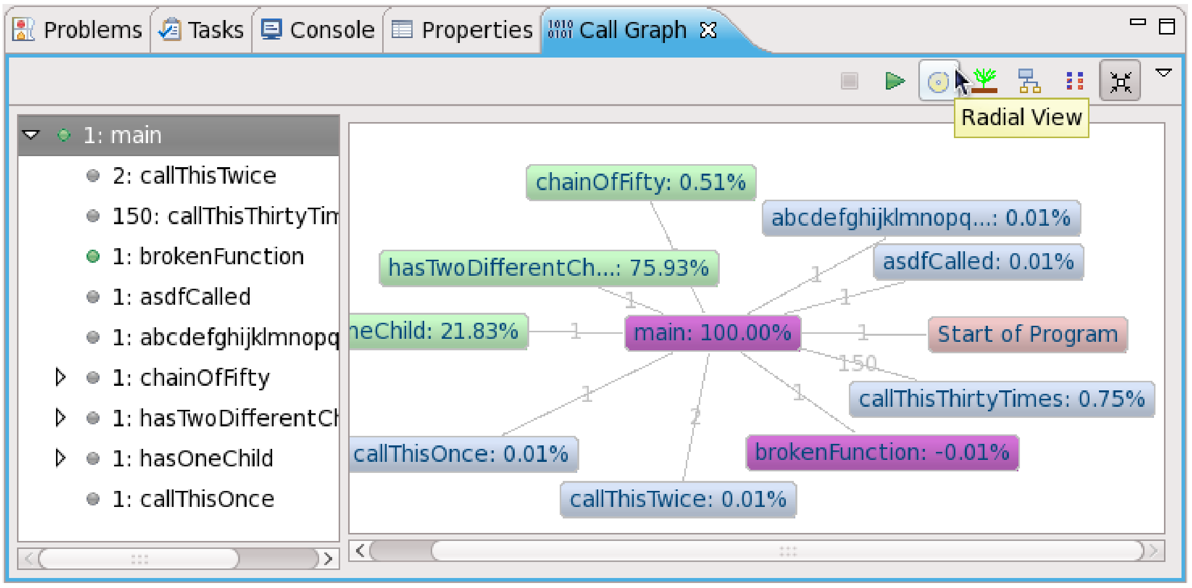


Figure 6.6. Radial View

The **Radial View** displays all functions branching out from **`main()`**, with each function represented as a node. A purple node means that the program terminates at the function. A green node signifies that the function call has nested functions, whereas gray nodes signify no nest functions. Double-clicking on a node will show its parent (colored pink) and children. The lines connecting different nodes also display how many times **`main()`** called each function.

The left window of the **Radial View** lists all of the functions shown in the view. This window also allows you to view nested functions, if any. A green bullet point means the program either starts or terminates at that function.

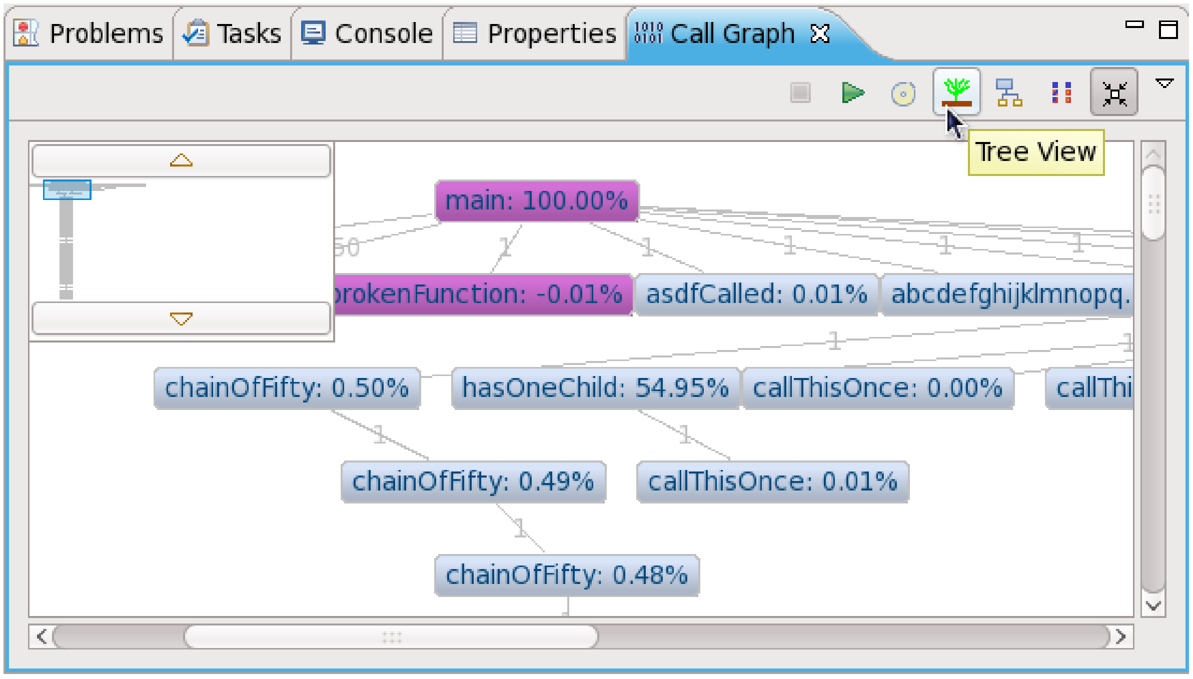


Figure 6.7. Tree View

The **Tree View** is similar to the **Radial View**, except that it only displays *all* descendants of a selected node (**Radial View** only displays functions one call depth away from a selected node). The top left of

**Tree View** also includes a thumbnail viewer to help you navigate through different call depths of the function tree.

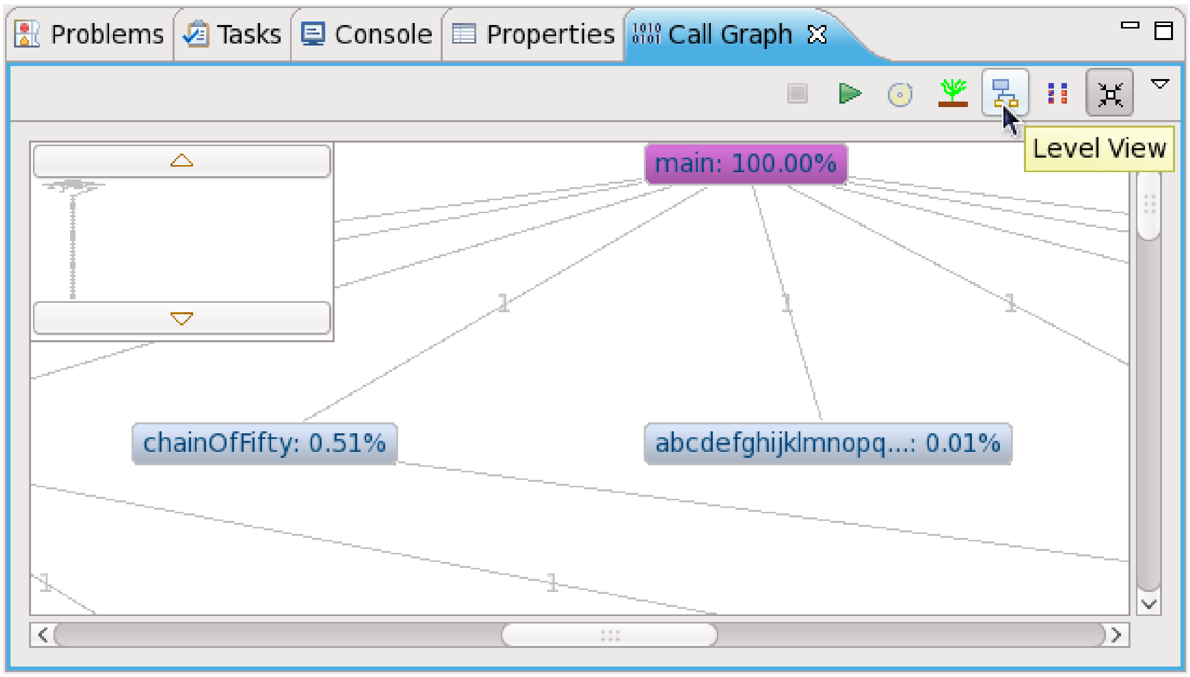


Figure 6.8. Level View

**Level View** displays all function calls and any nested function calls branching out from a selected node. However, **Level View** groups all functions of the same call depth together, giving a clearer visualization of a program's function call execution sequences. **Level View** also lets you navigate through different call depths using the thumbnail viewer's **More nodes above** and **More nodes below** buttons.

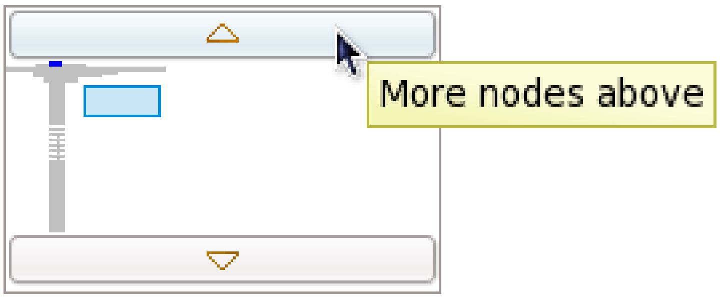


Figure 6.9. Thumbnail Viewer

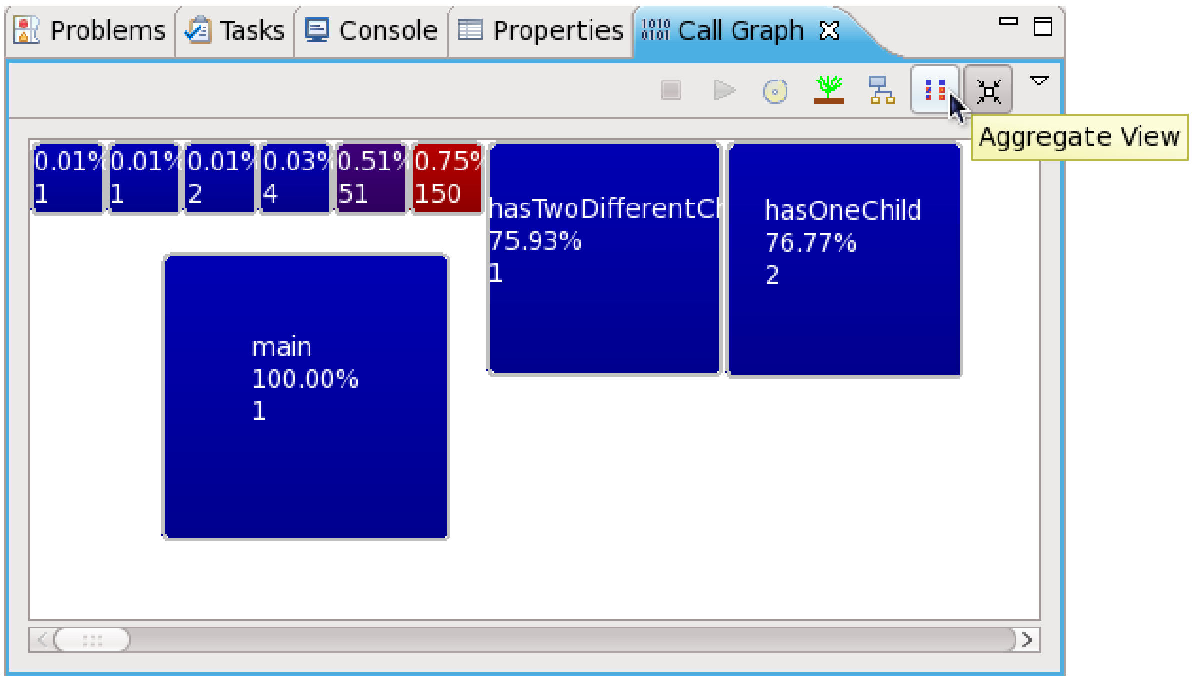


Figure 6.10. Aggregate View

The **Aggregate View** depicts all functions as boxes; the size of each box represents a function's execution time *relative* to the total running time of the program. Darker-colored boxes represent functions that are called more times relative to others; for example, in *Figure 6.10, "Aggregate View"*, the **`CallThisThirtyTimes`** function is called the most number of times (150).

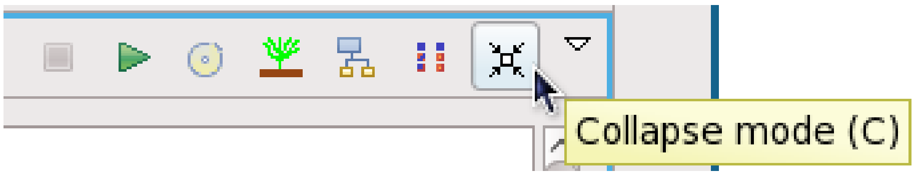


Figure 6.11. Collapse Mode

The **Callgraph** view's toolbar also features a **Collapse Mode** button. This groups all identical functions (i.e. those with identical names and call histories) together into one node. Doing so can be helpful in reducing screen clutter for programs where many functions get called multiple times.

### Go to Code

To navigate to a function in the code from any view, press **`Ctrl`** while double-clicking on its node. Doing so will open the corresponding source file in the Eclipse editor and highlight the function's declaration in the source.

## 6.6. Performance Counters for Linux (PCL) Tools and perf

*Performance Counters for Linux* (PCL) is a new kernel-based subsystem that provides a framework for collecting and analyzing performance data. These events will vary based on the performance monitoring hardware and the software configuration of the system. Red Hat Enterprise Linux 6 includes this kernel subsystem to collect data and the user-space tool **`perf`** to analyze the collected performance data.

The PCL subsystem can be used to measure hardware events, including retired instructions and processor clock cycles. It can also measure software events, including major page faults and context switches. For example, PCL counters can compute the *Instructions Per Clock* (IPC) from a process's counts of instructions retired and processor clock cycles. A low IPC ratio indicates the code makes poor use of the CPU. Other hardware events can also be used to diagnose poor CPU performance.

Performance counters can also be configured to record samples. The relative frequency of samples can be used to identify which regions of code have the greatest impact on performance.

## 6.6.1. Perf Tool Commands

Useful **`perf`** commands include the following:

perf stat
: This **`perf`** command provides overall statistics for common performance events, including instructions executed and clock cycles consumed. Options allow selection of events other than the default measurement events.

perf record
: This **`perf`** command records performance data into a file which can be later analyzed using **`perf report`**.

perf report
: This **`perf`** command reads the performance data from a file and analyzes the recorded data.

perf list
: This **`perf`** command lists the events available on a particular machine. These events will vary based on the performance monitoring hardware and the software configuration of the system.

Use **`perf help`** to obtain a complete list of **`perf`** commands. To retrieve **`man`** page information on each **`perf`** command, use **`perf help`** ***`command`***.

## 6.6.2. Using Perf

Using the basic PCL infrastructure for collecting statistics or samples of program execution is relatively straightforward. This section provides simple examples of overall statistics and sampling.

To collect statistics on **`make`** and its children, use the following command:

```
perf stat -- make all
```

The **`perf`** command will collect a number of different hardware and software counters. It will then print the following information:

```

Performance counter stats for 'make all':

  244011.782059  task-clock-msecs         #      0.925 CPUs
          53328  context-switches         #      0.000 M/sec
            515  CPU-migrations           #      0.000 M/sec
        1843121  page-faults              #      0.008 M/sec
   789702529782  cycles                   #   3236.330 M/sec
  1050912611378  instructions             #      1.331 IPC
   275538938708  branches                 #   1129.203 M/sec
     2888756216  branch-misses            #      1.048 %
     4343060367  cache-references         #     17.799 M/sec
      428257037  cache-misses             #      1.755 M/sec

  263.779192511  seconds time elapsed
```

The **`perf`** tool can also record samples. For example, to record data on the **`make`** command and its children, use:

**`perf record -- make all`**

This will print out the file in which the samples are stored, along with the number of samples collected:

```
[ perf record: Woken up 42 times to write data ]
[ perf record: Captured and wrote 9.753 MB perf.data (~426109 samples) ]
```

You can then analyze **`perf.data`** to determine the relative frequency of samples. The report output includes the command, object, and function for the samples. Use **`perf report`** to output an analysis of **`perf.data`**. For example, the following command produces a report of the executable that consumes the most time:

**`perf report --sort=comm`**

The resulting output:

```
# Samples: 1083783860000
#
# Overhead          Command
# ........  ...............
#
    48.19%         xsltproc
    44.48%        pdfxmltex
     6.01%             make
     0.95%             perl
     0.17%       kernel-doc
     0.05%          xmllint
     0.05%              cc1
     0.03%               cp
     0.01%            xmlto
     0.01%               sh
     0.01%          docproc
     0.01%               ld
     0.01%              gcc
     0.00%               rm
     0.00%              sed
     0.00%   git-diff-files
     0.00%             bash
     0.00%   git-diff-index
```

The column on the left shows the relative frequency of the samples. This output shows that **`make`** spends most of this time in **`xsltproc`** and the **`pdfxmltex`**. To reduce the time for the **`make`** to complete, focus on **`xsltproc`** and **`pdfxmltex`**. To list of the functions executed by **`xsltproc`**, run:

**`perf report -n --comm=xsltproc`**

This would generate:

```
comm: xsltproc
# Samples: 472520675377
#
# Overhead  Samples                    Shared Object  Symbol
# ........ ..........  .............................  ......
#
    45.54%215179861044  libxml2.so.2.7.6               [.] xmlXPathCmpNodesExt
```

```
     11.63%54959620202  libxml2.so.2.7.6               [.] xmlXPathNodeSetAdd__internal_alias
      8.60%40634845107  libxml2.so.2.7.6               [.] xmlXPathCompOpEval
      4.63%21864091080  libxml2.so.2.7.6               [.] xmlXPathReleaseObject
      2.73%12919672281  libxml2.so.2.7.6               [.] xmlXPathNodeSetSort__internal_alias
      2.60%12271959697  libxml2.so.2.7.6               [.] valuePop
      2.41%11379910918  libxml2.so.2.7.6               [.] xmlXPathIsNaN__internal_alias
      2.19%10340901937  libxml2.so.2.7.6               [.] valuePush__internal_alias
```

## 6.7. ftrace

The **`ftrace`** framework provides users with several tracing capabilities, accessible through an interface much simpler than SystemTap's. This framework uses a set of virtual files in the **`debugfs`** file system; these files enable specific tracers. The **`ftrace`** function tracer simply outputs each function called in the kernel in real time; other tracers within the **`ftrace`** framework can also be used to analyze wakeup latency, task switches, kernel events, and the like.

You can also add new tracers for **`ftrace`**, making it a flexible solution for analyzing kernel events. The **`ftrace`** framework is useful for debugging or analyzing latencies and performance issues that take place outside of user-space. Unlike other profilers documented in this guide, **`ftrace`** is a built-in feature of the kernel.

### 6.7.1. Using ftrace

The Red Hat Enterprise Linux 6 kernels have been configured with the **`CONFIG_FTRACE=y`** option. This option provides the interfaces needed by **`ftrace`**. To use **`ftrace`**, mount the **`debugfs`** file system as follows:

**`mount -t debugfs nodev /sys/kernel/debug`**

All the **`ftrace`** utilities are located in **`/sys/kernel/debug/tracing/`**. View the **`/sys/kernel/debug/tracing/available_tracers`** file to find out what tracers are available for your kernel:

**`cat /sys/kernel/debug/tracing/available_tracers`**

```
power wakeup irqsoff function sysprof sched_switch initcall nop
```

To use a specific tracer, write it to **`/sys/kernel/debug/tracing/current_tracer`**. For example, **`wakeup`** traces and records the maximum time it takes for the highest-priority task to be scheduled after the task wakes up. To use it:

**`echo wakeup > /sys/kernel/debug/tracing/current_tracer`**

To start or stop tracing, write to **`/sys/kernel/debug/tracing/tracing_on`**, as in:

**`echo 1 > /sys/kernel/debug/tracing/tracing_on`** (enables tracing)

**`echo 0 > /sys/kernel/debug/tracing/tracing_on`** (disables tracing)

The results of the trace can be viewed from the following files:

/sys/kernel/debug/tracing/trace
: This file contains human-readable trace output.

/sys/kernel/debug/tracing/trace_pipe
: This file contains the same output as **`/sys/kernel/debug/tracing/trace`**, but is meant to be piped into a command. Unlike **`/sys/kernel/debug/tracing/trace`**, reading from this file consumes its output.

## 6.7.2. ftrace Documentation

The **`ftrace`** framework is fully documented in the following files:

- *ftrace - Function Tracer*: **`file:///usr/share/doc/kernel-doc-`*`version`*`/Documentation/trace/ftrace.txt`**
- *function tracer guts*: **`file:///usr/share/doc/kernel-doc-`*`version`*`/Documentation/trace/ftrace-design.txt`**

# Documentation Tools

Red Hat Enterprise Linux 6 has two documentation tools available to include documentation with a project. These are Publican and Doxygen.

## 7.1. Publican

Publican a program is used to publish and process documentation through DocBook XML. In the process of publishing books, it checks the XML to ensure it is valid and in a publishable standard. It is particularly useful for publishing the documentation accompanying a newly created application.

### 7.1.1. Commands

Publican has a vast number of commands and actions available, all of which can be found in the **`--help`** or **`--man`** pages. The most common ones are:

**`build`**
: Converts the XML files into other formats more suitable for documentation (PDF, HTML, HTML-single, for example).

**`create`**
: Creates a new book, including all the required files as discussed in *Section 7.1.3, “Files”*.

**`create_brand`**
: Creates a new brand, allowing all books to look the same, as discussed in *Section 7.1.6, “Brands”*.

**`package`**
: Packages the files of a book into an RPM ready to distribute.

### 7.1.2. Create a New Document

Use the **`publican create`** command to create a new document including all the required files.

There are a number of options available to append to the **`publican create`**. These are:

**`--help`**
: Prints a list of accepted options for the **`publican create`** command.

**`--name`** ***`Doc_Name`***
: Set the name of the book. Keep in mind that the title must contain no spaces.

**`--lang`** ***`Language_Code`***
: If this is not set, the default is en-US. However, The **`--lang`** option sets the **`xml_lang`** in the **`publican.cfg`** file and creates a directory with this name in the document directory.

**`--version`** ***`version`***
: Set the version number of the product the book is about.

**`--product`** ***`Product_Name`***
: Set the name of the product the book is about. Keep in mind that this must contain no spaces.

**`--brand`** ***`brand`***
: Set the name of a brand to use to keep the look of the documents consistant.

Refer to **`--help`** for more options.

Remember to change into the directory the book is to be created in before running **`publican create`** lest the files and directories be added to the user's home directory.

### 7.1.3. Files

When a book is made, a number of files are created in the book's directory. These files are required for the book to be built properly and should not be deleted. They are, however, required to be edited for links (such as chapters) to work, as well as to contain the correct information regarding authors and titles etc. These files are:

**`publican.cfg`**

This file configures the build options and always includes the parameters *`xml_lang`* (the language the book is in, en-US for example), *`type`* (the type of document, a book or a set, for example), and *`brand`* (the branding the document uses, found here: *Section 7.1.6, “Brands”*. Red Hat, for example.). There are a number of optional parameters but these should be used cautiously as they can cause problems further on in areas like translation. A full list of these advanced parameters can be found in the Publican User Guide. The **`publican.cfg`** file is unlikely to be edited much beyond the initial creation.

**`book_info.xml`**

This file is essentially the template of the book. It contains information such as the title, subtitle, author, publication number, and the book's ID number. It also contains the basic Publican information printed at the beginning of each publication with information on the notes, cautions, and warnings as well as a basic stylistic guide. This file will be edited often as every time a book is updated the publication number needs to be incremented.

**`Author_Group.xml`**

This file is used to store information about the authors and contributors. Once initially set up it is unlikely further editing will be needed unless a change of authorship occurs.

**`Chapter.xml`**

This file is an example of what the actual content will be. It is created as a place holder but unless it is linked in the ***`Doc_Name.xml`*** (below) it will not appear in the actual book. When writing content for the publication, new XML files are created, named appropriately (ch-publican.xml, for example) and linked in **`Doc_Name.xml`**. When the book is built, the content of this file will form the content of the book. This specific file is unlikely to ever be edited but others like it will be edited constantly as content is changed, updated, added to or removed.

***`Doc_Name`*`.xml`**

This file is essentially the contents page of the publication. It contains a list of links to the various chapters a book is to contain. Naturally it won't actually be called 'Doc_Name' but will have whatever the title of the publication is in it's place (Developer_Guide.xml, for example). This will only be edited when new chapters are added, removed or rearranged. This must remain the same as ***`Doc_Name`*`.ent`** or the book will not build.

***`Doc_Name`*`.ent`**

This file contains a list of local entities. By default *YEAR* is set to the current year and *`HOLDER`* has a reminder to place the copyright owner's name there. As with ***`Doc_Name`*`.xml`**, this file will not be called 'Doc_Name' but will be replaced with the title of the document (Developer_Guide.ent, for example). This is only likely to be edited once at the beginning of publication or if the copyright owner changes. This must remain the same as ***`Doc_Name`*`.xml`** or the book will not build.

**`Revision_History.xml`**

When **`publican package`** is run, the first **`XML`** file containing a **`<revhistory>`** tag is used to build the RPM revision history.

#### 7.1.3.1. Adding Media to Documentation

Occasionally it may become necessary to add various media to a document in order to illustrate what is being explained.

##### Images

The **`images`** folder is created by publican in the document's directory. Store any images used in the document here. Then when entering an image into the document, link to the image inside the **`images`** directory (**`./images/image1.png`**, for example).

##### Code Examples

As time passes and technology changes, a project's documentation will need to be updated to reflect differences in code. To make this easier, create individual files for each code example in a preferred editor, then save them in a folder called **`extras`** in the document's directory. Then, when entering the code sample into the document, link to the file and the folder it is in. This way an example used in several places can be updated only once, and rather than search through a document looking for a specific item to change, all the code examples are located in the one place, saving time and effort.

##### Arbitrary Files

On occasion there may be a need for files not attached to the documentation to be bundled with the RPM (video tutorials, for example). Adding these files to a directory called **`files`** in the publication's directory will allow them to be added to the RPM when the book is compiled.

To link to any of these files, use the following XML:

```
<xi:include parse="text" href="extras/fork/fork1.c" xmlns:xi="http://www.w3.org/2001/
XInclude" />
```

### 7.1.4. Building a Document

In the root directory, first run a test build to ensure that all the XML is correct and acceptable by typing **`publican build --formats=`*`chosen_format`*` --langs=`*`chosen_language`***. For example, to build a document in US English and as a single HTML page, run **`publican build --formats=html-single --langs=en-US`**. Provided there are no errors the book will be built into the root directory where the pages can be viewed to see if it has the look required. It is recommended to do this regularly in order to make troubleshooting as easy as possible.

**`--novalid` Command**

When creating a build to test for any bugs in the XML code, sometimes it may be useful to use the **`--novalid`** option. This skips over any cross-references and links that point to files or sections of the document that do not yet exist. Instead they are shown as three question marks (???).

There are a number of different formats a document can be published in. These are:

html
: An ordinary HTML page with links to new pages for new chapters and sections.

html-single
: One long HTML page where the links to new chapters and sections at the top of the page directing the user further down the page, rather than to new page.

html-desktop
: One long HTML page where the links to new chapters and sections are in a panel on the left side of the document, directing the user further down the page, rather than to a new page.

man
: A man page for Linux, UNIX, and other similar operating systems.

pdf
: A PDF file.

test
: The XML is validated without actually creating a file for viewing.

txt
: A single text file.

epub
: An e-book in EPUB format.

eclipse
: An Eclipse help plug-in.

### 7.1.5. Packaging a Publication

Once the documentation is complete and can be built with no errors, run **`publican package --lang=`*`chosen_language`***. This will output SRPM packages to **`tmp/rpm`** in the document's directory, and binary RPM packages will go to **`tmp/rpm/noarch`** in the document's directory. By default, these packages are named ***`productname-title-productnumber-[web]-language-edition-pubsnumber.[build_target]`*`.noarch.`*`file_extension`*** with the information for each of these sections coming from **`publican.cfg`**.

### 7.1.6. Brands

Brands are used in a similar way as templates in that they create a level of consistency in appearance, with aspects like matching logos, images and color schemes, across a range of documents. This can be particularly useful when producing several books for the same application or the same bundle of applications.

In order to create a new brand, it must have a name and a language. Run **`publican create_brand --name=`*`brand`*` --lang=`*`language_code`***. This will create a folder called **`publican-brand`** and place it in the publication's directory. This folder contains the following files:

**`COPYING`**
: Part of an SRPM package and containing the copyright license and details.

**`defaults.cfg`**
: Provides default values for the parameters that can be set in **`publican.cfg`**. Specifications from this file are applied first before applying those in the **`publican.cfg`** file. Therefore, values in the **`publican.cfg`** file over ride those in the **`defaults.cfg`** file. It is best used for aspects that are routinely used throughout the documents but still allows writers to change settings.

**`overrides.cfg`**
: Also provides values for the parameters that can be set in **`publican-brand.spec`**. Specifications from this file are applied last, thus overriding both the **`defaults.cfg`** and the **`publican.cfg`**. It is best used for aspects the writers are not allowed to change.

**`publican.cfg`**
: This file is similar to the **`publican.cfg`** file for a publication in that it configures basic information for the brand, such as version, release number and brand name.

**`publican-brand.spec`**
: This file is used by the RPM Package Manager to package the publication into an RPM.

**`README`**
: Part of an SRPM package and providing a brief description of the package.

A subdirectory, named by the language code, is also placed in this directory and contains the following files:

**`Feedback.xml`**
: This is generated by default to allow readers to leave feedback. Customize it to contain the relevant contact details or a bug reporting process.

**`Legal_Notice.xml:`**
: Contains copyright information. Edit it to change the details of the chosen copyright license.

Two more subdirectories are within this directory. The **`images`** subdirectory contains a number of images of both raster (PNG) and vector (SVG) formats and serve as place holders for various navigation icons that can be changed simply by replacing the images. The **`css`** folder contains **`overrides.css`**, which sets the visual style for the brand, overriding those in **`common.css`**.

In order to package the new brand ready for distribution, use the **`publican package`** command. By default this creates *source RPM packages* (SRPM Packages) but it can also create *binary RPM packages* using the option **`--binary`**. Packages are named ***`publican-brand-version-release.[build_target].`***`[noarch]`***`.file_extension`*** with the required parameters taken from the **`publican.cfg`** file.

**File Extensions**

SRPM packages have the file extension .src.rpm while binary RPM packages have the file extension .rpm

Binary RPM packages include **`[build_target].noarch`** before the file extension, where **`[build_target]`** represents the operating system and version that the package is built for as set by the **`os_ver`** parameter in the **`publican.cfg`** file. The noarch element specifies that the package can be installed on any system, regardless of the system architecture.

## 7.1.7. Building a Website

Publican can also build websites to manage documentation. This is mostly useful when only one person is maintaining the documentation, but where a team is working on the documentation Publican can generate RPM packages of documentation to install on a web server. The website created consists of a homepage, product and version description pages, and the pages for the documentation. In the publication's root directory, Publican creates a configuration file, an SQLite database file, and two subdirectories. There could be many configuration files depending on how many languages the documentation is published in, with a new subdirectory for each language.

Refer to *Section 7.1.8, “Documentation”* for more information.

### 7.1.8. Documentation

Publican has comprehensive **`--man`**, **`--help`** and **`--help_actions`** pages accessed from the terminal.

For information on XML including the different tags available, see the DocBook guide, *DocBook: the definitive guide* by Norman Walsh and Leonard Muellner, found here: *http://www.docbook.org/tdg/en/html/docbook* and specifically *Part II: Reference*[1] for a list of all the tags and brief instructions on how to use them.

There is also the comprehensive Publican User Guide accessed online at *http://jfearn.fedorapeople.org/en-US/index.html* or installed locally with **`yum install publican-doc`**.

## 7.2. Doxygen

Doxygen is a documentation tool that creates reference material both online in HTML and offline in Latex. It does this from a set of documented source files which makes it easy to keep the documentation consistent and correct with the source code.

### 7.2.1. Doxygen Supported Output and Languages

Doxygen has support for output in:

- RTF (MS Word)
- PostScript
- Hyperlinked PDF
- Compressed HTML
- Unix man pages

Doxygen supports the following programming languages:

- C
- C++
- C#
- Objective -C
- IDL
- Java
- VHDL

[1] http://www.docbook.org/tdg/en/html/part2.html

- PHP
- Python
- Fortran
- D

## 7.2.2. Getting Started

Doxygen uses a configuration file to determine its settings, therefore it is paramount that this be created correctly. Each project needs its own configuration file. The most painless way to create the configuration file is with the command **`doxygen -g`** ***`config-file`***. This creates a template configuration file that can be easily edited. The variable *`config-file`* is the name of the configuration file. If it is committed from the command it is simply called Doxyfile by default. Another useful option while creating the configuration file is the use of a minus sign (**`-`**) as the file name. This is useful for scripting as it will cause Doxygen to attempt to read the configuration file from standard input (**`stdin`**).

The configuration file consists of a number of variables and tags, similar to a simple Makefile. For example:

```
TAGNAME = VALUE1 VALUE2...
```

For the most part these can be left alone but should the need arise to edit them refer to the *configuration page*[2] of the Doxygen documentation website for an extensive explanation of all the tags available. There is also a GUI interface called **`doxywizard`**. If this is the preferred method of editing then documentation for this function can be found on the *Doxywizard usage page*[3] of the Doxygen documentation website.

There are eight tags that are useful to become familiar with.

### INPUT

For small projects consisting mainly of C or C++ source and header files there is no need to change things. However, if the project is large and consists of a source directory or tree, then assign the root directory or directories to the INPUT tag.

### FILE_PATTERNS

File patterns (for example, **`*.cpp`** or **`*.h`**) can be added to this tag allowing only files that match one of the patterns to be parsed.

### RECURSIVE

Setting this to **`yes`** will allow recursive parsing of a source tree.

### EXCLUDE and EXCLUDE_PATTERNS

These are used to further fine-tune the files that are parsed by adding file patterns to avoid. For example, to omit all **`test`** directories from a source tree, use **`EXCLUDE_PATTERNS = */test/*`**.

[2] http://www.stack.nl/~dimitri/doxygen/config.html
[3] http://www.stack.nl/~dimitri/doxygen/doxywizard_usage.html

#### EXTRACT_ALL

When this is set to **yes**, doxygen will pretend that everything in the source files is documented to give an idea of how a fully documented project would look. However, warnings regarding undocumented members will not be generated in this mode; set it back to **no** when finished to correct this.

#### SOURCE_BROWSER and INLINE_SOURCES

By setting the **SOURCE_BROWSER** tag to **yes** doxygen will generate a cross-reference to analyze a piece of software's definition in its source files with the documentation existing about it. These sources can also be included in the documentation by setting **INLINE_SOURCES** to **yes**.

## 7.2.3. Running Doxygen

Running **doxygen** ***config-file*** creates **html**, **rtf**, **latex**, **xml**, and / or **man** directories in whichever directory doxygen is started in, containing the documentation for the corresponding filetype.

#### HTML OUTPUT

This documentation can be viewed with a HTML browser that supports cascading style sheets (CSS), as well as DHTML and Javascript for some sections. Point the browser (for example, Mozilla, Safari, Konqueror, or Internet Explorer 6) to the **index.html** in the **html** directory.

#### LaTeX OUTPUT

Doxygen writes a **Makefile** into the **latex** directory in order to make it easy to first compile the Latex documentation. To do this, use a recent teTeX distribution. What is contained in this directory depends on whether the **USE_PDFLATEX** is set to **no**. Where this is true, typing **make** while in the **latex** directory generates **refman.dvi**. This can then be viewed with **xdvi** or converted to **refman.ps** by typing **make ps**. Note that this requires **dvips**.

There are a number of commands that may be useful. The command **make ps_2on1** prints two pages on one physical page. It is also possible to convert to a PDF if a ghostscript interpreter is installed by using the command **make pdf**. Another valid command is **make pdf_2on1**. When doing this set **PDF_HYPERLINKS** and **USE_PDFLATEX** tags to **yes** as this will cause **Makefile** will only contain a target to build **refman.pdf** directly.

#### RTF OUTPUT

This file is designed to import into Microsoft Word by combining the RTF output into a single file: **refman.rtf**. Some information is encoded using fields but this can be shown by selecting all (**CTRL +A** or Edit -> select all) and then right-click and select the **toggle fields** option from the drop down menu.

#### XML OUTPUT

The output into the **xml** directory consists of a number of files, each compound gathered by doxygen, as well as an **index.xml**. An XSLT script, **combine.xslt**, is also created that is used to combine all the XML files into a single file. Along with this, two XML schema files are created, **index.xsd** for the index file, and **compound.xsd** for the compound files, which describe the possible elements, their attributes, and how they are structured.

#### MAN PAGE OUTPUT

The documentation from the **man** directory can be viewed with the **man** program after ensuring the **manpath** has the correct man directory in the man path. Be aware that due to limitations with the man page format, information such as diagrams, cross-references and formulas will be lost.

## 7.2.4. Documenting the Sources

There are three main steps to document the sources.

1. First, ensure that **`EXTRACT_ALL`** is set to **no** so warnings are correctly generated and documentation is built properly. This allows doxygen to create documentation for documented members, files, classes and namespaces.

2. There are two ways this documentation can be created:

   A *special* documentation block

   This comment block, containing additional marking so Doxygen knows it is part of the documentation, is in either C or C++. It consists of a brief description, or a detailed description. Both of these are optional. What is not optional, however, is the *in body* description. This then links together all the comment blocks found in the body of the method or function.

   **Concurrent brief or detailed descriptions**

   While more than one brief or detailed descriptions is allowed, this is not recommended as the order is not specified.

   The following will detail the ways in which a comment block can be marked as a detailed description:

   - C-style comment block, starting with two asterisks (*) in the JavaDoc style.

   ```
   /**
    * ... documentation ...
    */
   ```

   - C-style comment block using the Qt style, consisting of an exclamation mark (!) instead of an extra asterisks.

   ```
   /*!
    * ... documentation ...
    */
   ```

   - The beginning asterisks on the documentation lines can be left out in both cases if that is preferred.

   - A blank beginning and end line in C++ also acceptable, with either three forward slashes or two forward slashes and an exclamation mark.

   ```
   ///
   /// ... documentation
   ///
   ```

   or

```
//!
//! ... documentation ...
//!
```

- Alternatively, in order to make the comment blocks more visible a line of asterisks or forward slashes can be used.

```
/////////////////////////////////////////////////
/// ... documentation ...
/////////////////////////////////////////////////
```

or

```
/********************************************//**
 * ... documentation ...
 ***********************************************/
```

Note that the two forwards slashes at the end of the normal comment block start a special comment block.

There are three ways to add a brief description to documentation.

- To add a brief description use **`\brief`** above one of the comment blocks. This brief section ends at the end of the paragraph and any further paragraphs are the detailed descriptions.

```
/*! \brief brief documentation.
 *         brief documentation.
 *
 *  detailed documentation.
 */
```

- By setting **`JAVADOC_AUTOBRIEF`** to **`yes`**, the brief description will only last until the first dot followed by a space or new line. Consequentially limiting the brief description to a single sentence.

```
/** Brief documentation. Detailed documentation continues * from here.
 */
```

This can also be used with the above mentioned three-slash comment blocks (///).

- The third option is to use a special C++ style comment, ensuring this does not span more than one line.

```
/// Brief documentation.
/** Detailed documentation. */
```

or

```
//! Brief documentation.
//! Detailed documentation //! starts here
```

The blank line in the above example is required to separate the brief description and the detailed description, and **`JAVADOC_AUTOBRIEF`** needs to be set to **no**.

Examples of how a documented piece of C++ code using the Qt style can be found on the *Doxygen documentation website*[4]

It is also possible to have the documentation after members of a file, struct, union, class, or enum. To do this add a < marker in the comment block.\

```
int var; /*!< detailed description after the member */
```

Or in a Qt style as:

```
int var; /**< detailed description after the member */
```

or

```
int var; //!< detailed description after the member
         //!<
```

or

```
int var; ///< detailed description after the member
         ///<
```

For brief descriptions after a member use:

```
int var; //!< brief description after the member
```

or

```
int var; ///< brief description after the member
```

Examples of these and how the HTML is produced can be viewed on the *Doxygen documentation website*[5]

Documentation at other places

While it is preferable to place documentation in front of the code it is documenting, at times it is only possible to put it in a different location, especially if a file is to be documented; after all it is impossible to place the documentation in front of a file. This is best avoided unless it is absolutely necessary as it can lead to some duplication of information.

To do this it is important to have a structural command inside the documentation block. Structural commands start with a backslash (\) or an at-sign (@) for JavaDoc and are followed by one or more parameters.

```
/*! \class Test
    \brief A test class.

    A more detailed description of class.
 */
```

In the above example the command **`\class`** is used. This indicates that the comment block contains documentation for the class 'Test'. Others are:

- **`\struct`**: document a C-struct
- **`\union`**: document a union
- **`\enum`**: document an enumeration type
- **`\fn`**: document a fcuntion
- **`\var`**: document a variable, typedef, or enum value
- **`\def`**: document a #define
- **`\typedef`**: document a type definition
- **`\file`**: document a file
- **`\namespace`**: document a namespace
- **`\package`**: document a Java package
- **`\interface`**: document an IDL interface

3. Next, the contents of a special documentation block is parsed before being written to the HTML and / Latex output directories. This includes:

    1. Special commands are executed.
    2. Any white space and asterisks (*) are removed.
    3. Blank lines are taken as new paragraphs.
    4. Words are linked to their corresponding documentation. Where the word is preceded by a percent sign (%) the percent sign is removed and the word remains.
    5. Where certain patterns are found in the text, links to members are created. Examples of this can be found on the *automatic link generation page*[6] on the Doxygen documentation website.
    6. When the documentation is for Latex, HTML tags are interpreted and converted to Latex equivalents. A list of supported HTML tags can be found on the *HTML commands page*[7] on the Doxygen documentation website.

## 7.2.5. Resources

More information can be found on the Doxygen website.

- *Doxygen homepage*[8]
- *Doxygen introduction*[9]

- *Doxygen documentation*[10]
- *Output formats*[11]

# Appendix A. Revision History

**Revision 0-41** **Fri Feb 04 2011** **Jacquelynn East** *jeast@redhat.com*

BZ#561731: Doxygen content

**Revision 0-40** **Tue Jan 25 2011** **Jacquelynn East** *jeast@redhat.com*

BZ#642397: NSS Stack content

**Revision 0-39** **Tue Dec 21 2010** **Jacquelynn East** *jeast@redhat.com*

BZ#561732: Publican content

**Revision 0-38** **Tue Dec 14 2010** **Jacquelynn East** *jeast@redhat.com*

BZ#662822: Minor typo

**Revision 0-37** **Tue Dec 07 2010** **Jacquelynn East** *jeast@redhat.com*

Minor edits

**Revision 0-36** **Thu Dec 02 2010** **Jacquelynn East** *jeast@redhat.com*

Edited forked execution section

**Revision 0-35** **Thu Dec 02 2010** **Jacquelynn East** *jeast@redhat.com*

Edited documentation section

**Revision 0-34** **Wed Dec 01 2010** **Jacquelynn East** *jeast@redhat.com*

Rewrote ch-debugging.xml

**Revision 0-33** **Mon Nov 29 2010** **Michael Hideo-Smith** *mhideo@redhat.com*

Initialized

**Revision 0-32** **Mon Nov 15 2010** **Don Domingo** *ddomingo@redhat.com*

BZ#653200, removed content possibly inconsistent w/ stuff in App Compat Spec, to be re-added later

**Revision 0-31** **Mon Nov 14 2010** **Don Domingo** *ddomingo@redhat.com*

BZ#653200: adding backup copy of section containing compatibility content

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