Bluespec SystemVerilog User Guide

Revision: 24 November 2008

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1 Getting Started

1.1 Introduction

This document explains the mechanics and logistics of compiling and simulating a Bluespec SystemVerilog (**BSV**) specification. Bluespec SystemVerilog includes the development workstation, a full-featured graphical environment for designing with Bluespec. You can create, edit, compile, simulate, analyze, and debug Bluespec designs from within the workstation or from the command line. You can choose the editors, simulators, and waveform viewers to use along with Bluespec-based analysis tools. The development workstation builds on **Bluetcl**, a collection of Tcl extensions, scripts, and packages providing Bluespec-specific extensions to Tcl. A Bluetcl reference is provided in Appendix A.

Please refer to the BSV Reference Guide, style guide, and tutorials for information on how to design and write specifications in the Bluespec SystemVerilog environment.

1.2 Making sure you're ready to go

The BSV system runs on both 32 bit and 64 bit Linux platforms. To generate simulation executables using the Bluesim backend, your machine will need to have a C++ compiler installed which is compatible with the default compiler used in the release. Recommended configurations can be found in `README.txt` in the install directory, along with installation instructions.

The exact installation details for BSV may vary with different computing environments. The following are examples of setting the Unix environment variables for common shells. Note that the `BLUESPECDIR` variable must be set, while `BLUESPEC_HOME` is a convenience.

```
# Bluespec Environment for csh/tcsh
setenv BLUESPEC_HOME /tools/Bluespec-yyyy.mm
setenv BLUESPECDIR   $BLUESPEC_HOME/lib
setenv PATH          ${PATH}:${BLUESPEC_HOME}/bin

# Bluespec Environment for bash/ksh
export BLUESPEC_HOME=/tools/Bluespec-yyyy.mm
export BLUESPECDIR=$BLUESPEC_HOME/lib
export PATH=$PATH:$BLUESPEC_HOME/bin
```

1.3 Quick Start

Once Bluespec is installed, and the Unix environment variables are set, execute the command `bluespec` to start the development workstation:

```
bluespec
```

This command brings up main workstation window, from which you can perform all Bluespec tasks.

You can also add the name of an existing Bluespec project file as you start the workstation:

```
bluespec    project.bspec
```

where `project.bspec` is the project file name. This starts the workstation and opens the project. The project file contains the saved project preferences and settings.

From the command line, you can invoke the BSV compiler with:

```
bsc    arguments
```

1.4 Components of BSV Release

BSV is released with the following components:

- The BSV language syntax: BSV allows a designer to develop a high-level, behavioral, hardware design utilizing atomic rules, which can be compiled to a Verilog RTL design. For a complete description of the BSV language, refer to the BSV Reference Guide.
- BSV compiler: The compiler takes BSV syntax and generates a hardware description, for either Verilog or Bluesim.
- Library packages: BSV is shipped with a growing set of libraries which provide common and useful programming idioms and hardware structures.
- Verilog modules: Several primitive BSV elements, such as FIFOs and registers, are expressed as Verilog primitives.
- Bluesim: a cycle simulator for BSV designs.
- Bluetcl: a collection of Tcl extensions, scripts, and packages to link into a Bluespec design.

Also included is a complete set of documentation, including tutorials, examples and white papers. The `$BLUESPEC_HOME/doc/BSV` directory contains this user guide, the BSV Reference Guide, a style guide and a known problems and solutions reference (kpns).

- User Guide: This manual which explains how to run the development workstation, the compiler (binary), what flags are available, and how to read the tool output.
- BSV Reference Guide: The BSV Reference Guide is a stand-alone reference that fully describes the subset of SystemVerilog supported by the Bluespec Compiler.
- Style Guide: The style guide is a supplement that describes styles and patterns to help designers express their designs in the Bluespec environment.
- KPNS: The known problems and solutions (kpns) describe some known issues with the compiler and their solutions.

All of the documentation, along with tutorials, papers, and examples can be accessed from the **Help→BSV** option on the main toolbar of the development workstation. There is also available a hyperlinked documentation index, `index.html`, installed in the `$BLUESPEC_HOME` directory.

The workstation consists of a set of windows and browsers providing different views of the design. The particular window used for a task depends on the information you want to see and the stage of the design. The following table summarizes the windows and browsers in the workstation.

Bluespec Workstation Windows		
Stage	Window	Function
All	Main Window	Central control window. Manage projects, set project options, build projects, and monitor status.
	Project Files Window	View, edit and compile files in the project.
Pre-elaboration	Package Window	Load packages into the workstation and browse their contents. Provides a high-level view of the types, interfaces, functions and modules defined in the package.
	Type Browser	Primary means for viewing information about types and interfaces. Displays the full structure hierarchy and all the concrete types derived from resolution of polymorphic types.
Post-elaboration	Module Browser	Displays the design hierarchy and an overview of the contents of each module. Links to external waveform viewers.
	Schedule Analysis Window	View schedule information including warnings, method calls, and conflicts between rules for a module.
	Scheduling Graphs	Graphical view of schedules, conflicts, and dependencies.

Within the development workstation you choose the editors, Verilog simulators, and waveform viewers to use along with Bluespec-specific analysis tools. The following third-party products can be accessed from the workstation but are not provided by Bluespec:

- Editors: gvim and emacs
- Verilog Simulators: modelsim, ncverilog, vcs, vcsi, cver, iverilog, and veriwell
- Waveform Viewers: SpringSoft/Novas (Verdi, Debussy, nWave)
- Graph Software: graphviz

The package graphviz, including the Tcl extensions, must be installed to use the scheduling graphs in the development workstation. The graphviz Tcl extensions (TclDot) must be compatible with Tcl 8.5 to work with the development workstation. You may need to adjust the autopath for the graphvix package in the file `$HOME/.bluetclrc` for your installation.

1.5 License Files

Bluespec utilizes the FLEXnet licensing package. A Bluespec-issued license file must be installed before you can use BSV.

All licensing files are located in the `$BLUESPEC_HOME/util/flexlm` directory. This directory contains FLEXnet licensing executables and Bluespec specific daemons. The subdirectories are specific to machine architecture and operating system. The `README` file lists the daemons currently supported by Bluespec, as well as directions for editing the license file.

Refer to the FLEXnet user guide, `LicensingEndUserGuide.pdf`, for more details on managing and running the FLEXnet licensing package. Bluespec flags relating to licensing are discussed in Section 6.6.

1.6 Utilities

Bluespec provides BSV editing modes for the editors `emacs`, `vim`, and `jedit`. The files are in subdirectories in the `$BLUESPEC_HOME/util` directory. Each directory contains a `README` file with installation instructions for the editor.

The `$BLUESPEC_HOME/util` directory also contains an GNU enscript `.st` file for printing Bluespec SystemVerilog language files. A `README` file in the directory contains instructions for installation and use.

2 Designing with Bluespec

2.1 Components of a BSV Design

A BSV program consists of one or more outermost constructs called packages. All BSV code is assumed to be inside a package. Furthermore, the BSV compiler and other tools assume that there is one package per file, and they use the package name to derive the file name. For example, a package called `Foo` is assumed to be located in the file `Foo.bsv`.

When using the Bluespec development workstation you will also have a project file, (*project-name*`.bspec`), which is a saved collection of options and parameters. Only the development workstation defines project files; you do not have a `.bspec` project file if you use Bluespec completely from the Unix command line.

The design may also include Verilog modules and C functions. Additional files will be generated as a result of the compile, link, and simulation tasks. Some files are only generated for a particular back end (Bluesim or Verilog), others are used by both back ends. The following table lists the different file types and their roles.

File Types in the life of a BSV Design

File Type	Description	Bluesim	Verilog
`.bsv`	BSV source File	√	√
`.bspec`	Workstation project File	√	√
The `.bi` and `.bo` files are intermediate files not viewed by the user			
`.bi`	Text file containing information about the items exported from the package	√	√
`.bo`	Binary file containing code for the package in an intermediate form	√	√
`.ba`	Elaborated module file	√	√
`.v`	Generated Verilog file		√
`.h`	`C++` header files	√	
`.cxx`	Generated `C++` source file	√	
`.o`	Compiled object files	√	
`.so`	Compiled shared object files	√	

2.2 Overview of the BSV process

This section provides a brief overview of the stages of designing with BSV. Later sections contain more detailed explanations of the compilation and linking processes. Refer to Section 6 for a complete

listing of the flags available for guiding the compiler. All flags can be used both from within the development workstation or directly from the Unix command line.

Designing with BSV has three distinct stages. You can use the Bluespec development workstation or the Unix command line throughout each stage of the process. Figure 1 illustrates the following steps in building a BSV design:

1. A designer writes a BSV program, including Verilog and C components as desired.
2. The BSV program is compiled into a Verilog or Bluesim specification. This step is comprised of two distinct stages:
   (a) pre-elaboration - parsing and type checking
   (b) post-elaboration - code generation
3. The compilation output is either linked into a simulation environment or processed by a synthesis tool.

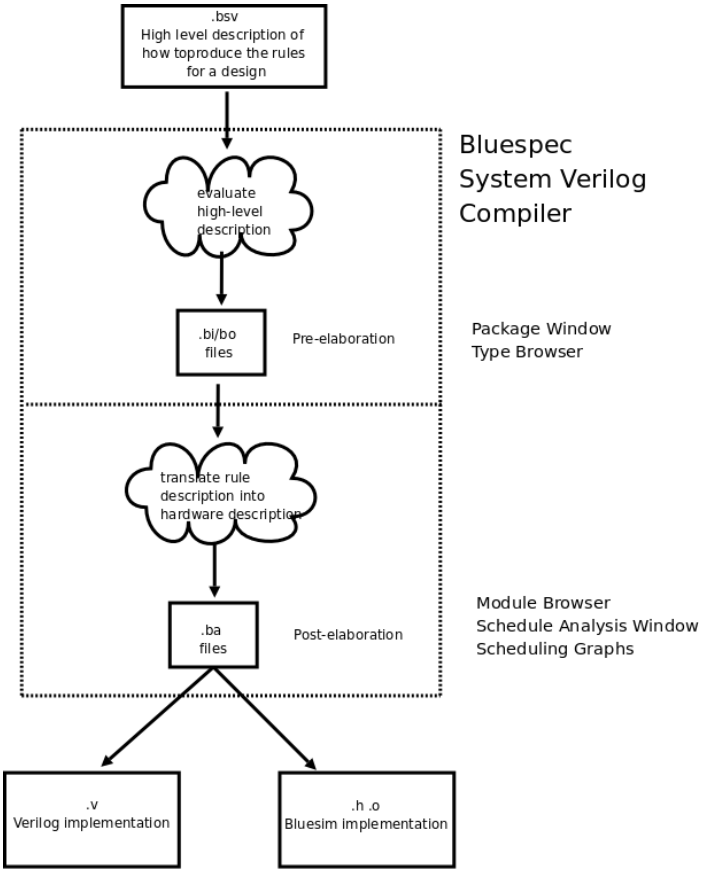

Figure 1: BSV compilation stages

We use the *compilation* stage to refer to the two steps, type checking and code generation, as shown inside the dotted box in Figure 1. As the figure shows, the code generation specification that is output by the BSV compiler is subject to a second run of the compiler to link it into a simulation or synthesis environment. We refer to this as the *linking* stage, even though the same compiler is used to perform the linking. The BSV compiler is required to link Bluesim generated modules. For Verilog, the generated modules can be handled as you would any other Verilog modules; they can

be linked with the Bluespec compiler or you can choose to use the generated Verilog files manually instead.

You perform the above actions: compile, link, and simulate, from the **Build** menu (Section 4) in the development workstation, or directly from a Unix command line.

Once you've generated the Verilog or Bluesim implementation, the development workstation provides the following tools to help analyze your design:

- Interface with an external waveform viewer, with additional Bluespec-provided annotations, including structure and type definitions
- Schedule Analysis viewer providing multiple perspectives of a module's schedule
- Scheduling graphs providing a graphical display of schedules, conflicts, and dependencies among rules and methods.

2.3 Using the Main Window

The **Main** window, as shown in Figure 2, is the control center of the Bluespec development workstation. From this window you can manage projects, set project options, and monitor status while working in the development workstation. The window displays all commands executed in addition to warnings, errors, and messages generated by the BSV compiler and the development workstation.

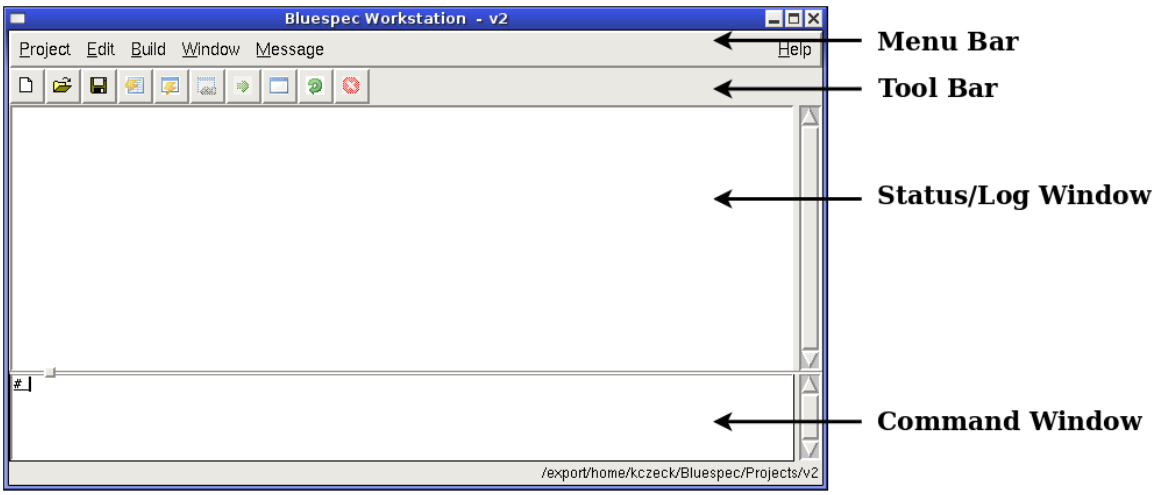

Figure 2: Main window components

The main window consists of the following components:

- The **menu bar**, from which you can launch all actions.
- The **toolbar**, a set of icons implementing shortcuts for frequently used actions. All toolbar icons also appear as menu bar items.
- The **status/log window** displaying commands, project status, messages, warnings, and errors.
- The **command window** where you can enter Tcl commands. All actions available through the development workstation user interface have analogous Tcl commands. (Refer to Appendix A for the full description of supported commands).

2.3.1 Messages

The messages displayed in the status/log window are generated by both the BSV compiler and the development workstation and are color-coded by type as follows:

- red: error or warning from the compiler
- black: a result or status from the compiler (example - compiling)
- dark red: error from the development workstation
- blue: information from the development workstation (example - compile finished)

The red and black messages are the same messages returned by the BSV compiler on the command line while the dark red and blue messages are generated by the development workstation. When the compiler returns errors or warnings (red messages), you can double-click on the message to open the file at the specified line.

2.3.2 Command Line

The workstation command line is a prompt to a Tcl shell. All standard Tcl as well as Bluetcl commands can be executed from this prompt. You can also write your own Tcl commands, procs, and scripts using any combination of Tcl and Bluetcl commands. These must be added to the `.bluetclrc` file before you can execute them from the development workstation command line. Section A.3 for more information on customizing with Bluetcl and the development workstation.

To display the list of available Bluetcl commands, type `Bluetcl::help` at the workstation command line. To display the list of Bluetcl workstation commands, type `WS::help -list`. For more information on Bluetcl commands refer to the Bluetcl reference guide in Appendix A.

3 Managing Projects

The basic unit of work within the Bluespec development workstation is the **Project**. The project file (*projectname*`.bspec`) is a named collection of project settings and options. You manage (open, create, save, close) projects from the **Project** menu. You modify the project options through the **Project→Options** menu, described in Section 3.2.

3.1 Creating a Project

When you create a new project in the Bluespec development workstation, a *projectname*`.bspec` file is created. This file takes the default project settings and tool selections from the file `.bluespec/setup.tcl` in your home directory.

To create a new project, select **New** from the **Project** pull-down menu. The dialog window, shown in Figure 3, will prompt you for the Project directory and the Project Name. When you create a new project the project directory may be empty or may already be populated with `.bsv` files. There may even already be an existing `.bspec` file. *New* indicates that you want to define a new project, creating a new `.bspec` file, even if it uses files in a directory already included in another project.

After you press **OK** to close the **New Project** window, the **Project Options** window will open, so you can set up your project.

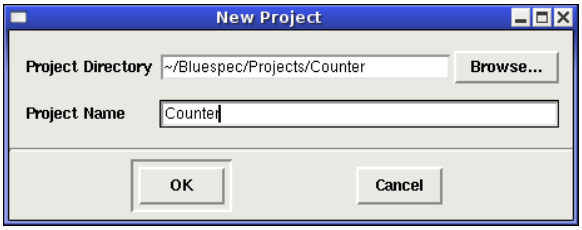

Figure 3: New Project Window

3.2 Setting Project Options

Once a project is created, the user options are modified through the **Project→Options** menu. The **Options** window contains the following tabs:

- Files
- Compile
- Link Simulate
- Editor
- Waveform Viewer

The default values for these options are taken from the file `.bluespec/setup.tcl` in your home directory. Edit this file to set up a default profile for new projects.

All of the fields in the **Options** tabs correspond either to bsc compiler flags or values passed to the bsc compiler, as described in Section 6. For a full listing of all bsc compiler flags, type:

```
exec bsc -help
```

in the workstation command window or:

```
bsc -help
```

from a Unix command prompt.

3.2.1 Files

The **Files** tab, shown in Figure 5, contains the following options:

- Top File and Top Module
- Location of generated and included files
- Search path directories
- Display criteria

The following table shows the fields on the **Files** tab along with the associated compiler flags. When you compile from the workstation, the workstation supplies the appropriate compile flag and value to the `bsc` command.

Field	flag	Task	Description
Top Module	-e	Link	Specifies the top-level module for simulation
.bo/.bi/.ba files	-bdir	Compile	output directory for .bi/.bo/ba files
Bluesim files	-simdir	Compile	output directory for Bluesim intermediate files
Verilog files	-vdir	Compile	output directory for .v files
Info Files	-info-dir	Compile	output directory for cross-info files
Search Path	-p	Compile	directory path for source and intermediate files

Figure 4: Compiler flags by Field

Top File and Top Module The top file contains the top package, which includes the top synthesized module of the hierarchy. The top file imports all other files all other files and modules used in the design. To compile a design, the top file must be specified. To link, the top module must also be specified.

The values for top file and top module are stored in the workstation meta variables `%P` and `%M` respectively. These variables can be used with Makefiles and custom commands for compiling, linking, and simulating in the workstation.

Files Location The 4 files location fields indicate where output files should be placed during build tasks, as well as where the development workstation looks for the generated files. The default is in the directory in which the input files reside. The flags the fields correspond to are shown in the table in Figure 4. See Section 6.5 for more details about these flags.

Search Path The Search Path contains the default locations where the compiler looks for source and intermediate files. These are the directories supplied to the `-p` flag.

When a project is created in the development workstation, the following directories are automatically added to the search path:

- **.**: the project directory
- **%/Prelude**:basic compiled BSV library packages
- **%/Libraries**: additional compiled BSV library packages

% is the {`$BLUESPECDIR`} environment variable, which must be set to `install_directory/lib`.

You can add, remove, and reorder directories in the search path.

Display patterns The display include and exclude patterns are used by the **Project Files** window to determine which files from the project path to display. The files displayed are selected by file extension. By default, all files in the search path with an extension of `.bsv` are displayed in the **Project Files** window. In this tab you can add patterns to include or exclude. For example, you may want to display Verilog files in the search path, in which case you would add `*.v` to the include patterns. Or if you wanted to display all files, except for `.bi` and `.bo` files, you would specify `*.*` for the **Include Patterns** and `*.bi` and `*.bo` for the **Exclude Patterns**.

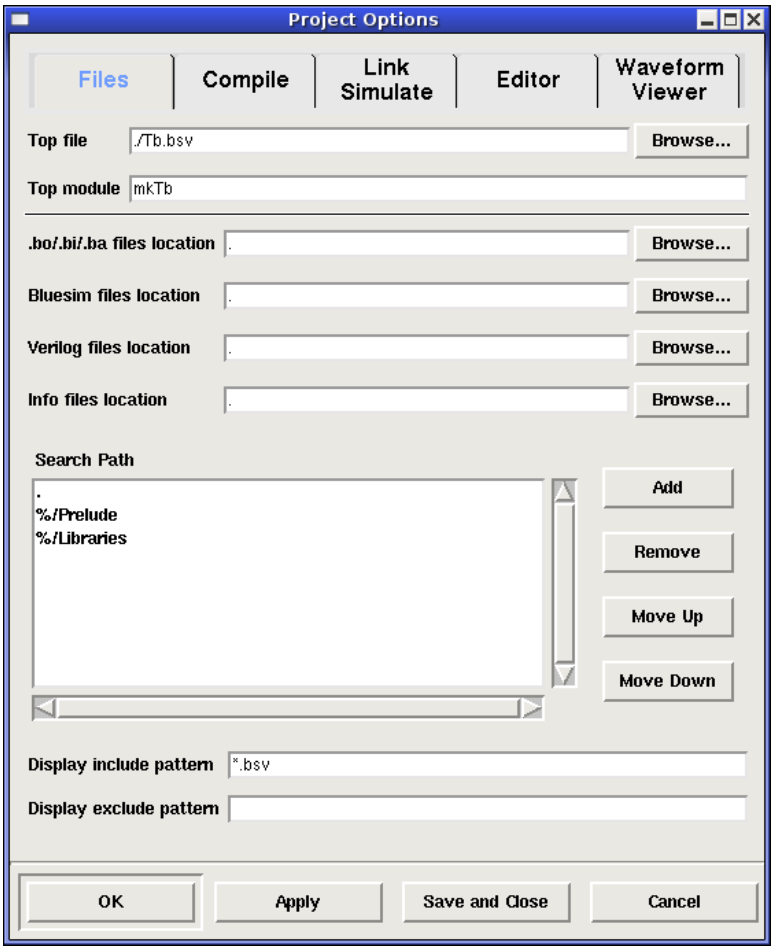

Figure 5: Compiler Options - Files

3.2.2 Compile

The **Compile** tab, shown in Figure 6, is where you indicate whether you are compiling to Bluesim or Verilog. This is the same value as on the **Link/Simulate** tab.

The rest of the tab is divided into two sections; one section contains options for when you are compiling via bsc, the other for when you are using a makefile.

There are two additional fields when the compilation type is `bsc`, compile options and RTS options. Compile options are any of the compile flags as described in Section 6, while the RTS options are the `-Hsize` and `-Ksize` flags, described in Section 6.8. All bsc compiler flags should be typed in exactly as they would be on the command line. When you compile the project, the specified flags will be applied. The following table lists the field on the **Compile** tab and the associated bsc compiler flags.

Field	Compiler flag	Description
Bluesim	-sim	Compiles for Bluesim
Verilog	-verilog	Compiles for Verilog
Compile options	BSC flags	Flags described in Section 6
RTS options	-Hsize -Ksize	Maximum heap size Maximum stack size

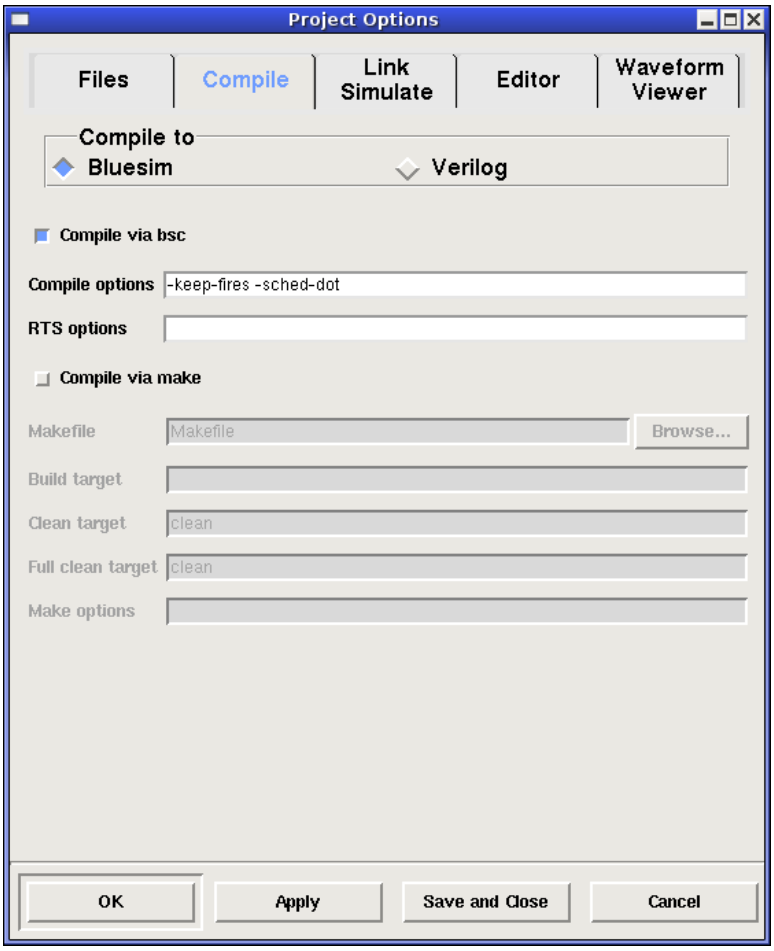

Figure 6: Project Options - Compile

When the compilation type is `make`, you can specify the following fields.

- Makefile: Name of the makefile
- Target
- Clean target
- Full clean target
- Make options: options for make command

You can use Unix environment variables and the workstation meta variables (`%P` for package name and `%M` for module name) in the makefile fields.

3.2.3 Link/Simulate

The link stage is the second call to the compiler which links the generated hardware description into the simulation environment. The target simulation environment (Bluesim or Verilog) is set on the **Compiler** tab, but can also be modified from the **Link/Simulate** tab.

The **Link/Simulate** tab, as shown in Figure 7, is used to specify options for linking and simulation. The three types of link operations available through the development workstation are as follows:

- **Link via bsc**: use the Bluespec compiler `bsc` command
- **Link via make**: use a makefile to control the link
- **Link via custom command**: specify a custom command to link to a different simulation environment

Different fields are required for each link operation type.

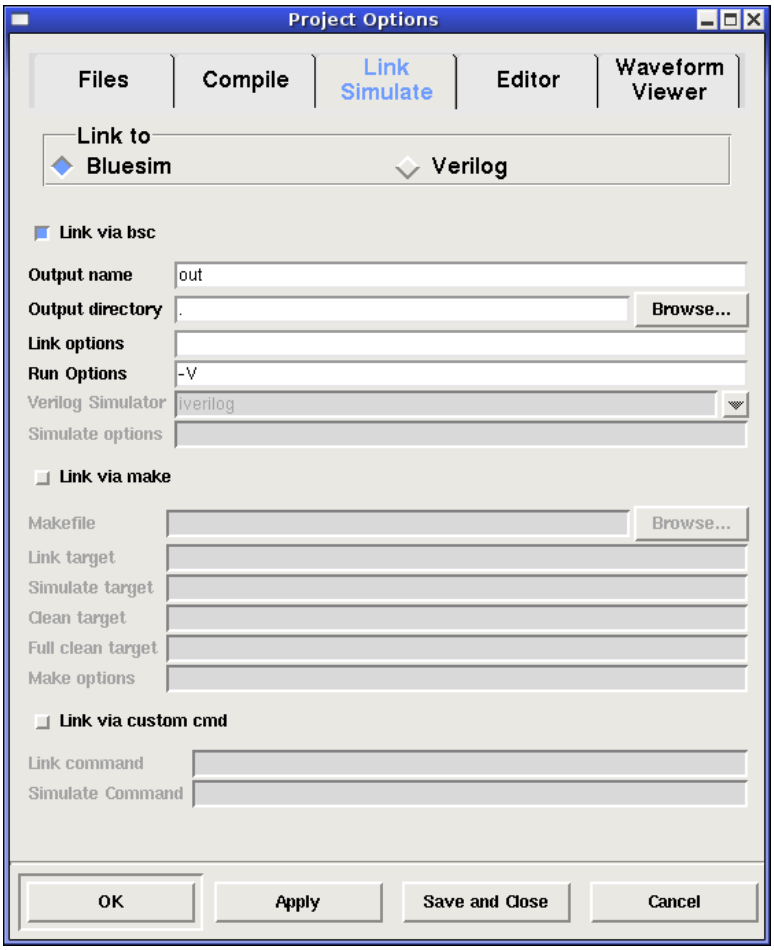

Figure 7: Project Options - Link

Link via bsc Linking via bsc runs the Bluespec compiler again to link the compiled hardware description into the simulation environment, Bluesim or Verilog, as determined by the option set on the top of the tab. On the **Link/Simulate** tab you specify the following fields:

- the name of the output file
- output directory
- linking flags

When left blank, the output directory defaults to the current working directory. The output file name and output directory are passed to the `bsc` command with the `-o` flag. The following table lists the field on the **Link/Simulate** tab and the associated bsc compiler flags.

Field	Compiler flag	Description
Bluesim	-sim	Compiles for Bluesim
Verilog	-verilog	Compiles for Verilog
Output name	-o	Name for the binary being created; the default name is `a.out`
Link options	BSC flags	Flags described in Section 6
Simulator	-vsim	Specifies which Verilog simulator to use

Simulate If compiling to Bluesim, you can specify Bluesim run options, such as the `-V` flag to generate `.vcd` files, in the Simulate options field.

If the **Compile to** target is Verilog, the following simulators can be chosen in the **Link/Simulate** tab:

- `iverilog`
- `modelsim`
- `ncverilog`
- `vcsi`
- `cver`
- `vcs`
- `veriwell`

When using any of the above simulators, use the Simulate options field to specify the simulation plusarg variables `+bscvcd` and `+bsccycle`, as described in Section 4.3.3.

Link via make The fields on the **Link/Simulate** tab for **Link via make** are as follows:

- Makefile
- Target
- Simulation Target
- Clean Target
- Options

You can use Unix environment variables and the workstation meta variables (`%P` for package name and `%M` for module name) in the makefile fields.

Linking via custom command You can use other simulation environments, by supplying the Link command and the command to launch the simulator (Simulate Command). This allows you to link the design with any simulation environment you choose.

You can use Unix environment variables and the workstation meta variables (`%P` for package name and `%M` for module name) in the link and simulate command fields.

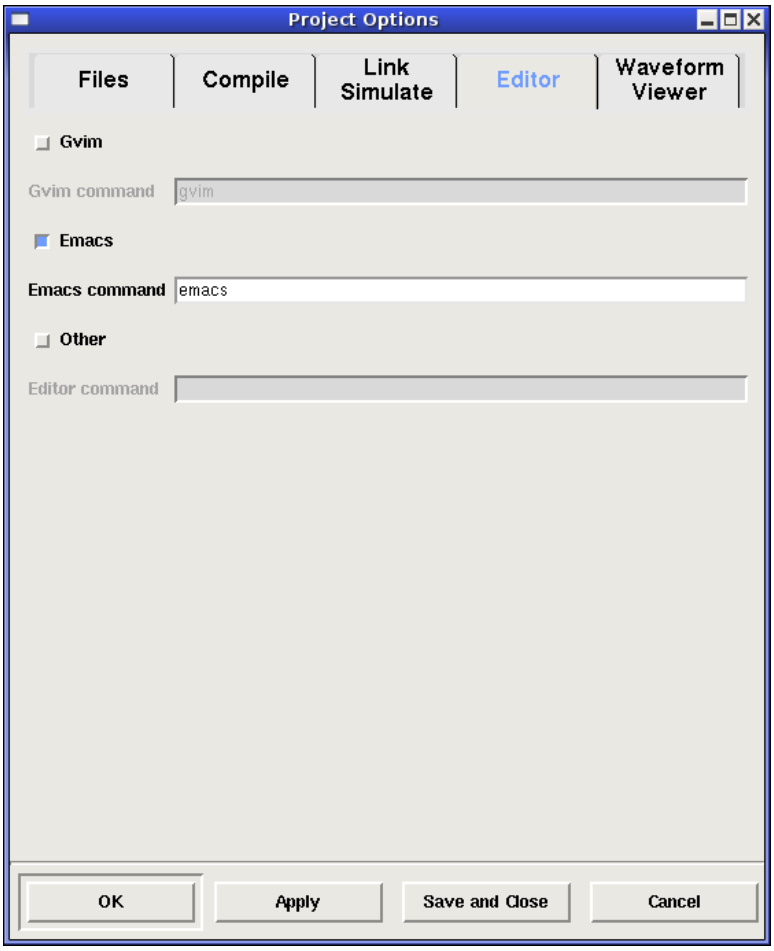

Figure 8: Project Options - Editor

3.2.4 Editor

The editor is selected in the **Editor** tab, as shown in Figure 8. The supported editors are `gvim` and `emacs`. The selected editor is used whenever files are opened within the development workstation. Bluespec editing modes for these editors are provided in the `$BLUESPEC_HOME/util` directory, along with `README` files for their use.

3.2.5 Waveform Viewer

The development workstation can interface to the waveform viewers provided by SpringSoft/Novas (Verdi, Debussy, nWave). The command for selecting and launching the waveform viewer, along with viewer options are set in the **Waveform Viewer** tab, as shown in Figure 9.

3.3 Editing Files with the Project Files Window

The **Project Files** window is the primary window for viewing, editing, and compiling individual design files. When you open a project, the workstation opens the **Project Files** window displaying all the files meeting the criteria specified in the **Files** option tab. By default, all `.bsv` files in the project search path are listed.

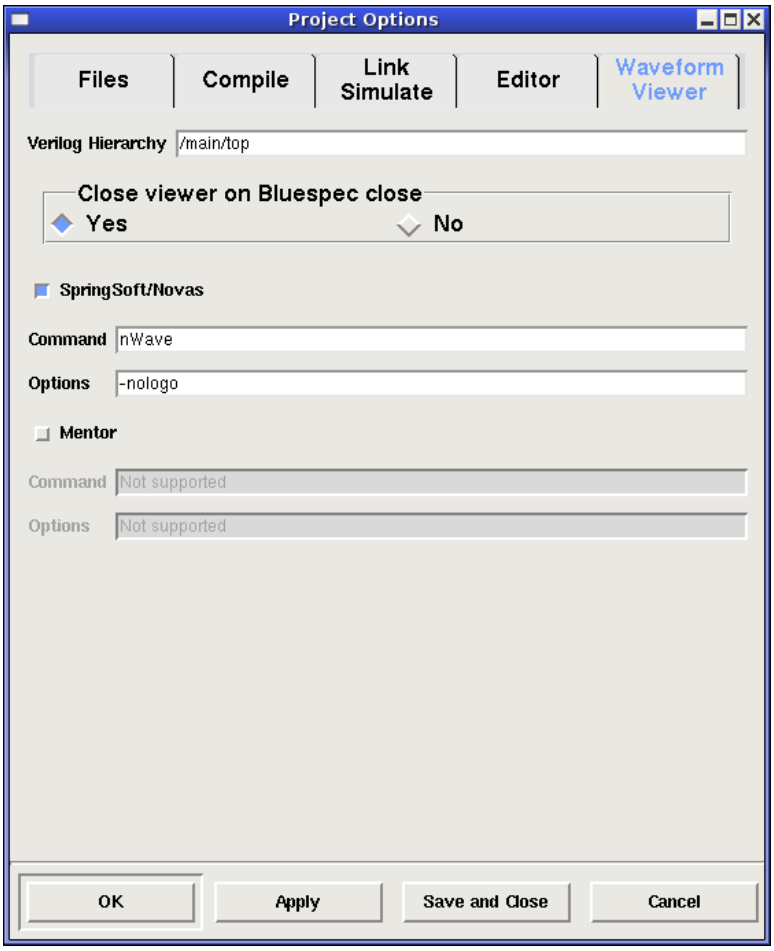

Figure 9: Project Options - Waveform Viewer

To edit a file from the **Project Files** window, you can either double-click on the file, or use the **Edit** pull down menu. The editor set in the **Editor** option tab (gvim or emacs) will be used.

You can also create a new file from the **Project Files** window. Select **Edit→New** and a new file will open in the text editor.

Within this window you can compile individual files or entire projects. Section 4.2 describes the compile process. You can execute an action (edit, refresh, typecheck, compile) on a file by selecting the file and then either using the context menu to select an action or the **File** pull-down menu.

To change the files displayed, editor used, or any of the other project options, use the **Project→Options** menu. See Section 3.2 for a complete description of the Project Options and how to modify them.

3.4 Saving a Project

When you save a project, either through the **Save** or **Save As** options on the **Project** menu, you are saving the options defined on the **Project Options** tabs.

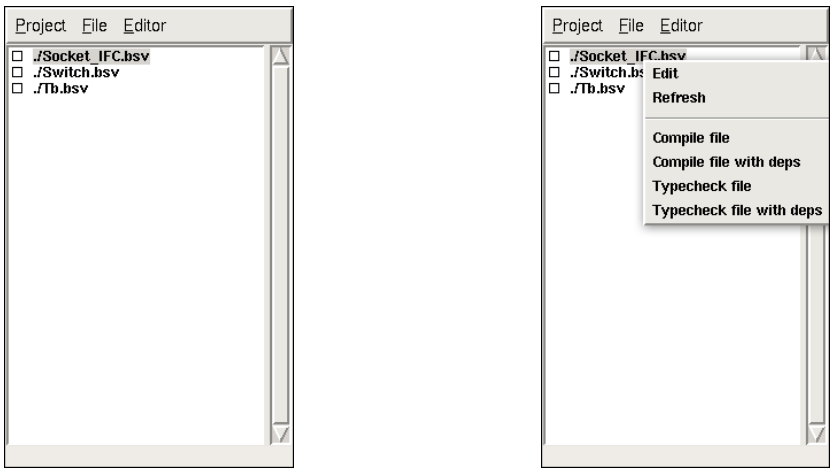

Figure 10: Project Files Window

3.4.1 Saving Window Placement

The development workstation consists of multiple windows, many of which may be open at the same time. You can save the relative placement of the windows by selecting **Save Placement** on the **Project** menu. The placement is only saved through the **Save Placement** option, it is not saved when saving a project.

3.4.2 Backup

Use the **Backup Project** option on the **Project** menu, shown in Figure 11, to create a tar file of your project. You choose which files to include by file type. The default is to include all the `.bsv` files from the search path.

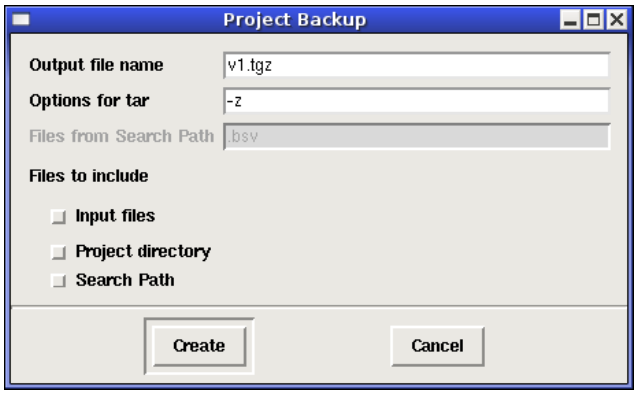

Figure 11: Backup Project Window

3.4.3 Export Makefile

Use the **Export Makefile** option on the **Project** menu to generate a Makefile based on the parameters set in the **Project Options**. The Makefile will include the following targets:

- compile

- link
- simulate
- clean
- full_clean

The development workstation will prompt you for the directory and name of the Makefile. The default is to create a file named `Makefile` in the project directory.

3.5 Maintaining Multiple Settings for a Single Design

A single design may have multiple sets of options or settings. For example, you may want to generate both Bluesim and Verilog targets from a single design, or save both test and production settings, or use different versions of library files. In each case you will have a unique set of options; each set is saved in its own project (`.bspec`) file.

The following example describes some the settings for generating both Bluesim and Verilog from a single set of `.bsv` files.

- Each target is its own project, defined by its own `.bspec` file.
- The same `.bsv` files are used in both projects therefore the project directories are the same.
- In the **Project Options** the following fields are different:
  - In the **Files** tab different output directories are specified for each project so the generated files are not overwritten when the other target is compiled. All output files (Bluesim or Verilog, `.bo/.bi/.ba`, Info files, have different directories specified for each project.
  - In the **Compile** tab, the target is set to Bluesim in one project, and Verilog in the other.
  - Also in the **Compile** tab different compiler flags may be used for each target.
- In the **Link/Simulate** tab, different output directories are specified and well as link compiler options for each project.
- Also in the **Link/Simulate** tab different simulators are specified along with any options for the simulator.

The development workstation project saves each group of settings and options in the `.bspec` file, allowing you to maintain multiple design environments for single set of `.bsv` files.

4 Building a Project

In the development workstation, the **Build** menu contains the following actions:

- Type Check
- Compile
- Link
- Simulate
- Full Rebuild

- Stop
- Clean
- Full Clean

Most of these actions are accessible from the toolbar, as shown in Figure 12.

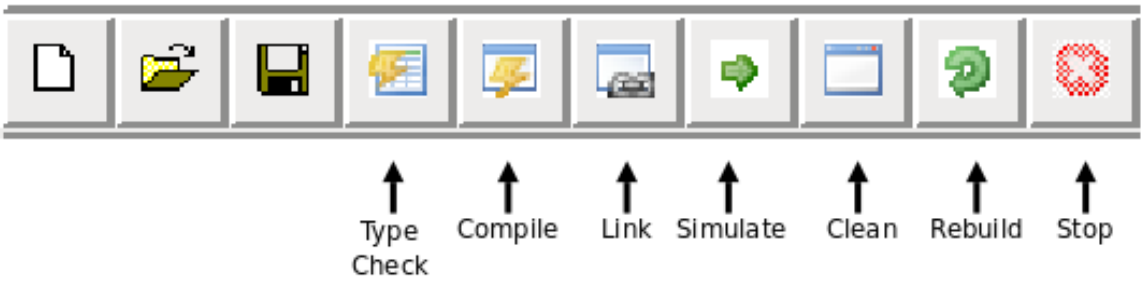

Figure 12: Workstation Toolbar

4.1 Type Check

There are two stages in compilation, type checking and code generation, executed by a single compile command. The simplest compilation of a BSV design is to run only the first stage of the compiler which is the **Type Check** task, generating the `.bi/.bo` files. Once the type check is complete, you have enough module information to use the **Package** and the **Type Browser** windows. When you select the **Type Check** task, the compiler stops before code generation, even if there are no errors in the compile.

A BSV design often imports other packages. The development workstation will automatically type check those packages, if necessary, when you type check a project. When type checking an individual file you must specify **typecheck with deps** if you want to type check the imported packages. Section 4.2.4 discusses importing packages in more detail.

4.2 Compile

The **Compile** task runs the full compilation including both the type checking and code generation stages. The first stage (type check) generates the `.bi/.bo` files. The second stage (code generation) generates an elaborated module file (`.ba`) and, when the target is Verilog, a (`.v`) file. These generated files have the same name as the module they implement, not the name of the package or file they come from.

To run the compiler through to code generation, a module must be marked for synthesis. The recommended method is to use the `synthesize` attribute in the BSV code. You can also specify a top module in the **Project Options→Files** tab, which is the same as passing the top module with the `-g` compiler flag. See Section 4.2.3 and the The BSV Reference Guide for information on synthesizable modules.

A package often imports other packages. The development workstation will automatically recompile imported packages, if necessary, when you compile a project. This is the same as specifying the `-u` option on the command line. When compiling an individual file you must specify **compile with deps** if you want to recompile imported packages. Section 4.2.4 discusses importing packages.

Section 4.2.5 contains a detailed explanation of techniques and considerations when compiling a collection of BSV modules.

The compiler automatically runs through to code generation if no errors are encountered in the type checking stage and a module is marked for synthesis. If errors are encountered in the type check stage, the compiler will halt before generating the `.bi/.bo` files. In this case the **Package** and **Type Browser** windows will not be able to display the project specific packages, as they depend on these intermediate files. If errors are encountered in the second stage, the `.bi/.bo` files will be created but the `.ba` files will not. In this case the **Module Browser**, **Schedule Analysis**, and **Scheduling Graphs** windows will not display project-specific packages. Bluespec-provided library packages can always be viewed in the workstation, since the `.bi/.bo` files for these packages are always available.

To view the scheduling graphs the compiler flag `-sched-dot`, described in Section 6.13, must be specified for compilation, in the **Project Options→Compile** tab. This flag generates the `.dot` files from which the graphs are generated.

4.2.1 Compiling a File

A project usually contains multiple packages and files. To compile a single file, use the **Project Files** window. Select the file to be compiled and then **Compile**, from either the **File** pull-down menu or the context menu.

Compiling with dependencies Compiling with dependencies means that you want to compile any imported files, if necessary, before compiling the selected file. This is equivalent to compiling with the `-u` flag. The compiler compares the time stamps on the `.bi/.bo` files to determine if the imported file has changed since the last compilation. When you compile with dependencies only changed files will be recompiled. You can choose **Compile with Deps** from both the **File** and the context menus.

4.2.2 Compiling a Project

You can compile your complete project from the toolbar, the **Build** menu or the **Project Files** window. Before compiling, the file to be compiled must be specified in the top file field on the **Files** option tab.

The top module is not required for compiling, but is required for linking. If the top module is not specified, the `synthesize` attribute must be used in the BSV code to compile through code generation. Otherwise, the project will only be compiled through elaboration, generating the `.bi/.bo` files, but not the `.ba` file. Specifying the top module in the **Files** tab is equivalent to using the `-g` flag with the name of the module.

When compiling a project from the development workstation the `-u` flag is always used; timestamps on all imported files are checked and files are recompiled as necessary.

4.2.3 Specifying modules for code-generation

A module can be selected for code-generation either in the BSV code or at compile-time. The recommended method is to mark the module for code-generation in the BSV code, using the `synthesize` attribute (see the BSV Reference Guide for more information on attributes). The alternative is at compile-time, to use the **Top Module** field which instructs the compiler to generate code for a particular module. This is the same as using the `-g` flag (Section 6.1) on the Unix command line with the `bsc` command, From the command line, the `-g` flag can be used multiple times within a compile command line to specify multiple modules for code generation.

Whether the generated code will be Bluesim or Verilog depends on which back end has been selected through the **Options** window or with the `-verilog` and `-sim` command line flags.

Not all modules written in BSV are synthesizable. To be synthesized the module must be of type `Module` and not of any other module type that can be defined with `ModuleCollect`. A module is synthesizable if its interface is a type whose methods and subinterfaces are all convertible to wires.

A method is convertible to wires if it meets the following conditions:

- its argument types are convertible to wires which means either
  - it is in the Bits class OR
  - it is a function whose argument and return type are convertible to wires
- its return type is `Action` OR
- its return type is a `value` or `ActionValue` where either
  - the value is convertible to bits (i.e. in the `Bits` class) OR
  - the field is an exported clock or reset.

A module to be synthesized is allowed to have non-interface inputs, such as clocks and resets. Parameters to the module are allowed if they are convertible to bits.

Clock and Reset subinterfaces are convertible to wires.

If none of the modules are marked for synthesis, the compiler will not generate a hardware description (a Verilog `.v` file or a Bluesim `.ba` file).

4.2.4 Importing other packages

To compile a package that imports another package, the BSV compiler needs the `.bi/.bo` files from the imported package. One way to provide these files is to run the compiler on each imported file before running the compiler. Or the development workstation will automatically determine which files are needed and recompile as necessary, when compiling a project. If the `.bi/.bo` files already exist, the compiler will only recompile if the file has changed since the last compilation, as indicated by the imported file having a more recent date than the file being compiled.

For example, to compile a package `Foo` that imports another package `Baz`, the BSV compiler needs to examine the files `Baz.bi` and `Baz.bo`. If `Baz` is in the file `Baz.bsv`, then this file needs to be run through the compiler to produce the necessary `.bi` and `.bo` files before the compiler can be invoked on `Foo.bsv`. If in the workstation you compile a project or compile a file with dependencies, or from the command line use the `-u` flag, the compiler will check to see if `Baz.bi` and `Baz.bo` exist, and if they exist, it will check the compilation date. The compiler will recompile the `Baz` file if necessary.

BSV is shipped with a large set of library files which provide common and useful hardware structures as described in the BSV Reference Guide. If a package being imported is one of these standard library package, such as `FIFO` or `UInt`, then the source code will already have been compiled and the resulting `.bi/.bo` files are available in a library directory with the compiler installation (in the same way that C header and object files are stored in standard *include* and *library* directories). The compiler looks for these files in:

```
%/Prelude/
%/Libraries/
```

If you are importing packages from other directories, the directories must be added to the search path on the **Files** tab on the **Options** menu, as described in Section 3.2.1. The Bluespec `Prelude` and `Libraries` directories are automatically added to the search path when a project is created.

BSV is also shipped with a set of library files for which both the BSV source is provided in the `BSVSource` directory, along with compiled `.bi/.bo` files in the `Libraries` directory. You can use these packages as provided, or edit and customize them to your own specifications. To use a customized version of the these files, include the directory containing the `.bsv` source files in the search path. If the directory containing the `.bsv` files is in any position in the search path, the modified `.bsv` will be used, and not the precompiled `.bi/.bo` files from the `Libraries` directory.

4.2.5 Understanding separate compilation

The BSV compiler has two main stages; first it converts BSV modules into a collection of states and rules, and then it converts the rule-representation into a hardware description.

When compiling a collection of BSV modules, it is up to the user to decide which of these modules should be compiled to hardware separately, and which should be subsumed into the parent module. By default, all hierarchy is flattened into one top-level module in the final hardware description, but the user can specify modules which should stay in the hierarchy and have separate hardware descriptions.

What happens when a module `m1` instantiates another module `m2`? If the sub-module `m2` is provided as a BSV description, that description will need to be compiled into a set of rules and then those rules combined with the rules for `m1` to be converted, by the code-generation stage, into a hardware description.

If `m2` is provided as a hardware description (that is, implemented in a Verilog file or in Bluesim header and object files), then the hardware description for `m1` will contain an instantiation of `m2`. The implementation of `m2` is kept in its own file. For the Verilog back end, this produces a `m1.v` file with a Verilog module `m1` which instantiates `m2` by name and connects to its ports but doesn't contain the implementation of `m2`. Both implementation files, `m1.v` and `m2.v`, must be provided to the simulation or synthesis tools.

Even if `m2` is provided as a BSV description, the user can decide to generate a separate hardware description for the module. This is done by putting the `synthesize` attribute in the BSV description or using the `-g` flag, indicating that the module should be synthesized as a separate module, apart from the instantiating module.

The implementation in a `.bo` reflects whether hardware was generated for a module. If a hardware description was generated for a module, then the implementation in the `.bo` will be merely a pointer to the location of that description (be it `.v` or `.o`). If hardware was not generated for the module, then an entirely BSV representation will be stored in the `.bo` file.

Thus, a single `.bsv` file can be compiled in different ways to produce very different `.bo` files. When the compiler is generating hardware for another BSV file that imports this package, it will need to read in the information in the `.bo` file. How it is compiled depends on the flags used. Therefore, compiling the new file will be affected by how the imported file was compiled earlier! It is important, therefore, to remove these automatically generated files before beginning a new compilation project, especially if a different module hierarchy is desired.

For example, if a user were to generate Verilog for a module `mkFoo` just for testing purposes, the `Foo.bo` would encapsulate into its own description the information that a Verilog module had been generated for module `mkFoo`. If the user then wanted to generate Verilog for a larger design, which included this module, but wanted the larger design to be compiled into one, hierarchy-free Verilog module, then the `.bo` file would have to be deleted so that a new version could be created that only contained the state-and-rules description of the module.

When using the development workstation the **Clean** tasks (Section 4.7) will remove these files. The **Clean** task removes the `.bo` files, while the **Real Clean** task removes the generated Verilog (`.v`) files as well.

4.2.6 Interfacing to foreign modules and functions

Foreign modules and functions can be included as part of a BSV model. A designer can specify that the implementation of a particular BSV module is provided as either a Verilog module or a C function.

Importing Verilog modules

Using the importBVI syntax, a designer can specify that the implementation of a particular BSV module is a Verilog module, as described in the BSV Reference Guide. The module is treated exactly as if it were originally written in BSV and then converted to hardware by the compiler, but instead of the `.v` file being generated by the compiler, it was supplied independently of any BSV code. It may have been written by hand or supplied by a vendor as an IP, etc. The Verilog files for these modules need to be linked in to the simulation. This process is described in Section 4.3.1 for Bluesim simulations and 4.3.3 for Verilog simulations.

Several primitive BSV elements, such as FIFOs and register files, are expressed this way — as Verilog primitives. When simulating or synthesizing a design generated with the Verilog back end, you will need to include the appropriate hardware descriptions for these primitives. Verilog descriptions for Bluespec-provided primitive elements can be found in:

```
${BLUESPECDIR}/Verilog/
```

Note: We attempt to be sure that the Bluesim and Verilog models simulate identically. Simulations using 4-state (X and Z) logic, user supplied Verilog, or other unsupported or nonstandard parts are never guaranteed to match.

Importing C functions

Using the importBDPI syntax, the user can specify that the implementation of a BSV function is provided as a C function. The same implementation can be used when simulating with Bluesim or with Verilog. In Bluesim, the imported functions are called directly. In Verilog, the functions are accessed via the Verilog VPI. The compilation and linking procedures for these backends are described in Sections 4.3.1 for Bluesim simulations, and 4.3.3 for Verilog simulations.

4.3 Link

The compiled hardware description must be linked into a simulation environment before you can simulate the project. The result of the linking stage is a binary which, when executed, simulates a module. The Bluespec compiler is required for linking Bluesim generated modules. You can also use the Bluespec development workstation and compiler to link Verilog files and to run the Verilog simulator specified in the **Link/Simulate** tab of the **Project→Options** window.

To link the project, select **Link** from the toolbar or the **Build** menu.

The simulation environment and location of the implementation files are specified in the **Files** tab of the **Options** menu. The top-level module must also be specified in **Files** tab of the the **Options** menu. You can specify additional link compiler flags, as described in Section 6, in the **Link/Simulate** tab of the **Options** menu.

If you've compiled your design and you still cannot link (the **Link** option is grayed out), the design is not ready to be linked. To determine the cause, you should verify that:

- The compile completed successfully and `.ba` files were generated for the `.bsv` files.
- A **top module** is specified in the **Project Options** menu, **Files** tab.

4.3.1 Linking with Bluesim

For the Bluesim back end, linking means incorporating a set of Bluesim object files that implement BSV modules into a Bluesim simulation environment. See Section 9 for a description of this environment. Bluesim is specified in the **Project Options** window or by using the `-sim` flag. In an installation of the BSV compiler, the files for this simulation environment are stored with the other Bluesim files at: `${BLUESPECDIR}/Bluesim/`.

Specifically, the linking stage generates a C++ object for each elaborated module. For each module, it generates `.h` and `.cxx` files which are compiled to a `.o` file. The C++ compiler to use is determined from the `CXX` environment variable (the default is `c++`) and any flags specified in `CXXFLAGS` or `BSC_CXXFLAGS` are added to the command line. Also generated are the files `schedule.h` and `schedule.cxx`, which implement the global schedule computed by combining the schedules from all the individual modules in the design. Once compiled to `.o` files, these objects are linked with the Bluesim library files to produce an `.so` shared object file. This shared object file can be dynamically loaded into Bluetcl using the `sim load` command. For convenience, a wrapper script is generated along with the `.so` file which automates loading and execution of the simulation model.

If you want to see all the `CAN_FIRE` and `WILL_FIRE` signals, you must specify the `-keep-fires` flag (described in Section 6.12) when compiling and linking with Bluesim.

The typical command to link BSV files to generate Bluesim executables is:

```
bsc -sim -e -keep-fires mkFoo mkFoo.ba
```

Imported Verilog modules in Bluesim

Using the importBVI syntax, a designer can specify that the implementation of a particular BSV module is a Verilog module. The module is treated exactly as if it were originally written in BSV, but was converted to hardware by the compiler.

Bluesim does not currently support importing Verilog modules directly. If a Bluesim back end is used to generate code for this system, then a Bluesim model of the Verilog module needs to be supplied in place of the Verilog description. Such a model would need to be compiled from a BSV description and used conditionally, depending on the backend. The environment functions `genC` and `genVerilog` (as defined in the BSV Reference Guide) can be used to determine when to compile this code.

For example, you might have a design, `mkDUT`, which instantiates a submodule `mkSubMod`, which is a pre-existing Verilog file that you want to use when generating Verilog:

```
module mkDUT (...);
   ...
   SubIFC submod <- mkSubMod;
   ...
endmodule
```

You would write an importBVI statement:

```
import "BVI" module mkSubMod (SubIFC); ... endmodule
```

But this won't work for a Bluesim simulation - Bluesim expects a `.ba` file for `mkSubMod`.

The way to write one BSV file for both Verilog and Bluesim is to change `mkSubMod` to be a wrapper, which conditionally uses a Verilog import or a BSV-written implementation, depending on the backend:

```
module mkSubMod (SubIFC);
   SubIFC _i <- if (genVerilog)
                   mkSubMod_verilog
                else
                   mkSubMod_bluesim;
   return _i;
endmodule

// note that the import has a different name
import "BVI" mkSubMod =
    module mkSubMod_verilog (SubIFC); ... endmodule

// an implementation of mkSubMod in BSV
module mkSubMod_bluesim (SubIfc);
   ...
endmodule
```

This code will import Verilog when compiled to Verilog and it will use the native BSV implementation otherwise (when compiling to Bluesim).

Imported C functions in Bluesim

Using the importBDPI syntax, the user can specify that the implementation of a BSV functions is provided as a C function. When compiling a BSV file containing an import-BDPI statement, an elaboration file (`.ba`) is generated for the import, containing information about the imported function. When linking, the user will specify the elaboration files for all imported functions in addition to the elaboration files for all modules in the design. This provides the Bluespec compiler with information on how to link to the foreign function. In addition to this link information, the user will have to provide access to the foreign function itself, either as a C source file (`.c`), an object file (`.o`), or from a library (`.a`).

When user provided `.c` files are to be compiled and linked, the C compiler to be used is given by the `CC` environment variable and the flags by the `CFLAGS` and `BSC_CFLAGS` variables. The default compiler is `cc`. If the extension on the file is not `.c`, but `.cxx`, `.cpp` or `.cc`, the C++ compiler will be used instead. The default C++ compiler is `c++`, but the compiler invocation can be controlled with the `CXX`, `CXXFLAGS` and `BSC_CXXFLAGS` environment variables.

Arguments can also be passed through `bsc` directly to the C compiler, C++ compiler and linker using the **-Xc**, **-Xc++** and **-Xl** options, respectively.

As an example, let's say that the user has a module `mkDUT` and a testbench `mkTB` in the file `DUT.bsv`. The testbench uses the foreign C function `compute_vector` to compute an input/output pair for testing the design. Let's assume that the source code for this C function is in a file called `vectors.c`. The command-line and compiler output for compiling and linking this system would look as follows:

```
# bsc -u -sim DUT.bsv
checking package dependencies
compiling DUT.bsv
Foreign import file created: compute_vector.ba
code generation for mkDUT starts
Elaborated Bluesim module file created: mkDUT.ba
code generation for mkTB starts
Elaborated Bluesim module file created: mkTB.ba

# bsc -sim -e mkTB -o bsim mkTB.ba mkDUT.ba compute_vector.ba vectors.c
Bluesim object created: mkTB.{h,o}
Bluesim object created: mkDUT.{h,o}
Bluesim object created: schedule.{h,o}
User object created: vectors.o
Simulation shared library created: bsim.so
Simulation executable created: bsim
```

An elaboration file is created for the foreign name of the function, not the BSV name that the function is imported as. In this example, `compute_vector` is the link name, so the elaboration file is called `compute_vector.ba`.

In this example, the user provided a C source file, which BSC has compiled into an object (here, `vectors.o`). If compilation of the C source file needs access to header files in non-default locations, the user may specify the path to the header files with the `-I` flag (see Section 6.5).

If the user has a pre-compiled object file or library, that file can be specified on the link command-line in place of the source file. In that situation, the Bluespec compiler does not need to compile an object file, as follows:

```
# bsc -sim -e mkTB -o bsim mkTB.ba mkDUT.ba compute_vector.ba vectors.o
Bluesim object created: mkTB.{h,o}
Bluesim object created: mkDUT.{h,o}
Bluesim object created: schedule.{h,o}
Simulation shared library created: bsim.so
Simulation executable created: bsim
```

In both situations, the object file is finally linked with the Bluesim design to create a simulation binary. If the foreign function uses any system libraries, or is itself a system function, then the linking stage will need to include those libraries. This is done on the **Project Options→Files** tab in the workstation. From the command line the user can specify libraries to include with the `-l` flag and can specify non-default paths to the libraries with the `-L` flag (see Section 6.5).

4.3.2 Creating a SystemC Model Instead of a Bluesim Executable

Instead of linking `.ba` files into a Bluesim executable, the linking stage can be instructed to generate a SystemC model by replacing the `-sim` flag with the `-systemc` flag, or by putting the `-systemc` flag in the options field of the **Link/Simulate** option tab. All other aspects of the linking stage, including the use of environment variables, the object files created, and linking in external libraries, are identical to the normal Bluesim tool flow.

When using the `-systemc` flag, the object files created to describe the design in C++ are not linked into a Bluesim executable. Instead, some additional files are created to provide a SystemC interface to the compiled model. These additional SystemC files use the name of the top-level module extended with a `_systemc` suffix.

```
# bsc -sim GCD.bsv
Elaborated Bluesim module file created: mkGCD.ba

# bsc -systemc -e mkGCD mkGCD.ba
Bluesim object created: mkGCD.{h,o}
Bluesim object created: schedule.{h,o}
SystemC object created: mkGCD_systemc.{h,o}
```

There are a few additional restrictions on models with which `-systemc` can be used. The top-level interface of the model must not contain any combinational paths through the interface. For the same reason, ActionValue methods and value methods with arguments are not allowed in the top-level interface.

Additionally, value methods in the top-level interface must be free of scheduling constraints that require them to execute after rules in the design. This means that directly registered interfaces are the most suitable boundaries for SystemC model generation.

The SystemC model produced is a clocked, signal-level model. Single-bit ports use the C++ type `bool`, and wider ports use the SystemC type `sc_bv<N>`. Subinterfaces (if any) are flattened into the top-level interface. The names of ports obey the same naming conventions (and the same port-naming attributes) as the Verilog backend (See Section 8.1).

The SystemC model interface is defined in the produced `.h` file, and the implementation of the model is split among the various `.o` files produced. The SystemC model can be instantiated within a larger SystemC design and linked with other SystemC objects to produce a final system executable, or it can be used to cosimulate inside of a suitable Verilog or VHDL simulator.

Division of Functionality Among Files	
File	Purpose
*_systemc.{cxx,h,o}	Top-level SystemC interface
*.{cxx,h,o}	Implementation of modules
schedule.{cxx,o}	Implementation of schedule ordering and constraints

The *.{cxx,h,o} files contain the implementations of the modules, each as its own C++ class. The classes have methods corresponding to the rules and methods in the BSV source for the module and member variables for many logic values used in the implementation of the module.

The *_systemc.{cxx,h,o} files contain the top-level SystemC module for the system. This module is an SC_MODULE with ports for the module clocks and resets as well as for the signals associated with each method in the top-level interface. Its constructor instantiates the implementation modules and initializes the simulation kernel. Its destructor shuts down the simulation kernel and releases the implementation module instances. The SystemC module contains SC_METHODs which are sensitive to the module's clocks and transfer data between the SystemC environment and the implementation classes, translating between SystemC data types and BSV data types.

The schedule.{cxx,o} files contain the scheduling logic which sequences rules and method calls and enforces the scheduling constraints during rule execution. The scheduling functions are called only through the simulation kernel, never directly from user code.

When linking the produced SystemC objects into a larger system, all of the `.o` files produced must be linked in, as well the standard SystemC libraries and Bluesim kernel and primitive libraries.

```
# c++ -I/usr/local/systemc-2.1/include -L/usr/local/systemc-2.1/lib-linux \
      -I$BLUESPECDIR/Bluesim -L$BLUESPECDIR/Bluesim/g++4 \
      -o gcd.exe mkGCD.o mkGCD_systemc.o schedule.o top.cxx TbGCD.cxx \
      -lsystemc -lbskernel -lbsprim -lpthread
```

Note: The proper Bluesim library search directory depends on the compiler ABI version used for linking. The utility program `$BLUESPECDIR/bin/c++family` can be used to determine the correct subdirectory (`g++3`, `g++4`, `g++3_64`, `g++4_64`, etc.).

4.3.3 Linking with Verilog

For the Verilog back end, linking means invoking a Verilog compiler to create a simulator binary file or a script to execute and run the simulation. Section 8 describes the Verilog output in more detail. The Verilog simulator is specified in the **Project Options→Link/Simulate** tab or by using the `-vsim` flag.

The **Link/Simulate** tab and the `-vsim` flag (along with the equivalent `BSC_VERILOG_SIM` environment variable) govern which Verilog simulator is employed; at present, natively supported choices for `-vsim` are `vcs`, `vcsi`, `ncverilog`, `modelsim`, `cver`, `iverilog`, and `veriwell`. If the simulator is not specified `bsc` will attempt to detect one of the above simulators and use it.

When the argument to `-vsim` contains the slash character (`/`), then the argument is interpreted as the name of a script to run to create the simulator binary. Indeed, the predefined simulator names listed above refer to scripts delivered with the Bluespec distribution; thus, `-vsim vcs` is equivalent to `-vsim $BLUESPECDIR/bin/bsc_build_vsim_vcs`. The simulator scripts distributed with Bluespec are good starting points should the need to use an unsupported simulator arise.

In some cases, you may want to append additional flags to the Verilog simulator command that is used to generate the simulator executable. The `BSC_VSIM_FLAGS` environment variable is used for this purpose. Thus, for instance, setting its value to `-y verilog_libs` will add the directory `verilog_libs` to the simulator search path (for simulators such as `iverilog` and `vcs`).

The generated Verilog can be put into a larger Verilog design, or run through any existing Verilog tools. Bluespec also provides a convenient way to link the generated Verilog into a simulation using a top-level module (`main.v`) to provide a clock for the design. The Bluespec-provided `main.v` module instantiates the top module and toggles the clock every five simulation time units. The default `main.v` is the default used when running a Verilog simulation in the development workstation. From the command line the following command generates a simulation binary `mkFoo.exe`:

```
bsc -verilog -e mkFoo -o mkFoo.exe mkFoo.v
```

With this command the top level Verilog module `main` is taken from `main.v`. `main.v` provides a clock and a reset, and instantiates `mkFoo`, which should provide an `Empty` interface. An executable file, `mkFoo.exe` is created.

The default `main.v` allows two plusarg arguments to be used during simulation: `+bscvcd` and `+bsccycle`. The argument `+bscvcd` generates a value change dump file (VCD); `+bsccycle` prints a message each clock cycle. These are specified in the Simulate options field of the **Link/Simulate** tab on the **Options** menu. Or from the command line:

```
./mkFoo.exe +bscvcd +bsccycle
```

Imported Verilog functions in Verilog

When Verilog code is generated for a system that uses a Verilog-defined module, the generated code contains an instantiation of this Verilog module with the assumption that the `.v` file containing its definition is available somewhere. This file is needed if the full system is to be simulated or synthesized (the linking stage). Note that VHDL modules can be used instead of Verilog modules if your simulator supports mixed language simulation.

When simulating or synthesizing a design generated with the Verilog back end, you need to include the Verilog descriptions for these primitives. The Verilog descriptions for Bluespec-provided primitive elements (FIFOs, registers, etc.) can be found in:

```
${BLUESPECDIR}/Verilog/
```

Imported C functions in Verilog

In a BSV design compiled to Verilog, foreign functions are simulated using the Verilog Procedural Interface (VPI). The generated Verilog calls a user-defined system task anywhere the imported function is needed. The system task is implemented as a C function which is a wrapper around the user's imported C function, to handle the VPI protocols.

The usual Verilog flow is that BSV modules are generated to Verilog files, which are linked together into a simulation binary. The user has the option of doing the linking manually or by calling BSC. Imported functions can be linked in either case.

As with the Bluesim flow, when compiling a BSV file containing an import-BDPI statement, an elaboration file is generated for the import, containing information about the imported function. However, with Verilog generation, the VPI wrapper function is also generated. For example, using the scenario from the previous section but compiling to Verilog, the user would see the following:

```
# bsc -u -verilog DUT.bsv
compiling DUT.bsv
Foreign import file created: compute_vector.ba
VPI wrapper files created: vpi_wrapper_compute_vector.{c,h}
code generation for mkDUT starts
Verilog file created: mkDUT.v
code generation for mkTB starts
Verlog file created: mkTB.v
```

The compilation of the import-BDPI statement has not only generated an elaboration file for the imput but has also generated the file `vpi_wrapper_compute_vector.c` (and associated header file). This file contains both the wrapper function `compute_vector_calltf()` as well as the registering function for the wrapper, `compute_vector_vpi_register()`. The registering function is what tells the Verilog simulator about the user-defined system task. Included in the comment at the top of the file is information needed for linking manually.

When linking manually, this C file typically needs to be compiled to an object file (`.o` or `.so`) and provided on the command line to the Verilog linker, along with the object files for the user's function (in this example, `vectors.c`). The Verilog linker also needs to be told about the registering function. For some Verilog simulators, the registering function is named on the command-line. For other simulators, a C object file must be created containing the array `vpi_startup_array` with pointers to all of the registering functions (to be executed on start-up of the simulation). An example of this start-up array is given in the comment at the top of the generated wrapper C files. Some simulators require a table for imported system functions (as opposed to system tasks). The table is provided in a file with `.tab` or `.sft` extension. The text to be put in these files is also given in the comment at the top of the wrapper file. The text also appears later in the file with the tag "`tab:`" or "`sft:`" prepended. A search for the appropriate tag (with a tool like `grep`) will extract the necessary lines to create the table file.

Linking via BSC does all of this automatically:

```
# bsc -verilog -e mkTB -o vsim mkTB.v mkDUT.v compute_vector.ba vectors.c
VPI registration array file created: vpi_startup_array.c
User object created: vectors.o
VPI object created: vpi_wrapper_compute_vector.o
VPI object created: vpi_startup_array.o
Verilog binary file created: vsim
```

To perform linking via BSC, the user provides on the command-line not only the Verilog files for the design but also the foreign import files (`.ba`) for each imported function and the C source or object files implementing the foreign functions. As shown in the above example, the linking process will create the file `vpi_startup_array.c`, containing the registration array, and will compile it to an object file. The linking process will then pass all of the VPI files along to the Verilog simulation build script (see Section 4.3.3) which will create any necessary table files and invoke the Verilog simulator with the proper command-line syntax for using VPI.

If the foreign function uses any system libraries, or is itself a system function, then the Verilog linking will need to include those libraries. As with the Bluesim flow, the user can specify to BSC the libraries to include with the `-l` flag and can specify non-default paths to the libraries with the `-L` flag (see Section 6.5).

4.4 Simulate

The **Simulate** task simulates the output generated by the linking task, using the simulator and options specified in the **Options** window. The results are displayed in the status/log window.

To view waveforms, you must generate a waveform dump file (`.vcd`) during simulation. This can be done with the `-V` flag for a Bluesim simulation, or for Verilog simulators using the Bluespec-provided `main.v` file, specifying the `+bscvcd` flag during simulation. Simulation flags are entered in the options field of the **Project Options→Link/Simulate** window, as described in Section 3.2.3.

4.5 Full Rebuild

The **Full Rebuild** task combines the following build steps:

1. Full Clean
2. Compile
3. Link
4. Simulate

4.6 Stop

To stop a build process before completion, use the **Stop** option. It stops a compile, link or simulation by sending a kill to the process and any subprocesses. You can also **Stop** during a **Full Rebuild** or to end a simulation which doesn't complete.

4.7 Clean and Full Clean

There are two options to clean your files: **Clean** and **Full Clean**. **Clean** removes the intermediate files generated during compilation: the `.bi/.bo`, `.ba`, and `.o` files. Before recompiling, you may want to remove the intermediate files to force the compiler to recompile all imported packages. **Full Clean** removes all generated result files - `.sched`, `.v`, `.so`, and `.exe` - in addition to the intermediate compilation files.

If you are compiling via a makefile, then both **Clean** and **Full Clean** will instead execute the appropriate target in the makefile, as specified in the **Compile** and **Link/Simulate** tabs of the **Project→Options** window.

5 Analyzing the Project

The design browsers within the development workstation provide different views of the design. The following table summarizes the windows and browsers in the development workstation.

Bluespec Development Workstation Windows		
Window	Function	Required Files
Main Window	Central control window. Manage projects, set project options, build projects, and monitor status.	`.bspec`
Project Files Window	View, edit and compile files in the project.	`.bsv`
Package Window	Pre-elaboration viewer for the design. Load packages into the development workstation and browse their contents. Provides a high-level view of the types, interfaces, functions and modules defined in the package.	`.bi/.bo`
Type Browser	Primary means for viewing information about types and interfaces. Displays the full structure hierarchy and all the concrete types derived from resolution of polymorphic types.	`.bi/.bo`
Module Browser	Post-elaboration module viewer, including rules and method calls. Displays the design hierarchy and an overview of the contents of each module. Provides an interface to the waveform viewer.	`.ba`
Schedule Analysis Window	View schedule information including warnings, method calls, and conflicts between rules for a module.	`.ba`
Scheduling Graphs	Graphical view of schedules, conflicts, and dependencies.	`.ba` `.dot`

5.1 Viewing Packages with the Package Window

The **Package** window provides a high-level view of the contents of the project, sorted by package. You can perform the following tasks in the **Package** window:

- View a complete list of packages.
- View the import hierarchy by selected package.
- View the contents of each package.

- View basic information on types, interfaces, functions, and modules.
- Navigate to the **Type Browser** for a particular type.
- Open and edit source code.
- Search types and functions for a string or a regular expression.

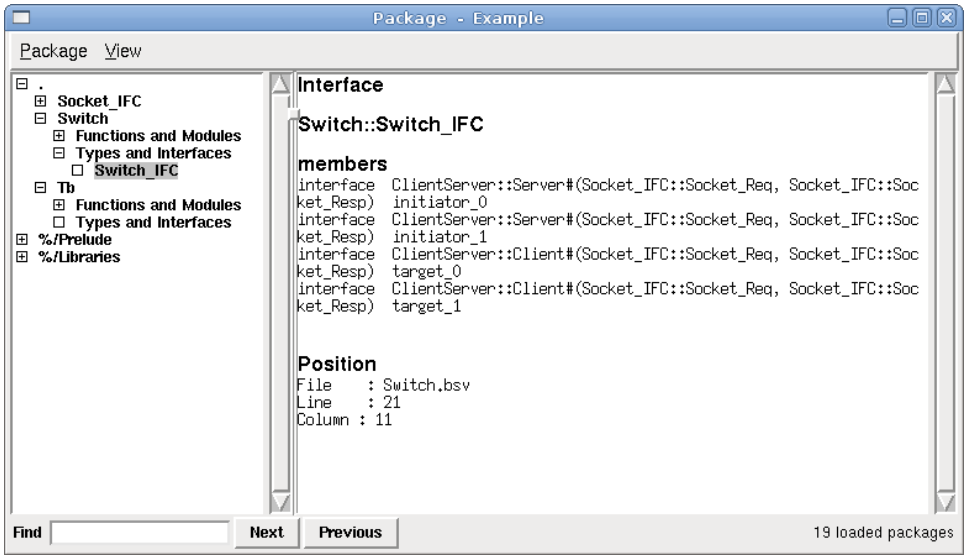

Figure 13: Package Window

The **Package** window has two panes. The left pane lists packages by directory, the right pane displays the definition of the selected object. To view a package or any object within it, the package must first be loaded (**Package→Load**) into the development workstation. When you load a package, all packages imported by that package are loaded along with it. Therefore, if you load the top package (**Package→Load Top Package**), all packages used by the project will be loaded. The `Prelude` package is automatically imported in every BSV design and will be loaded along with the first package you load. If you don't see a specific package in the left pane, has not been loaded yet.

The **Package** window will only display packages which have `.bi/.bo` files. Since library files (Bluespec-provided files in the %/Prelude and %/Libraries directories) are precompiled, these are always available, even before compiling the project. Project specific files have to be compiled through type checking (`.bi/.bo` files) to view them in the **Package** window.

Click on the icon next to the package name to expand and view the types, interfaces, functions and modules defined in the package. Click on the name of any item in the package to view its definition in the right pane. The **Package** window can be helpful in displaying the functions defined in a package, especially for packages such as `Vector` which contain many functions.

The amount of information displayed for each item type is limited and detailed information is only available for leaf items - types, interfaces and modules. For more details on types and interfaces, including full structure hierarchies and the resolution of polymorphic types, select a type and navigate (**View→Send to Type**) to the **Type Browser**.

For any object in which the `.bsv` file is in the path, you can view (and modify) the source code directly by selecting **View Source**. You cannot view (or edit) the source code for any object defined in the Prelude or Bluespec Foundation libraries, since only compiled versions are provided for these packages.

The action **Package→Import hierachy** uses the selected package as the top of the hierarchy and displays a hierarchical list of imported packages. To view the entire hierarchy of the project, select the top package and then view the **Import hierarchy**.

To search for a string anywhere in a package, use the **Package→Search** function, either from the **Package** menu or at the bottom of the **Package** window (**Find**). With this function you can search all loaded packages for a name or regular expression. This can help you find a type or function, as well as its arguments.

5.2 Viewing Types with the Type Browser

The **Type Browser** is the primary means for viewing information about types and interfaces. The **Type Browser** expands the first-level type definition available in the **Package** window, displaying the full structure hierarchy and the concrete types derived from the resolutions of polymorphic types. For interfaces, the **Type Browser** displays the methods and attributes defined on the interface. The **Type Browser** can be used to view size, width, and hierarchy information for types.

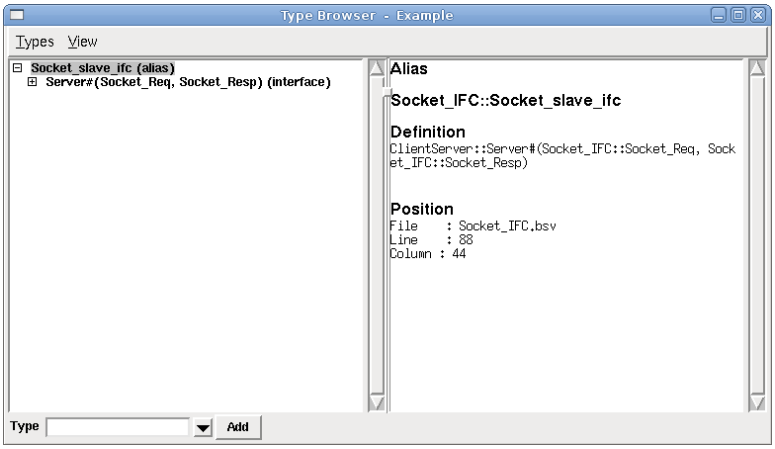

Figure 14: Type Browser

Before using the **Type Browser** you must first **Load** a package into the development workstation from the **Package** Window or the **Type Browser**. The following methods load a type into the workstation:

- **Send to Type** from the **Package** Window
- **Type→Add** from **Type** pull down menu
- **Type** entry field at the bottom of the browser.

When using **Type→Add**, you can select a type or enter a type (existing or new), in the entry window. You can also add a new type in the entry field at the bottom of the browser. The arrow provides a history function of all types you've entered in the field.

As in the **Package** window, you can view the source code for any type that you can modify, that is the source (`.bsv`) file is in the search path of the project. You cannot view (or edit) the source code for any object defined in the Prelude or Bluespec Foundation libraries, since only compiled versions are provided for these packages. Bluespec does provide some source libraries in the `BSVSource` directory.

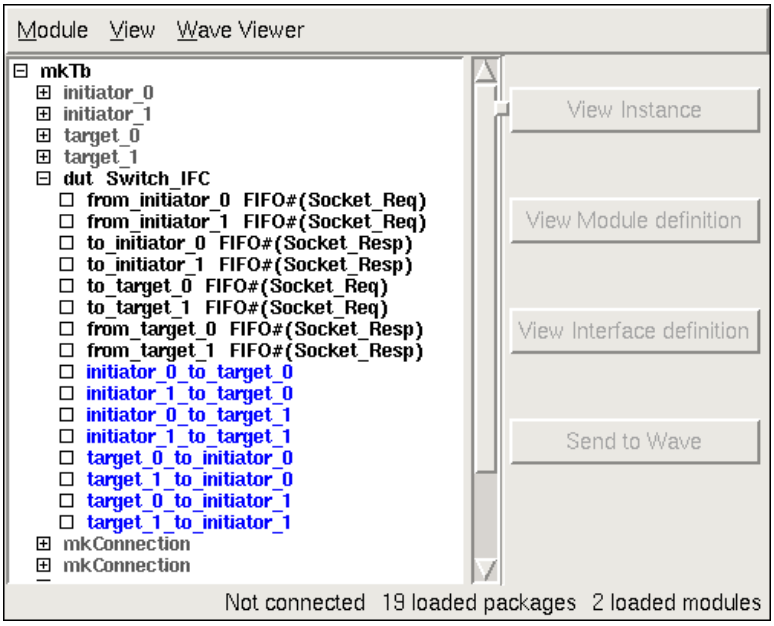

Figure 15: Module Browser

5.3 Viewing Waveforms with the Module Browser

The **Module Browser**, shown in Figure 15, provides a post-elaboration view of the instantiated module hierarchy. It also provides a link to an external waveform viewer, using the instantiated module hierarchy and type definitions along with waveform dump files to display additional Bluespec type data along with the waveforms.

The development workstation currently interfaces to separately installed third-party waveform viewers supplied by SpringSoft/Novas, appending type data and full type hierarchies to the bit types typically displayed in waveform viewers. When viewing designs through the development workation you can see signals with full type definition, including structures, structure hierarchies, and enumerated types, as shown in Figure 16.

In order to view waveforms, you must have generated a waveform dump file during simulation, as described in Section 4.4. Only synthesized modules are simulated and can be viewed with a waveform viewer.

Follow these steps to view waveforms from the development workstation:

1. Load the top module (**Module→Load Top Module**) to obtain the module hierarchy from the `.bi/.bo` files.
2. Start or Attach the waveform viewer (**Wave Viewer→Start** or **Wave Viewer→Attach**) to initiate communication between the workstation and the waveform viewer.
3. Load the waveform dump file either from the workstation (**Wave Viewer→Load Dump File**) or from within the waveform viewer itself.
4. Select a module or signals and send (**Send to Wave**) to the viewer.

You can modify the waveform viewer settings directly from **WaveViewer→Options**. See Section 3.2.5 for more information about waveform viewer options.

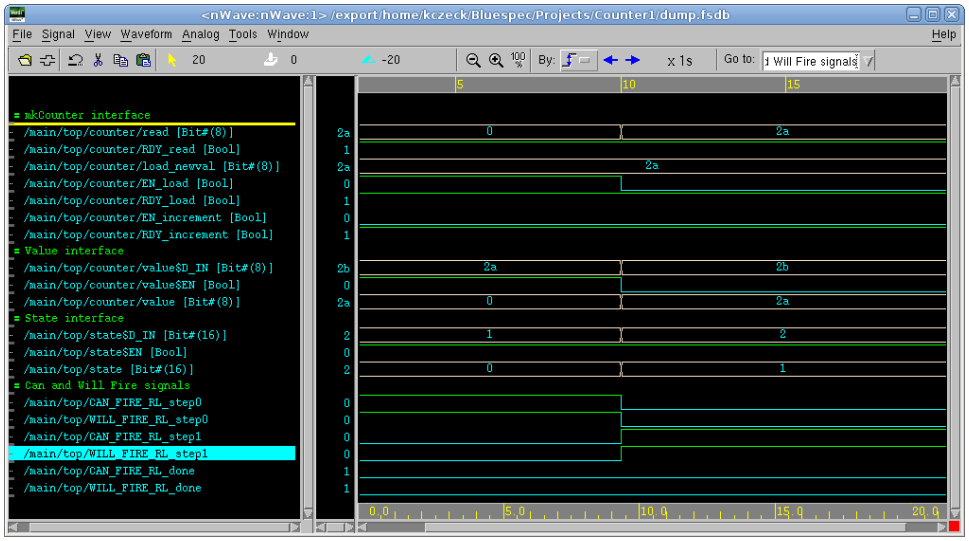

Figure 16: Sample Waveforms

5.4 Analyzing the Schedule

The **Schedule Analysis** window is for viewing and querying information about the schedule for a single module. The following four tabs each display a different perspective of the schedule:

- Warnings: displays warnings generated by the compiler about scheduling decisions.
- Rule Order: displays which methods are called by a selected rule.
- Method Call: displays which rules use a selected method.
- Rule Relations: displays conflicts between two selected rules.

A module has to be loaded in the workstation before you can view its scheduling information. If the module has not already been loaded through another window, you can load it from the **Module→Load** menu. The workstation will read the bluespec generated files and load in the module and all dependent modules. You can load the entire project by loading the top module (**Module→Load Top Module**).

The **Schedule Analysis** window shows the schedule for a specific module. Since multiple modules may be loaded at the same time, use the **Module→Set Module** option to chose the module for analysis. The title bar of **Schedule Analysis** window displays the name of the active module.

5.4.1 Warnings

The **Warnings** tab displays two types of warnings: static execution warnings and urgency warnings, as shown in Figure 17.

When three or more rules cannot execute in the same cycle, even though any two of the rules can, the compiler will introduce a conflict between two of the rules and generate a static execution warning message.

When two rules conflict and the user has not specified the urgency of the rules, the compiler generates an urgency warning, indicating that it has made an arbitrary choice as to which rule is more urgent.

More detail about these messages can be found in the BSV Users Guide.

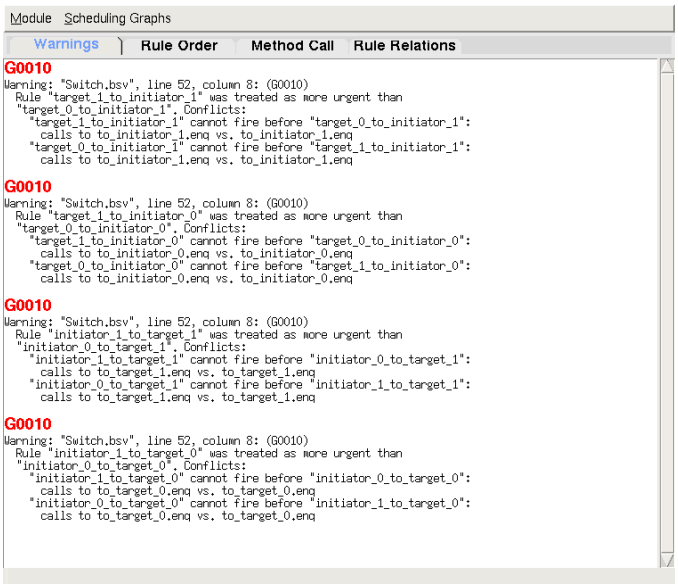

Figure 17: Schedule Browser - Warnings Tab

5.4.2 Rule Order

The **Rule Order** tab, shown in Figure 18, displays the details of the rules in a module. The module is divided in two panes; the left listing the rules and methods in the module in execution order, the right displaying information about the selected rule or method. When you select a rule from the left pane, the right pane displays the following details:

- Predicate or condition to fire
- Methods called
- Blocking rules - scheduling conflicts which block execution
- Position in the source file

The predicate is the condition for the rule to fire. If the predicate is `True`, the rule fires every cycle. If it is `False`, it never fires.

To view the source for a rule, select **Module→View Source**. It will open an editor window with the source file in which the rule is defined, at the position indicated on the right pane. If no position is listed, the rule or method is part of the BSV library and cannot be modified and the source file cannot be opened.

5.4.3 Method Call

The **Method Call** tab displays all instances of method calls in the module. It is divided into two panes, as shown in Figure 19. The left pane lists the method calls by module instance. The right pane displays information on the object selected in the left pane.

When first opened, the left pane displays a list of module instances. To display the method calls for each instance, click on the expand icon next to the method.

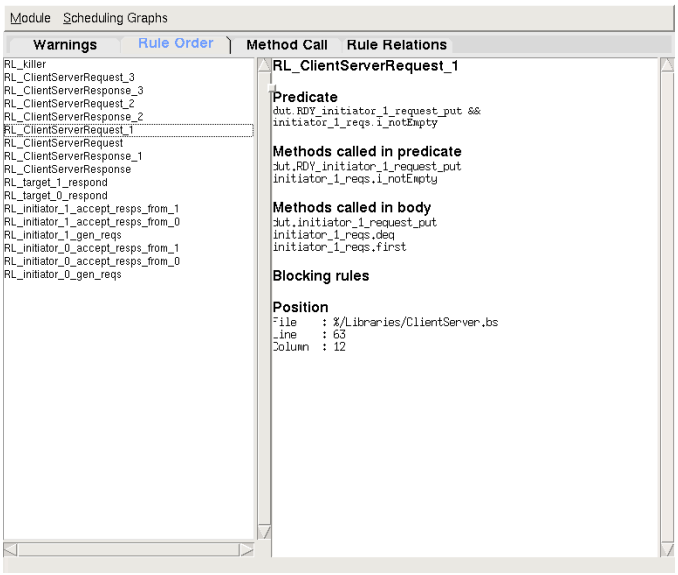

Figure 18: Schedule Browser - Rule Order Tab

When an instance is selected, the right pane displays more detail about the module instance: the module, the input and output ports and, if available, the position in the source code. To view the source for an instance, select **Module→View Source**. It will open an editor window with the source file in which the instance is defined, at the position indicated on the right pane. If no position is listed, the module is part of the BSV library and cannot be modified, and therefore, the source file cannot be opened.

When a method is selected, the rules and submodules which use the method are displayed in the right pane.

5.4.4 Rule Relations

The **Rule Relations** tab describes conflicts between any two rules, as shown in Figure 20. This is the same information generated from the `-show-rule-rel` compile flag, Section 6.13.

If the compiler can determine that the predicates of the two rules are mutually exclusive (disjoint), then the two rules can never be ready in the same cycle and therefore conflicts are irrelevant and will not be computed.

For each conflict found, the conflicting calls are listed. The types of conflicts are as follows:

- <>: The rules use a pair of methods which are not conflict free. The rules either cannot be executed in the same clock cycle or they can but one must be sequenced first. The compiler lists the methods used in each rule which are the source of the conflict.
- <: The first rule cannot be executed in sequence before the second rule, because they use methods which cannot sequence in that order. Again, the compiler lists the methods used in each rule which are the source of the conflict.
- resource: A conflict introduced because of resource arbitration, where more rules are vying for a method than there are available ports for the method.
- cycle: A conflict introduced by the compiler to break an execution order cycle.
- attribute: A conflict introduced by a scheduling attribute, such as the `preempts` attribute.

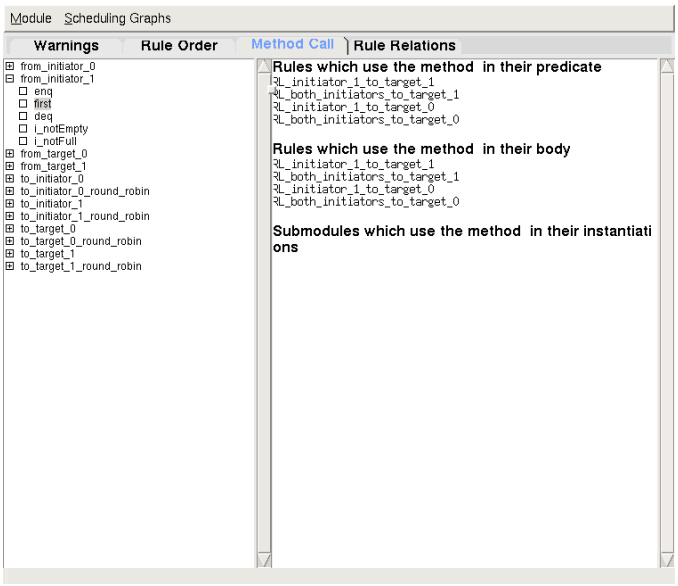

Figure 19: Schedule Browser - Method Call Tab

5.5 Viewing Scheduling Graphs

The **Scheduling Graphs** option on the **Schedule Analysis** displays the scheduling graphs. To view the graphs, the following conditions must be met:

- The graphviz Tcl extensions (TclDot) must be installed as described in Section 1.4.
- The `.dot` files must have been generated during compilation by specifying the compiler flag `-sched-dot` (Section 6.13) in the options field on the **Project Options→Compiler** tab.
- You must have a synthesized module.

The following five graphs are available for each synthesized module:

- Conflict
- Execution Order
- Urgency
- Combined
- Combined Full

In each of these graphs, the nodes are rules and methods and the edges represent some relationship between pairs of rules/methods. Methods are represented by a box and rules are represented by an ellipse, so that they are visually distinguishable.

You can perform the following tasks for each of the **Scheduling Graphs**:

- Filter the graph by selecting specific nodes and edges to display or to remove from the graph. The conflict graph in Figure 21 shows the filter options on the left side of the window.
- Change the text label on the graph with the **Rename** button.

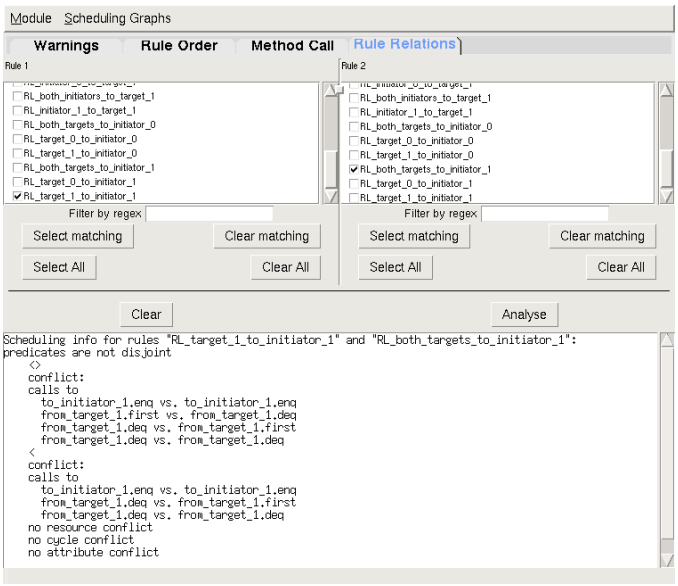

Figure 20: Schedule Browser - Rule Relations Tab

- Hide the filter options with the **Hide** button. Use **View→Show Filter** to unhide the filter options.
- Save the graph as a file from the **View→Export** menu. You will be prompted for a name and format for the export file.
- Zoom by using the **Zoom** menu or the slide bar at the top of the screen.

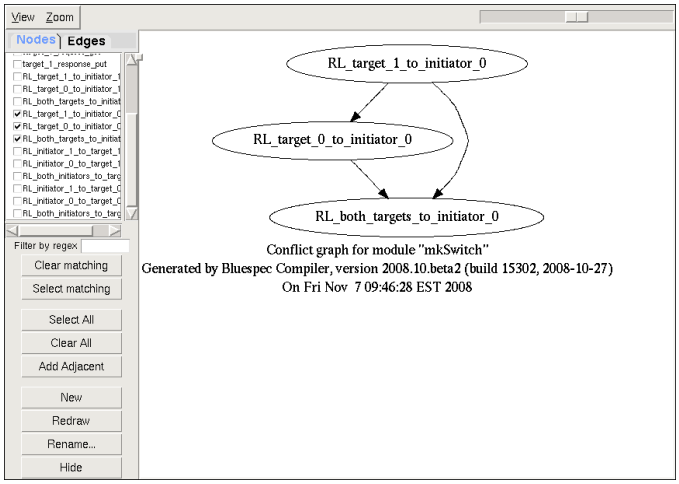

Figure 21: Conflicts Graph with filter options

5.5.1 Conflict

The conflicts graph, shown in Figure 21, displays rules/methods which conflict either completely (they cannot execute in the same cycle) or in one direction (if they execute in the same cycle, it

has the be in the opposite order). Complete conflicts are represented by bold non-directional edges. Ordering conflicts are represented by dashed directional edges, pointing from the node which must execute first to the node which must execute second.

When a group of nodes form an execution cycle, as shown in Figure 21, the compiler breaks the cycle by turning one of the edges into a complete conflict and emits a warning. This graph is generated before that happens, so it includes any cycles and can be used to debug any such warnings.

5.5.2 Execution Order

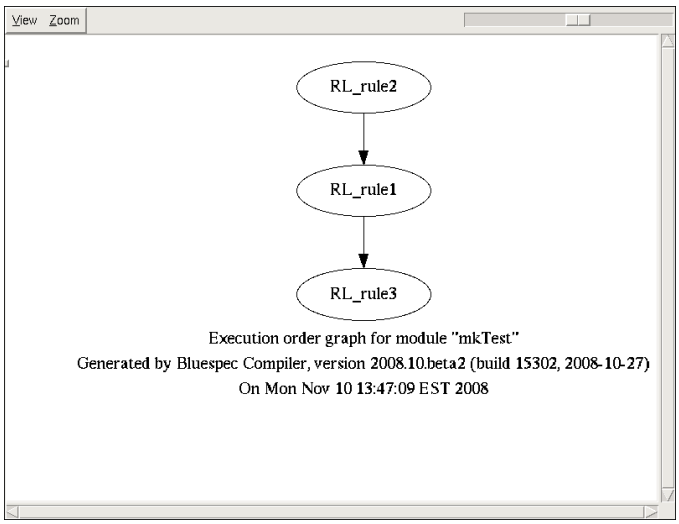

Figure 22: Execution Order Graph

The execution order graph, shown in Figure 22, is similar to the conflicts graph, except that it only includes the execution order edges; the full-conflict edges have been dropped. As a result, there is no need to distinguish between the types of edges (bold versus dashed), so all edges appear as normal directional edges.

This graph is generated after cycles have been broken and therefore describes the final execution order for all rules/methods in the module.

5.5.3 Urgency

The edges in the urgency graph, as shown in Figure 23, represent urgency dependencies. They are directional edges which point from a more urgent node to a less urgent node (meaning that if the rules/methods conflict, then the more urgent one will execute and block the less urgent one). Two rules/methods have an edge either because the user specified a `descending_urgency` attribute or because there is a data path (though method calls) from the execution of the first rule/method to the predicate of the second rule/method.

If there is a cycle in the urgency graph, the compiler reports an error. This graph is generated before such errors, so it will contain any cycles and is available to help debug the situation.

5.5.4 Combined

In the combined graph, shown in Figure 24 and the combined full graph, shown in Figure 25, there are two nodes for each rule/method. One node represents the scheduling of the rule/method

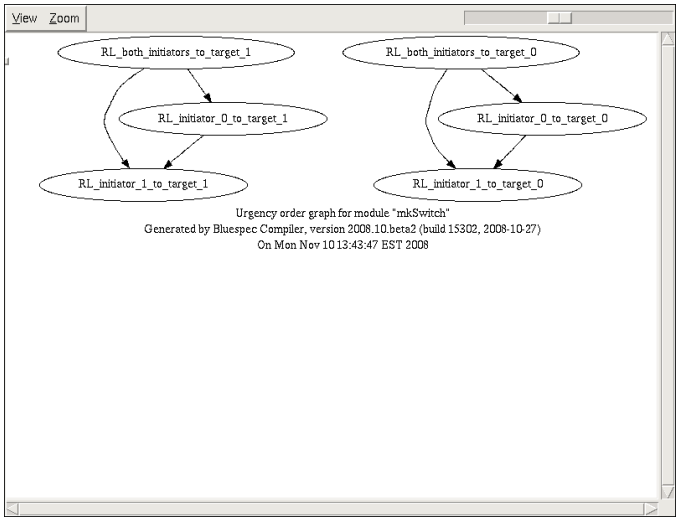

Figure 23: Urgency Graph

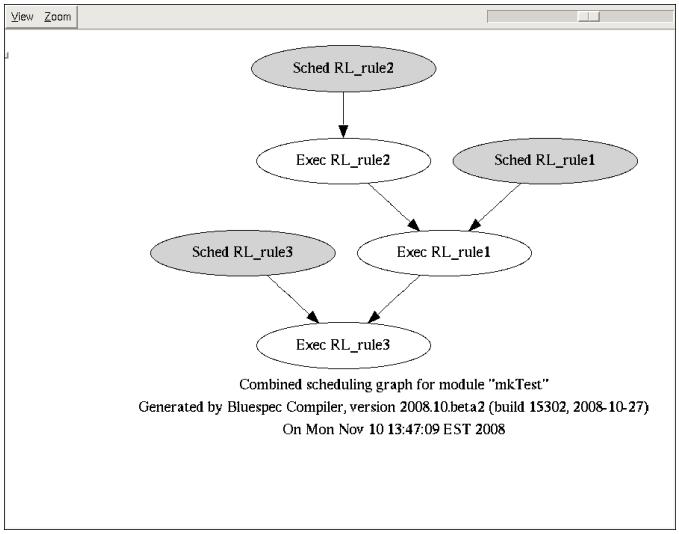

Figure 24: Combined Graph

(computing the `CAN_FIRE` and the `WILL_FIRE` signals) and one node represents the execution of the rule/method's body. The nodes are labelled `Sched` and `Exec` along with the rule/method name. To further help visually distinguish the nodes, the `Sched` nodes are shaded.

The edges in this graph are a combination of the execution order and urgency graphs. This is the graph in which the microsteps of a cycle are performed: compute whether a rule will fire, execute a rule, and so on.

In the rare event that the graph has a cycle, the compiler will report an error. This graph is generated prior to that error, so it will contain the cycle and be available to help in debugging the situation.

5.5.5 Combined Full

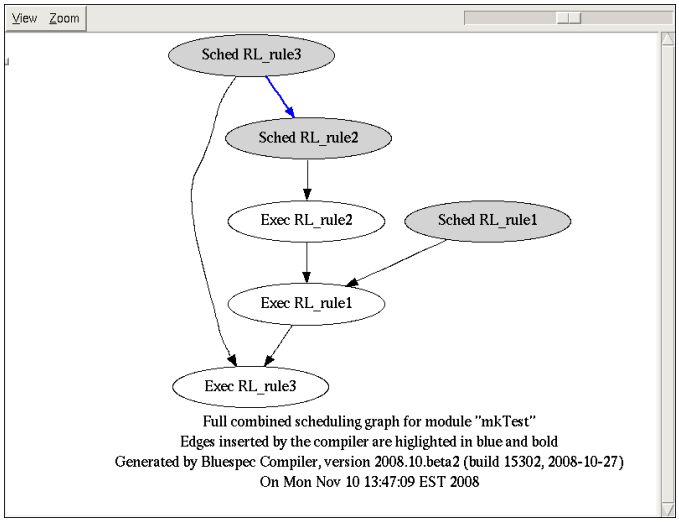

Figure 25: Combined Full Graph

Sometimes the execution or urgency order between two rules/methods is underspecified and either order is a legal schedule. In those cases, the compiler picks an order and warns the user that it did so.

The combined full graph, shown in Figure 25 is the same as the combined graph above, except that it includes the arbitrary edges which the compiler inserted. The new edges are bold and colored blue, to help highlight them visually.

This is the final graph which determines the static schedule of a module (the microsteps of computing predicates and executing bodies).

As with the above graph, there are separate `Sched` and `Exec` nodes for each rule/method, where the `Sched` nodes are shaded.

6 BSC flags

There are a number of flags used by the compiler for compilation (synthesis) and linking. Flags are entered on the command line or, in the development workstation, added to the compile or link options fields in the **Project→Options** window.

You can obtain an up-to-date listing of the available flags along with brief explanations by going to a Unix command line and entering:

```
bsc  -help
```

Or from the workstation command line type:

```
exec bsc  -help
```

Most flags may be preceded by a `-no` to reverse their effect. Flags that appear later on the command line override earlier ones.

The following flags make the compiler print progress-report messages as it does its work:

```
-verbose              be talkative
-v                    same as -verbose
```

6.1 Common compile and linking flags

The following flags are the common flags used by the compiler. These flags are automatically generated by the development workstation, so you will only use them when executing bsc from a Unix command line.

```
-g module             generate code for 'module' (requires -sim or -verilog)
-u                    check and recompile packages that are not up to date
-sim                  compile BSV generating Bluesim object
-verilog              compile BSV generating Verilog file
-vsim simulator       specify which Verilog simulator to use
-e module             top-level module for simulation
-o name               name of generated executable
```

The `-vsim` flag (along with the equivalent `BSC_VERILOG_SIM` environment variable) governs which Verilog simulator is employed. The natively supported choices for `-vsim` are `vcs`, `vcsi`, `ncverilog`, `modelsim`, `cver`, `iverilog`, and `veriwell`. If a simulator is not specified `bsc` will attempt to detect one of the above simulators and use it.

6.2 Controlling default flag values

The environment variable `BSC_OPTIONS` enables the user to set default flag values to be used each time the compiler is called. If set, the value of `BSC_OPTIONS` is automatically prepended to the compiler option values typed on the bsc command line. This avoids the need to set specified flag values each time the compiler is called.

For instance, in order to control the default value of the `-p` (path) option, the `BSC_OPTIONS` environment variable could be set as follows:

```
# Bluespec Environment for csh/tcsh
setenv BSC_OPTIONS "-p .:./MyLib:+"

# Bluespec Environment for bash/ksh
export BSC_OPTIONS="-p .:./MyLib:+"
```

Once set, the BSV compiler would now search for packages in the `./MyLib` directory before looking in the default Prelude and Library areas. Note that since the compiler recognizes multiple uses of the same flag on the command line, the user can use the `-p` flag along with the `BSC_OPTIONS` environment variable to control the search path. For example, if in addition to the `BSC_OPTIONS` set above the user enters the following bsc command, :

```
bsc -verilog -p ./MyLib2:+ Foo.bsv
```

the compiler would now use the path

```
./MyLib2:.:./MyLib:+
```

which is a prepending of the `-p` command line value to the value set by the `BSC_OPTIONS` environment variable.

6.3 Verilog back-end

The following additional flags are available when using the Verilog back end.

```
-remove-unused-modules  remove unconnected modules from the Verilog
-v95                    generate strict Verilog 95 code
-unspecified-to val     remaining unspecified values are set to:
                         'X', '0', '1', 'Z', or 'A'
-remove-dollar          remove dollar signs from Verilog identifiers
-Xv arg                 pass argument to the Verilog link process
```

The `-remove-unused-modules` will remove from the generated Verilog any modules which are not connected to an output. This has has the effect of removing redundant or unused modules, which would also be done by synthesis tools. This option should be used on modules undergoing synthesis, and not be used for testbench modules.

The `-v95` flag restricts the Verilog output to pure Verilog-95. By default, the Verilog output uses features which are not in the Verilog-95 standard. These features include passing module parameters by name and use of the `$signed` system task for formatting `$display` output. When the `-v95` flag is turned on, uses of these features are removed, but comments are left in the Verilog indicating the parameter names or system tasks which were removed.

The `-unspecified-to val` flag defines the value which any remaining unspecified values should be tied to. The valid set of values are: `X`, `0`, `1`, `Z`, or `A`, where the first four correspond to the Verilog value, and `A` corresponds to a vector of alternating ones and zeros. The default value is `A`. The choice of value is used by both the Verilog and Bluesim back ends. However, since Bluesim is a two-value simulator, it does not support the values `X` and `Z`. For final synthesis runs, the use of `X` (or `0`) is strongly suggested to give the best synthesis results.

The `-remove-dollar` flag causes identifiers in Verilog output to substitute underscores instead of dollar signs to separate instance names from port names. If this substitution causes a name collision, the underscore is suffixed with a number until a non-colliding name is found.

The `-Xv` flag passes the specified string argument to the Verilog link process. Only one argument can be passed with each `-Xv` flag. If you want to pass multiple arguments, then the flag must be specified multiple times, once for each argument.

6.4 Resource scheduling (all back ends)

The following flags are available to direct resource scheduling:

```
-resource-off           fail on insufficient resources
-resource-simple        reschedule on insufficient resources
```

Resource scheduling for a particular interface method involves finding all rules that call that method. A single method name can refer to multiple ports in the hardware — for example, a double-ported RAM can have two *read* ports, but a design in BSV can use the name `read` and it will rely on the compiler to determine which port is being used. If the number of rules that use `read` is two or less, then there is no problem; each rule is connected to its own port and there is never any contention. If the number of rules vying for a method is more than the number of copies of that method, then a problem exists.

If `-resource-off` is specified, the compiler will give up and tell the user that resource scheduling is not possible. This is the default behavior. The straightforward way to proceed is by adding logic that explicitly arbitrates between the competing rules (choosing the more important one to fire depending on the situation).

The alternative way to resolve a resource conflict is to block competing rules until the number of rules vying for a method is less than the number of available ports for that method. This behavior can be turned *on* with the `-resource-simple` flag. The compiler selects rules to block from the competing rules arbitrarily (and may change its selection when different compilation flags or compiler versions are used), so this flag is not recommended for a completed design, but automatic resource arbitration can be useful when experimenting.

6.5 Setting the path

`-i dir`	override $BLUESPECDIR
`-p path`	directory path (':' sep.) for source and intermediate files
`-bdir dir`	output directory for .bi, .bo, and .ba files
`-simdir dir`	output directory for Bluesim intermediate files
`-vdir dir`	output directory for .v files
`-info-dir dir`	output directory for cross-info files
`-I path`	include path for compiling foreign C/C++ source
`-L path`	library path for linking foreign C/C++ objects
`-l library`	library to use when linking foreign C/C++ objects

There are default locations where the compiler looks for source and and intermediate files. The flags `-i` and `-p` are available to override the default locations or to specify additional directories to search in. See Section 4.2.4 for more information. The `-i` flag overrides the environment variable `BLUESPECDIR`, which is used in the default value for the directory path of the `-p` flag. The `-p` flag takes a path argument, which is a colon-delimited list of directories. This path is used to find Bluespec source and intermediate files imported by the package being compiled (including the standard prelude, and files included by the BSV preprocessor). The path can contain the character `%`, representing the `BLUESPECDIR` directory, as well as `+`, representing the current path. The default path is:

```
.:%/Prelude:%/Libraries
```

The `-bdir`, `-simdir`, `-vdir`, and `-info-dir` flags specify where output files should be placed. The default is the directory in which the input file(s) reside.

The flags `-I`, `-L`, and `-l` are used during the linking stage when foreign C functions are imported. The `-I` and `-L` flags add to the path of where to find C header files and libraries, respectively. The libraries to be used during linking are specified by the `-l` flag.

6.6 License-related flags

The following flags are related to the license:

`-licenseWarning days`	sets the number of days before a license expires to issue a warning
`-print-expiration`	print the expiration date and exit
`-show-license-detail`	show more details regarding license acquisition
`-wait-for-license`	wait for license to free rather than exit
`-license-type`	sets the type of license to checkout
`-runtime-license`	control use of run-time license vs. compile-time license

To find out when your Bluespec compiler license expires, use `-print-expiration`. By default, bsc warns when the license expires in 30 days or less, use `-licenseWarning` to set the warning period. The option `-show-license-detail` shows details of the license acquisition including search path and the server where the license was acquired.

The option `-wait-for-license` is useful for batch operations when the user does not want the job to fail due to a busy license. Under this option, the Bluespec compiler will queue a request for a license and then block execution until a license is freed. License queuing is under the control of the FLEXnet^{TM}software. If you kill a process which is waiting for a license, ensure that all threads are killed; FLEXnet^{TM}starts a separate thread to communicate with the license server. You should always specify the license type when waiting for a license.

The option `-license-type` specifies the type of license to check out. Bluespec offers floating and seat licenses. A floating (or `BComp`) license is held until the compile completes. A seat (or `BSeat`) license is tied to a user and is held for a specified amount of time, usually a workday. The time a seat license is held is determined in your site contract.

Valid arguments to the `-license-type` flag are `Any`, `Floating`, or `Seat`. The default behavior is `Any`, in which case the compiler will first attempt to check out a seat license, and then, if that fails, a floating license. If this fails, the compiler will terminate (unless the `-wait-for-license` flag was specified).

By default, Bluesim models require a `BSIM` license at run-time. The option `-no-runtime-license` generates SystemC or Bluesim models that do not require a runtime license. This option requires the existence of either a `SYSCUNLIC` or `BSIMUNLIC` license at compile time in order to create the unlicensed runtime model.

6.7 Miscellaneous flags

Here are some other flags recognized by the compiler:

`-D macro`	define a macro for the SystemVerilog preprocessor
`-E`	run just the preprocessor, dumping result to stdout
`-print-flags`	print flag values after command-line parsing
`-steps n`	terminate elaboration after this many function unfolding steps
`-steps-max-intervals n`	terminate elaboration after this number of unfolding messages
`-steps-warn-interval n`	issue a warning each time this many unfolding steps are executed

Preprocessor macros may be defined on the command line using the `-D` option. Two versions are supported, a simple macro definition and an assignment of a string to a macro:

```
-D foo
-D size=148
```

Note that a space is required after the `-D`, and that no spaces are allowed in the macro names, values or around the equals.

Function definitions in BSV are purely compile-time entities. The compiler replaces all function calls by their bodies and continually simplifies expressions. Function definitions may be recursive as long as this substitution and simplification process terminates, but of course the compiler cannot predict whether it will terminate. The `-steps`, `-steps-warn-interval` and `-steps-max-intervals` flags provide feedback and safety mechanisms for potentially infinite function unfoldings. The `-steps-warn-interval` tells the compiler to issue a compilation warning every time that many function unfolding steps are executed. This provides feedback to a designer that a particular design requires an unusual amount of effort to elaborate. A designer may choose to terminate elaboration and investigate whether there is a bug, infinite loop or an inefficient construct in a design or they may choose to let elaboration proceed to see if additional time will result in elaboration completing. The `-steps-max-intervals` flag is the safety mechanism. It prevents an unattended compilation from consuming resources indefinitely by terminating elaboration after a certain number of function unfolding warnings. This means, for example, with the default values of 100000 for `-steps-warn-interval` and 10 for `-steps-max-intervals` an infinite compilation will execute for 1000000 steps, issuing 9 unfolding warnings before terminating with an unfolding error message. The `-steps` flag is a simpler version of this mechanism. It is equivalent to setting `-steps-warn-interval` to the argument of `-steps` and `-steps-max-intervals` to 1.

The settings that are being used by the compiler can be dumped with `-print-flags`.

6.8 Run-time system

These flags are passed along to the Haskell compiler run-time system that is used to execute the Bluespec compiler. Among the RTS flags available are:

```
-Hsize                  set the maximum heap size
-Ksize                  set the maximum stack size
```

As the compiler executes, it allocates its internal intermediate data structures in a heap memory managed by its run-time system (RTS). When compiling a large BSV design, the compiler may run out of heap space. If you encounter this, please rerun the compiler with a larger heap space, using the flags:

```
bsc ... +RTS -H<size> -RTS ...
```

For example, to use an 80-megabyte heap, you would enter:

```
bsc ... +RTS -H80M -RTS ...
```

Similarly, if you run out of stack space, you can increase the stack with the `-K` RTS flag. If a design runs out of stack space, it is probably caught in an infinite loop. For large designs that involve many recursive functions, it may be necessary to increase the stack size. If you run out of stack space, first try increasing the stack to a reasonable size, such as 10 or 15 megabytes. If you still exhaust the stack memory, try examining your design for infinite loops.

Any flags encapsulated between `+RTS` and `-RTS` are passed to the run-time system and are not given to the BSV compiler itself. In addition to `-H` and `-K`, various flags are available to control garbage collection, memory usage, function unfolding, etc. However, the user should never need to use these other flags.

6.9 Automatic recompilation

`-u`	check and recompile packages that are not up to date
`-show-compiles`	show recompilations

The `-u` flag implements a `make`-like functionality. If a needed `.bi` or `.bo` file is found to be older or non-existent compared to the `.bsv` file, the latter is recompiled. Similarly, if a `.bsv` file has a modification time that is more recent than that of any of its generated Verilog or Bluesim modules, the `.bsv` file is recompiled.

The `-show-compiles` flag turns *on* the compiler output during recompilation of auxiliary files. It can also be used as `-no-show-compiles` to suppress the compiler output.

For the purposes of comparing modification times, the intermediate files (`.bi`, `.bo`, and `.ba`) are assumed to be in the same directory as the `.bsv` source file. If no file is found there, the compiler then searches in the directory specified by the `-bdir` flag (if used). The generated Verilog files and Bluesim files are assumed to be in the same directory as the source unless the `-simdir` or `-vdir` flag is used, respectively.

6.10 Compiler transformations

`-aggressive-conditions`	construct implicit conditions aggressively
`-split-if`	split "if" in actions
`-lift`	lift method calls in "if" actions

When a rule contains an `if`-statement, the compiler has the option either of splitting the rule into two mutually exclusive rules, or leaving it as one rule for scheduling but using MUXes in the production of the action. Rule splitting can sometimes be desirable because the two split rules are scheduled independently, so non-conflicting branches of otherwise conflicting rules can be scheduled concurrently. The `-split-if` flag tells the compiler to split rules. Splitting is turned *off* by default for two reasons:

- When a rule contains many `if`-statements, it can lead to an exponential explosion in the number of rules. A rule with 15 `if`-statements might split into 2^{15} rules, depending on how independent the statements (and their branch conditions) are. An explosion in the number of rules can dramatically slow down (and cause other problems) for later compiler phases, particularly scheduling.
- Splitting propagates the branch condition of each `if` to the predicates of the split rules. Resources required to compute rule predicates are reserved on every cycle. If a branch condition requires a scarce resource, this can starve other parts of the design that want to use that resource.

If you need the effect of splitting for certain rules, but do not want to split all the rules in an entire design using `-split-if`, use the `(*split*)` and `(*nosplit*)` attributes, as described in the BSV Reference Guide.

When rules are not split along `if`-statements, it is important to lift actions through the `if`-statement. If both branches of an `if`-statement call the same method but with different arguments, it's better to make one call to the method and MUX the argument. The `-lift` flag turns *on* this optimization. Lifting is recommended when rule splitting is turned *off*. When rule splitting is *on*, lifting is not required and can make rules more resource hungry. Currently, lifting with splitting *off* can result in poor resource allocation, so we recommend using `-no-lift` with `-split-if`.

When the action in a branch of an `if`-statement has an implicit condition, that condition needs to be propagated to the rule predicate. This can be done conservatively, by simply placing implicit conditions for all branches in the predicate. Or it can be done more aggressively (i.e. attempting to fire the concerned rule more often), by linking each implicit condition with its associated branch condition. The flag `-aggressive-conditions` turns *on* this feature. This flag is off by default because, as discussed above, propagating branch conditions to rule predicates can have undesirable effects. However, if `-split-if` is on, branch conditions will be propagated to rule predicates regardless, so we recommend using `-aggressive-conditions` with `-split-if`, since it may improve the generated schedule.

6.11 Compiler optimizations

`-O`	`turn on various optimizations`
`-opt-undetermined-vals`	`aggressive optimization of undetermined values`

The `-O` flag turns *on* several compiler optimizations. Using these optimization, there may be an increase in `bsc` runtime, memory use or both.

In late stages of the compiler, don't-care values are converted into specific constants. In order that the Verilog and Bluesim simulation paths produce exactly the same value dumps, the compiler assigns a value to the don't-care signals at the point where the Verilog and Bluesim back ends diverge. However, the Verilog back end can generate more efficient hardware if it is allowed to assign the don't-care signals better values based on context. The `-opt-undetermined-vals` flag permits the Verilog back end of the compiler to make better decisions about don't-care values. This flag is *off* by default. Turning this flag on may produce better hardware in Verilog, but can result in the Bluesim and Verilog simulations producing different intermediate values.

Some non-deterministic optimizations are used during scheduling, which may result in excessive run time or conversely, a too conservative (less optimal) schedule. The effort is controlled with the following switches.

`-scheduler-effort limit`	`set effort for disjoint testing during scheduling`
`-warn-scheduler-effort`	`displays warnings when the scheduler limit is reached`

The default limit is 20, and typical values range from 10 to 500. This value should not be changed unless a less-than-optimal schedule is observed, and `-warn-scheduler-effort` shows that the limit is indeed exceeded. Larger limits may cause excessive runtime, and still not produce optimal schedules. Note that the scheduled Verilog is logically correct even if this limit is exceeded.

6.12 BSV debugging flags

The following flags might be useful in debugging a BSV design:

-check-assert	test assertions with the Assert library
-keep-fires	preserve CAN_FIRE and WILL_FIRE signals
-keep-inlined-boundaries	preserve inlined register and wire boundaries
-remove-false-rules	remove rules whose condition is provably false
-remove-starved-rules	remove rules that are never fired by the generated schedule
-remove-empty-rules	remove rules whose bodies have no actions
-show-module-use	output instantiated Verilog modules names
-show-range-conflict	show predicates when reporting a parallel composability error
-show-method-conf	show method conflict information in the generated code
-show-stats	show package statistics
-Werror	make warnings to errors
-continue-after-errors	aggressively continue compilation after an error has been detected
-warn-method-urgency	warn when a method's urgency is arbitrarily chosen
-warn-action-shadowing	warn when a rule's action is overwritten by a later rule

The `-check-assert` flag instructs the compiler to abort compilation if an boolean assertion ever fails. These are assertions which are explicitly embedded in a BSV design using the `Assert` package (see the Bluespec Reference Guide). If this flag is *off*, assertions of this type in a BSV design are ignored.

To view rule firings in the Verilog output, use the `-keep-fires` flag. This flag will direct the compiler to leave the `CAN_FIRE` and `WILL_FIRE` signals in the output Verilog (some of which might otherwise be optimized away). These signals are generated for each rule and indicate whether a rule's predicate would allow the rule to fire in the current cycle and whether the scheduler chose the rule to fire in the current cycle, respectively. Leaving these signals in the Verilog allows the designer to dump the signals to VCD and view the firings in a waveform viewer.

When elaborating a design, if the compiler determines that a rule's explicit condition is always false, it issues a warning about the situation and removes the rule from the design (so the presumably irrelevant rule does not interfere with scheduling). Sometimes, for debugging purposes it can be helpful to preserve this (never enabled) rule in the output code. That can be done by disabling the `-remove-false-rules` flag (i.e. passing `-no-remove-false-rules`). As you might expect, the compiler will find more false rules when aggressive optimization (i.e. `-O`) is turned on, but it can be helpful to turn *off* `-O` when you want to examine the condition that the compiler can prove false.

Similarly, the compiler might determine, after scheduling, that a rule will never fire because conflicting rule(s) block it whenever it is enabled. The compiler warns about such rules, but does *not* remove them by default because they probably indicate an important problem in scheduling the design. If you wish to removed these rules, you can use the `-remove-starved-rules` flag.

The compiler may also determine that the body of a rule has no actions, either because there are no actions in the body or because the compiler can prove at elaboration time that none of the actions in the body can happen. The `-remove-empty-rules` flag causes these rules to be removed when it is on, which it is by default. The compiler will generate a warning for such rules, since they are likely to indicate a problem in the design.

Conflict relationships between methods of the generated module's interface can be dumped (in the generated code) with the `-show-method-conf` flag. This is enabled by default and is useful for documenting the interface protocol a generated module expects (particularly when the generated module is going to be called by non-Bluespec modules). The `-show-stats` flag dumps various statistics at the end of each compiler stage (such as the number of rules and number of definitions). To find out what Verilog modules are instantiated by the generated module, use the `-show-module-use` flag. This flag causes the compiler to create a file `mkFoo.use` which contains a list of each Verilog module instantiated by module `mkFoo`, separated by newlines.

The `-show-range-conflict` flag is used to display more information when the compiler reports error message `G0004`. By default, the compiler omits the conditions of the method calls, because they can be very large expressions in some cases, which distract from debugging rather than help. When more detail is required, the `-show-range-conflict` flag can be turned on and the full condition is displayed.

By default, the compiler stops once it finds errors in a module. The `-continue-after-errors` flag allows the compiler to continue on to other modules and other phases after an error is encountered. This may be helpful in finding multiple errors in a single compile, though some of later errors may be misleading and vanish once the cause of initial error is fixed. Note that the compiler may not be able to successfully complete because of the cumulative effects of errors encountered.

The `-warn-method-urgency` flag displays a warning when a method and a rule have an aribitrary urgency order. By defualt the flag is on.

The `-warn-action-shadowing` flag displays a warning when there are two rules executing in the same cycle and calling the same Action method. In this case, the state update of the first method is ignored because it is overwritten by the state update of the second method. This can only occur for methods which are annotated as non-conflicting, for example, register writes. Otherwise the Action methods will conflict. This flag is on by default.

6.13 Understanding the schedule

These flags generate output to help you understand the schedule for a generated module.

`-show-rule-rel r1 r2`	`display scheduling information about rules r1 and r2`
`-show-schedule`	`show generated schedule`
`-sched-dot`	`generate .dot files with schedule information`

If the rules in a design are not firing the way you thought they would, the `-show-schedule` and the `-show-rule-rel` flags may help you inspect the situation. See section 7.2.2 for a description on the output generated by these flags.

The `-sched-dot` flag generates `.dot` (DOT) files which contain text representation of a graph. There are many tools in the `graphviz` family, for example `dotty`, which read, manipulate, and render DOT files to visible format. See `www.graphviz.org` for more information.

When specified, the following graph files are generated for each synthesized module (*mod* is the module name):

1. **conflicts** (*mod*_conflict.dot)
2. **execution order** (*mod*_exec.dot)
3. **urgency** (*mod*_urgency.dot)
4. **combined** (*mod*_combined.dot)
5. **combined full** (*mod*_combined_full.dot)

In each of these graphs, the nodes are rules and methods and the edges represent some relationship between pairs of rules/methods. In all graphs, methods are represented by a box and rules are represented by an ellipse, so that they are visually distinguishable.

conflicts (*mod*_conflict.dot) A graph of rules/methods which conflict either completely (cannot execute in the same cycle) or conflict in one direction (if they execute in the same cycle, it has the be in the opposite order). Complete conflicts are represented by bold non-directional edges. Ordering conflicts are represented by dashed directional edges, pointing from the node which must execute first to the node which must execute second.

When a group of nodes form an execution cycle (such as A before B before C before A), the compiler breaks the cycle by turning one of the edges into a complete conflict and emits a warning. This DOT file is generated before that happens, so it includes any cycles and can be used to debug any such warnings.

execution order (*mod*_exec.dot) This is similar to the conflicts graph, except that it only includes the execution order edges; the full-conflict edges have been dropped. As a result, there is no need to distinguish between the types of edges (bold versus dashed), so all edges appear as normal directional edges.

This DOT file is generated after cycles have been broken and therefore describes the final execution order for all rules/methods in the module.

urgency (*mod*_urgency.dot) The edges in this graph represent urgency dependencies. They are directional edges which point from a more urgent node to a less urgent node (meaning that if the rules/methods conflict, then the more urgent one will execute and block the less urgent one). Two rules/methods have an edge either because the user specified a `descending_urgency` attribute or because there is a data path (though method calls) from the execution of the first rule/method to the predicate of the second rule/method.

If there is a cycle in the urgency graph, BSC reports an error. This DOT file is generated before such errors, so it will contain any cycles and is available to help debug the situation.

combined (*mod*_combined.dot) In this and the following graph, there are two nodes for each rule/method. One node represents the scheduling of the rule/method (computing the `CAN_FIRE` and the `WILL_FIRE` signals) and one node represents the execution of the rule/method's body. The nodes are labelled `Sched` and `Exec` along with the rule/method name. To further help visually distinguish the nodes, the `Sched` nodes are shaded.

The edges in this graph are a combination of the execution order and urgency graphs. This is the graph in which the microsteps of a cycle are performed: compute whether a rule will fire, execute a rule, and so on.

In the rare event that the graph has a cycle, BSC will report an error. This DOT file is generated prior to that error, so it will contain the cycle and be available to help in debugging the situation.

combined full (*mod*_combined_full.dot) Sometimes the execution or urgency order between two rules/methods is under specified and either order is a legal schedule. In those cases, BSC picks an order and warns the user that it did so.

This DOT graph is the same as the combined graph above, except that it includes the arbitrary edges which the compiler inserted. The new edges are bold and colored blue, to help highlight them visually.

This is the final graph which determines the static schedule of a module (the microsteps of computing predicates and executing bodies).

As with the above graph, there are separate `Sched` and `Exec` nodes for each rule/method, where the `Sched` nodes are shaded.

6.14 C/C++ flags

These flags run the C preprocessor and pass arguments to C tools.

```
-cpp                    preprocess the source with the C preprocessor
-Xc arg                 pass argument to the C compiler
-Xc++ arg               pass argument to the C++ compiler
-Xcpp arg               pass argument to the C preprocessor
-Xl arg                 pass argument to the C/C++ linker
```

The `-cpp` flags runs the C preprocessor on the source file before the BSV preprocessor is run. The `CC` environment variable specifies which C compiler will be used. If the environment variable is not specified, the compiler will run the default (`cc`) which must be found in the path.

The flags `-Xcpp`, `-Xc`, `-Xc++`, and `-Xl` pass the specified argument to the C preprocessor, C compiler, C++ compiler and C/C++ linker respectively. Only one argument can be passed with each `-X` flag. If you want to pass multiple arguments, then the flag must be specified multiple times, once for each argument. Example:

```
-Xcpp -Dfoo=bar -Xcpp /l/usr/local/special/include
```

7 Compiler messages

7.1 Warnings and Errors

The following is an example of a warning from the Bluespec compiler:

```
Warning: "Test.bsv", line 5, column 9: (G0021)
  According to the generated schedule, rule "r1" can never fire.
```

All warnings and errors have this form, as illustrated below. They begin with the position of the problem, a tag which is unique for each message, and the type (either "Error" or "Warning").

```
<type>: <position>: (<tag>)
  <message>
```

The unique tag consists of a letter, indicating the class of message, and a four digit number. There are four classes of messages. Tags beginning with `P` are for warnings and errors in the *parsing* stage of the compiler. Tags beginning with `T` are *type-checking* and elaboration messages. Tags beginning with `G` are for problems in the back-end, or code-*generation*, including rule scheduling. Tags beginning with `S` are for file handling problems, command-line errors, and other *system* messages.

7.1.1 Type-checking Errors

If there is a type mismatch in your design, you will encounter a message like this:

```
Error: "Test.bsv", line 3, column 10: (T0020)
  Type error at:
  x

  Expected type:
  Prelude::Bool

  Inferred type:
  Prelude::Bit#(8)
```

This message points to an expression (here, `x`) whose type does not match the type expected by the surrounding code.

You can think of this like trying to put a square block into a round hole. The square type and the round type don't match, so there is a problem. The type of the expression (the block) doesn't match the type that the surrounding code is expecting (the hole). In the error message, the "expected type" is hole and the "inferred type" is the block.

7.1.2 Scheduling Messages

Static execution order When multiple rules execute in the same cycle, they must execute in a sequence, with each rule completing its state update before the next rule begins. In order to simplify the muxing logic, the Bluespec compiler chooses one execution order which is used in every clock cycle. If rule `A` and rule `B` can be executed in the same cycle, then they will always execute in the same order. The hardware does not dynamically choose to execute them in the order "`A` before `B`" in one cycle and "`B` before `A`" in a later cycle.

There may be times when three or more rules cannot execute in the same cycle, even though any two of the rules can. Consider three rules `A`, `B`, and `C`, where `A` can be sequenced before `B` but not after, `B` can only be sequenced before `C`, and `C` can only be sequenced after `A`. For any two rules, there is an order in which they may be executed in the same cycle. But there is no order for all three. If the conditions of all three rules are satisfied, the scheduler cannot execute all of them. It must make a decision to execute only two – for example, only `A` and `B`. But notice that this is not all. The scheduler must pick an order for all three rules, say "`A` before `B` before `C`." That means that not only will `C` not fire when both `A` and `B` are chosen to execute, but also that `C` can never fire when `A` is executed. This is because the compiler has chosen a static order, with `A` before `C`, which prevents rule `C` from ever executing before rule `A`. Effectively, the compiler has created a conflict between rules `A` and `C`.

If the compiler must introduce such a conflict, in order to create a static execution order, it will output a warning:

```
Warning: "Test.bsv", line 30, column 0: (G0009)
  The scheduling phase created a conflict between the following rules:
      ‘RL_One’ and ‘RL_Two’
  to break the following cycle:
      ‘RL_One’ -> ‘RL_Two’ -> ‘RL_Three’ -> ‘RL_One’
```

Rule urgency The execution order of rules specifies the order in which chosen rules will appear to execute within a clock cycle. It does not say anything about the order in which rules are chosen. The scheduling phase of the compiler chooses a set of rules to execute, and then that set is executed in the order specified by the static execution order. The order in which the scheduling phase chooses rules to put into that set can be different from the execution order. The scheduling phase may first

consider whether to include rule `B` before considering whether to include rule `A`, even if rule `A` will execute first. This order of consideration by the scheduling phase is called the *urgency order*.

If rule `A` and `B` conflict and cannot be executed in the same cycle, but can be ready in the same cycle, then the first one chosen by the scheduler will be the one to execute. If rule `B` is chosen before rule `A` then we say that `B` is *more urgent than* `A`.

If two rules conflict and the user has not specified which rule should be more urgent, the compiler will make its own (arbitrary) choice and will warn the user that it has done so, with the following warning:

```
Warning: "Test.bsv", line 24, column 0: (G0010)
  Rule "one" was treated as more urgent than "two". Conflicts:
    "one" cannot fire before "two": calls to x.write vs. x.read
    "two" cannot fire before "one": calls to y.write vs. y.read
```

As you can see, this warning also includes details about how the compiler determined that the rules conflict. This is because an unexpected urgency warning could be due to a conflict that the user didn't expect.

If the conflict is legitimate, the user can avoid this warning by specifying the urgency order between the rules (and thus not leave it up to the vagaries of the compiler). The user can specify the urgency with the `descending_urgency` attribute. See the BSV Reference Guide for more information on scheduling attributes.

Note that methods of generated modules are treated more urgent than internal rules.

Urgency between two rules can also be implied by a data dependency between the more urgent rule's action and the less urgent rule's condition. This is because the first rule must execute before the scheduler can know whether the second rule is ready. See Section 7.1.3 for more information on how such paths are created.

If a contradiction is created, between the user-supplied attributes, the path-implied urgency relationships, and/or the assumed relationship between methods and rules, then an error is report, as follows:

```
Error: "Test.bsv", line 8, column 8: (G0030)
  A cycle was detected in the urgency requirements for this module:
    ‘bar’ -> ‘RL_foo’
  The relationships were introduced for the following reasons:
    (bar, RL_foo) introduced because of method/rule requirement
    (RL_foo, bar) introduced because of the following data dependency:
      [WillFire signal of rule/method ‘RL_foo’,
       Enable signal of method ‘wset’ of submodule ‘the_rw’,
       Return value of method ‘whas’ of submodule ‘the_rw’,
       Output of top-level method ‘RDY_bar’,
       Enable signal of top-level method ‘bar’,
       CanFire signal of rule/method ‘bar’]
```

7.1.3 Path Messages

Some state elements, such as `RWire`, allow reading of values which were written in the same cycle. These elements can be used to avoid the latency of communicating through registers. However, they should only be used to communicate from a rule earlier in the execution sequence to a rule later in the sequence. Other uses are invalid and are detected by the compiler.

For example, if a value read in a rule's condition depends on the writing of that value in the rule's action, then you have an invalid situation where the choosing of a rule to fire depends on whether that rule has fired! In such cases, the compiler will produce the following error:

```
Error: "Test.bsv", line 20, column 10: (G0033)
  The condition of rule ‘RL_flip’ depends on the firing of that rule. This is
  due to the following path from the rule’s WILL_FIRE to its CAN_FIRE:
    [WillFire signal of rule/method ‘RL_flip’,
     Control mux for arguments of method ‘wset’ of submodule ‘the_x’,
     Argument 1 of method ‘wset’ of submodule ‘the_x’,
     Return value of method ‘wget’ of submodule ‘the_x’,
     CanFire signal of rule/method ‘RL_flip’]
```

Similarly, if the ready signal of a method has been defined as dependent on the enable signal of that same method, then an invalid situation has been created, and the compiler will produce an error (`G0035`). The ready signal of a method must also be computed prior to knowing the inputs to the method. If the ready signal of a method depends on the values of the arguments to that method, an error message will be reported (`G0034`).

A combinational cycle can result if a bypass primitive is used entirely within a single rule's action. In such cases, the compiler will produce an error explaining the source objects involved in the combinational path, in data-dependency order:

```
Error: "Test.bsv", line 4, column 8: (G0032)
  A cycle was detected in the design prior to scheduling. It is likely that
  an action in this module uses circular logic. The cycle is through the
  following:
    [Argument 1 of method ‘wset’ of submodule ‘the_rw’,
     Return value of method ‘wget’ of submodule ‘the_rw’]
```

7.2 Other messages

The Bluespec compiler can also emit status messages during the course of compilation.

7.2.1 Compilation progress

When the compiler finishes generating Verilog code for a module, it will output the location of the file which it generated:

```
Verilog file created: mkGCD.v
```

The following message is output when elaborating a design for Bluesim:

```
Elaborated Bluesim module file created: mkGCD.ba
```

When an elaboration file is generated to a Bluesim object, the following message is given:

```
Bluesim object created: mkGCD.{h,o}
```

If previously generated Bluesim object files still exist, are newer than the **.ba** file from which they were generated, and the module does not instantiate any modified sub-modules, then the existing object files will be reused. In this case the following message is seen instead of the message above:

```
Bluesim object reused: mkGCD.{h,o}
```

When the Bluesim object is linked to create a simulation binary, the following message is given:

```
Simulation shared library created: mkGCD.so
Simulation executable created: mkGCD
```

Automatic recompilation As described in Section 6.9, the `-u` flag can be used to check dependencies and recompile any needed packages which have been updated since their last compilation. The `-show-compiles` flag, which is *on* by default, will have the compiler output messages about the dependent files which need recompiling, as follows:

```
checking package dependencies
compiling ./FindFIFO2.bsv
compiling ./FiveStageCPUStall.bsv
compiling CPUTest.bsv
code generation for mkCPUTest starts
packages up to date
```

Verbose output The `-v` flag causes the compiler to output much progress information. First, the version of the Bluespec compiler is displayed, followed by license information. Then, as each phase of compilation is entered, a `starting` message is displayed. When the phase is completed, a `done` message is displayed along with the time spent in that phase. During the `import` phase, the compiler lists all of the header files which were read, including the full path to the files. During the `binary` phase, the compiler lists all of the binary files which were read. Prior to code generation, all of the modules to be compiled in the current package are listed:

```
modules: [mkFiveStageCPUStall_]
```

Then, code generation is performed for each module, in the order listed. Each is prefaced by a divider and the name of the module being generated:

```
*****
code generation for mkFiveStageCPUStall starts
```

After all modules have been generated, the header (`.bi`) and binary (`.bo`) files are output for the package with the following message:

```
Generate interface files
```

Finally, the total elapsed time of compilation is displayed.

Whenever the C or C++ compiler is invoked from BSC (such as during Bluesim compilation or when compiling or linking foreign C functions), the executed command is displayed:

```
exec: c++ -Wall -Wno-unused -O3 -fno-rtti -g -D_FILE_OFFSET_BITS=64
-I/tools/bsc/lib/Bluesim -c -o mkGCD.o mkGCD.cxx
```

7.2.2 Scheduling information

There are two flags which can be used to dump the schedule generated by the compiler and the information which led to that schedule: `-show-schedule` and `-show-rule-rel`.

The `-show-schedule` flag outputs three groups of information: method scheduling information (if the module has methods), rule scheduling information, and the linear execution order of rules and methods (see the paragraph on static execution order in Section 7.1.2). The output is in a file *modulename*`.sched` in the directory specified by the `info-dir` (Section 6.5) flag.

For each method, the following information is given: the method's name, the expression for the method's ready signal (`1` if it is always ready), and a list of conflict relationships with other methods. Any methods which can execute in the same clock cycle as the current method, in any execution order, are listed as "conflict-free." Any methods which can execute in the same clock cycle but only in a specific order are labelled either "sequenced before" (if the current method must execute first) or "sequenced after" (if the current method must execute second). Any methods which cannot be called in the same clock cycle as this method are listed as "conflicts." The following is an example entry:

```
Method: imem_get
Ready signal: True
Conflict-free: dmem_get, dmem_put, start, done
Sequenced before: imem_put
Conflicts: imem_get
```

For each rule, the following information is given: the rule's name, the expression for the rule's ready signal, and a list of more urgent rules which can block the execution of this rule. The more urgent rules conflict with the current rule and, if chosen to execute, they will prevent the current rule from executing in the same clock cycle (see the paragraph on rule urgency in Section 7.1.2). The following is an example entry:

```
Rule: fetch
Predicate: the_bf.i_notFull_ && the_started.get
Blocking rules: imem_put, start
```

The `-show-schedule` flag will inform you that a rule is blocked by a conflicting rule, but won't show you why the rules conflict. It will show you that one rule was sequenced before another rule, but it won't tell you whether the other order was not possible due to a conflict. For conflict information, you need to use the `-show-rule-rel` flag.

The `-show-rule-rel` flag can be used, during code generation, to query the compiler about the conflict relationship between two rules. Since this requires re-running the compiler, it is most useful to give the wildcard arguments `\* \*` and dump all rule relationships in one compile.

```
-show-rule-rel \* \*
```

If you only want to see the conflict relationships for a single rule, you can use:

```
-show-rule-rel \* rulename2
```

which will output all the rule relationships for `rulename2`. No other uses of the wildcard argument `\*` are valid with this flag.

The following is an example entry in the `-show-rule-rel` output:

```
Scheduling info for rules "RL_execute_jz_taken" and "RL_fetch":
predicates are not disjoint
    <>
    conflict:
    calls to
      the_pc.set vs. the_pc.get
      the_bf.clear_ vs. the_bf.i_notFull_
      the_pc.set vs. the_pc.set
      the_bf.clear_ vs. the_bf.enq_
    <
    conflict:
    calls to
      the_pc.set vs. the_pc.get
      the_bf.clear_ vs. the_bf.i_notFull_
      the_bf.clear_ vs. the_bf.enq_
    no resource conflict
    no cycle conflict
    no attribute conflict
```

For the two rules given, several pieces of information are provided. If the compiler can determine that the predicates of the two rules are mutually exclusive, then the two rules can never be ready in the same cycle and therefore we need never worry about whether the actions can be executed in the same clock cycle. In the above example, the predicates could not be determined to be disjoint, so conflict information was computed.

Two rules have a `<>`-type conflict if they use a pair of methods which are not conflict free. The rules either cannot be executed in the same clock cycle or they can but one must be sequenced first. The compiler lists the methods used in each rule which are the source of the conflict.

Two rules have a `<`-type conflict if the first rule mentioned cannot be executed in sequence before the second rule, because they use methods which cannot sequence in that order. There is no entry for `>`-type conflicts; for that information, look for an entry for the two rules in the opposite order and consult the `<`-type conflict. Again, the compiler lists the methods used in each rule which are the source of the conflict.

If a conflict was introduced between two rules because of resource arbitration (see Section 6.4), that information will be displayed third. The fourth line indicates whether a conflict was introduced to break an execution order cycle (see Section 7.1.2). The fifth, and last, line indicates whether a conflict was introduced by a scheduling attribute or operator in the design, such as the `preempts` attribute (see the BSV Reference Guide for more information on pre-emption).

8 Verilog back end

The Verilog code produced by the BSV compiler can either be executed using standard Verilog execution/interpretation tools or it can be compiled into netlists using standard synthesis tools. The generated code uses Bluespec-defined modules such as registers and FIFOs; these can be found in `$BLUESPECDIR/Verilog`. These modules must be used for simulation or synthesis, though creating a simulator with `bsc -e` automatically includes them. For example, to run the `vcs` simulator, use the following command:

```
bsc -vsim vcs -e mkToplevel mkToplevel.v otherfiles.v
```

See Section 4.3.3 for details on choosing the Verilog simulator.

8.1 Bluespec to Verilog name mapping

To aid in the understanding and debugging of the generated Verilog code, this section describes the general structure and name transformations that occur in mapping the original BSV source code into Verilog RTL. The section is based on a single example, which implements a greatest common denominator (GCD) algorithm. The source BSV code for the example is shown in Figure 26. The generated Verilog RTL is shown in Figures 27 and 28.

8.1.1 Interfaces and Ports

The interface section of a BSV design is used to specify the ports (input and outputs) of the generated Verilog code. The BSV interface specification for the GCD example is repeated below.

```
interface ArithIO_IFC #(parameter type aTyp); // aTyp is a parameterized type
    method Action start(aTyp num1, aTyp num2);
    method aTyp result();
endinterface: ArithIO_IFC
```

This interface specification leads to the following Verilog port specification. In the BSV specification shown in Figure 26, the type parameter `aTyp` has been bound to be a 51-bit integer.

```
module mkGCD(CLK,                  // input   1 bit  (implicit)
             RST_N,                // input   1 bit  (implicit)
             start_num1,           // input  51 bits (explicit)
             start_num2,           // input  51 bits (explicit)
             EN_start,             // input   1 bit  (implicit)
             RDY_start,            // output  1 bit  (implicit)
             result,               // output 51 bits (explicit)
             RDY_result            // output  1 bit  (implicit)
             );
```

Note that the generated Verilog includes a number of ports in addition to the `num1`, `num2`, and `result` signals that are specified explicitly in the interface definition. More specifically, each BSV interface has implicit clock and reset signals, whereas the generated Verilog includes these signals as `CLK` and `RST_N`. In addition, both the `start` and `result` methods have associated implicit signals.

The Verilog implementation of the `start` method (an input method) includes input signals for the arguments `num1` and `num2` which were explicitly declared in the BSV interface. The Verilog port names corresponding to these inputs have the method name prepended, however, to avoid duplicate port names. They have the generated names `start_num1` and `start_num2`. In addition to these explicit signals, there are also the implicit signals `EN_start`, a 1-bit input signal, and `RDY_start`, a 1-bit output signal.

Similarly, the Verilog implementation of the `result` method (an output method) includes the `result` output signal specified by the BSV interface, as well as the implicit signal `RDY_start`, a 1-bit output signal.

Since the implicit signal names are generated automatically by the BSV compiler, the BSV syntax provides a way in which the user can control the naming of these signals using attributes specified in the BSV source code. In order to rename the generated clock and reset signals, the following syntax is used:

```
(* osc="clk" *)
(* reset="rst" *)
```

More information on clock and reset naming attributes is available in the Bluespec Reference Guide.

The user may remove *Ready* signals by adding the attribute `always_ready` to the method definition. Similarly, the user may remove *enable* signals by adding the attribute `always_enabled` to the method definition. The syntax for this is shown below.

```
(* always_ready, always_enabled *)
```

More information on interface attributes is available in the BSV Reference Guide.

In addition to the *provided* interface, a BSV module declaration may include parameters and arguments (such as clocks, resets, and *used* interfaces). When such a module is synthesized, these inputs become input ports in the generated Verilog. If a Verilog parameter is prefered, the designer can specify this by using the optional `parameter` keyword. For example, consider the following module:

```
module mkMod #(parameter Bit#(8) chipId, Bit#(8) busId) (IfcType);
```

This module has two instantiation parameters, but only one is marked to be generated as a parameter in Verilog. This BSV module would synthesize to a Verilog module with parameter `chipId` and input port `busId` in addition to the ports for the interface `IfcType`:

```
module mkMod(busId,
             ...);
  parameter chipId = 0;
  input  [7 : 0] busId;
  ...
```

Parameters generated in this way have a default value of 0.

8.1.2 State elements

State elements, synthesized from `mkFIFO` and the like, are instantiated as appropriate elements in the generated Verilog. For example, consider the following BSV code fragment:

```
FIFO #(NumTyp) queue1 <- mkFIFO;   // queue1 is the FIFO instance
```

The above fragment produces the following Verilog instantiation:

```
FIFO2 #(.width(51)) queue1(.CLK(CLK),
                           .RST_N(RST_N),
                           .D_IN(queue1$D_IN),
                           .ENQ(queue1$ENQ),
                           .DEQ(queue1$DEQ),
                           .D_OUT(queue1$D_OUT),
                           .CLR(queue1$CLR),
                           .FULL_N(queue1$FULL_N),
                           .EMPTY_N(queue1$EMPTY_N));
```

Note that the Verilog instance name matches the instance name used in the BSV source code. Similarly, the associated signal names are constructed as a concatenation of the Verilog instance name and the Verilog port names.

Registers instantiated with `mkReg`, `mkRegU`, and `mkRegA` are treated specially. Rather than declare a bulky module instantiation, they are declared as Verilog `reg` signals and the contents of the module (for setting and initializing the register) are inlined. For example, consider the following BSV code fragment:

```
Reg #(NumTyp) x(); // x is the interface to the register
mkReg reg_1(x);   // reg_1 is the register instance

Reg #(NumTyp) y();
mkRegU reg_2(y);

Reg #(NumTyp) z();
mkRegA reg_3(z);
```

Which generates the following Verilog instantiation:

```
reg [50 : 0] reg_1, reg_2, reg_3;
wire [50 : 0] reg_1$D_IN, reg_2$D_IN, reg_3$D_IN;
wire reg_1$EN, reg_2$EN, reg_3$EN;

always@(posedge CLK)
begin
  if (!RST_N)
    reg_1 <= `BSV_ASSIGNMENT_DELAY 51'd0;
  else
    if (reg_1$EN) reg_1 <= reg_1$D_IN;
  if (reg_2$EN) reg_2 <= reg_2$D_IN;
end

always@(posedge CLK , negedge RST_N)
if (!RST_N)
  reg_3 <= `BSV_ASSIGNMENT_DELAY 51'd0;
else
  if (reg_3$EN) reg_3 <= `BSV_ASSIGNMENT_DELAY reg_3$D_IN;

`ifdef BSV_NO_INITIAL_BLOCKS
`else // no BSV_NO_INITIAL_BLOCKS
// synopsys translate_off
initial
begin
  reg_1 = 51'h2AAAAAAAAAAA;
  reg_2 = 51'h2AAAAAAAAAAA;
  reg_3 = 51'h2AAAAAAAAAAA;
end
// synopsys translate_on
`endif // BSV_NO_INITIAL_BLOCKS
```

Register assignments are guarded by the macro `BSV_ASSIGNMENT_DELAY`, defined to be empty by default. In simulation, delaying assignment to registers and other state elements with respect to the

relevant clock may be effected by defining `BSV_ASSIGNMENT_DELAY` (generally to "`#0`" or "`#1`") in the Verilog simulator.[1]

All registers are initialized with the distinguishable hex value `A` in order to guarantee consistent simulation in both Verilog and Bluesim, in the presence of multiple clocks and resets. This initialization is guarded by the macro `BSV_NO_INITIAL_BLOCKS`, which, if defined in the Verilog simulator or synthesis tool, disables the `initial` blocks.

The bsc command line option `-remove-unused-modules` can be used to remove primitives and modules which do not impact any output port. This option should only be used on synthesized modules, and not on testbenches.

8.1.3 Rules and related signals

For each instantiated rule, two combinational signals are created:

- `CAN_FIRE_rulelabel`: This signal indicates that the preconditions for the associated rule have been satisfied and the rule can fire at the next clock edge. The rule may not fire (execute) because the scheduler has assigned a higher priority to another rule and simultaneous rule firing causes resource conflicts.
- `WILL_FIRE_rulelabel`: This signal indicates that the rule will fire at the next clock edge. That is, its preconditions have been met, and the scheduler has determined that no resource conflicts will occur. Multiple rules can fire during one cycle provided that there are no resource conflicts between the rules.

The `rulelabel` substring includes an unmangled version of the source rule name as well as a `RL_` prefix and optionally a `_<n>` suffix. This suffix appears when it is needed to create a unique name from the instances from different submodules.

8.1.4 Other signals

Signals beginning with an underscore (_) character are internal combinational signals generated during elaboration and synthesis. These should not be used during debug.

8.2 Verilog header comment

When the Bluespec compiler generates the Verilog file for a module, it includes a comment with information about the compile and the module's interface. The header for the GCD example is shown in Figure 29. This comment would appear at the top of the file `mkGCD.v`.

The header begins with information about the version of the Bluespec software which was used to generate the file and the date of compilation. The subsequent information relates to the module's interface and its Verilog properties.

The method conflict information documents the scheduling constraints on the methods. These are Bluespec semantics which must be respected when using the module. They are the same details which the user must provide when importing his own Verilog module (see `BVI` import in the BSV Reference Guide). This information is included or omitted based on the `-show-method-conf` flag, which is *on* by default. The format of the information is similar to the method output of the `-show-schedule` flag (see Section 7.2.2).

[1] While the creative possibilities this feature opens—such as defining `BSV_ASSIGNMENT_DELAY` to "`~`"—may seem tempting at times, we discourage uses for purposes other than delaying assignment with respect to the clock edge.

```
typedef UInt#(51) NumTyp;

interface ArithIO_IFC #(parameter type aTyp); // aTyp is a paramerized type
    method Action start(aTyp num1, aTyp num2);
    method aTyp result();
endinterface: ArithIO_IFC

// The following is an attribute that tells the compiler to generate
// separate code for mkGCD
(* synthesize *)
module mkGCD(ArithIO_IFC#(NumTyp)); // here aTyp is defined to be type Int

    Reg#(NumTyp) x(); // x is the interface to the register
    mkRegU reg_1(x);  // reg_1 is the register instance

    Reg #(NumTyp) y(); // y is the interface to the register
    mkRegU reg_2(y);   // reg_2 is the register instance

    rule flip (x > y && y != 0);
        x <= y;
        y <= x;
    endrule

    rule sub (x <= y && y != 0);
        y <= y - x;
    endrule

    method Action start(NumTyp num1, NumTyp num2) if (y == 0);
        action
            x <= num1;
            y <= num2;
        endaction
    endmethod: start

    method NumTyp result() if (y == 0);
        result = x;
    endmethod: result

endmodule: mkGCD
```

Figure 26: BSV Source Code For The GCD Example

```
`ifdef BSV_ASSIGNMENT_DELAY
`else
`define BSV_ASSIGNMENT_DELAY
`endif

module mkGCD(CLK,
     RST_N,

     start_num1,
     start_num2,
     EN_start,
     RDY_start,

     result,
     RDY_result);
  input  CLK;
  input  RST_N;

  // action method start
  input  [50 : 0] start_num1;
  input  [50 : 0] start_num2;
  input  EN_start;
  output RDY_start;

  // value method result
  output [50 : 0] result;
  output RDY_result;

  // signals for module outputs
  wire [50 : 0] result;
  wire RDY_result, RDY_start;

  // register reg_1
  reg [50 : 0] reg_1;
  wire [50 : 0] reg_1$D_IN;
  wire reg_1$EN;

  // register reg_2
  reg [50 : 0] reg_2;
  reg [50 : 0] reg_2$D_IN;
  wire reg_2$EN;

  // rule scheduling signals
  wire WILL_FIRE_RL_flip, WILL_FIRE_RL_sub;

  // inputs to muxes for submodule ports
  wire [50 : 0] MUX_reg_2$write_1__VAL_3;

  // remaining internal signals
  wire reg_1_ULE_reg_2___d3;
```

Figure 27: Generated Verilog GCD Example (part 1)

```
 // action method start
  assign RDY_start = reg_2 == 51'd0 ;

  // value method result
  assign result = reg_1 ;
  assign RDY_result = reg_2 == 51'd0 ;

  // rule RL_sub
  assign WILL_FIRE_RL_sub = reg_1_ULE_reg_2___d3 && reg_2 != 51'd0 ;

  // rule RL_flip
  assign WILL_FIRE_RL_flip = !reg_1_ULE_reg_2___d3 && reg_2 != 51'd0 ;

  // inputs to muxes for submodule ports
  assign MUX_reg_2$write_1__VAL_3 = reg_2 - reg_1 ;

  // register reg_1
  assign reg_1$D_IN = EN_start ? start_num1 : reg_2 ;
  assign reg_1$EN = EN_start || WILL_FIRE_RL_flip ;

  // register reg_2
  always@(EN_start or
  start_num2 or
  WILL_FIRE_RL_flip or
  reg_1 or WILL_FIRE_RL_sub or MUX_reg_2$write_1__VAL_3)
  begin
    case (1'b1) // synopsys parallel_case
      EN_start: reg_2$D_IN = start_num2;
      WILL_FIRE_RL_flip: reg_2$D_IN = reg_1;
      WILL_FIRE_RL_sub: reg_2$D_IN = MUX_reg_2$write_1__VAL_3;
      default: reg_2$D_IN = 51'h2AAAAAAAAAAA /* unspecified value */ ;
    endcase
  end
  assign reg_2$EN = EN_start || WILL_FIRE_RL_flip || WILL_FIRE_RL_sub ;

  // remaining internal signals
  assign reg_1_ULE_reg_2___d3 = reg_1 <= reg_2 ;

  // handling of inlined registers

  always@(posedge CLK)
  begin
    if (reg_1$EN) reg_1 <= `BSV_ASSIGNMENT_DELAY reg_1$D_IN;
    if (reg_2$EN) reg_2 <= `BSV_ASSIGNMENT_DELAY reg_2$D_IN;
  end

  // synopsys translate_off
  `ifdef BSV_NO_INITIAL_BLOCKS
  `else // not BSV_NO_INITIAL_BLOCKS
  initial
  begin
    reg_1 = 51'h2AAAAAAAAAAA;
    reg_2 = 51'h2AAAAAAAAAAA;
  end
  `endif // BSV_NO_INITIAL_BLOCKS
  // synopsys translate_on
endmodule  // mkGCD
```

Figure 28: Generated Verilog GCD Example (part 2)

```
//
// Generated by Bluespec Compiler, version 3.8.68 (build 8860, 2006-06-16)
//
// On Mon Aug  7 10:34:26 EDT 2006
//
// Method conflict info:
// Method: start
// Sequenced after: result
// Conflicts: start
//
// Method: result
// Conflict-free: result
// Sequenced before: start
//
//
// Ports:
// Name                         I/O  size props
// RDY_start                      O     1
// result                         O    51 reg
// RDY_result                     O     1
// CLK                            I     1 clock
// RST_N                          I     1 unused
// start_num1                     I    51
// start_num2                     I    51
// EN_start                       I     1
//
// No combinational paths from inputs to outputs
//
//
```

Figure 29: Generated Verilog Header For The GCD Example

The port information provides RTL-level information about the Verilog design. There is an entry for each port which specifies whether the port is an input or an output, the port's size in bits, and any properties of the port. The possible properties are `reg`, `const`, `unused`, `clock`, `clock gate`, and `reset`. The `reg` property indicates that there is no logic between the port and a register – if the port is an input then the value is immediately registered, and if the port is an output than the value comes directly from a register. The `const` property indicates that the value of the port never changes, it is constant. Ports with the `unused` property are not connected to any state element or other port, and so their values are unused. The `clock`, `clock gate`, and `reset` properties indicate that the port is a clock oscillator, clock gate, and reset port, respectively.

The final information in the comment is a list of any combinational paths from inputs to outputs. If there is an unregistered path from an input port `write_val` (corresponding to the `val` argument of method `write`) to an output port `read`, it will appear as follows:

```
// Combinational paths from inputs to outputs:
//   write_val -> read
```

Multiple inputs which have a combinational path to one output are grouped together, for brevity, as follows:

```
// Combinational paths from inputs to outputs:
//   (add_x,  add_y,  add_z) -> add
```

This situation arises often for read methods with arguments. Multiple outputs are not grouped; there is only ever one output listed on the right-hand side.

9 Bluesim back end

Bluesim is a cycle simulator for generated BSV designs. It is cycle-accurate with the Verilog generated for the same designs. Bluesim can output VCD files for a simulation and offers other debugging capabilities as described below.

9.1 Bluesim tool flow

When a BSV design is compiled and linked using the Bluesim back end, the compiler links the design with a driver, to produce a stand-alone executable. When the executable is invoked, the default driver "clocks" the circuit and executes it.

The Bluesim back-end compiles modules in a Bluespec design to C++ objects which contain the module data and temporaries and which define routines for executing the rules and methods of each module. In addition to the modules, scheduling routines are generated which coordinate the execution of rules throughout the entire design. Primitive modules, functions, and system tasks are implemented as elements of a library supplied with the compiler.

9.2 Bluesim simulation flags

The following flags can be given on the command line to the Bluesim simulation executable:

```
-c <commands> = execute commands given as an argument
-f <file>     = execute script from file
-h            = print help and exit
-m <N>        = execute for N cycles
-v            = print version information and exit
-V [<file>]   = dump waveforms to VCD file (default: dump.vcd)
-w            = wait for a license if none is immediately available
+<arg>        = Verilog-style plus-arg
```

The `-c` flag provides one or more commands to be executed by the simulator (see Section 9.3 for command syntax).

The `-f` flag directs the simulator to execute commands from the given script file (see Section 9.3 for command syntax).

The `-h` flags directs the simulator to print a help message which describes the available flags.

The `-m` flag forces the simulation to stop after a certain number of cycles; the default behavior is to execute forever or until the `$finish` system task is executed.

The `-v` flag directs the simulator to print some version information related to the simulation model, including the compiler version used to create it and the time and date at which it was created.

The `-V` flag causes the simulator to dump waveforms to a VCD file. If a file name is provided the waveforms will be written the named file, otherwise the default file name "dump.vcd" will be used.

The `-w` flag directs the simulator to wait for a license to become available when none is available immediately. Without the `-w` flag, the simulator will exit if it no license is available. You can generate Bluesim models which do not require a Bluesim license at runtime by using the `no-untimed-license` flag (Section 6.6).

Arguments can be passed to the simulation model with `+<arg>`. These values can be tested by the BSV model via the `$test$plusargs` system task.

9.3 Interactive simulation

The simulator can be executed in an interactive or scripted mode. Commands and scripts can be given using the `-c` and `-f` flags. Alternatively, the simulation object can be loaded directly in Bluetcl using the `sim load` command.

Bluetcl extends a TCL shell with a `sim` command whose sub-commands control all aspects of loading, executing and interacting with a Bluesim simulation object. For a list of Bluetcl `sim` sub-commands, see the Bluetcl appendix A.4.2.

There are two ways to access these simulation commands, through scripting or interactively. When a model is compiled through the Bluesim backend, it generates a `.so` file containing the simulation object. It also generates an executable program that provides a convenient way to run and use the simulation object. Passing the `-c` or `-f` flags to the executable enables scripting the simulation.

To run the simulation interactively, the standard `Bluetcl` tool should be used.

In addition to these actions accessible through the `sim` command, all of the normal functions of a TCL interpreter as well as additional Bluespec-specific extensions are available in Bluetcl and they can be freely intermixed.

Note that the TCL interpreter behaves differently when executing a script than when running interactively. In an interactive session, the TCL interpreter will print the value returned by each command (if any), but when executing a script output is only generated in response to an explicit output command (eg. `puts`).

load and unload

Before working with a Bluesim simulation object, it must be loaded – this is done automatically when using the `-c` and `-f` options but must be done manually when using `Bluetcl` directly. The full command to load a simulation object in `Bluetcl` is `sim load` followed by the name of the `.so` file.

Loading a simulation object triggers the checkout of a BSIM license, unless the object was created using the `no-runtime-license` option (Section 6.6). If you are manually loading a simulation object and would like to wait if a license is unavailable, add the keyword `wait` after the name of the `.so` file. When using the `-c` or `-f` flags, in which the model is loaded automatically, adding the `-w` flag indicates the desire to wait for a license.

A simulation object can be unloaded using the `sim unload` command. Unloading the simulation will check in the BSIM license. Any active object is automatically unloaded when the simulator exits or before loading a new simulation object, so it is not normally necessary to manually perform a `sim unload`.

arg

The `sim arg` command allows a Verilog-style plusarg to be set interactively. The command `sim arg <string>` adds the supplied string to the end of the list of plusargs searched by the `$test$plusargs` system task. The "+" character should not be included in the string argument.

run, step, stop and sync

The `sim run` command runs the current simulation to completion.

The `sim runto` command runs the current simulation to the time given as its argument.

The `sim step` command advances the current simulation for a given number of cycles of the currently active clock domain.

The `sim nextedge` command advances the current simulation until the next edge in any clock domain. The currently active domain does not change, so a subsequent `sim step` command will still execute according to the active domain regardless of the clock edge to which a `sim nextedge` command advances.

By default, these commands will not return until the requested simulation activity is complete. However, `sim step`, `sim runto` and `sim run` can be instructed to return immediately by adding the keyword `async` to the end of the command sequence (eg. `sim step 100 async`). This will cause the command to return immediately so that additional commands can be processed while the simulation continues to run asynchronously.

There are two commands that synchronize with an asynchronously spawned simulation: `stop` and `sync`. The `stop` command will pause the simulation at the end of the currently executing simulation cycle. The `sync` command will wait for the simulation to complete normally before returning.

As examples of the behavior of the `run` and `step` simulation commands, assume that we have a simulation executable named "bsim". Then

```
bsim -c 'sim run'
```

is equivalent to just

```
bsim
```

and

```
bsim -c 'sim step 100'
```

is equivalent to using the `-m` flag

```
bsim -m 100
```

Note that when a model is loaded, simulation time is at 0 and no clock edges have occurred. Stepping 1 cycle from that point will advance past the first clock edge, and if the first rising edge of the active clock occurs at time 0 then the step command will move from before the edge at time 0 to after the edge at time 0.

time

The `sim time` command returns the current simulation time.

It could be used interactively within `Bluetcl`

```
% sim load bsim.so
% sim step 10
% sim time
90
```

or within a script

```
bsim -c 'sim step 10; puts [sim time]'
90
```

clock

The `sim clock` command provides information on the currently defined clocks and allows the user to change the active clock domain used by the `sim step` command.

With no argument, the `sim clock` command returns a list containing a clock description for each currently defined clock. Each clock description is itself a list of 10 different pieces of information about the clock domain:

- a unique number assigned to the clock domain
- a flag indicating if the clock is the currently active domain (1 indicates active, 0 indicates not active)
- the textual name of the clock domain
- the initial value of the clock (0 or 1)
- the delay before the first edge of the clock
- the duration of the low clock phase
- the duration of the high clock phase
- the number of elapsed cycles of this clock

- the current value of the clock signal (0 or 1)
- the time of the last edge of the clock

Here is sample output from a `sim clock` command for a design with 2 clock domains:

```
% sim clock
{0 1 CLK 0 0 5 5 12 1 110} {1 0 {mc$CLK_OUT} 0 0 0 0 3 0 100}
```

This output indicates that there are 2 domains. The first is domain number 0 and is the currently active clock. It is called "CLK" and is initially low, rises at time 0 and then alternates every five time units. At the current simulation time, 12 cycles have elapsed in the "CLK" clock domain and its current clock value is 1, after a rising edge at time 110. The second domain is number 1 and is not the currently active clock used for stepping. It is called "mc$CLK_OUT" and we have no timing information because it is not a periodic waveform (it is internally generated in the model). At the current simulation time, 3 cycles have elapsed in the "mc$CLK_OUT" domain and its current value is 0, after a falling edge at time 100.

To change the currently active clock, simply use the `sim clock <name>` form of the command, where the name argument specifies which clock to be made active. After executing this command, future `sim step` commands will step through cycles in the newly activated clock domain.

```
% sim clock {mc$CLK_OUT}
% sim clock
{0 0 CLK 0 0 5 5 12 1 110} {1 1 {mc$CLK_OUT} 0 0 0 0 3 0 100}
```

Note that the clock name argument was quoted in curly braces so that the TCL interpreter would treat the dollar-sign in the clock domain name as a literal dollar-sign.

ls, cd, up and pwd

Bluesim allows the user to navigate through the hierarchy of module instantiations using the `sim cd` and `sim up` commands.

To move down one or more levels of hierarchy, provide a path to the `sim cd` command. The path must consist of a sequence of instance names separated by '`.`'. A path which begins with `.` is considered to be an absolute path from the top of the hierarchy, but a path which does not begin with `.` is interpreted as a path relative to the current location.

The `sim up` command is used to move up the hierarchy into parents of the current directory. It can be given a numeric argument to control how many levels to ascend, or it can be used without an argument to move up one level.

As a special case, the `sim cd` command will return the user to the uppermost point in the hierarchy if used without a path argument.

To find your current location in the module hierarchy, use the `sim pwd` command.

At any point in the hierarchy, the `sim ls` command can be used to list the sub-instances, rules and values at that level of hierarchy. The command can be given any number of patterns to control which names are listed. If no argument is given, it is equivalent to `sim ls *`.

The patterns follow the standard syntax for filename globbing:

- ?: Matches any single character

- *: Matches any number of characters (possibly none)
- [...]: Matches any character inside of the brackets
- [a-z]: Matches any character in the specified range
- [!...]: Matches any character which does not match specification inside the brackets

The instance separator character '`.`' is never matched in a pattern. The special characters `?`,`*` and `[` can be escaped in a pattern using a backslash (\).

```
% sim pwd
.
% sim ls
{b__h380 signal} {CAN_FIRE_RL_done signal} {CAN_FIRE_RL_incr signal}
{count module} {level1 module} {mid1 module} {mid2 module} {RL_done rule}
{RL_incr rule} {WILL_FIRE_RL_done signal} {WILL_FIRE_RL_incr signal}
% sim ls level1.*
{level1.level2 module}
% sim cd level1.level2
% sim pwd
.level1.level2
% sim ls RL_*
{RL_incr rule} {RL_sub1_flip rule} {RL_wrap rule}
% sim up
% sim pwd
.level1
```

lookup, get and getrange

In addition to navigating through the instance hierarchy, Bluesim allows the user to examine the simulation values at run-time, using the `sim lookup`, `sim get` and `sim getrange` commands.

To get the value for a signal, you must first obtain a "handle" for the value using the `sim lookup` command. The command takes as an argument a pattern describing the absolute or relative path to the desired signal. A relative path is interpreted in the current directory unless an optional second argument is given containing the handle to a different starting directory. `sim lookup` will return a handle for every simulation object which matches the pattern argument.

Once the handle of a signal is known, its value can be obtained using the `sim get` command. This command takes one or more handles as arguments and returns the raw values associated with the handles, as sized hexadecimal numbers.

```
% set WF_incr [sim lookup .level1.level2.WILL_FIRE_RL_incr]
150533432
% sim get $WF_incr
1'h1
% sim ls .mid?.count
{mid1.count module} {mid2.count module}
% eval sim get [sim lookup .mid?.count]
4'h9 4'h1
```

The `sim getrange` command is a specialized command to get values for handles which represent multiple values, such the storage inside of a FIFO or register file. The command takes the handle for the value range object along with either a single address or a start and end address pair.

```
% sim getrange [sim lookup rf] 0 3
16'h0 16'h1 16'h2 16'h3
% sim getrange [sim lookup rf] 2
16'h2
% sim getrange [sim lookup fifo] 0
16'h8
```

Details about the simulation object referenced by a handle can be obtained using the `sim describe` command.

vcd

The `sim vcd` command controls dumping of waveforms to a VCD file. Use `sim vcd on` to enable dumping and `sim vcd off` to disable it. The form `sim vcd <file>` enables dumping to a file of the given name, rather than the default file named "`dump.vcd`".

version

The `sim version` command prints details about the tool version used to build the current simulation object. It returns a list of 5 TCL objects: the year of the release, the month of the release, the (optional) release tag, the revision number of the release, and the time at which the object was created (as a number of seconds since the start of 1970).

An example of using the `sim version` command to print the date and time at which a simulation object was created:

```
% puts [clock format [lindex [sim version] 4]]
Fri Dec 14 01:24:39 PM EST 2007
```

9.3.1 Command scripts for Bluesim

The Bluesim simulator can be run with a command script by using the `-c` or `-f` arguments.

```
./bluesim -f script.tcl
```

The contents of the script file can be standard TCL commands or any Bluetcl command extensions, including the `sim` commands. When used in this way, some aspects of Bluesim's behavior change to be more appropriate for executing scripts:

- No prompt is displayed.
- The result of each command is not printed. An explicit `puts` should be used to print command output in a script.
- Error messages include line numbers and stack traces.
- Errors and Ctrl-C end the simulation.

No `sim load` command is required when using a script, because the model will automatically be loaded before the script is executed and unloaded on exit.

No `exit` command is required when using a script, because the simulator will automatically exit when it reaches the end of the script file.

Comments can be included in the script file by starting a line with the TCL comment character `#`.

```
# Run 300 cycles
sim step 300

# Enable dumping VCD waveforms for the next 10 cycles
sim vcd on
sim step 10
```

9.4 Value change dump (VCD) output

The Bluesim simulator supports generation of a value change dump (VCD) to record the changes in user-selected state components. VCD files are an industry-standard way to record simulator state changes for use by external post-processing tools. For example, Novas Debussy, Undertow, and gtkWave are graphical waveform display programs that can be used to browse simulator state recorded in VCD files.

The Verilog system task `$dumpvars` may be used with no arguments to request VCD for all variables. Selective dumping with this task is not supported at this time. The Verilog system tasks `$dumpon` and `$dumpoff` can be used to turn VCD dumping on and off at specific times during simulation. Specifying `-V <file>` argument or using the `sim vcd <file>` command in a script will cause the simulator to output a VCD file of that name, in which the state of all registers and the internal signals of all BSV modules are dumped at the end of each cycle.

VCD files dumped by Bluesim attempt to match VCD files generated by Verilog simulation as closely as possible. Known differences between Bluesim- and Verilog-generated VCD files are documented in the *Known Problems and Solutions* (*KPNS*) document accompanying each release.

9.5 Bluesim multiple clock domain support

The Bluesim backend supports a subset of the multiple-clock-domain (MCD) features supported by the Verilog backend, including bit, pulse and word synchronizers as well as synchronized FIFOs. However, some MCD features supported in Verilog are not supported in Bluesim:

- mkNullCrossing

A Bluetcl Reference

Bluetcl is a Tcl extension with a collection of scripts and packages providing an interface into the Bluespec view of a design; Bluewish adds the tk windowing commands to Bluetcl. This document uses Bluetcl to refer to the combination of Bluetcl and Bluewish. You can execute Bluetcl commands and scripts from a unix command line or from the command window in the development workstation.

Bluetcl contains several layers (scripts, commands, packages) which should be familiar to the Tcl programmer. You can use Bluetcl extensions within Tcl scripts. More information on Tcl is available at `www.tcl.tk` or from the many books and references written about Tcl/Tk.

A.1 Invoking Bluetcl

Bluetcl commands can be run either interactively or through Tcl scripts. These commands load, execute, and interact with Bluespec-generated files. As with the Bluespec compiler, pre-elaboration information is obtained from the `.bi/.bo` files, and post-elaboration information is obtained from the `.ba` files.

Bluetcl commands can be invoked in the following ways.

- You can invoke Bluetcl from a unix prompt by typing `bluetcl`. This command provides a Tcl shell with the Bluetcl extensions.
- You can type `bluewish` at a unix prompt. This adds the `Wish` extensions to the Bluetcl shell.
- When in the Bluespec Development Workstation, the command window provides a Bluetcl shell.
- Finally, you can write and use Tcl scripts which utilize Bluetcl. For an example of a Tcl script provided by Bluespec, see Section A.7.1.

A.2 Packages and namespaces

Bluetcl is organized into a collection of packages, which are described in this appendix. The major packages are:

- The Bluetcl package which contains the low-level commands to interact with Bluespec files and designs.
- The Bluesim package containing Bluesim command extensions.[2]
- The WS package contains commands for interacting with the workstation.

The standard Tcl packages `Itcl`, `Itk`, and `Iwidgets` are available with Bluetcl and can be used when creating your own scripts.

All commands in the `Bluetcl` package are in the `Bluetcl` namespace. All commands in the `Bluesim` package are in the `Bluesim` namespace. The commands in the `WS` package are divided into multiple namespaces.

When referencing a command you must specify the namespace. Example:

```
Bluetcl::version
```

[2]The `sim` command for interacting with Bluesim simulation objects (`.so` files) is contained in both the Bluetcl and Bluesim packages.

Alternately, you can import commands from a namespace. The following example imports all the commands in a namespace:

```
namespace import ::Bluetcl::*
```

Or you can import a single command:

```
namespace import ::Bluetcl::schedule
```

Since the `WS` package contains multiple namespaces, you must specify the full namespace when referencing a `WS` command or importing the commands from the namespace. Example:

```
WS::Build::link
namespace import ::WS::Build::link
```

Refer to the `Tcl` documentation for additional information on packages and namespaces.

A.3 Customizing Bluetcl

You can use Bluetcl, along with all standard Tcl constructs, to write scripts, issue commands, and customize the development workstation. Bluetcl, Bluewish, and the development workstation all source the setup file `$HOME/.bluetclrc` during initialization. You can customize Bluetcl and the development workstation by adding to the `.bluetclrc` file.

The `namespace import` command can be put in the `.bluetclrc` file, providing the command into the current namespace when the file is sourced. This will allow you to use just the command name in scripts or from the command line.

A.4 General Bluetcl package command reference

A.4.1 Conventions

The following conventions are used within the command reference:

name	identifier
keyword	as is
[...]	optional
{...}	repeated

Note: For repeated arguments ({ }), one or more arguments may be specified. If only one item is specified, no brackets ({ }) are necessary. If multiple arguments are specified the list must be enclosed in brackets.

A.4.2 Bluetcl

This sections describes the commands in the Bluetcl package. These commands provide a low-level interface to access Bluespec-specific files (`.bo/.bi/.ba`) for use by Tcl programmers; they are not intended for interactive use.

Before using a command from the Bluetcl package, the following Tcl command must be executed, either in a script, from the command line, or in the `.bluetclrc` file:

```
package require Bluetcl
```

All commands in the `Bluetcl` package are in the `Bluetcl::` namespace. The namespace must be referenced, as described in Section A.3, either by using the `namespace import` command or by prepending the command name with `Bluetcl::`. Example:

```
Bluetcl::bpackage list
```

Bluetcl::bpackage

Controls loading and unloading of packages and returns package information. When a package is loaded, all dependent (imported) packages are loaded as well.

bpackage load *packname*	Reads in the .bi/.bo package and all imported packages. Packages are searched in the standard bsc way, via the `-p` flag. Returns a list of all packages which are loaded.
bpackage list	Returns the list of packages which are loaded.
bpackage clear	Clear all currently loaded packages.
bpackage depend	Returns package dependencies of all currently loaded packages.
bpackage search *regex*	Searches packages for names matching a regular expression.
bpackage types *packname*	Returns a list of type names found in the package.

Bluetcl::defs

Returns a list of the components defined in a package. Components returned include types, synthesized modules, and functions.

defs all {*packname*}	Returns a list of all components which are defined in the package.
defs type {*packname*}	Returns a list of all types which are defined in the package.
defs module {*packname*}	Returns a list of all module names defined in the package which are marked synthesize.
defs func {*packname*}	Returns a tagged structure list of all functions which are defined in the package.

Bluetcl::flags

Returns or sets the status of flags used by the Bluespec compiler.

flags show {*flagname*}	Show the value of the specified flags.
flags set {*flagname* = *value*}	Set the flags to the value provided. Multiple flags may be set in a single command.

Bluetcl::help

Help with no arguments will list all available help topics. Optionally, an argument can be provided to get help on a specific topic. Also, 'help list' will return a string listing the names of all commands.

help	Returns a list of all help topics.
help list	Returns a string listing the name of all commands
help *command*	Returns help for the specified command.

Bluetcl::module

Returns information on synthesized (post elaboration) modules.

module load *modname*	Loads the module and all instantiated submodules into the workstation. Returns a list of the modules loaded.
module clear	Clear all loaded modules
module submods *modname*	Returns a 3-tuple. The first element of the tuple is a tag (primitive or user), the second is a list of pairs contain the synthesized submodule name and its interface type. The third element is a list of function which have not been in-lined.
module rules *modname*	Returns a list of rule names in the module.
module ifc *modname*	Returns a list of interface types in the module.
module methods *modname*	Returns a list of the flattened methods in the module.
module ports *modname*	Returns a list of the ports in the module.
module porttypes *modname*	Returns a list of the types of the ports in the module.
module list	Returns a list of all loaded modules.

Bluetcl::rule

Returns information about rules in a post elaboration module.

rule rel *modname* {*rule1 rule2*}	Shows the relationship between two rules in the module.
rule full *modname rule*	Returns a tagged structure detailing the rules position, predicates expression, attributes and method calls.

Bluetcl::schedule

Returns scheduling information for a synthesized module. The `schedule` command requires a subcommand and the module name.

schedule execution *modname*	Returns a list of rule/method names in execution order. For example, if `r1` fires after `r2`, then the output would be: `RL_r1 RL_r2`.
schedule methodinfo *modname*	Returns scheduling relationships between all pairs of methods.
schedule pathinfo *modname*	Returns a list of combinational paths through the module. Each element is a list of two elements: a list of inputs and an output that they connect to.
schedule urgency *modname*	Returns a list of lists, one for each rule/method, in urgency order. Each lists contains two elements: the rule name and a list of rules which would block that rule from firing.
schedule warnings *modname*	Returns a list of scheduling warnings. The result is a list of three elements: the position of the warning, the tag for the warning, and the complete warning message.

Bluetcl::sim

Controls all aspects of loading, executing and interacting with a Bluesim simulation object. These commands are used when running Bluesim interactively, as described in section 9.3.

This command is also provided in the `Bluesim` package. See section A.4.3 for the complete definition.

Bluetcl::submodule

Returns information about each submodule and which rules use the methods of the submodule.

submodule full *modname*	Returns information about each submodule in the specified module and the rules which use the methods of the submodule.

Bluetcl::type

Finds and returns type information.

type constr *typename*	Shows the type constructor for the provided type name. The type constructor is the type arguments needed for the type. Returns an error if the typename is not found in any of the loaded packages.
type full *typeconstructor*	Returns a tagged structure based on the type constructor argument. The type constructor provided must be fully qualified.

Bluetcl::version

Returns the current compiler version

version	Returns a list of 3 items: the compiler version, the version date, and the build version. The compiler version is provided in year-month-(annotation) format.

A.4.3 Bluesim

The Bluesim package contains the `sim` command which controls Bluesim interactive mode. This command is also found in the `Bluetcl` package.

Before using a command from the Bluesim package, the following Tcl command must be executed, either in a script, from the command line, or in the `.bluetclrc` file:

```
package require Bluesim
```

All commands in the `Bluesim` package are in the `Bluesim::` namespace. The namespace must be referenced, as described in Section A.3, either by using the `namespace import` command or by prepending the command name with `Bluesim::`. Example:

```
Bluesim::sim clock
```

sim

Controls all aspects of loading, executing and interacting with a Bluesim simulation object. These commands are used when running Bluesim interactively, as described in section 9.3. This command is also provided in the `Bluetcl` package (A.4.2).

sim arg *string*	Set a simulation plus-arg. Adds the supplied *string* to the end of the list of plusargs searched by the `$test$plusargs` system task.

sim cd [*path*]	Change location in hierarchy. The path must consist of a sequence of instance names separated by a period (`.`). A path which begins with a `.` is an absolute path from the top of the hierarchy, but one which does not begin with a `.` is relative to the current location. No provided *path* will return the user to the uppermost point in the hierarchy.
sim clock	Returns a list containing a clock description for each currently defined clock.
sim clock [*name*]	Select the named clock, make it the active clock.
sim describe*handle*	Describe the object to which a symbol handle refers.
sim get *handle*	Returns the simulation value for the object with the provided *handle*. The value is returned as a sized hexadecimal number.
sim getrange *handle addr*	Get simulation values from a range.
sim load *model [wait]*	Load a bluesim model object. Checks out a BSIM license. Use the `wait` argument to wait for an available license.
sim lookup *pattern* [*root*]	Lookup symbol handles. Returns a handle for every simulation object which matches the *pattern*.
sim ls *pattern**	List the sub-instances, rules and values at that level of the hierarchy. If a *pattern* is provided, it controls which names are listed. No pattern is equivalent to `sim ls *`.
sim nextedge	Advance simulation to the next clock edge in any domain.
sim pwd	Print current location in hierarchy.
sim run [**async**]	Run simulation to completion. The keyword `async` cause the command to return immediately so that additional commands can be processed while the simulation continues to run asynchronously.
sim runto *time* [**async**]	Run simulation to a given time. The keyword `async` cause the command to return immediately so that additional commands can be processed while the simulation continues to run asynchronously.
sim step [*cycles*] [**async**]	Advance simulation a given number of cycles. The keyword `async` cause the command to return immediately so that additional commands can be processed while the simulation continues to run asynchronously.
sim stop	:stop the simulation at the end of the currently executing simulation cycle.
sim sync	Wait for simulation to complete normally before returning
sim time	Display current simulation time.
sim unload	Unload the current bluesim model. Checks in the BSIM license.
sim up [*N*]	Move up the module hierarchy into the parents of the current directory. It will move up `N` levels if N is provided.
sim vcd [**on** | **off** | *file*]	Control dumping waveforms to a VCD file named *file*. If no file name is provided, it will use the default file `dump.vcd`.
sim version	Show Bluesim model version information.

A.4.4 Types

Before using a command from the `Types` package, the following Tcl command must be executed, either in a script, from the command line, or in the `.bluetclrc` file:

```
package require Types
```

All commands in the `Types` package are in the `Types::` namespace. The namespace must be referenced, as described in Section A.3, either by using the `namespace import` command or by prepending the command name with `Types::`. Example:

```
Types::import_package packagename
```

import_package

This command is used to load or reload packages into the workstation.

import_package *packname*	Loads the necessary package information into the workstation. You can use the command to reload a package or add additional packages.

show_types

Returns information on the types in a design.

show_types *packname*	Shows all the type constructors found in the package.
show_type_size *Type*	Shows the expanded sub-fields and structure positions of *Type*. Type must be non-polymorphic, i.e. `Maybe#(Int#(1))` is acceptable, but not `Maybe#(a)`.
show_type_field *Type position*	Similar to the `show_type_size` command, except it only shows the field of the structure which contains the bit at the specified *position*.

A.4.5 InstSynth

The `InstSynth` package contains scripts to generate instance specific synthesis in Bluespec SystemVerilog. These scripts use Bluespec's typeclass and overloading to match a module's instantiation with a specific instance which may instantiate a synthesized module.

When using any of the commands in the `InstSynth` package, the package must be loaded first.

```
package require InstSynth
```

The `InstSynth` package contains the commands `genTypeClass`, `genSpecificInst`, and `genSynthMod`.

InstSynth Commands	
`genTypeClass`	**genTypeClass** *packname* {*modname*}
	Creates an include file for a package containing a typeclass for overloading of a module and a default instance for the module. Multiple modules within the same package can be specified in a single command.
`genSpecificInst`	**genSpecificInst** *packname modname type*
	Modifies the *packname*`.include.bsv` file with an instance for each missing type.
`genSynthMod`	**genSynthMod** *packname modname type*
	Generates a synthesize module wrapper for a given module and type within a package. The generated module is returned as a string from this function.

Example using InstSynth.tcl to generate instance specific synthesis modules

Overview: This example demonstrates how to use the `InstSynth.tcl` package to use Bluespec's typeclass and overloading to match a module's instantiation with a specific instance to instantiate a synthesized module.

The example is composed of three `.bsv` files: `m1.bsv` which contains the module definition for `mkM1`, `m2.bsv` which contains the module definition for `mkM2` and instantiates multiple instances of `mkM1`, and `Top.bsv` containing the testbench `mkTb`. The two modules `mkM1` and `mkM2` are polymorphic. The testbench `mkTb` instantiates `mkM2` and is not polymorphic.

The polymorphic modules are instantiated in the hierarchy as shown in figure 30.

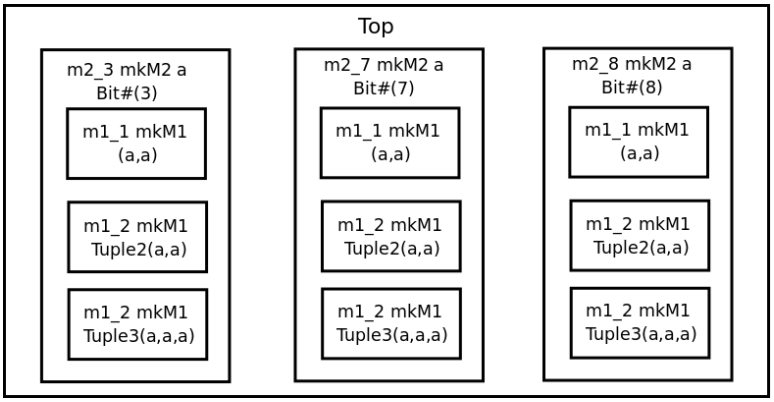

Figure 30: Example Module Hierarchy

Steps for using InstSynth

1. Compile your design with bsc as normal, creating the `.bi` and `.bo` files.
2. Generate typeclass and default instances for modules with the `genTypeClass` command, specifying the packages and modules for instance specific synthesis. The `genTypeClass` command will generate an include file (`<package>.include.bsv`) for each package.

The include file will contain a type class (named `MakeInst_<module>`) for each module and a general catch-all instance of that type class.

The type class contains one method, which is a module constructor. The method is named `<module>_Synth` and has the same arguments as the general polymorphic module. The instance of this type class is a thin wrapper which instantiates the polymorphic module and prints a message about the type which is synthesized.

Example of the include file for `m1.bsv` (`m1.include.bsv`) after this step:

```
typeclass MakeInst_mkM1 #(type ifc_t);
    module mkM1_Synth ( ifc_t ifc) ;
endtypeclass

instance MakeInst_mkM1 #(  ClientServer::Server#(a, a) )
    provisos (Bits#(a, sa)) ;

    module mkM1_Synth ( ClientServer::Server#(a, a) ifc) ;
        let _i <- mkM1  ;
        messageM ("No concrete definition of mkM1 for type " +
                    (printType (typeOf (_i))));
        messageM ("Execute: InstSynth::genSpecificInst m1 mkM1 {" +

                    " {" + (printType (typeOf(asIfc (_i)))) + "}"
                    + " }"  );
        return _i ;
    endmodule
endinstance
```

3. Manually edit the `.bsv` file to include the generated file. For example, add the line `‘include "<package>.include.bsv"` at the bottom of the file for `<package>`. In this example, you would add the line `‘include "m1.include.bsv"` to the file `m1.bsv`.

4. Manually edit the `.bsv` file to change the module constructor from `<module>` to `<module_Synth>` at each point you would like an instance synthesized. In this example, change `mkM1` to `mkM1_Synth` in the `m2.bsv` file, and change `mkM2` to `mkM2_Synth` in the `Top.bsv` file where you want to synthesize an instance.

5. Compile the design again with bsc. The compile will generate messages listing mising instances along with the `genSpecificInst` command to create each missing instance. Execute the commands one at a time to generate an instance for each missing type.

   The `genSpecificInst` command will modify the `include.bsv` files, adding the instances. For example, in this step, the following lines are added to the `m1.include.bsv` file to resolve the `Server#(a,a)` type.

```
module mkM1__ClientServer_Server_Bit_3_Bit_3_(
                            ClientServer::Server#(Bit#(3), Bit#(3)) ifc ) ;
    let _i <- mkM1  ;
    return _i ;
endmodule

instance MakeInst_mkM1 #( ClientServer::Server#(Bit#(3), Bit#(3)) ) ;
    module mkM1_Synth ( ClientServer::Server#(Bit#(3), Bit#(3)) ifc );
        let _i <- mkM1__ClientServer_Server_Bit_3_Bit_3_  ;
        messageM("Using mkM1__ClientServer_Server_Bit_3_Bit_3_ for mkM1 of
```

```
                type: " +
                  (printType (typeOf (_i))));
          return _i ;
      endmodule
endinstance
```

Note that the code added in this step does not add to or change the behavior of the design. Only the additional hierarchy is added.

6. Add provisos to the polymorphic modules to avoid early binding of the module. Otherwise compiling at this point will not show the specific instances because the instance of the `_Synth` is bound before the specific type of the module is known. In this example, `mkM1_Synth` would be bound before the specific type of `mkM2` is known. To fix this, provisos are added to the polymorphic module `mkM2`. The module `mkM2` has three instantiations of `mkM1`, therefore a proviso for each instantiation is added.

```
module mkM2 (Server#(a,a)) provisos (Bits#(a,sa)
                     ,MakeInst_mkM1#(Server#(a,a))
                     ,MakeInst_mkM1#(Server#(Tuple2#(a,a),Tuple2#(a,a)))
                     ,MakeInst_mkM1#(Server#(Tuple3#(a,a,a),Tuple3#(a,a,a)))
                     );
```

7. Compile with bsc again.

8. Continue until there are no missing instance messages. A Verilog file will be created for each synthesized module instance.

SynthInst Example Files

m1.bsv: Module `mkM1` is defined in the package (file) `m1.bsv`:

```
import ClientServer :: *;
import GetPut :: *;
import FIFOF :: * ;

module mkM1 (Server#(a,a))    provisos (Bits#(a,sa));
   FIFOF#(a) fifo <- mkFIFOF;

   interface request = toPut (fifo);
   interface response = toGet (fifo);
endmodule
```

m2.bsv: Module `mkM2` is defined in the package `m2.bsv`. Note that there are three instantiations of `mkM1`. You can choose to synthesize any or all of the instances.

```
import FIFO::*;
import GetPut::*;
import ClientServer::*;
import m1 :: *;

module mkM2 (Server#(a,a))    provisos (Bits#(a,sa)
   Server#(a,a) m1_1 <- mkM1;
   Server#(Tuple2#(a,a),Tuple2#(a,a)) m1_2 <- mkM1;
```

```
   Server#(Tuple3#(a,a,a),Tuple3#(a,a,a)) m1_3 <- mkM1;

   rule r0;
      let { x1,x2 } <- m1_2.response.get();
      m1_3.request.put (tuple3 (x1,x2,x2));
   endrule

   interface Put request;
      method Action put (a x);
         m1_2.request.put (tuple2(x,x));
      endmethod
   endinterface

   interface Get response;
      method ActionValue#(a) get ();
         let { y1,y2,y3 } <- m1_3.response.get();
         return (y1);
      endmethod
   endinterface
endmodule
```

Top.bsv: The testbench is contained in the file `Top.bsv`

```
import ClientServer :: *;
import GetPut :: *;
import m2 :: *;

(* synthesize *)
module mkTb (Empty);
   Reg#(int) cycle <- mkReg (0);

   Server#(Bit#(3), Bit#(3)) m2_3 <- mkM2;
   Server#(Bit#(7), Bit#(7)) m2_6 <- mkM2;
   Server#(Bit#(8), Bit#(8)) m2_8 <- mkM2;

   rule r1;
      $display ("%0d: r1: put (%0d)", cycle, cycle);
      m2_3.request.put (truncate (pack (cycle)));
      m2_6.request.put (truncate (pack (cycle)));
      cycle <= cycle + 1;
      if (cycle > 8) $finish(0);
   endrule

   rule r2;
      let x_3 <- m2_3.response.get ();
      let x_6 <- m2_6.response.get ();
      $display ("%0d: r2: %0d,%0d <= get", cycle, x_3, x_6);
   endrule
endmodule
```

A.5 Workstation package command reference

The `WS` package provides a programming interface to customize the workstation. Specifically, commands available from the workstation menus and toolbars can be executed from the workstation

command line or included in `Tcl` scripts which are executed from the workstation. These commands are only available in the workstation. Attempting to use them in Bluetcl or Bluewish will result in an error.

Tcl scripts using `WS` commands must be added to the `.bluetclrc` file.

The `WS` package is divided into several sub-namespaces. To execute a command you must either specify the full path, including the package and namespace, or import the namespace before executing the command.

For example, to execute the link command, in the workstation command line you would type:

```
WS::Build::link
```

Or, you could import the `Build` namespace, then execute the command:

```
namespace import ::WS::Build::*
link
```

The namespace only has to be imported once in a session. After it has been imported, you can execute any of the commands in the namespace without providing the full path name. The `Tcl` documentation provides additional information on using namespaces.

A.5.1 Help

The `help` command is in the `WS` namespace. Examples:

```
WS::help
WS::help -command reload_packages
```

help	Displays help for the `help` command.
[**-list**]	Displays all available WS commands.
[**-content**]	Activates Help → Content window.
[**-bsv**]	Activates Help → BSV window.
[**-about**]	Activates Help →About window.
[**-command** *command_name*]	Displays help for the specified command

A.5.2 WS::Analysis

The `Analysis` namespace contains the workstation commands used to analyze the current design and populate the workstation browser windows.

Example:

```
WS::Analysis::get_schedule_warnings
```

load_module *module_name*	Loads the specified module.
module_collapse_all	Collapses the hierarchical view to show only module list.
reload_module *module_name*	Reloads the currently loaded module.
add_type *type*	Adds the specified type/types to the Type Browser window.

type_collapse_all	Collapses the type hierarchy.
import_hierarchy [*package_name*]	Shows the imports hierarchy for the specified package or the top file in a separate window.
load_package *package_name*	Loads a package with the specified name.
package_collapse_all	Collapse the hierarchical view to show only package list.
package_refresh	Refreshes the package hierarchy.
reload_packages	Reloads all loaded packages.
remove_type *key*	Removes information for specified type from the Type Browser window.
search_in_packages *pattern* [**-next** | **-previous**]	Searches for the pattern in the package hierarchy. If not specified defaults to **-next**.
get_execution_order [*module_name*]	Displays rules and methods for the specified module in the Schedule Analysis window.
get_method_call [*module_name*]	Displays the Method Call perspective of the Schedule Analysis window for the specified module.
get_rule_info *rule_name*	Displays information for the specified rule in the Rule Order perspective of the Schedule Analysis window.
get_rule_relations *rule1 rule2*	Displays relations for the given pair of rules in the Rule relations perspective of the Schedule Analysis window. In case of multiple rules *rule* should be given in "" quotes
get_schedule_warnings [*module_name*]	Displays warnings occurred during scheduling for the specified module in the Schedule Analysis window.
show_schedule *module_name*	Opens the Schedule Analysis window for the specified module.

A.5.3 WS::Build

The `Build` namespace contains the workstation commands available on the Build menu.

Example:

```
WS::Build::link
```

clean	Removes compilation/simulation specific result files.
compile	Compiles the current project with already defined options.
compile_file *file_name* [**-withdeps**] [**-typecheck**]	Compiles the specified file. Consider file dependencies Typecheck only
full_clean	Removes all logs and result files created during last compilation/simulation. If compilation via makefile has been defined then appropriate target will be executed.
link	Links the project

simulate	Calls simulator for the current project with already defined options.

typecheck	Typechecks the current project with already defined options.

A.5.4 WS::File

The `File` namespace contains the commands used to open files and create new files. A file is opened with editor specified in the project options.

new_file *file_name* [**-path** *location*]	Creates a new file and launches the editor on it.

open_file *location* [**-line** *number*] [**-column** *number*]	Launches the editor line number and column number where filed opened

A.5.5 WS::Project

The `Project` namespace contains the commands to manage projects, including creating new projects, opening and closing projects, and the actions to set and get project options for the current project.

Example:

```
WS::Project::close_project
```

backup_project*archive_file_name* [**-input_files**] [**-project_dir**] [**-search_path**] [**-options** *option*] [**-search_path_files** *file_ext*]	Archives the project to the file named. Include all input files. Include all files in project directory. Include files on search path Options for tar command Include files in search path with these extensions only.

close_project	Closes the current project without saving any changes.

get_bluesim_options	Returns Bluesim options for the current project.

get_bsc_options	Returns bsc options for the current project.

get_compilation_results_location	Returns paths where compilation results are located.

get_compilation_type	Returns compilation type (bsc or make) for current project.

get_link_bsc_options	Returns link bsc options for the current project.

get_link_custom_command *command*	Returns link custom command for the current project.

get_link_make_options	Returns link make options for the current project.

get_link_type	Returns link type for the current project.

get_make_options	Returns compile make options.

get_project_editor	Returns editor specific information for the current project.

get_sim_custom_command *command*	Returns simulation custom command for the current project.

get_top_file	Returns top file and top module for the current project.

get_verilog_simulator	Returns verilog simulator for the current project.

new_project *project_name* [**-location** *project_path*] [**-paths** {*search_path_location*}]	Creates a new project with the project_name. project location Search path separated by **;**

open_project *project_file*	Opens the specified project.

refresh [*file_name*]	Refreshes information about current project.

save_project	Saves all information related to the current project.

save_project_as *project_name* [**-path** *location*]	Saves current project with a new name. Can optionally specify a new location.

set_bluesim_options	Specifies bluesim options for the current project.

set_bsc_options **-bluesim** | **-verilog** [**-options** *options*]	Specifies bsc compile options for the current project. Target (Bluesim or Verilog) Additional options

set_compilation_results_location [**-vdir** *location*] [**-bdir** *location*] [**-simdir** *location*]	Specifies paths where the compilation results should be written. Verilog output bsc files simulation results

set_compilation_type **bsc** | **make**	Specifies the compilation type for the current project. Must be either **bsc** or **make**.

set_link_bsc_options *filename* [**-bluesim** | **-verilog**] [**-path** *directory]* [**-options** *option*]	Specifies link bsc options for the current project. Link via Bluesim or Verilog

set_link_custom_command *command*	Specifies link custom command for the current project.

set_link_make_options *Makefile* [**-target** *target*] [**-clean** *target*] [**-fullclean** *target*] [**-options** *options*]	Specifies link make options Name of Makefile Name of Build target Name of Clean target Name of Full clean target Options for make command

set_link_type *type* **bsc** | **make** | **custom_command**	Specifies link type for the current project. Must be **bsc**, **make**, or **custom_command**

set_make_options *Makefile* [**-target** *target*] [**-clean** *target*] [**-fullclean** *target*] [**-options** *options*]	Specifies compile makefile and make options. Name of Build target Name of Clean target Name of Full clean target Options for make command

set_project_editor *editor_name* [**-command** *command*]	Specifies editor for the current project. Command used to launch editor

set_search_paths {*location:location* }	Adds search paths to the current project. Directories are separated by :

set_sim_custom_command *command*	Specifies simulation custom command for the project.

set_top_file *file* [**-module** *module_name*]	Specifies top file for the current project. Optional top module.

set_verilog_simulator *simulator_name* [**-options** *options*]	Specifies verilog simulator for the current project.

A.5.6 WS::Wave

The `Wave` namespace contains the commands used with the waveform viewer.

Example:

```
WS::Wave::reload_dump_file
```

attach_waveform_viewer	Attaches to the waveform viewer.

get_nonbsv_hierarchy *hier*	Returns the hierarchy for the current waveform viewer.

get_waveform_viewer	Returns the waveform viewer for the current project.

load_dump_file *dump_file_path*	Loads the dump file.

reload_dump_file	Reloads the currently loaded dump file.

set_nonbsv_hierarchy *hier*	Specifies the hierarchy for the waveform viewer.

set_waveform_viewer *viewer_name* [**-command** *command*] [**-options** *options*] [**-close 0 or 1**]	Specifies the waveform viewer for the current project. Command to launch the viewer. Viewer options 1 to close viewer on Bluespec close

start_waveform_viewer	Starts the specified waveform viewer.

A.5.7 WS::Window

The `Window` namespace contains the commands to show, minimize, and close the windows and graphs in the workstation.

Example:

```
WS::Window::show -package
```

close_all	Closes all currently opened windows.

minimize_all	Minimizes all currently active windows except the main window.

show	Activates the specified window. If the window is already active then focus will be set on it.
-project	Project Files window.
-editor	Editor window.
-schedule_analysis	Schedule Analysis window.
-module_browser	Module Browser window.
-type_browser	Type Browser window.
-package	Package Browser window.

show_graph	Activates or sets focus on the specified graph window.
-conflict	conflict graph
-exec	execution order graph
-urgency	urgency graph
-combined	combined graph
-combined_full	combined full graph

A.6 Customizing the Workstation

The files `.bluetclrc` and `/.bluespec/setup.tcl` can be edited to customize the workstation. The file `.bluetclrc` is used to add Bluetcl commands and scripts to the workstation and is sourced when the workstation is started. The file `/.bluespec/setup.tcl` contains the default settings for project options and is read when a new project is created. All other files in `/.bluespec` are used by the workstation and must not be edited.

A.6.1 Bluetcl interpreters in the workstation

The Bluespec workstation uses two separate interpreters: the main interpreter controls all the windows and the state of the workstation, while the second, slave interpreter is the user command shell in the main window. Both interpreters source the file `$HOME/.bluetclrc`, which is where you add your customizations. Each interpreter is independent from the other; it has its own name space for commands, procedures, and global variables, as described in the standard Tcl documentation.

Customization for the workstation interpreter is limited to adding toolbar items. The user command interpreter has the same flexible features of Bluetcl, plus the commands from the `WS` namespaces to interface with the workstation. To annotate the different interpreter use, global variables are defined. For the main interpreter, the global variable `bscws` is defined. For the command shell, the global variable `bscws_interp` is defined.

Workstation customizations can be added to the `.bluetclrc` file as well, but since those commands are only valid when using the workstation, their execution must be conditional on the global variable.

A.6.2 Adding items to the toolbar

To add a new item to the toolbar, use the Bluetcl command `register_tool_bar_item` which has the following prototype:

```
proc register_tool_bar_item itemname "command" iconfilename "helpstring "
```

Example: Customizing the Workstation

In this example three additional toolbars items are added. The first displays the Bluespec version, the second launches a window for a command named `simplePopUp`, and the third automates a common series of tasks. You can execute the `simplePopUp` script from either the toolbar or from a Bluewish prompt. The proc `waveFormLoad` will not work outside the workstation.

The bottom of the example demonstrates how to customize the workstation command window, in this case by importing the Build commands from the WS namespace.

To use these commands add them to the `.bluetclrc` file.

```
##########################################
## Customizations for the Bluespec Development Workstation
## Add 3 items to the toolbar
```

```
if { [info exists bscws] } {
   puts "Customizing the Bluespec Development workstation"

   # Print out the version
   register_tool_bar_item myVersion "puts {[Bluetcl::version]}" Bluespec.gif "Version"
   # Simple popup window example
   register_tool_bar_item myGlobals "simplePopUp" cog.gif "Simple PopUp Script"
   # Grouping common actions in the WS.
   register_tool_bar_item bu "waveFormLoad" add.gif "Show module browser"

}

# Simple pop up window callable from the toolbar or command line
proc simplePopUp {} {
   package require Tk
   set msg "Popup window example for customizing Bluespec\nVersion
[Bluetcl::version]"
   tk_messageBox -icon info -message $msg -title "Pop Up Window"
}

# Script to automate a common task
# This will from a workstation toolbar, or Workstation command window
# but will not work outside the workstation
proc waveFormLoad {} {
   WS::Window::show -module_browser
   WS::Analysis::load_module [WS::Project::get_top_module]
   WS::Wave::start_waveform_viewer
   after 10000
   WS::Wave::load_dump_file dump.vcd
}


## Customizations for the workstation command line
if { [info exists bscws_interp] } {

   # Import all the Build commands into the command interp
   # I.e.  compile, link, simulate
   namespace import WS::Build::*
}

#########################################################################
```

A.7 Bluetcl Scripts

Scripts are self-contained commands you run from a shell. A Tcl script may be include any combination of Bluetcl and Tcl commands.

The scripts described in this section are provided by Bluespec in the `$BLUESPECDIR/tcllib/bluespec` directory. To execute a script, type the fully qualified script name. For example, to execute the `expandPorts` script from a command prompt you would type:

```
$BLUESPECDIR/tcllib/bluespec/expandPorts.tcl
```

If you are already in a Tcl shell, type `exec` before the script name:

```
exec $BLUESPECDIR/tcllib/bluespec/expandPorts.tcl
```

To execute your own Tcl scripts from within the Bluespec development workstation they need to be added to the workstation in the `~/.bluetclrc` file.

A.7.1 expandPorts

Script to create a Verilog wrapper file which expands structures into separate Verilog ports.

Usage:

expandPorts.tcl {options} *packname modname module.v*

options	Optional command line switches:
-p *path*	path, if supplied to the bsc command
-verilog	compile to verilog (default)
-sim	compile to bluesim
-include *outfile*	output file for `include.vh`
-wrapper *outfile*	output file for `wrapper.v`
-rename file.tcl	Tcl script creating rename pin structure
-makerename	Create empty `.rename.tcl` file to edit for `-rename`
-interface *name*	Interface to expand - defaults to package name (*packname*)
packname	Name of the input `.bo` file.
modname	Name of the top level module.
module.v	bsc generated Verilog (`.v`) file for the module being wrapped.

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