ClearSpeed™

Software Development Kit

Reference Manual

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1 SDK overview

This manual describes ClearSpeed's Software Development Kit (SDK) for its CSX processors.

This manual assumes you are already familiar with the CSX processor architecture and programming concepts. An overview of the architecture can be found in the respective Core Architecture Manual. Programming concepts are described in *SDK Introductory Programming Manual [3]* provided with the SDK.

1.1 A brief description of the software development tools

The tool chain contains all the tools necessary to compile, run and debug programs on ClearSpeed's simulators and hardware. The main tools used in the tool chain are:

`cscn`	Compiler driver. This controls the following stages of processing:
	`cscpp`: A standard C macro preprocessor
	`cncc`: **C^n** language compiler
	`mass`: Macro assembler
	`cld` : The object code linker
`arcs`	Library archive builder.
`isim`	Functional (instruction set) simulator.
`csgdb`	Debugger based on GDB.
`csdump`	This tool converts an object file in to a human readable form, including a disassembly listing.

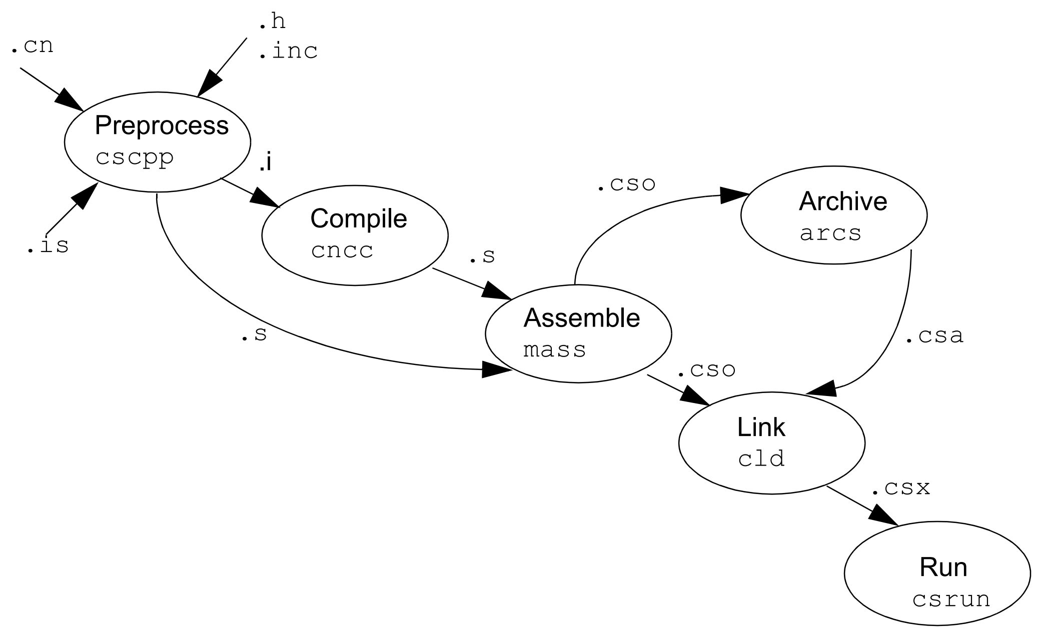


Figure 1.The ClearSpeed software tool chain

Each of the tools is described in detail in later chapters.

The following tools are also used when running code:

- `csrun` : A simple host application program to load the code and provide basic I/O facilities.
- `csreset` : A tool to reset the simulator or hardware to a known state.

These tools are part of the runtime support for the Advance^{TM} Accelerator cards and are documented in the *CSX600 Runtime Software User Guide [4]*.

The tools have a standard command line interface and use a common set of command-line options as well as options specific to each tool. The generic tool options are described in *Section 1.2.3: Generic options on page 14*.

All the tools use a configuration file which stores a number of configurable values appropriate for the target architecture (see *Section 1.9: Configuration file on page 17*). All of the values defined in the configuration file can be overridden from the command line to make it easier to configure individual tools.

Note: There are versions of the SDK tools for Linux and Microsoft Windows. The files are, in general, compatible between the two and object files compiled on one platform can be used on the other. Because of the different conventions for marking the end of line, some tools may have problems with source files copied from other systems. Use your editor or a standard system tool (for example,`dos2unix`) to convert the files if necessary.

1.2 Command line

The command line for each tool consists of the command name followed by a series of *arguments*. These arguments can be categorized as *operands* and *options*. The operands are typically names of input files. Options provide further control over the behavior of the program.

In general, operands and options can be provided in any order and some options can be specified multiple times to provide multiple values. The order of some operands and options is significant as, for example, it may determine the order in which files are processed.

1.2.1 Syntax

The following notation is used to describe the command line arguments:

`filename`	an argument which is to be substituted with a value is shown in italics
`true	false`	a choice of literal values for an argument
`[`*`option`*`]`	an optional argument is shown in brackets
`[`*`option`*`]*`	an optional argument that can be repeated zero or more times
`[,`*`argument`*`]*`	an optional argument that can be repeated zero or more times separated by commas

Any other characters, such as '`=`', appear literally in the argument.

1.2.2 Options

Command-line options are used to control the behavior of the tools. There are a set of generic options and options specific to each tool.

Many of the options have both long and short forms. The short forms are usually a single character. The long forms are prefixed by a double dash, `--`, and the short forms by a single dash, `-`. The long and short forms are otherwise identical in their use and function.

Some options require a following argument as a value for that option. For example, the `--output` option is followed by the file name to be used for the output from the command.

Command-line options which are unrecognized are ignored and a suitable warning is printed.

1.2.3 Generic options

These are options which are not specific to a specific tool. These options are shown in *Table 1*.

Long name	Short name	Valid values	Description
`--help`	`-h`		Displays a list of command options and exits.
`--output`	`-o`	*`filename`*	Specifies the output file name.
`--verbose`	`-v`		Switches on verbose output.
`--version`	`-V`		Outputs version information for a utility and exits.

Table 1. Generic command-line options

Command-line options for each tool are described in the appropriate chapter.

1.3 File naming conventions

A number of standard file name extensions are used by convention throughout the tool chain, as follows:

`.cn`	**Cⁿ** language source file
`.h`	**Cⁿ** include file
`.csi`	Preprocessed **Cⁿ** source file
`.is`	Assembler source file
`.inc`	Assembler include file
`.s`	Preprocessed assembler source
`.cso`	Object file
`.csa`	Library file
`.csx`	Executable file

1.4 Libraries

The SDK includes most of the standard C libraries. Some functions, such as file I/O, which are not appropriate for an embedded co-processor core may not be supported on all architectures.

Most of the library functions will be provided as both mono and poly variants.

The default search path for libraries is specified by the `CSLIB` environment variable.

1.5 Header files

The reference manual for the libraries is provided as a separate document *The C^n Standard Library Reference Manual [2]*.

A set of standard header files are provided with the libraries. These define the function prototypes for the standard (mono) and poly variants of the library functions, and some other macro definitions relevant to the ClearSpeed SDK.

The default search path for **C^n** and assembler header files is specified by the `CSINC` environment variable.

1.6 Environment variables

The toolchain uses a number of environment variables to specify various parameters such as the search paths for various files. These are listed in *Table 2*.

Environment variable	Description
`CSINC`	The default search path for included header files.
`CSLIB`	The default search path for library (`.csa`) files.
`CSPATH`	The default search path for executable, configuration and instruction set files.
`CLEARSP_LICENSE_FILE`	The path to FLEXlm license file. This can be a license-file list, separated by '`:`' on Linux and '`;`' on Microsoft Windows operating systems. This can also be *`port@host`* where *`port`* and *`host`* are the TCP/IP port number and host name from the license file SERVER line. The *`port`* can be omitted if a port in the default range (27000 to 27009) is used. See the FLEXlm user manual for more details.

Table 2. Toolset environment variables

1.7 Predefined macros

The macros listed in *Table 3* are automatically defined when compiling Cn code.

Environment variable	Description
`__ASM__`	Defined with the value 1 if the source file is assembler code. Otherwise undefined.
`__BIG_ENDIAN__`	Defined with the value 1 if the target processor is big endian. Otherwise undefined.
`__CSCN_VERSION__`	Defines the current version of the SDK tool-chain.
`__DATE__`	The date of compilation as a string literal in the form `"Mmm dd yyyy"`.
`__DEBUG__`	Set to 1 if the `-g` option was used. Otherwise set to `0`.
`__ELF__`	Set to 1 to indicate that ELF object file format will be generated.
`__FILE__`	A string literal representing the name of the file being compiled.
`__LINE__`	The current line number as a decimal constant.
`__LITTLE_ENDIAN__`	Defined with the value 1 if the target processor is little endian. Otherwise undefined.
`__OPT_LEVEL__`	Indicates the optimization level specified with the `-On` options, `n` ranges from 0 to 4.
`__NUM_PES__`	Defined to the number of configured PEs.
`__PREPROCESS_ONLY__`	Defined with the value 1 if the `--preprocess-only` option was specified. Otherwise undefined.
`__STDC__`	Set to 1 to indicate that standard C is accepted.
`__STDCN__`	Defined with the value 1 if the source file is **C*n*** code. Otherwise undefined.
`__TIME__`	The time of compilation as a string literal in the form `"hh:mm:ss"`.

Table 3. Preprocessor symbols used in the tool chain

1.8 Error reporting

The tools will generate error messages when errors are found in command-line options or input files.

The tools may also report an *internal error* which is due to a bug in the tool itself, such as being unable to handle unexpected input. When such an internal error occurs, please submit an online report via the ClearSpeed support website:

http://support.clearspeed.com

When submitting a report, you are requested send the output created by the tool, the SDK version, environment settings and platform on which the error occurred in order to facilitate ClearSpeed support staff to recreate the problem.

1.9 Configuration file

All the tools in the SDK make use of a configuration file which holds information about the target architecture, as well as specific configuration options for each stage of processing. A configuration file will be provided for each target architecture. The default search path for configuration files is specified with the `CSPATH` environment variable. The configuration file (`target_device.cfg`) is normally in the `config` directory of the SDK installation.

The configuration file is split into a number of sections. Sections are organized in a hierarchy with different levels of the hierarchy delimited by a fullstop in the names of the configuration parameters. Each section contains parameters relevant to a particular aspect of the target architecture or part of the tool chain.

1.10 Licensing and open source components

The SDK tools use the FLEXlm license server to manage the software licenses. You will be provided with a license key for your copy of the SDK. Information for installing FLEXlm and how to request a license key can be found in the SDK Installation Guide.

Some tools and the standard C libraries are provided under the GNU General Public License or Lesser General Public License: see the files `GPL.html` and `LGPL.html` in the SDK documentation directory for details. The source code for these components is provided as part of the SDK installation.

2 Building programs

This chapter describes how to use the `cscn` command to compile a **C"** source code file into an executable file for ClearSpeed's CSX processors.

2.1 Hello world

The source of a simple example program is shown in *Example 2.1*. This is a parallel (or *poly*) version of the traditional "hello world" program. This will print out the message 96 times, once for each processing element.

hello_world.cn:

```
#include <stdiop.h>
#include <lib_ext.h>

int main(void) {
   poly int N = get_penum();

   printfp("Hello %d\n", N);
   return 0;
}
```

Example 2.1

To compile the program to an executable, use the following command:

```
cscn hello_world.cn
```

This compiles the source and links the object file with the standard libraries. The output is written to a file called `a.csx`, by default. Any errors in the generation of the executable will be displayed on the terminal.

The resulting executable file can be loaded and run on the processor by using the command:

```
csrun a.csx
```

See the *[3]: SDK Introductory Programming Manual* and the *[4]: CSX600 Runtime Software User Guide*, for more information on how to run programs on the processor or simulator.

The name of the output file can be specified with the `-o` option. For example, the following command will create an executable file called `hello_world.csx`.

```
cscn hello_world.cn -o hello_world.csx
```

2.2 Multiple source files

A similar command can be used to build an executable from multiple source files. In this case, each source file will be compiled and the resulting object files linked to generate the executable code. *Example 2.2* shows two source files which together make up a simple (nonparallel or mono) "hello world" program.

hello.cn:

```
#include <stdio.h>

extern char *world;

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

world.cn:

```
char * world = "world!";
```

Example 2.2

To compile the two files into the executable `hello.csx`, use the following command:

```
cscn -o hello.csx hello.cn
world.cn
```

This can be extended to building programs from multiple source files, including assembler code, as well as object code files and libraries (the standard libraries are included automatically). The `cscn` command will do the appropriate thing for each file, based on the file name extension.

The file in *Example 2.3* shows an assembly language equivalent of the code in `world.cn`. This can be used to build an executable with the following command:

```
cscn -o hello.csx hello.cn
world.is
```

world.is:

```
.section    .mono.data
    .align  4
world::
    .int    .LL_1
    .global world

.LL_1::
    .asciz  "world!
```

Example 2.3

2.3 Processing performed by cscn

When you invoke `cscn`, it performs the following series of processing steps to convert the source code to an executable:

- Preprocessing
- Compilation
- Assembly
- Linking

The steps `cscn` performs are based on the file extension. For more information, see *Section 1.3: File naming conventions on page 14*. Some examples of the processing stages are as follows:

`cscn file.cn`	– preprocess, compile, assemble and link
`cscn file.is`	– preprocess, assemble and link
`cscn file.cso`	– link

Options are available to allow you to stop this process at any of the intermediate steps. For example, the `-c` option says not to run the linker. The output in this case consists of object files created by the assembler.

The “hello world” code, Example 2.1, could be compiled to an executable with the following sequence of commands:

`cscn -E -o hello_world.csi hello_world.cn`	preprocess source to `hello_world.cn`
`cscn -S hello_world.csi`	compile to `hello_world.is` (assembly language file)
`cscn -c hello_world.is`	assemble source to `hello_world.cso` (object code)
`cscn hello_world.cso`	link object code to executable, `a.csx`

The following sections provide more details of all the command-line options available and the processing performed at each step.

2.4 Invoking cscn

The compiler takes a number of source and object files and, by default, builds an executable program from them. The command line format is:

```
cscn [option]* [file_name]*
```

At least one *`file_name`* is required for `cscn` to compile.

The command-line options may be specified in any order, and may be repeated.

2.4.1 Generic options

These are options which are not specific to a specific stage of processing. These options are shown in *Table 4*.

Long name	Short name	Valid values	Description
`--cncc_stdout`			Redirect the standard output from cncc to the file cncc_stdout.txt
`--help`	`-h`		Displays a list of command options and exits.
`--nothing`	`-n`		Does not run the underlying commands
`--output`	`-o`	*`filename`*	Specifies the output file name.
`--verbose`	`-v`		Switches on verbose output. This displays the individual commands and their arguments executed by `cscn`.
`--version`	`-V`		Outputs version information for cscn and exits.

Table 4. Generic command-line options

The remaining options are organized by the stage of processing in the following sections.

In addition to the `cscn` options to control each stage of processing, there are a series of `cscn` options to pass command line options directly to each tool. For example, the `-Wcn` or `--cncc-options` option can be used to pass options directly to the compiler, `cncc`. To allow these options to pass both options (with their `-` or `--` prefix) and values to the underlying tools, the syntax is slightly different from other options. For example, to pass the option "`-e newstart`" to the linker using this method, the command line would be:

```
cscn -Wl,-e=newstart
```

Or, equivalently:

```
cscn -cld-options -e=newstart
```

2.4.2 Preprocessor options

The preprocessor options are summarized in *Table 5*.

Long name	Short name	Valid values	Description
`--define`	`-D`	*name*[=*value*]	Define *name* when preprocessing input.
`--inc-dir`	`-I`	*path*	Add *path* to the include file search path.
`--no-cpp-comments`			Disallow C++ style line comments.
`--no-lines`	`-P`		Do not produce `#line` information in preprocessed output.
`--preprocess-only`	`-E`		Preprocess only: do not compile.
`--preprocess-only-comments`	`-C`		Halts after preprocessing with comments left in the output.
`--preprocess-options`	`-Wp`	[,*option*[=*value*]]*	Comma separated list of options to be passed directly through to preprocessor.
`--un-define`	`-U`	*name*	Undefine a predefined symbol

Table 5. Summary of preprocessor command-line options

-D*name*[=*value*]
--define *name*[=*value*]

These options define a preprocessor macro called *name*. The *value* is optional and defaults to 1 if omitted. The option can be used multiple times to define more than one macro.

The following example defines macros `TRUE` and `FALSE` with the values 1 and 0 respectively:

```
-DTRUE -DFALSE=0
--define TRUE --define FALSE=0
```

-I*path*
--inc-dir *path*

Adds *path* to the list of directories to be searched for include files. The default list is specified by the `CSINC` environment variable. Multiple directories may be specified by using the option multiple times. The directories will be searched in the order specified.

The following example appends /`local/includes` to the `CSINC` include path:

```
-I/local/includes
--inc-dir /local/includes
```

--no-cpp-comments

By default, the preprocessor will accept both traditional C block comments (`/* ... */`) and C++ line comments (`//...`). This option disables the use of C++ style comments.

-P
--no-lines

The preprocessor normally inserts lines in the output file of the form:

```
# linenumber filename flags
```

This indicates that the output came from line *linenumber* in file *filename*. The file name is followed by zero or more flags separated by spaces. The flags have the meanings shown in *Table 6*.

Flag	Meaning
`1`	This indicates the start of a new file.
`2`	This indicates returning to a file (after having included another file).
`3`	This indicates that the following text comes from a system header file, so certain warnings should be suppressed.
`4`	This indicates that the following text should be treated as C.

Table 6. Line information flags

The `-P` / `--no-lines` option can be used to suppress the generation of this line information. This may be useful if the preprocessor is used to process something other than source files.

`-E`
`--preprocess-only`

Preprocesses only. This halts after the preprocessing stage. The preprocessed output from a `.cn` file (**C″** source) is written to the standard output, unless it is redirected to a file using the `-o` option.

`-U`*`name`*
`--un-define` ***`name`***

These options remove the definition of a macro defined on the command line with `-D` or predefined by the driver. The set of predefined macros is shown *Table 3 on page 16*. For example, using

`-Wp,`*`option`*`[=`*`value`*`][,`*`option`*`[=`*`value`*`]]*`
`--preprocess-options [,`*`option`*`[=`*`value`*`]]*`

passes options directly through to preprocessor.

Where: `option` means the option preceded by one or two dashes as appropriate. Options with parameters must be followed by the symbol "=" and then the value to be passed to the preprocessor.

For example, to pass the option `-Wall` (enable all warnings) directly to the preprocessor, use the option:

```
-Wp,-Wall
```

2.4.3 Compiler options

These options are summarized in *Table 7*.

Long name	Short name	Valid values	Description
`--check-mono-frame-size`		*integer*	Set maximum size (in bytes) of the mono stack frame for all functions (default 64 KB).
`--check-poly-frame-size`		*integer*	Set maximum size (in bytes) of the poly stack frame for all functions (default 3 KB).
`--cncc-options`	`-Wcn`	`[,`*option*`[=`*value*`]]*`	Comma separated list of options to be passed directly through to the compiler.
`--compile-only`	`-S`		Halts after compile stage.
`--debug`	`-g`		Generate debug information.
`--dynamic-stack-check`			Enables run-time stack checking at function entry.
`--error-mono-frame`			Issue error when mono frame checks fail.
`--error-poly-frame`			Issue error when poly frame checks fail.
`--force-mono-align`		*integer*	Force alignment of mono data.
`--inliner-info`			Output information about function inlining progress
`--inliner-disable`			Completely switch off function inlining
`--inliner-poly_local_size`		*integer*	Maximum size of poly locals in any function to be inlined in bytes (default: 512)
`--inliner-mono_local_size`		*integer*	Maximum size of mono locals in any function to be inlined in bytes (default: 1024)
`--inliner-max_statements`		*integer*	Maximum size of functions to be inlined counted by statement (default: 50)
`--inliner-auto`			Enable the compiler to automatically choose functions to be inlined (default at O3 and above)
`--inliner-noauto`			Prevent the compiler from automatically choosing functions to be inlined
`--no-check-ldst-offsets`			Disable compile-time checks on stack-pointer-relative loads/stores.
`--check-mono-frame`			Enable mono stack frame size checks.

Table 7. Summary of compiler command-line options

Long name	Short name	Valid values	Description
`--check-poly-frame`			Enable poly stack frame size checks.
`--no-dynamic-stack-check`			Disables run-time stack checking at function entry.
`--nopeephole`			Disables peephole optimizations.
`--no-poly-ecc`			Disables support for poly ECC memory.
`--no-relative-branches`			Stops the compiler emitting relative branch instructions.
`--optimize-level-O`*`n`*	`-O`*`n`*		Set optimization level *`n`* (default 1).
`--peephole`			Enables peephole optimizations.
`--sched`			Enable both the expression-level and instruction-level schedulers.
`--nosched`			Disable both the expression-level and instruction-level schedulers.
`--presched`			Enable the expression-level scheduler.
`--nopresched`			Disable the expression-level scheduler.
`--postsched`			Enable the instruction-level scheduler.
`--nopostsched`			Disable the instruction-level scheduler.

`--set-mono-stack-size-thread-`*`n`*
`--set-poly-stack-size-thread-`*`n`*
		`integer`	Set the stack sizes (in bytes) for thread *`n`*.

`--strip-asm-comments`			Remove comments from inline assembly sections in the assembly output.
`--warning-level`	`-W`	`ansi|all|strict`	Warning level.

Table 7. Summary of compiler command-line options (Continued)

`--check-mono-frame-size` ***`integer`***
`--check-poly-frame-size` ***`integer`***

The compiler can check that the mono and poly stack frames used by any function do not exceed a certain size. These options set the upper limit (in bytes) for the mono and poly stack frames. The defaults are 64 KB for mono and 3 KB for poly.

`-S`
`--compile-only`

Preprocesses and compiles only. This halts after the compilation stage. The output is the assembler source code for the compiled code. The assembler code output is written to a file with the extension `.is`. The default file name can be changed with the `-o` option.

```
-Wcn,option[=value][,option[=value]]*
--cncc-options [,option[=value]]*
```

Passes options directly through to the compiler. Options with parameters must be followed by the symbol "=" and then the value to be passed to the compiler.

Where: `option` means the option preceded by one or two dashes as appropriate.

```
-g
--debug
```

Causes the compiler and the assembler to include debugging information in the object files. The debugging information is in DWARF 2.0 format (see *Section 13.8: Debugging information format on page 176* for more information). The `-g` option can be used with optimized code although this may produce some unexpected results: some variables may not exist, the flow of control may be different from expected, some statements may have moved or may never be executed and so on.

```
--dynamic-stack-check
```

Enables run time checking of stack usage on function entry. This adds code to each function to test that the calculated stack usage of the function does not overrun the available stack space. If the stack usage is calculated to cause a stack overflow, then a warning message will will be issued by the runtime.

This will cause some performance impact and so is not enabled by default.

```
--error-mono-frame
--error-poly-frame
```

By default, the compiler issues a warning if the stack frame exceeds the specified maximum size. These options causes the compiler to treat this as an error. The maximum stack frame size can be set with the `check-mono-frame-size` and `check-mono-frame-size` options.

```
--force-mono-align integer
```

Causes the compiler to force the alignment of all mono data to the specified alignment. You can override this option with the use of specific alignment pragmas, See *Section 11.10: Pragmas on page 125*.

```
--no-check-ldst-offsets
```

Disables internal checks on stack-pointer-relative loads and stores.

The compiler normally performs compile-time checks on these instructions to try and detect if you are likely to run off the end of the allocated space within a function.

Since this has no performance penalty, being compile-time rather than runtime checking, it is always enabled by default.

```
--check-mono-frame
--check-poly-frame
```

Enables the compile-time stack frame checks. If a function's stack frame exceeds the specified limit, then a warning message will be displayed.

Because this is a compile-time check, it has no effect on performance.

```
--no-dynamic-stack-check
```

Disables run-time stack checking. Note that this check is disabled by default.

```
-On
--optimize-level-On
```

These options set the optimization level. `-O0` corresponds to no optimization. `-O4` is the highest optimization level. The default level is 1. The optimizations enabled at each level are described in *Section 4.4: Compiler optimizations on page 44*.

```
--peephole
--nopeephole
```

Enable or disable peephole optimizations. This will replace sequences of instructions with less-expensive versions which have the same effect.

```
--no-poly-ecc
```

Produce code assuming that the poly memory has no ECC support. This enables the use of one-byte poly stores with do not perform a read-modify-write. Setting this option can improve performance on architectures which do not have ECC on poly memory.

```
--sched
--nosched
--presched
--nopresched
--postsched
--nopostsched
```

These options enable and disable the two phases of the scheduler in the compiler; the pre-scheduler (expression-level scheduler) and post-scheduler (instruction-level scheduler). Attempts are made to rearrange expressions or instructions (depending on the scheduler phase) to a more optimal ordering, increasing overlap between load/store and compute instructions. The latencies of instructions are used to find the most optimal sequence. The allowed reordering is determined by the dependencies between statements or instructions.

The scheduler will not schedule around control-flow, for example function calls, returns, branches, and so on. Only straight-line code in a single basic-block gets scheduled. This also means that the larger a single basic block is, the greater the possibilities open to the scheduler for moving instructions around.

Instructions in inline assembly code are not reordered by the scheduler, however other instructions can be moved around the inline assembly code. The correct setting of constraints on inline assembly code is very important to ensure that the scheduler has enough information about a block. Without sufficient information the scheduler may move instructions before or after inline assembly blocks in an invalid manner. As stated in *Section 11.11.4: Constraint directives on page 131*, the default is that a `.barrier` constraint is applied so that nothing is allowed to move across an inline assembly block unless explicitly enabled by the programmer (using `.nobarrier`).

```
--set-mono-stack-size-thread-n size
--set-poly-stack-size-thread-n size
```

These options specify the stack size to be used by a thread: *n* is the thread number that the stack is being defined for and *size* is the size of the stack in bytes.

Stacks are automatically created for the main execution thread (thread 0). Thread 7 is used by the asynchronous memcpy functions: mono and poly stacks of zero size are allocated for this thread. If you use any other threads in your program then you must allocate mono and poly stacks for each thread. See *Section 12.1: Stack allocation on page 150* for more information.

```
--strip-asm-comments
```

Removes comments from inline assembly sections in the assembly output.

```
-W ansi | strict | all
--warning-level ansi | strict | all
```

This option controls the types of warning messages generated by the compiler. The default is a low level of warnings that includes most, but not all, of the ANSI C warnings. Extra warnings can be enabled as shown in *Table 8*.

Level	Warnings enabled
`ansi`	Enables generation of ANSI C warnings.
`strict`	Enables generation of strict warnings.
`all`	Enables generation of both ANSI and strict warnings.

Table 8. Compiler warning levels

2.4.4 Assembler options

These options are summarized in *Table 9*.

Long name	Short name	Valid values	Description
`--compile-assemble-only`	`-c`		Halts after the assembly stage.
`--debug`	`-g`		Generates debugging information.
`--mist-file`	`-m`		Specifies a file containing extra instruction definitions. May be specified more than once.
`--mass-options`	`-Wa`	`[,`*`option`*`[=`*`value`*`]]*`	Comma separated list of options to be passed directly through to the assembler.

Table 9. Summary of assembler command-line options

```
-c
--compile-assemble-only
```

Preprocesses, compiles and assembles only. This halts after the assembly stage. The output is an object file ready for linking. The object code output is written to a file with the extension `.cso`. The default file name can be changed with the `-o` option.

```
-g
--debug
```

Makes the compiler and the assembler include debugging information in the object files. The debugging information is in DWARF 2.0 format (see *Section 13.8: Debugging information format on page 176* for more information). The `-g` option can be used with optimized code although this may produce some unexpected results: some variables may not exist, the flow of control may be different from expected, some statements may have moved or may never be executed and so on.

```
-m file_name
--mist-file file_name
```

The assembler uses a macro language to define the instruction set. The standard instruction set definition file is called `iset.mst`. This option can be used to extend the instruction set by specifying a file containing further instruction definitions.

```
-Wa,option[=value][,option[=value]]*
--mass-options [,option[=value]]*
```

Passes options directly through to the assembler. Options with parameters must be followed by the symbol "=" and then the value to be passed to the assembler.

Where: `option` means the option preceded by one or two dashes as appropriate.

2.4.5 Linker options

The options which control linking are summarized in *Table 10*.

Long name	Short name	Valid values	Description
`--creff`			Create a cross reference table.
`--cld-options`	`-Wl,`	`[,`*`option`*`[=`*`value`*`]]*`	Comma separated list of options to be passed directly through to the linker.
`--defsym`		*`symbol=value`*	Define the value of a symbol.
`--discard-all`	`-x`		Discard all local symbols.
`--dynamic`			Link the executable for dynamic loading.
`--entry`	`-e`	*`symbol`*	Specifies the symbol that should be used as an entry point for the executable.
`--library`	`-l`	*`lib_name`*	Specify an input library.
`--library-path`	`-L`	*`directory`*	Add to library search path.
`--Map`		*`filename`*	Create a map and write it to a file.
`--nostdlibpath`			Do not search for libraries in standard library paths.
`--nostdlibs`			Suppress the inclusion of standard libraries.
`--nostdsymbols`			Do not force resolution of standard symbols.
`--Pbss`		*`address`*	Start address of the poly bss section.
`--Pdata`		*`address`*	Start address of the poly data section.
`--print-map`	`-M`		Create a map of the object file.
`--relocatable`	`-r`		Include relocation info in the output file.

Table 10. Summary of linker command-line options

Long name	Short name	Valid values	Description
`--restrict`		*`chip-index`*	Restrict the memory available to the linker to that associated with a specified chip.
`--static`			Lays out the memory for the CSX statically using a linker script present in the path.
`--strip-all`	`-s`		Do not include the symbol table in the output file.
`--strip-debug`	`-d`		Do not include the debug info in the output file.
`--Tbss`		*`address`*	Start address of the mono bss section.
`--Tdata`		*`address`*	Start address of the mono data section.
`--trace-symbol`	`-y`	*`symbol_name`*	Print references to the given symbol.
`--Ttext`		*`address`*	Start address of the text section.
`--use-script [filename]`			Allows the user to link statically using a hand crafted linker script file[a]

Table 10. Summary of linker command-line options (Continued)

a. The linker script is straight forward and is similar to ld linker scripts for memory layout.

They each have the form:

```
MEMORY
{
monodram : ORIGIN = 0x80000000, LENGTH = 512M
monosram : ORIGIN = 0x02000000, LENGTH = 128K
polyram : ORIGIN = 0x0, LENGTH = 6K
noload : ORIGIN = 0x0, LENGTH = 512M
}
```

with the sizes filled in correctly for the different ranges.

`-Wl,`*`option`*`[=`*`value`*`][,`*`option`*`[=`*`value`*`]]*`
`--cld-options [,`*`option`*`[=`*`value`*`]]*`

Passes options directly through to linker. Options with parameters must be followed by the symbol "=" and then the value to be passed to the linker.

Where: `option` means the option preceded by one or two dashes as appropriate.

Category: files and paths

`-l`*`library`*
`--library `*`library`*

Defines an input library file name. By convention, the linker converts the library name specified into a file name by prepending `lib` to the name and appending the file extension `.csa`. This file name is then looked for in the library search path. The default search path is the current directory and any paths specified in the `CSLIB` environment variable.

For example, the command:

```
cscn hello.cn -lworld
```

will look for a library file called `libworld.csa` in the standard library search path.

Note: It is also possible to specify the full library name as an argument as if it were a regular object file. In this case, the library search is limited to the current directory.

This options can be used multiple times to link multiple libraries.

Some libraries are included automatically (see the description of the `--nostdlibs` option below for details).

`-L`*`dir`*
`--library-path` ***`dir`***

Adds a directory to the library search path. This option can be used multiple times to add more than one directory to the search path. The default library search path is the current directory and any paths specified in the `CSLIB` environment variable.

Libraries specified with the `-l` option will be searched for in the default path and then the paths specified with the `-L` option. The search will commence with the current directory and continue in the order in which the directories appear on the command line.

To support differing conventions on different operating systems, both forward and back slashes are supported as directory separators in the path. The path can finish with a trailing slash. If this slash is omitted, one is appended to the path.

For example, the following command will search for the library `libworld.csa` in the standard search path and in the directory `libs`:

```
cscn hello.cn -lworld -Llibs
```

`--nostdlibpath`

Forces the linker to ignore the default library search paths specified in the `CSLIB` environment variable.

`--nostdlibs`

Suppresses the inclusion of standard libraries. The libraries to be automatically scanned for symbols by the linker can be specified in the SDK configuration file.

The standard libraries are `cn`, `cn_poly`, and `cn_ext`. This option ignores those libraries unless they are explicitly named with the `-l` option as shown in the example below.

```
cscn --nostdlibs -lcn -lcn_poly -lcn_ext hello.cn
```

Category: file layout

`-e` ***`entry_symbol`***
`--entry` ***`entry_symbol`***

Forces the linker to use the symbol *`entry_symbol`* as the entry point. The default entry point for programs is `_start`.

`--Pbss` ***`address`***

Sets the start address of the `.poly.bss` section. *`address`* is a numeric value. Both decimal and hexadecimal formats are supported. A hexadecimal value is specified using C syntax.

```
--Pbss 0x1000
```

`--Pdata` ***`address`***

Sets the start address of the `.poly.data` section. *`address`* is a numeric value. Both decimal and hexadecimal formats are supported. A hexadecimal value is specified using C syntax.

```
--Pdata 0x800
```

`--restrict` ***`chip-index`***

Restricts memory resources visible to the linker to a selected chip. The chip index is zero based. For example, to restrict the memory resources of a particular CSX executable to the first chip the following option would be used:

```
--restrict 0
```

`--Tdata` ***`address`***

Sets the start address of the `.mono.data` section. *`address`* is a numeric value. Both decimal and hexadecimal formats are supported. A hexadecimal value is specified using C syntax.

```
--Tdata 0x0a000000
```
`--Ttext address`

Sets the start address of the `.text` section. *`address`* is a numeric value. Both decimal and hexadecimal formats are supported. A hexadecimal value is specified using C syntax.

--Ttext 0x80000000

`--Tbss address`

Sets the start address of the `.mono.bss` section. *`address`* is a numeric value. Both decimal and hexadecimal formats are supported. A hexadecimal value is specified using C syntax.

```
--Tbss 0x02000000
```

Category: map

`-M`
`--print-map`

Generates a map of the object file and prints it to standard output. The map details layout of sections, segments and symbols in the executable image as well as the physical file. The information is presented in two formats: one for sections and segments, and one for symbols, see *Figure 2*.

```
+-----------------------------------------------------------------------
| Sections: file_offset[size]  virt_address[size]  section_name type

+-----------------------------------------------------------------------
| Segments: file_offset[size]  virt_address[size]  segment_name type

+---------------------------------------------------------------------
| Symbols:  address   symbol_name   section_name   module_name
```

Figure 2.Contents of linker map

Here the `file_offset[size]` pair represents the file location of the given section or segment in the `csx` file. The `virt_address[size]` pair gives the location of the section or segment as it will be loaded in the device memory. The `type` field says whether the section or segment is loadable into mono or poly memory space of the device or whether it is purely data that is stored in the object file. The valid values are: `MONO_LOAD`, `POLY_LOAD` and `UNDEF`.

The symbol information consists of a relocated address, symbol name, section name in which the symbol has been defined and the module name which supplied the definition. If the symbol was defined in the user file, the name with extension will be given. If the symbol comes from the library, the library name without the prefix or a suffix will be printed. For instance, if the full library name were `libdbg.csa`, the `module_name` shown will be `dbg`.

`--Map filename`

Generates a map and writes it to a file. The format of the map file is as described above.

Category: symbols

`--creff`

Generates a cross-reference table. The cross-reference table lists symbols, the definitions of which have been found, and details all locations where the symbols have been referenced. By default, the cross-reference table is printed to standard output. If the `--Map` option is also specified, the table is appended to the map file.

The format of the cross-reference table is shown in *Figure 3*.

```
+-----------------------------------------------------------------------
| X reference:  sym_name in module_name:section_name @ addr_org[relocated]
|                   ref_in_module @ addr_org[relocated]
```

Figure 3.Format of cross-reference table

The first line displays the symbol name, module (file) name, and the section name in which the symbol was defined. Also, the address pair is given that specifies this location. The *`addr_org`* field is an address relative to the start of the section before relocation (always 0). The `relocated` field reflects the actual placement of the sections in the executable image and is the true address where the symbol can be found in the relevant domain (mono or poly) of the address space of the device.

This line is followed by zero or more lines, which contain the module name and the address pair describing the location where the symbol has been referenced.

`--defsym` ***`name=value`***

Sets the value of a symbol. *`name`* is a string, *`value`* an integer given in decimal or hexadecimal format. If the symbol was external, it is redefined to be global. This option can be used multiple times to define multiple symbols.

`--defsym start_address=0x00400000`

This defines an absolute symbol. That is, it specifies the final value of the symbol after linking (see section *Section 14.3.2: Symbols* for more information about symbol types).

`--dynamic`

Links the executable for dynamic loading.

`--nostdsymbols`

It is possible to specify symbols in the configuration file that the linker will treat as external symbols to be resolved, even if they were never explicitly referenced in the code. This is useful for forcing special libraries, such as the bootstrap or prologue/epilogue code, to be included with the executable.

This option switches off this default linker behavior.

`-r`
`--relocatable`

Makes the output file relocatable. All relocation information will be included in the output file.

`-s`
`--strip-all`

Omits all symbol information from the output file.

```
-d
--strip-debug
```

Omits debugger symbol information (but not all symbols) from the output file.

```
-x
--discard-all
```

Omits all local symbol information from the output file. Similar to `-s` but global symbols are left in the output file.

```
-y symbol_name
--trace-symbol symbol_name
```

Causes the specified symbol to be *traced*. Each reference to the chosen symbol will be reported (together with a module name and local address). This option can be specified multiple times to trace multiple symbols. If the `--Map` option was specified as well, the symbol trace information is appended to the map file.

The format in which the information is presented is analogous to the `--creff` option.

3 The preprocessor

This is a port of the GNU C preprocessor, `cpp`(1) with some modifications to enable it to work under Microsoft Windows. Because of this, it does not support all the usual ClearSpeed SDK command-line options.

The preprocessor expands textual macros and strips comments from the source code. In the ClearSpeed tool chain, the preprocessor can be used with both **Cⁿ** and assembly source files so it is provided as a standalone tool.

3.1 Invoking the preprocessor

The preprocessor takes a source file (**Cⁿ** or assembler) and generates an output file. The output filename will be based on the input file by replacing the extension with `.i`, unless this can be overridden with the `-o` option. The preprocessor command line is:

```
cscpp [option]* source_file
```

For example, the following command will preprocess a **Cⁿ** file, `foo.cn`, and place the output in `foo.i`, in the same directory:

```
cscpp foo.cn -o foo.i
```

3.2 Command-line options

Note: `cscpp` *does not use the standard command-line options used by the other SDK tools.*

Table 11 shows a list of the most relevant command-line options.

Short name	Valid values	Description
`-D`	*`name[=value]`*	Sets a preprocessor symbol to be defined or to the given value.
`-I`	*`directory`*	Adds a directory to the path which is searched for include files.
`-o`	*`filename`*	Defines the output filename.

Table 11. Summary of `cscpp` command-line options

Options may be given in any order and may be repeated.

`-D` ***`name`***

Defines the macro `name` with the string "`1`" as its definition.

`-I` ***`directory`***

Appends a directory to the search path for include files. The directories are searched in the order specified.

1. Note that this is not the current GNU implementation, because that has been rolled into the gcc compiler, but an older, stand-alone version. However, cscpp has all the functionality that is required for its use in the ClearSpeed SDK tool chain.

-o filename

Specifies the output file. Conventionally, the suffix `.i` is used for preprocessed files.

4 Compiler reference

The compiler takes a preprocessed source file containing **C^n** code and generates an output file containing assembly language source. The compiler expects *preprocessed* files as input.

A separate tool, called `cscpp`, is used to preprocess source files, before passing them to the compiler. This is described in more detail in *Chapter 3: The preprocessor*. Note that any standard C preprocessor could be used in place of `cscpp` as long as it emits line directives in the right form (see *Section 14.5: Directives on page 188*).

4.1 Invoking the compiler

The compiler takes a preprocessed file, and generates an output file, containing assembly code, ready to be assembled. The compiler will construct the output filename from the input filename by changing the file extension to `.s`, unless this has been overridden by using the `-o` option. The compiler command is:

```
cncc [option]* source_file
```

Assuming you have a preprocessed file called `foo.i`, the command to compile this into assembly code is:

```
cncc foo.i
```

This will create a file called `foo.s` located in the same directory as `foo.i`. To override the default output file name, use the following command:

```
cncc foo.i -o bar.s
```

Where `bar.s` is the name of the desired output file.

4.2 Command-line options

As well as the common command-line options defined in *Chapter 1: SDK overview*, the compiler has its own set of specific options. These are summarized in *Table 12*.

Note: The command line options to cncc are different from the other tools in that all options, inlcuding long forms, are prefixed by a single dash, '–'.

Long name	Short name	Valid values	Description
	`-D`	*name*[=*value*]	Define *name* when preprocessing input.
	`-g`		Produce debug information.
	`-I`	*path*	Add *path* to the include file search path.
	`-o`	*file*	Place the output into *file*.

Table 12. Summary of `cncc` command-line options

Long name	Short name	Valid values	Description
	-U	*name*	Undefine *name* when preprocessing input.
`-bigendian`			Produce code targeted at big-endian target.
`-check-mono-frame-size`		*integer*	Set maximum size (in bytes) of the mono stack frame for all functions (default 64 KB).
`-check-poly-frame-size`		*integer*	Set maximum size (in bytes) of the poly stack frame for all functions (default 3KB).
`-dynamic-stack-check`			Enables run-time stack checking at function entry.
`-error-mono-frame`			Issue error when mono frame checks fail.
`-error-poly-frame`			Issue error when poly frame checks fail.
`-littleendian`			Produce code targeted at little-endian target (default).
`-inliner-info`			Output information about function inlining progress
`-inliner-disable`			Completely switch off function inlining
`-inliner-poly_local_size`		*integer*	Maximum size of poly locals in any function to be inlined in bytes (default: 512)
`-inliner-mono_local_size`		*integer*	Maximum size of mono locals in any function to be inlined in bytes (default: 1024)
`-inliner-max_statements`		*integer*	Maximum size of functions to be inlined counted by statement (default: 50)
`-inliner-auto`			Enable the compiler to automatically choose functions to be inlined (default at O3 and above)
`-inliner-noauto`			Prevent the compiler from automatically choosing functions to be inlined
`-no-check-ldst-offsets`			Disable compile-time checks on stack pointer relative loads/stores.
`-check-mono-frame`			Enable mono stack frame size checks.
`-check-poly-frame`			Enable poly stack frame size checks.
`-no-dynamic-stack-check`			Disables run-time stack checking at function entry.
`-nopeephole`			Disables peephole optimizations. `-nopeephole` implies all the `-nopeephole*` options to signify that the `-nopeephole-pred-then-jump`, `-nopeephole-redundant-compare`, and so on, options are all set when `-nopeephole` is set.

Table 12. Summary of `cncc` command-line options (Continued)

Long name	Short name	Valid values	Description
`-nopeephole-redundant-compare`			Disables removal of redundant comparisons with zero following an arithmetic operation.
`-nopeephole-pred-then-jump`			Disables merging of predicate-movement instructions with subsequent jump instructions.
`-nopeephole-mono-stack-changes`			Disables merging of back-to-back decreases and increases in the mono stack pointer.
`-nopeephole-poly-stack-changes`			Disables merging of back-to-back decreases and increases in the poly stack pointer
`-nopeephole-combine-ldst`			Disables merging of stack-pointer-relative loads and stores to the largest possible sizes.
`-peephole`			Enables peephole optimizations.
`-no-poly-ecc`			Disables support for poly ECC memory.
`-no-relative-branches`			Stops the compiler emitting relative branch instructions.
`-set-mono-stack-size-thread-`*n* `-set-poly-stack-size-thread-`*n*		*integer*	Set the stack sizes (in bytes) for thread *n*.
`-sched`			Enable both the expression-level and instruction-level schedulers.
`-nosched`			Disable both the expression-level and instruction-level schedulers.
`-presched`			Enable the expression-level scheduler.
`-nopresched`			Disable the expression-level scheduler.
`-postsched`			Enable the instruction-level scheduler.
`-nopostsched`			Disable the instruction-level scheduler.

Table 12. Summary of `cncc` command-line options (Continued)

The command-line options may be specified in any order, and may be repeated.

`-D` ***`name`***
`-D` ***`name=value`***

Define *`name`* when preprocessing the source file. The *`value`* is optional and defaults to zero if not specified.

`-g`

This option causes the compiler to include debugging information in the output file.

`-I` ***`path`***

Add *`path`* to the list of directories to be searched for include files. Multiple directories may be specified by using the `-I` option multiple times.

`-o` ***`file`***

The output file name. If no name is specified, the compiler generates an output filename from the input file name with the extension `.s`.

`-U` ***`name`***

Undefine *`name`* when preprocessing the source file.

`-bigendian`

Produce code for a big-endian target.

```
-check-mono-frame-size integer
-check-poly-frame-size integer
```

The compiler can check that the mono and poly stack frames used by any function do not exceed a certain size. These options set the upper limit (in bytes) for the mono and poly stack frames. The defaults are 64 KB for mono and 3 KB for poly.

`-dynamic-stack-check`

Enables run time checking of stack usage on function entry. This adds code to each function to test that the calculated stack usage of the function does not overrun the available stack space. If the stack usage is calculated to cause a stack overflow, then a warning message will will be issued by the runtime.

This will cause some performance impact and so is not enabled by default.

```
-error-mono-frame
-error-poly-frame
```

By default, the compiler issues a warning if the stack frame exceeds the specified maximum size. These options causes the compiler to treat this as an error. The maximum stack frame size can be set with the `check-mono-frame-size` and `check-mono-frame-size` options.

`-littleendian`

Produce code for a little-endian target (default).

`-no-check-ldst-offsets`

Disables internal checks on stack-pointer-relative loads and stores.

The compiler normally performs compile-time checks on these instructions to try and detect if you are likely to run off the end of the allocated space within a function.

Since this has no performance penalty, being compile-time rather than runtime checking, it is always enabled by default.

```
-check-mono-frame
-check-poly-frame
```

Enables the compile-time stack frame checks. If a function's stack frame exceeds the specified limit, then a warning message will be displayed.

Because this is a compile-time check, it has no effect on performance.

`-no-dynamic-stack-check`

Disables run-time stack checking. Note that this check is disabled by default.

```
-peephole
-nopeephole
```

Enable or disable peephole optimizations. This will replace sequences of instructions with less-expensive versions which have the same effect.

```
-no-poly-ecc
```

Produce code assuming that the poly memory has no ECC support. This allows using 1-byte poly stores with no read-modify-write, which are otherwise disallowed when ECC is enabled. Setting this option can improve performance on architectures where poly memory does not have ECC enabled.

```
-set-mono-stack-size-thread-n size
-set-poly-stack-size-thread-n size
```

These options specify the stack size to be used by a thread: `n` is the thread number that the stack is being defined for and `size` is the size of the stack in bytes.

Stacks are automatically created for the main execution thread (thread 0). Thread 7 is used by the asynchronous memcpy functions: mono and poly stacks of zero size are allocated for this thread. If you use any other threads in your program then you must allocate mono and poly stacks for each thread. See *Section 12.1: Stack allocation on page 150* for more information.

```
-sched
-nosched
-presched
-nopresched
-postsched
-nopostsched
```

These options enable and disable the two phases of the scheduler in the compiler; the pre-scheduler (expression-level scheduler) and post-scheduler (instruction-level scheduler). Attempts are made to rearrange expressions or instructions (depending on the scheduler phase) to a more optimal ordering, increasing overlap between load/store and compute instructions. The latencies of instructions are used to find the most optimal sequence. The allowed reordering is determined by the dependencies between statements or instructions.

The scheduler will not schedule around control-flow, for example function calls, returns, branches, and so on. Only straight-line code in a single basic-block gets scheduled. This also means that the larger a single basic block is, the greater the possibilities open to the scheduler for moving instructions around.

Instructions in inline assembly code are not reordered by the scheduler, however other instructions can be moved around the inline assembly code. The correct setting of constraints on inline assembly code is very important to ensure that the scheduler has enough information about a block. Without sufficient information the scheduler may move instructions before or after inline assembly blocks in an invalid manner. As stated in *Section 11.11.4: Constraint directives on page 131*, the default is that a `.barrier` constraint is applied so that nothing is allowed to move across an inline assembly block unless explicitly enabled by the programmer (using `.nobarrier`).

4.3 Function inlining

Function inlining is where a function or procedure call statement is replaced by the code that comprises the body of the called function. This can be done where the code that contains the function call is compiled in the presence of the definition of the called function. References within the body of the inlined function to the parameters of the function are substituted with the corresponding arguments that were given in the function call. Similarly, return statements that return a value within the body of the inlined function are replaced by assignments to the object that was assigned to by the original function call statement.

The major benefit of this optimization is to completely eliminate function call overhead and thereby speed up the execution of the code. Inlining may also allow the compiler to optimize the code more effectively when the barrier of a function call is removed. Overly aggressive use of function inlining can, however, result in undesired code bloat and in some circumstances may cause poorer performance by negatively impacting the use of the instruction cache.

4.3.1 Conditions on inlining

There is a pragma available to force the compiler to always inline a function (see below), but unless this is used, the compiler always has the option of not inlining a function, whatever options, pragmas or keywords are specified. The compiler contains rules to determine whether it makes sense for a function to be inlined. The information about a function that is taken into account is the size of the function (in terms of the number of statements the function contains) and the number of local variables the function has, which impacts the potential register pressure within the calling function as well as the stack usage of the caller. By default, the compiler will not inline a function that has over 50 statements in its body, or which has more than 512 bytes of poly local variables, or more than 1024 bytes of mono local variables. These limits can be changed via the compiler command-line options listed in *Table 13*. There are a number of other reasons why a function may not be inlined, these are:

- Variable argument (varargs) functions
- Recursive functions
- Use of computed gotos

If the `--inliner-info` command line option is given to `cscn`, the compiler will indicate the reasons why a function has not been inlined.

The optimization level at which inlining is first enabled is `-O0`.

Note: Function inlining is enabled at all levels of optimization (including no optimization, `-O0`) in order to allow the consistent compilation of functions that take vector-type arguments and/or return a vector type. Passing or returning vector types is, at present, not permitted by the ABI (see *Chapter 13: Application binary interface on page 157*). The only way such functions can be used is by forcing inlining of the functions (by using the forceinline pragma).

4.3.2 User controls

As noted above, inlining is an optimization that should be used with care as there is the possibility that it will degrade performance. At levels of optimization below `-O3`, inlining will only occur if you indicate that a certain function should be inlined via the use of the inline keyword or inlining pragmas. At `-O3` and above, the compiler will undertake to automatically inline functions that it evaluates it to be advantageous to do so. The evaluation of the functions to be inlined is based on the above rules.

Keywords to control inlining

Use of the 'inline' keyword is consistent with the C99 specification. The keyword is placed on the function declaration as follows:

```
inline int compute(int x, float y)
{
   return x + (int)y;
}
```

According to C99, such a declaration is only used for inlining; the function will not appear in its own right in the generated code as an externally visible symbol. If the function is required to be available to be called against from other compiled modules, the function must be separately declared without the inline keyword, in a different **C"** file. It is also possible that despite the use of the keyword, the function will not be inlined (if the function does not meet the conditions described above), in which case a separate, noninline, copy of the function must be available in a compiled module to prevent a build error.

An inline pragma can be used; functions marked with the pragma are not subject to the C99 constraints on inlining.

Compiler options to control inlining

Table 13 shows a set of command-line options for control inlining.

Long name	Valid values	Description
`--inliner-info`		Output information about function inlining progress
`--inliner-disable`		Completely switch off function inlining
`--inliner-poly_local_size`	*integer*	Maximum size of poly locals in any function to be inlined in bytes (default: 512)
`--inliner-mono_local_size`	*integer*	Maximum size of mono locals in any function to be inlined in bytes (default: 1024)
`--inliner-max_statements`	*integer*	Maximum size of functions to be inlined counted by statement (default: 50)
`--inliner-auto`		Enable the compiler to automatically choose functions to be inlined (default at `-O3` and above)
`--inliner-noauto`		Prevent the compiler from automatically choosing functions to be inlined

Table 13. Summary of `inliner` command-line options

Pragmas to control inlining

`#pragma inline`

This pragma should be placed immediately before the definition of a function. It is a request for the following function to be inlined, but doesn't guarantee inlining. The behavior when marking functions for inlining using this pragma is not the same as when the inline keyword is used. Using the inline pragma does not affect whether or not a function is generated in its own right. This does mean, however, that you may need to use the static keyword to avoid multiple symbol definitions where an inline function is defined in a header file and included in multiple source files within a project.

The inline pragma can be used with on/off placed after it, for example:

```
#pragma inline on
```

The effect of this is to mark all functions declared after the pragma with an inline pragma, until a `#pragma inline off` is seen.

`#pragma inlinecalls`

This pragma can be placed before a function call site to indicate that the called function (or functions) within the succeeding statement should be inlined. This pragma can also be turned 'on' or 'off' in the same way as the inline pragma.

`#pragma noinline`

This pragma can be placed immediately before a function definition and will ensure that the function is not inlined, even at `-O3` and above when auto-inlining is enabled.

`#pragma forceinline`

This pragma is again placed just before a function definition and indicates that the function will always be inlined. This overcomes the inlining rules above, except for those rules that affect functional correctness (varags, recursive functions and computed gotos).

4.4 Compiler optimizations

Table 14 summarizes the optimizations implemented at each level. These are described in more detail in the following sections.

Optimization	Level at which first enabled
Dead object removal	`-O0`
Constant evaluation	`-O0`
Function inlining	`-O0`
Switch transformation	`-O0`
Global register allocation	`-O1`
Basic-block ordering	`-O1`
Share string initializers	`-O1`
Dead block removal	`-O1`
Basic-block merging	`-O1`
Move post-operator assignments	`-O1`
Copy propagation	`-O1`
Strength reduction	`-O1`
Constant propagation	`-O1`

Table 14. Summary of optimization levels

Optimization	Level at which first enabled
Dead code removal	`-O1`
Live range splitting	`-O1`
Global register pre-allocation	`-O1`
Common subexpression elimination	`-O1`
Tail recursion elimination	`-O1`
Loop invariant code motion	`-O1`
Tail merging	`-O1`
Algebraic simplification	`-O2`
Chain-flow optimization	`-O2`
Peephole optimizer	`-O2`
Scalar replacement	`-O3`
Remove empty loops	`-O3`
Loop inversion	`-O3`
Expression-level scheduler	`-O3`
Ld/st offset normalization	`-O3`
Instruction-level scheduler	`-O3`
Loop reversal	`-O4`
Loop fusion	`-O4`
Loop scalar replacement	`-O4`
Loop strength reduction	`-O4`
Loop induction variable elimination	`-O4`
Loop unrolling	`-O4`

Table 14. Summary of optimization levels (Continued)

4.4.1 Dead object removal

Description: Removes objects that are not in use and that cannot be used implicitly from outside the current compilation unit.

Optimization level at which first enabled: `-O0`

4.4.2 Constant evaluation

Description: Attempt to replace expressions by simpler or cheaper expressions that have the same semantics. This is done using constant folding, algebraic identities, tree transformation and canonization of expressions.

Optimization level at which first enabled: `-O0`

4.4.3 Switch transformation

Description: Replace switch statements by jump-tables or if-else chains

Optimization level at which first enabled: `-O0`

Notes: If-else chains will be produced unless a jump-table pragma is used.

User Controls: A pragma is available to produce a jump-table for any particular switch statement. To instrument any particular switch, the following text should be added immediately before the switch statement of concern:

```
#pragma switch jumptable
```

4.4.4 Global register allocation

Description: Allocate local variables and function parameters to registers where possible.

Optimization level at which first enabled: `-O1`

4.4.5 Basic-block ordering

Description: Try and place the basic blocks within the current procedure's control-flow graph into the most efficient order possible. The engine uses information concerning how often a block is likely to be used, the probability of taking any particular edge when branching from the block and the cost of taking branches from the block. The engine reorders sequences of blocks that have unconditional jumps between them to minimize the number of unconditional jumps.

Optimization level at which first enabled: `-O1`

4.4.6 Share-string initializers

Description: Duplicate constant initializers that have equal size and contents are replaced by a single version.

Optimization level at which first enabled: `-O1`

4.4.7 Dead block removal

Description: Removal of basic blocks that are not reachable from the procedure entry point.

Optimization level at which first enabled: `-O1`

4.4.8 Basic-block merging

Description: Merge basic blocks that have a one-to-one flow relation, for example basic blocks A and B when block B is the only successor of block A and block A is the only predecessor of block B.

Optimization level at which first enabled: `-O1`

4.4.9 Move post-operator assignments

Description: An optimization to produce more optimal code sequences resulting from C post-fix operations, than are produced automatically by the compiler front-end, and to try to eliminate the unnecessary use of temporaries.

Optimization level at which first enabled: `-O1`

4.4.10 Copy propagation

Description: Identify statements that assign one variable to another and replace all subsequent uses of the left-hand side by the right-hand side. The variables involved will be local variables or parameters.

Optimization level at which first enabled: `-O1`

4.4.11 Strength reduction

Description: Try to replace some operations with forms that will execute more efficiently on the target hardware, for example quite often integer multiplication can be done using cheaper shift instructions.

Optimization level at which first enabled: `-O1`

4.4.12 Constant propagation

Description: Find assignments of constant expressions to variables and replace subsequent uses of the variable that are reached by the constant assignment with the constant expression.

Optimization level at which first enabled: `-O1`

4.4.13 Dead code removal

Description: Remove assignments to objects that are not subsequently used.

Optimization level at which first enabled: `-O1`

4.4.14 Live range splitting

Description: The live range of an object goes from the point at which it is defined to the points at which it is used and ultimately ends when the object is redefined (this is termed a `killing definition'). When objects are allocated to registers, long live ranges generally correspond to high register pressure, this optimization attempts to split live ranges, which in turn may help to prevent high register pressure.

Optimization level at which first enabled: `-O1`

4.4.15 Global register preallocation

Description: Local or global variables that are not likely to be allocated to registers are considered for caching in newly created (local) temporary variables, which are made high priority register candidates. Uses of the local or global variable are replaced by used of the new temporary where this can be done. Statements are inserted to synchronize the contents of the temporary with the contents of the corresponding variable where required.

Optimization level at which first enabled: `-O1`

4.4.16 Common subexpression elimination

Description: Common subexpression elimination at the basic-block level. Identify expressions that are considered to be expensive and try to replace multiple evaluations of the same expression by one evaluation that is assigned to a new temporary variable, using the temporary to replace subsequent evaluations of the same expression.

Optimization level at which first enabled: `-O1`

4.4.17 Tail recursion elimination

Description: Tail recursion is where a procedure body ends with a call to itself. This optimization seeks to eliminate unnecessary function call overhead by transforming such procedures that have a void result. This is done by replacing the call that ends the procedure with assignments of each parameter expression in the call to the corresponding formal parameter in the current function. A jump is then inserted back to the start of the procedure.

Optimization level at which first enabled: `-O1`

4.4.18 Loop invariant code motion

Description: Identify statements within the body of a loop, that could be moved outside the loop without affecting the semantics of the code. Such statements are moved outside the loop, but are prevented from executing if the loop itself does not iterate.

Optimization level at which first enabled: `-O1`

4.4.19 Tail merging

Description: In this case a tail consists of the last statements of a basic block. This optimization attempts to identify basic blocks that have identical tails and merging them into a single block inserting appropriate jumps. The aim here is to improve the code size.

Optimization level at which first enabled: `-O1`

4.4.20 Algebraic simplification

Description: Algebraic simplification and expression normalization on clusters of related operators.

For example:

```
a * c + a * d
```

becomes

```
a * (c + d)
```

Optimization level at which first enabled: `-O2`

4.4.21 Chain flow optimization

Description: Where possibly, eliminate unnecessary control flow.

Optimization level at which first enabled: `–O2`

4.4.22 Peephole optimizer

Description: Replace sequences of instructions with less-expensive versions which have the same effect. For example, combining two adjacent load instructions which have sufficiently-aligned register and address arguments into one larger load instruction, when all appropriate constraints are met. Several small optimizations are performed at this level as long as the semantics of the code are not altered.

Optimization level at which first enabled: `–O2`

4.4.23 Scalar replacement

Description: Replace local variables that have aggregate type (for example structures, unions and arrays) where only the components of the aggregate structure are addressed (and not the whole entity), by a set of local variables that represent the fields or elements of the structure. The aim of doing this is to try and get the individual elements into registers and reduce unnecessary stack-address calculations.

Optimization level at which first enabled: `–O3`

4.4.24 Remove empty loops

Description: Remove loops that have an empty body, if necessary leave an assignment to the loop control variable.

Optimization level at which first enabled: `–O3`

4.4.25 Loop inversion

Description: Where possible, change a while-do loop into a do-while loop with the goal of reducing the number of branches required. The transformed loop is protected by a new if condition when it is not known at compile time whether the loop will iterate at all.

Optimization level at which first enabled: `–O3`

4.4.26 Expression-level scheduler

Description: Respecting dependencies, attempt to rearrange expressions into the most optimal order, giving the shortest runtime according to the expected latency of the sum of instructions used by an expression.

Optimization level at which first enabled: `–O3`

4.4.27 ld/st offset normalization

Description: The compiler will try to use mono registers to cache commonly used offsets to load/store instructions that are greater than 128. A load/store with an offset greater than

128 is slower than a normal load/store. So the optimization will store a common offset in a register to be reused instead of performing the more expensive operation.

Optimization level at which first enabled: `-O3`

4.4.28 Instruction-level scheduler

Description: Respecting dependencies, attempt to rearrage instructions into the most optimal order, giving the shortest runtime according to the expected latency. Often this improves the overlap between load/store instructions and compute instructions.

Optimization level at which first enabled: `-O3`

4.4.29 Loop reversal

Description: Rewrite a loop so as to execute the iterations in reverse order.

Optimization level at which first enabled: `-O4`

4.4.30 Loop fusion

Description: Two adjacent loops are fused into one loop when a number of constraints are met. The loops must have the same iteration count and be data-independent from each other. When the iteration counters for the loops are different, one of them will be eliminated.

Optimization level at which first enabled: `-O4`

4.4.31 Loop scalar replacement

Description: Search for address locations that are overwritten in each loop iteration, where the location is expected to be in memory. The location is replaced by a scalar object throughout the loop, and assigned upon loop exit.

For example:

```
for(i=0; i<10; i++){
   arr[j] = arr[j] + i;
}
```

can be rewritten as:

```
for(i=0, tmp=arr[j]; i<10; i++){
   tmp = tmp + i;
}
arr[j] = tmp;
```

Optimization level at which first enabled: `-O4`

4.4.32 Loop strength reduction

Description: Rewrite array index expressions of loop variables into pointer operations and rewrite pointer expressions of loop variables into incremented pointers.

Optimization level at which first enabled: `-O4`

4.4.33 Loop induction variable elimination

Description: Try to reduce the number of variables in the body of a loop by rewriting variables into functions of the loop control variable where possible. This should reduce register pressure within a loop.

Optimization level at which first enabled: `-O4`

4.4.34 Loop unrolling

Description: Duplicate the body of a loop multiple times in order to eliminate loop control overhead. This may also offer more opportunity for scheduling improvements within the body of the unrolled loop.

Optimization level at which first enabled: `-O4`

Notes: Using the pragmas below will only have an effect at an optimization level at which loop unrolling is enabled (`-O4`).

User controls: There are a number of pragmas available for the programmer to use to influence the behavior of the loop unroller. Each of these pragmas should be placed immediately before the loop to be affected.

```
#pragma loop no unroll
```

This can be used to prevent the loop from being unrolled.

```
#pragma loop unroll(nr)
```

This can be used to request a loop to be unrolled a certain number of times. The parameter *`nr`* should be a positive integral value.

```
#pragma loop maxunroll(nr)
```

This pragma sets a limit on the number of times the loop will be unrolled. Set immediately before the loop you want to affect.

`nr` should be replaced for use by a positive integral value indicating the maximum unroll factor for the following loop.

5 Macro assembler reference

`mass` is a generic macro assembler which produces object files for CSX processors. The same assembler can be used for multiple targets, depending on the current configuration, see section *Section 1.9: Configuration file on page 17* in *Chapter 1: SDK overview*.

For information on the format and syntax of the assembly language, see *Chapter 14: Assembly language*.

5.1 Invoking the assembler

The assembler takes a file containing assembler source code and generates an output object file. The assembler will generate the output filename from the input filename by replacing the file suffix with `.cso`, unless this has been overridden by using the `-o` option. The assembler command is:

```
mass [option]* input-file
```

For example, the following command will assemble the source file `foo.s` and generate the output file `foo.cso` in the same directory:

```
mass -o foo.cso foo.s
```

5.2 Command-line options

As well as the standard command-line options, see the *Chapter 1: SDK overview*, there are a set of assembler-specific command-line options. These are summarized in *Table 15*.

Long name	Short name	Valid values	Description
`--chip-id`	`-C`	*integer*	
`--dwarf2`	`-g`		Generates debugging information
`--enable-stack-size`		*integer*	
`--endianness`	`-E`	`big` | `little`	Endianness of the device
`--info`	`-i`	*instruction*	Display a description of a given instruction specified as a string constant.
`--mist-file`	`-m`		Adds a file containing an instruction set definition. May be specified more than once.
`--xml`	`-x`		Generate instruction documentation in XML format

Table 15. Summary of `mass` command-line options

The command-line options may be specified in any order, and may be repeated.

```
-g
```

This option causes the assembler to generate line number information for use by the debugger.

```
-o file_name
--output file_name
```

The output file name. If no name is specified, the assembler generates an output filename from the input file name with the extension `.cso`.

```
-m file_name
--mist-file file_name
```

This option specifies a file containing defintiions of extra instructions for use by the assembler. If not specified, only the standard file, `iset.mst`, will be used.

-i *instruction*
--info *instruction*

Provides online help on the assembler instructions. If *instruction* is "`index`", it will list the names of all the instructions. An example of the output is shown in *Figure 4*.

```
Name                                                      : add (integer)
Arguments                                                 : dst, src0, src1
Synopsis            : dst = src0 + src1.
Constraints:
                                                          All operands have
equal width to
                                                          All operands have
type integer.
Side Effects        : Updates the status register.
Note:
This can be chained together with addc to make a larger add. For example,
add 0:p2, 2:p2, 4:p2 is equivalent to add 0:p1, 2:p1, 4:p1 followed by addc
1:p1, 3:p1, 5:p1 (little endian).


Details:
m2us                     m2us                      m2us                1
hardware
m2us                     m2us                      il2us               2
hardware
p1us                     p1us                      p1us                1
microcode
p1us                     p1us                      m2us                1
microcode
p1us                     p1us                      il1us               1
microcode
p2us                     p2us                      p2us                2
microcode
p2us                     p2us                      m2us                2
microcode
p2us                     p2us                      il2us               2
microcode
p4us                     p4us                      p4us                4
microcode



Name                                          : add (floating point 32 bit)
Arguments                                     : dst, src0, src1
Synopsis                                      : dst = src0 + src1.
Constraints:
                                              All operands have type float.
                                              All operands have width of 4.
                                              src1 has not a domain of label.
Note:
The mono version of this instruction will set the predicates. The negative
and zero flag will map onto the normal status flags. See the reference
manual for more information on how the other predicates are set. The poly
version will set a seperate floating point add status register. This
register can be accessed by the instruction status fpadd get and also the
```

Figure 4.Sample --info output

```
Name                                  : add (floating point 64 bit)
Arguments                             : dst, src0, src1
Synopsis                              : dst = src0 + src1.
Constraints:
                                      All operands have type float.
                                      All operands have width of 8.
                                      src1 has not a domain of label.
Note:
The mono version of this instruction will set the predicates. The negative
and zero flag will map onto the normal status flags. See the reference
manual for more information on how the other predicates are set. The poly
version will set a seperate floating point add status register. This
register can be accessed by the instruction status.fpadd.get and also the
instructions prefixed with if.fpadd and andif.fpadd. There is no way to
restore the poly floating point status, so it is advisable to only do poly
floating point operations in a single thread.

Details:
m8f                             m8f                   m8f                   4
hardware
p8f                             p8f                   p8f                   4
microcode
```

Figure 4 (cont.) Sample --info output

6 Linker reference

To get the most out of this chapter, you need to have a working knowledge of the fundamental concepts related to executable file organization, symbolic data representation and low level programming. Some of these concepts are introduced in the *Chapter 5: Macro assembler reference*, for other sources information see the *Bibliography*.

The linker constructs executable files by combining a set of input object files and libraries, relocating the data and resolving the symbolic references. This is a *multi pass* linker. This means that the order in which input files are presented for linking is not vital for the success of the process. In a situation where a file references a symbol defined in a library which preceded that file, the linker will re-scan the set of input libraries until no new symbols are found.

The supported object file format is ELF *[9]: Executable and Linkable Format (ELF)*.

6.1 Basic terminology and concepts

This section briefly introduces some of the key terms that will be used throughout this chapter.

- **Section:** Sections provide storage for common types of information, such as data, program code (or “text”), debugging information and so on. Sections may be *loadable*: these are sections that contain data that will be loaded into the processors memory before a program is executed.
- **Segment:** Segments group together sections of a common type. The purpose of this is mainly to facilitate the loader in loading the executable image onto the device.
- **Symbol:** A named representation of a piece of data or a location in the code.
- **Symbolic reference:** Addresses or other values defined in terms of symbols in the program text or a data section. Some symbols, particularly addresses, may not get their final value until the executable object code is generated.
- **Relocation:** The process of resolving symbolic references by calculating and inserting the true addresses of the symbols into locations which reference them.

6.2 Invoking the linker

The linker takes a list of object files and generates an output executable file. The linker will generate an output file called `a.out`, unless this has been overridden by using the `-o` option. The linker command is:

```
cld [option]* input_files
```

For example, the following command will link the object file `foo.cso` with the library `bar.csa` and generate the executable file `foo.csx` in the same directory:

```
cld -o foo.csx foo.cso bar.csa
```

6.3 Command-line options

As well as the standard command-line options, see the *Chapter 1: SDK overview*, there are a set of linker-specific command-line options. These are summarized in *Table 16*.

Long name	Short name	Valid values	Description
`--output`	`-o`	*`file_name`*	the name of the output file
`--library`	`-l`	*`lib_name`*	the name of the input library
`--library-path`	`-L`	*`directory`*	library search path
`--nostdlibs`			suppress the inclusion of standard libraries
`--nostdlibpath`			do not search for libraries in standard library paths
`--nostdsymbols`			do not force resolution of standard symbols
`--entry`	`-e`	*`symbol_name`*	specifies what symbol should be used as an entry point for the executable
`--Tbss`		*`address`*	start of the mono bss section
`--Tdata`		*`address`*	start of the mono data section
`--Ttext`		*`address`*	start of the text section
`--Pbss`		*`address`*	start of the poly bss section
`--Pdata`		*`address`*	start of the poly data section
`--restrict`		*`chip-index`*	restrict memory resources visible to the linker to a selected chip. The chip index is zero based.
`--print-map`	`-M`		create a map of the object file
`--Map`		*`file_name`*	create a map and write it to a file
`--creff`			create a cross reference table
`--endianness`	`-E`	`big | little`	link for big or little-endian target.
`--relocatable`	`-r`		include relocation info in the output file
`--dynamic`			build this executable to be dynamically loaded
`--trace-symbol`	`-y`	*`symbol_name`*	print references to the given symbol
`--defsym`		*`symbol_name=expr`* Where *`symbol_name`* is an identifier and *`expr`* a numeric value	define the symbol and set its value to *expr*
`--strip-all`	`-s`		do not include the symbol table in the output file
`--strip-debug`	`-S`		do not include the debug info in the output file
`--discard-all`	`-x`		discard all local symbols
`--warn-layout`			allow the linker to warn and continue even when segment layout errors have been detected

Table 16. Summary of `cld` command-line options

Long name	Short name	Valid values	Description
	`-v`		verbose mode
`--version`	`-V`		print the versioning and emulation information
`--help`	`-h`		print this message and exit

Table 16. Summary of `cld` command-line options (Continued)

The command-line options to `cld` may be specified in any order, and may be repeated. The arguments which are not options are assumed to be input object files or libraries. Command-line options which are unrecognized, are ignored and a suitable warning is printed.

6.3.1 Category: files and paths

`-o` ***`file_name`***
`--output` ***`file_name`***

Specifies the output file name (the default is `a.out`).

`-l` ***`library`***
`--library` ***`library`***

Defines an input library file name. By convention, the linker converts the library name specified into a file name by pre-pending `lib` to the name and appending the file extension `.csa`. This file name is then looked for in the search path.

Note that it is also possible to specify the full library name as an argument as if it were a regular object file. In this case the library search is limited to the current directory.

Some libraries are included automatically (see the description of the `--nostdlibs` option below for details).

`-L` ***`dir`***
`--library-path` ***`dir`***

Specifies another directory library search path. Libraries specified with the `-l` option will be searched for in the paths specified with the `-L` option. The search will commence, by default, with the current directory and continue in the order in which the directories appear on the command line.

To support differing conventions on different operating systems, both forward and back slashes are supported as directory separators in the path. The path can finish with a trailing slash; if this is omitted, one is appended to the path.

`--nostdlibs`

Suppresses the inclusion of standard libraries. The libraries to be automatically scanned for symbols by the linker can be specified in the SDK configuration file.

`--nostdlibpath`

Forces the linker to ignore the default library search paths specified in the configuration file.

6.3.2 Category: file layout

-e *entry_symbol*
--entry *entry_symbol*

Forces the linker to use the symbol `entry_symbol` as the entry point. The default entry point for programs is `_start`.

--Tbss *org*

Sets the start address of the `.mono.bss` section. *org* is a numeric value. Both hex and decimal formats are supported.

--Tdata *org*

Sets the start address of the `.mono.data` section.

--Ttext *org*

Sets the start address of the `.text` section.

--Pbss *org*

Sets the start address of the `.poly.bss` section.

--Pdata *org*

Sets the start address of the `.poly.data` section.

Note: The `--Txxx` and `--Pxxx` options will be ignored if the `--dynamic` option is also specified.

--restrict *chip-index*

Restricts memory resources visible to the linker to a selected chip. The chip index is zero based.

6.3.3 Category: map

-M
--print-map

Generates a map of the object file and prints it to standard output. The map details layout of sections, segments and symbols in the executable image as well as the physical file. The information is presented in two formats; one for sections and segments, and one for symbols, see *Figure 5*.

```
+-----------------------------------------------------------------
| Sections: file_offset[size]  virt_address[size]  section_name type

+-----------------------------------------------------------------
| Segments: file_offset[size]  virt_address[size]  segment_name type

+---------------------------------------------------------------
| Symbols:  address   symbol_name   section_name   module_name
```

Figure 5.Contents of linker map

Here the `file_offset[size]` pair represents the file location of the given section or segment in the `csx` file. The `virt_address[size]` pair gives the location of the section or segment as it will be loaded in the device memory. The `type` field says whether the section or segment is loadable into mono or poly memory space of the device or whether it is purely data that is stored in the object file. The valid values are: `MONO_LOAD`, `POLY_LOAD` and `UNDEF`.

The symbol information consists of a relocated address, symbol name, section name in which the symbol has been defined and the module name which supplied the definition. If the symbol was defined in the user file, the name with extension will be given. If the symbol comes from the library, the library name without the prefix or a suffix will be printed. For instance, if the full library name were `libdbg.a`, the `module_name` shown will be `dbg`.

Examples of how the map information can be used are presented in *Section 6.7*.

`--Map` ***`filename`***

Generates a map and writes it to a file.

`--creff`

Generates a cross-reference table. The cross-reference table lists symbols, the definitions of which have been found, and details all locations where the symbols have been referenced. By default, the cross-reference table is printed to standard output. If the `--Map` option is also specified, the table is appended to the map file.

The format of the cross-reference table is shown in *Figure 6*.

```
+-----------------------------------------------------------------
| X reference:  sym_name in module_name:section_name @ addr_org[reloced]
|                     ref_in_module @ addr_org[reloced]
```

Figure 6.Format of cross-reference table

The first line displays the symbol name, module (file) name, and the section name in which the symbol was defined. Also, the address pair is given that specifies this location. The *`addr_org`* field is an address relative to the start of the section before relocation (always 0). The `reloced` field reflects the actual placement of the sections in the executable image and is the true address where the symbol can be found in the relevant domain (mono or poly) of the address space of the device.

This line is followed by zero or more lines, which contain the module name and the address pair describing the location where the symbol has been referenced.

6.3.4 Category: symbols

`--defsym` ***`name=value`***

Sets the value of a symbol. *`name`* is a string, *`value`* an integer given in decimal or hex format. If the symbol was external, it is redefined to be global. This option can be used multiple times.

This defines an absolute symbol; that is, the *`value`* parameter is the final value of the symbol (see section *Section 14.3.2: Symbols on page 182* for more information about symbol types).

`--dynamic`

Builds this executable to be dynamically loaded. If this option is used then any options which specify absolute addresses, such as `--Ttext`, will be ignored.

`--nostdsymbols`

It is possible to specify symbols in the configuration file that the linker will treat as external symbols to be resolved, even if they were never explicitly referenced in the code. This is useful for forcing special libraries, such as the bootstrap or prologue/epilogue code, to be included with the executable.

This option switches off this default linker behavior.

`-r`
`--relocatable`

Makes the output file relocatable. All relocation information will be included in the output file.

`-s`
`--strip-all`

Omits all symbol information from the output file.

`-S`
`--strip-debug`

Omits all debug information from the output file.

`--warn-layout`

Warns when detecting that segments overlap in memory. This may occur when the `--Txxx` or `--Pxxx` family of options are used incorrectly. The default linker behavior is to report an error and exit should a conflict be detected. This option disables the default behavior. See *Section 6.4: File layout on page 62* for details of file layout.

`-x`
`--discard-all`

Omits all local symbol information from the output file. Similar to `-s` but global symbols are left in the output file.

`-y` ***`symbol_name`***
`--trace-symbol` ***`symbol_name`***

Causes the specified symbol to be *traced*. Each reference to the chosen symbol will be reported (together with a module name and local address). This option can be specified multiple times to trace multiple symbols. If the `--Map` option was specified as well then the symbol trace information is appended to the map file.

The format in which the information is presented is analogous to the `--creff` option.

6.3.5 Category: other

`-E big | little`
`--endianness big | little`

Link for big or little-endian target.

-h

--help

Prints information on command line usage and exits.

-v

Verbose mode.

-V

--version

Prints version information and exits.

6.4 File layout

By default, the linker lays out the file by collecting all *loadable sections* of the same multiplicity (mono or poly) and combining them into logical entities known as *segments*. The linker attempts to create the minimum number of segments possible, which speeds up the load process. A typical application using both mono and poly spaces will have just two loadable segments, as illustrated in *Figure 7*.

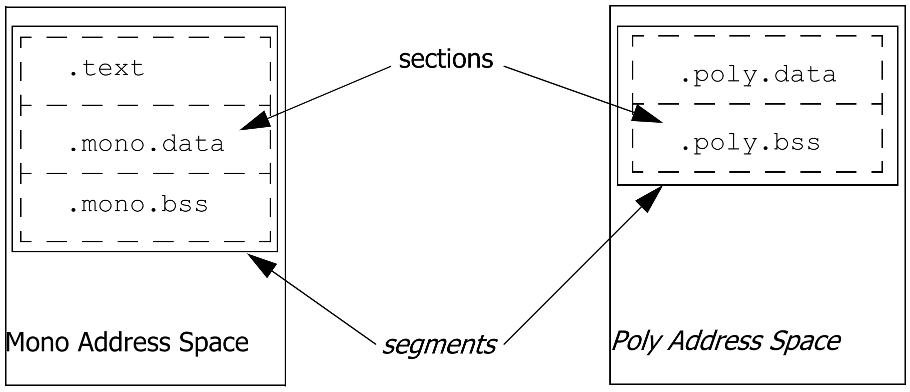


Figure 7.Default section layout within two distinct segments

The default starting addresses of the mono and poly segments are dependent on the details of the target architecture, as defined in the configuration file.

However, there are many situations where the you might wish to override the defaults. For example, to fit two programs into separate memory ranges and run them as two separate processes, or to simulate dynamic libraries.

On architectures supporting multiple memory ranges of the same multiplicity with varying access speeds, the linker attempts to fill the fastest blocks of memory first. The algorithm used creates an optimal layout from the point of view of memory fill ratio and access times.

Because the linker performs an optimal allocation of resources, the order of placement of sections in memory is undetermined until after the allocation process. To load the sections into memory in a particular order, as illustrated by *Figure 8*, you need to use the --Txxx and --Pxxx groups of command-line options for specifying load addresses of sections.

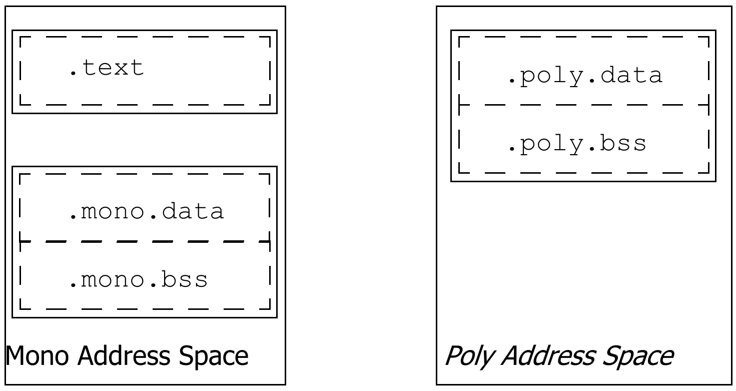


Figure 8.Custom section layout with three distinct segments

For more information on linker command-line options, see *Section 2.4.5: Linker options on page 28*.

6.5 Order of processing input files

The order in which the linker searches libraries and object files to resolve symbols is not the same as the order in which the files are specified on the command line. The files are processed in groups, depending on their type.

The groups are processed in the following order:

1. Object files specified on the command line
2. Library files named explicitly on the command line
3. Libraries named with `-l` options
4. The standard libraries (defined in the target configuration file)

Within groups 1 and 2, files are processed in the same order that they appear on the command line. Within groups 3 and 4, the libraries are processed in the reverse of the order in which they are specified. This allows you to override the definition of a symbol in a standard library by providing their own library and specifying this on the end of the command line with a `-l` option.

For example, when processing the command:

```
cscn -o exe.csx A.csa file1.cso -l L1 B.csa -l L2 file2.cso
```

where `A.csa` and `B.csa` are libraries that can be found in the local directory. The files will be processed in the following order and with the following names: `file1.cso`, `file2.cso`, `A.csa` `B.csa`, `libL2.csa`, `libL1.csa`, followed by the standard libraries. For more information on how to use the `cscn` command, see *Chapter 2: Building programs on page 18*.

6.6 Search paths

The linker expects any object files or libraries specified as command line arguments to be in the current directory. These files can also be specified with absolute or relative paths (relative to the current directory).

The linker searches for standard libraries and libraries specified with the `-l` option in the linker's search path. This is made up of three parts, searched in the following order: the current directory, the standard search path, and any extra paths specified with `-L` options. The standard search path is specified in the environment variable CSLIB.

6.7 Example

In most cases, the linker will be invoked with only the basic options: those setting the input files, libraries, and output file name.

```
cscn -L ../lib_search_path -l a -l b my_lib.csa obj1.cso -o appl.csx
```

Executing the above command will result in `appl.csx` being built. The `liba.csa` and `libb.csa` libraries will be searched for in `../lib_search_path` and the default paths. The library `my_lib.csa` will be looked for in the current directory only. The default libraries will be linked automatically and will be searched for symbols only after the ones given explicitly on the command line.

6.8 Related tools

The ClearSpeed archiver, `arcs`, is used to create libraries of object files. For more information, see *Chapter 9: Archiver*.

Since the object files conform to the ELF specification, the standard 'binutils' tools (for example, `nm`, `objdump`) can be used to inspect their contents.

Finally, the `csdump` tool can be used to display an object file's sections together with disassembly and relocation information. For more information, see *Chapter 10: Object file dump*.

7 Debugger reference

This chapter describes the changes made to the standard GDB command set to allow debugging of the CSX architecture.

`csgdb` is a port of the GNU open source debugger GDB to support the CSX family of microprocessors. It has been extended to provide support for the **C″** language and the data-parallel architecture of the CSX processors.

The aim in porting GNU GDB to support the CSX architecture is to utilize as much of the standard functionality provided and change only what is required to allow access to novel features of CSX processors. The standard GDB reference manual *[12]: Debugging with GDB* is provided with the SDK. This is a comprehensive document that explains how to use all of the standard features of the debugger.

7.1 New commands and features

The following new features have been added to the debugger:

- `connect` command (see *Connect command and options on page 67*).
- support for *linked* instructions (see *Disassemble command on page 71*).
- `peregs` command (see *Reading poly registers – `peregs` command on page 73*).
- `pex` command (see *Reading poly memory – `pex` command on page 74*).
- `whatis` command displays information about poly values (see *Symbolic debug on page 76*).
- `sysreg` command (see *System register viewer on page 79*).
- `semaphores` command (see *TSC semaphore viewer on page 83*).

In addition to these new commands, it is now also possible to display the enable state (see *Viewing the enable state on page 74*).

7.2 Invoking the debugger

When debugging a "stand-alone" application that runs entirely on the CSX processor, use the following command to start the debugger from the command line:

```
csgdb [executable-file]
```

The name of the executable file to be debugged can be passed on the command line.

The debugger initializes, prints a copyright notice and then displays a command prompt: `(gdb)`.

7.3 Using the debugger with a host application

When the code running on the CSX processor is loaded by an application running on the host, use the following method to allow both the host application and the debugger to connect to the CSX code:

1. Set the environment variable `CS_CSAPI_DEBUGGER=1` to initialize the debug interface inside the host application.
2. Start the host application.

   The `csgdb` debugger will appear in a window connected to processor 0 on card instance 0. It will be stopped by the function `_start`.
3. Set a breakpoint in your code and continue the session.

The environment variables related to host application debug interface are described in *Table 17*.

Environment Variable	Description
`CS_CSAPI_DEBUGGER`	Initializes the host application debug interface when set to 1.
`CS_CSAPI_DEBUGGER_PROC`	Allows you to specify the processor connection mask for the debugger auto-start code. It defaults to 0.0, which references processor 0 on card instance 0. If you specify “0.0 and 0.1” in the processor mask variable, a debug session will be started for both processors 0 and 1 on card instance 0. The string “all” can also be specified in the variable. This will start up a debug session for every processor on every card that is in use by the host application.
`CS_CSAPI_DEBUGGER_CMD`	Allows you to change the command used by the automatic debugger launching code.
`CS_CSAPI_DEBUGGER_PORT`	Allows you to create the debugger interface using a specified socket port.
`CS_CSAPI_DEBUGGER_ATTACH`	Disables the debugger auto start code and allows you to attach manually to the processor.
`CS_CSAPI_DEBUGGER_DETACH`	Prompts for a key press when the host application terminates and allows final debugger commands to be issued.
`CS_CSAPI_DEBUGGER_SCRIPT`	Lets you specify a `csgdb` script file to be executed when the debugger is started. It can be used to automate a debug session, for example, of a trace collection. This only works in conjunction with the automatic debugger starting code and not when attaching the debugger using the `CS_CSAPI_DEBUGGER_ATTACH` variable.

Table 17. Environment variables

7.3.1 Connecting to multiple processors

To connect to and debug both processors running on a single card:

1. Set the environment variable `CS_CSAPI_DEBUGGER=1`.
2. Set the environment variable `CS_CSAPI_DEBUGGER_PROC=”0.0.0.1”` (or *all* if there is only 1 card).
3. Start the host application.

   The csgdb debugger will appear in a window connected to both processors on the selected card. They will stop at the `_start` function.
4. Set breakpoints in your code and continue both debug sessions.

7.3.2 Connecting to the processor manually

To connect to the processor manually:

1. Set the environment variables `CS_CSAPI_DEBUGGER=1`, `CS_CSAPI_DEBUGGER_ATTACH=1` and `CS_CSAPI_DEBUGGER_DETACH=1`.

   Setting `CS_CSAPI_DEBUGGER` initializes the debug interface inside the host application.

   Setting `CS_CSAPI_DEBUGGER_ATTACH` allows you to attach to the device before the host application executes any code, and set a breakpoint.

   Setting `CS_CSAPI_DEBUGGER_DETACH` allows you to execute debugger commands prior to the host application terminating.

   The `ATTACH` and `DETACH` environment variables do not need to be set if you want to attach to the processor once the device has started running.
2. Start the host application and note the port, instance and chip numbers displayed by the host application. The full path of the file loaded is also displayed by the host application.
3. In another window, start the debugger with a command line of the form:

   ```
   csgdb csx_file_name port_number.instance.chip
   ```

   or:

   ```
   ddd --debugger csgdb csx_file_name port_number.instance.chip
   ```

   where *`port_number`* , *`instance`* and *`chip`* are the values that are displayed by the host application.

   For each chip that is in use by the host application, you will get a prompt to attach if the `CS_CSAPI_DEBUGGER_ATTACH` environment variable is set. If you do not wish to attach to that particular processor, press **[Enter]** to continue. To connect to the second chip in a single board system, start the host application, press **[Enter]** to skip attaching to the first chip and then connect the debugger to the second chip with the command supplied in the output. It is important that you only connect the debugger when it has stopped waiting for you to press **[Enter]** as this synchronizes the host application and the debugger.
4. Set a breakpoint in the CSX code where you want to stop.
5. Press **[Run]** in `ddd`, or use the `r` command in `csgdb`.
6. Press a key in the host application window to allow it to continue.

7.4 Commands

The following sections provide an overview of the debugger commands with a detailed description of the new features for the CSX architecture. For clarity, irrelevant output from `csgdb` has been omitted from the following examples. Where necessary, these omissions are marked with ellipses (`...`).

7.4.1 Connect command and options

`csgdb` is a cross-debugger, that is, it runs on a host machine and debugs a program running on another system (the CSX processor). The `connect` command has been added to allow you to specify and initialize the connection between `csgdb` and the remote device. This connection must be made before any code can be executed within the debugger environment.

The connect command is executed from the `csgdb` prompt:

```
(gdb) connect
0x80000000 in ?? ()
(gdb)
```

When connected, `csgdb` shows the current program counter (PC) value and the symbolic information associated with that location.

There are a number of options to the connect command, shown in *Table 18*. These are the same as those used with `csrun`. See the *CSX600 Runtime Software User Guide* for details of the `csrun` command.

Long name	Short name	Valid values	Description
`--chip`	`-c`	*`integer`*	Select a given chip.
`--host`		*`name`* or *`address`*	Connect to a specified host.
`--instance`	`-i`	*`integer`*	Select a board or a simulator instance.
`--mode`	`-m`	`direct` | `attach`	Select the mode of operation.
`--sim`	`-s`		Connect to a simulator rather than hardware.

Table 18. Connect options summary

`-c` ***`chip-id`***
`--chip` ***`chip-id`***

Selects the chip to connect to. Note that chip numbering starts with 1, as opposed to instancing, which is zero based. The default is 1.

`--host` ***`name`*** `|` ***`address`***

If the simulator is running on a different host (that is, not the same computer as the debugger, use this option to inform `csgdb` where the connection should be made.

`-i` ***`number`***
`--instance` ***`number`***

Specifies which instance of the board or the simulator to connect to. Instancing is 0 based. The default is 0.

`-m direct | attach`
`--mode attach | attach`

Specifies which mode `csgdb` should use to access the device. The default mode is `direct`. By specifying `attach` the device can be accessed via the debug interface built into CSAPI host applications.

`-s`
`--sim`

Specifies that `csgdb` should connect to a simulator rather than search for hardware.

7.4.2 Loading code

The executable code to be debugged needs to be loaded into the target device. This can be done in two ways:

- If the executable file name has been passed to the debugger on the command line, it can be loaded by using the `load` command with no arguments:

  ```
  csgdb cfitest.csx
  ...
  (gdb) connect
  0x80000000 in __FRAME_BEGIN_MONO__ ()
  (gdb) load
  (gdb)
  ```

- The executable file name can also be provided as an argument to the `load` command:

  ```
  csgdb
  ...
  (gdb) connect
  0x80000000 in ?? ()
  (gdb) load /csxtests/cfitest.csx
  (gdb)
  ```

7.4.3 Executing code

Once code is loaded you can start the code executing. The continue command, `c`, starts the code from the entry point and runs until the program terminates:

```
csgdb
...
(gdb) connect
0x80000000 in ?? ()
(gdb) load /csxtests/cfitest.csx
(gdb) c
Continuing.

Mtap 0 has terminated.
Program exited normally.
(gdb)
```

The code can also be single stepped at the instruction or source code statement level by using the `stepi` or `step` commands. Subroutine branches can be stepped over at the instruction or source code level by using the `nexti` or `next` command.

The command `run` performs the equivalent of a `load` followed by `continue` and is very useful for starting or restarting program execution.

7.4.4 Mono debugging

`csgdb` supports debugging mono code at both the instruction and source code level. The standard GDB commands documented in *[12]: Debugging with GDB* are all available for use when debugging mono code.

Reading mono registers – `regs` command

The `regs` command is used for reading mono registers and takes a *size* parameter to allow the registers to be viewed as 2, 4 or 8-byte values. The register size is optional. If not supplied, it defaults to 2 bytes.

For example, to display mono registers as 4-byte values:

```
(gdb) regs 4
pc       0x8001380c
ret      0x80013898
pred     0x0035
0m4      0x80000000
4m4      0x0
8m4      0x0
12m4     0x0
...
56m4     0x0
60m4     0x80013898
(gdb)
```

The three other registers (`pc`, `ret` and `pred)` are provided whenever the mono registers are displayed. These correspond to the program counter, the function return address and the predicates register.

Individual registers can be specified within the GDB command language by using register names displayed by the `regs` or `peregs` command. The register names must be preceded by a $. The register names correspond to the names in the assembler syntax for registers, without the colon (:). That is, `0:m4` becomes `$0m4` in the debugger command language syntax.

For a detailed description of the assembly mapping, refer to *Section 7.5: Registers on page 90*.

For example:

```
(gdb) p/x $16m4
$1 = 0x8001380c
(gdb) p/x $ret+8
$2 = 0x800138a0
(gdb)
```

For further information on the GDB command language variables, see *[12]: Debugging with GDB*.

Writing mono registers – `regs` command

The debugger supports writing values into mono registers via the command language. This is done using the following syntax:

```
(gdb) set $16m4=0x11223344
(gdb) p/x $16m4
$1 = 0x11223344
(gdb) set $16m2=0x8899
(gdb) p/x $16m4
$2 = 0x11228899
```

The values are written to the device on a restart such as a step or continue. Currently only mono registers can be written.

Reading mono memory – `x` command

The standard GDB `x` command is used to read mono memory and can be used to display a variety of formats.

Example 1: Displaying 3 words from address `0x80000000`:

```
(gdb) x/3w 0x80000000
0x80000000 <__FRAME_BEGIN_MONO__>: 0x00000000 0x80013898 0x00000000
(gdb)
```

Example 2: Displaying 10 bytes from the current PC:

```
(gdb) x/10b $pc
0x8001380c <main+20>: 0x00  0x00  0x80  0x30  0x00  0x00  0x80  0x30
0x80013814 <main+28>: 0x0a  0x00
(gdb)
```

The symbolic register names can be passed to this command and also symbolic information from the code.

Example 3: Displaying 10 bytes from `main()`:

```
(gdb) x/10b main
0x800137f8 <main>:   0x00  0x00  0xa0  0x11  0x80  0x79  0x78    0x88
0x80013800 <main+8>: 0x80  0x59
(gdb)
```

The `x` command can also be used to list instructions in the following way:

```
(gdb) x/11i main
0x800137f8 <main>:      st                0:m4       16:m4
0x800137fc <main+4>:    mono.result.get 60:m2      Return_Lo
0x80013800 <main+8>:    mono.result.get 62:m2      Return_Hi
0x80013804 <main+12>:   st                0:m4       60:m4          0x4
0x80013808 <main+16>:   st                4:m2       8:p4
0x8001380c <main+20>:   nop.poly
0x80013810 <main+24>:   nop.poly
0x80013814 <main+28>:   mono.immed        0xa                      \
0x80013818 <main+32>:   mov               0:p2       mono_immediate /
0x8001381c <main+36>:    mono.immed       0x0                      \
0x80013820 <main+40>:   mov               2:p2       mono_immediate /
(gdb)
```

The `\` and `/` marks at the end of a pair of lines denote *linked* instructions. When you set a breakpoint on the second half of the linked pair, the debugger automatically moves it back one instruction. When you attempt to single step over the first part of a linked instruction, the debugger does not return until all parts of the sequence have been executed.

Disassemble command

The `x` command can be used to display a number of instructions but the `disassemble` command can be used to display the assembler instructions for a whole function.

For example, to disassemble the whole of the function `main()`:

```
(gdb) disassemble main
Dump of assembler code for function main:
0x800137f8 <main+0>:    st              0:m4      16:m4
0x800137fc <main+4>:    mono.result.get 60:m2     Return_Lo
0x80013800 <main+8>:    mono.result.get 62:m2     Return_Hi
0x80013804 <main+12>:   st              0:m4      60:m4       0x4
0x80013808 <main+16>:   st              4:m2      8:p4
...
0x80013858 <main+96>:   ld              16:m4     0:m4
0x8001385c <main+100>:  ld              60:m4     0:m4        0x4
0x80013860 <main+104>:  j.lo            60:m2          \
0x80013864 <main+108>:  j.hi            62:m2          /
End of assembler dump.
(gdb)
```

Breakpoints

Breakpoints are used to stop execution of code at a particular point of interest. GDB has good support for various different kinds of breakpoints and these are well documented in *[12]: Debugging with GDB*.

As you have full symbolic debug you can set a breakpoint on a function call. For example:

```
(gdb) b main
Breakpoint 1 at 0x8001380c: file cfitest.cn, line 27.
(gdb) c
Continuing.
Breakpoint 1, main () at cfitest.cn:27
27        poly int value = 10;
(gdb)
```

Breakpoints can also be set on a specific address in the code, as shown below:

```
Breakpoint 1, main () at cfitest.cn:27
27        poly int value = 10;
(gdb) x/4i $pc
0x8001380c <main+20>:   nop.poly
0x80013810 <main+24>:   nop.poly
0x80013814 <main+28>:   mono.immed      0xa                  \
0x80013818 <main+32>:   mov             0:p2  mono_immediate /
(gdb) b *0x80013814
Breakpoint 2 at 0x80013814: file cfitest.cn, line 27.
(gdb) c
Continuing.
Breakpoint 2, 0x80013814 in main () at cfitest.cn:27
27        poly int value = 10;
(gdb)
```

Symbolic debug

Full symbolic debug of functions and variables is available for mono types. Objects can be viewed using the standard commands described in *[12]: Debugging with GDB*.

The most common way of viewing symbolic data is with the `print` (or `p`) command.

For example, printing a mono integer variable:

```
Breakpoint 1, main () at csgdb_example.cn:22
22        mono_int++;
(gdb) print mono_int
$1 = 1
(gdb)
```

Printing a mono array and an array element:

```
Breakpoint 1, main () at csgdb_example.cn:22
22        mono_int++;
(gdb) p mono_int_array
$1 = {1000, 1001, 1002, 1003}
(gdb) p mono_int_array[3]
$2 = 1003
(gdb)
```

7.4.5 Poly debugging

`csgdb` has been extended to provide support for the poly multiplicity specifier in the **Cⁿ** language and to allow visibility of the processing elements (PEs) in the CSX architecture. As with mono data, *[12]: Debugging with GDB* provides the majority of the command descriptions for debugging poly code but there are some additional commands which are documented here.

Reading poly registers – `peregs` command

This command is the poly equivalent of the `regs` command.

The `peregs` command is used for reading poly registers and takes a *size* parameter to allow the registers to be viewed as 1, 2, 4 or 8-byte values. The register size is optional. If not supplied, it defaults to 1 byte.

Also, the poly registers are special as they encapsulate the value from all of the PEs in a single register value. If the value is the same across the whole array, the value is only printed once but the debugger informs you how many times the value repeats.

For example, displaying poly registers as 4-bytes values:

```
(gdb) peregs 4
0p4     {0x34 <repeats 96 times>}
4p4     {0x34 <repeats 96 times>}
8p4     {0x0, 0x1, 0x2, 0x3, 0x4, 0x5, 0x6, 0x7, 0x8, 0x9, 0xa, 0xb,
0xc, 0xd, 0xe, 0xf, 0x10, 0x11, 0x12, 0x13, 0x14, 0x15, 0x16, 0x17,
0x18, 0x19, 0x1a, 0x1b, 0x1c, 0x1d, 0x1e, 0x1f, 0x20, 0x21, 0x22,
0x23, 0x24, 0x25, 0x26, 0x27, 0x28, 0x29, 0x2a, 0x2b, 0x2c, 0x2d,
0x2e, 0x2f, 0x30, 0x31, 0x32, 0x33, 0x34, 0x35, 0x36, 0x37, 0x38,
0x39, 0x3a, 0x3b, 0x3c, 0x3d, 0x3e, 0x3f, 0x40, 0x41, 0x42, 0x43,
0x44, 0x45, 0x46, 0x47, 0x48, 0x49, 0x4a, 0x4b, 0x4c, 0x4d, 0x4e,
0x4f, 0x50, 0x51, 0x52, 0x53, 0x54, 0x55, 0x56, 0x57, 0x58, 0x59,
0x5a, 0x5b, 0x5c, 0x5d, 0x5e, 0x5f, 0x60, 0x61, 0x62, 0x63, 0x64,
0x65, 0x66, 0x67}
...
116p4   {0xdeaddddd <repeats 96 times>}
120p4   {0xdeadeeee <repeats 96 times>}
124p4   {0xdeadffff <repeats 96 times>}
(gdb)
```

As with the `regs` command the register names are available in the command language. The poly registers are accessed from the command line with the name preceded by a `$`, as shown below:

```
(gdb) print/d $8p4
$3 = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17,
18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34,
35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51,
52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68,
69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85,
86, 87, 88, 89, 90, 91, 92, 93, 94, 95}
(gdb)
```

The poly registers can also be indexed to view the value on an individual PE. In this example, the values of register 8 on PEs 10 and 84 are displayed:

```
(gdb) print/d $8p4[10]
$4 = 10
(gdb) print/d $8p4[84]
$5 = 84
(gdb)
```

Reading poly memory – `pex` command

This command is the poly equivalent of the standard `x` command.

The `pex` command is used to display memory across a range of PEs using the same formats available with the `x` command. Symbolic names can also be passed to the `pex` command.

Example 1: printing a word in decimal from the address `0x28` on PEs 0 to 20:

```
(gdb) pex/dw 0x28 0..20
(PE 0)   0x28 <__FRAME_BEGIN_POLY__+40>:        1000
(PE 1)   0x28 <__FRAME_BEGIN_POLY__+40>:        1001
(PE 2)   0x28 <__FRAME_BEGIN_POLY__+40>:        1002
...
(PE 18)  0x28 <__FRAME_BEGIN_POLY__+40>:        1018
(PE 19)  0x28 <__FRAME_BEGIN_POLY__+40>:        1019
(PE 20)  0x28 <__FRAME_BEGIN_POLY__+40>:        1020
(gdb)
```

Example 2: printing 4 bytes from address `&poly_int_array` on PEs 50 to 75:

```
(gdb) pex/4b &poly_int_array 50..75
(PE 50)  0x28 <__FRAME_BEGIN_POLY__+40>:  0x1a   0x04   0x00   0x00
(PE 51)  0x28 <__FRAME_BEGIN_POLY__+40>:  0x1b   0x04   0x00   0x00
(PE 52)  0x28 <__FRAME_BEGIN_POLY__+40>:  0x1c   0x04   0x00   0x00
...
(PE 73)  0x28 <__FRAME_BEGIN_POLY__+40>:  0x31   0x04   0x00   0x00
(PE 74)  0x28 <__FRAME_BEGIN_POLY__+40>:  0x32   0x04   0x00   0x00
(PE 75)  0x28 <__FRAME_BEGIN_POLY__+40>:  0x33   0x04   0x00   0x00
(gdb)
```

Viewing the enable state

When debugging applications that use poly conditional code, it is useful to see the enable state of the PEs. In `csgdb`, the enable state is mapped into a register name `$enable`. This register can be viewed using the standard `print` command.

Displaying the PE enable state info

Printing the enable state at `main`, where all PEs are enabled:

```
Breakpoint 1, main () at csgdb_example.cn:4
4         mono int mono_int = 0;
(gdb) p/x $enable
$1 = {0xff <repeats 96 times>}
(gdb)
```

Printing the enable state inside a poly conditional:

```
Breakpoint 2, main () at csgdb_example.cn:23
23          mono_int++;
(gdb) p/x $enable
$2 = {0xfe <repeats 48 times>, 0xff <repeats 48 times>}
(gdb)
```

Printing the enable state as binary to see all eight levels within each PE:

```
(gdb) p/t $enable
$3 = {11111110 <repeats 48 times>, 11111111 <repeats 48 times>}
(gdb)
```

Printing a simplified view of the enable state can be done as follows with + denoting enabled and – denoting disabled:

```
Breakpoint 4, main () at simple.cn:8
8           X = 10;
(gdb) p $enabled
$1 = '-' <repeats 49 times>, '+' <repeats 47 times>
(gdb)
```

The number of enabled PEs can be displayed by doing the following:

```
(gdb) p $numenb
$3 = 47
```

In a similar fashion, the total number of PEs can be retrieved:

```
(gdb) p $numpes
$4 = 96
```

The number of disabled PEs can be worked out using the command language:

```
(gdb) p $numpes-$numenb
$5 = 49
```

Displaying the PE status info

This is done by viewing the `$status` command language variable:

```
(gdb) p/x $status
$6 = {0xc9 <repeats 48 times>, 0xd2, 0xc2 <repeats 47 times>}
(gdb) p/t $status
$7 = {11001001 <repeats 48 times>, 11010010, 11000010 <repeats 47
times>}
(gdb)
```

Displaying the status of the PE floating point adder

The floating point adder status is displayed by viewing the `$fpadd` command language variable:

```
(gdb) p/x $fpadd
$8 = {0xc0 <repeats 96 times>}
(gdb) p/t $fpadd
$9 = {11000000 <repeats 96 times>}
```

Displaying the status of the PE floating point multiplier

The floating point multiplier status is displayed by viewing the `$fpmul` command language variable:

```
(gdb) p/x $fpmul
$10 = {0xc2 <repeats 96 times>}
(gdb) p/t $fpmul
$11 = {11000010 <repeats 96 times>}
```

Symbolic debug

Full symbolic debug of variables is available for poly types. Objects can be viewed using the standard commands described in the GDB reference value. Poly variables are special inside the debugger as they are expanded to display the value on every PE.

For example, displaying the value of a poly integer produces the following result:

```
(gdb) p poly_int
$4 = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17,
18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34,
35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51,
52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68,
69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85,
86, 87, 88, 89, 90, 91, 92, 93, 94, 95}
(gdb)
```

The value of the variable `poly_int` from each PE is displayed.

A poly array produces similar results with the array values displayed from each PE. For example, to display a four element poly integer array.

```
(gdb) p poly_int_array
$2 = {{1000, 1001, 1002, 1003, 1004, 1005, 1006, 1007, 1008, 1009,
1010, 1011, 1012, 1013, 1014, 1015, 1016, 1017, 1018, 1019, 1020,
1021, 1022, 1023, 1024, 1025, 1026, 1027, 1028, 1029, 1030, 1031,
1032, 1033, 1034, 1035, 1036, 1037, 1038, 1039, 1040, 1041, 1042,
1043, 1044, 1045, 1046, 1047, 1048, 1049, 1050, 1051, 1052, 1053,
1054, 1055, 1056, 1057, 1058, 1059, 1060, 1061, 1062, 1063, 1064,
1065, 1066, 1067, 1068, 1069, 1070, 1071, 1072, 1073,  1074, 1075,
1076, 1077, 1078, 1079, 1080, 1081, 1082, 1083, 1084, 1085, 1086,
1087, 1088, 1089, 1090, 1091, 1092, 1093, 1094, 1095}, {2000, 2002,
2004, 2006, 2008, 2010, 2012, 2014, 2016, 2018, 2020, 2022, 2024,
2026, 2028, 2030, 2032, 2034, 2036, 2038, 2040, 2042, 2044, 2046,
2048, 2050, 2052, 2054, 2056, 2058, 2060, 2062, 2064, 2066, 2068,
2070, 2072, 2074, 2076, 2078, 2080, 2082, 2084, 2086, 2088, 2090,
2092, 2094, 2096, 2098, 2100, 2102, 2104, 2106, 2108, 2110, 2112,
2114, 2116, 2118, 2120, 2122, 2124, 2126, 2128, 2130, 2132, 2134,
2136, 2138, 2140, 2142, 2144, 2146, 2148, 2150, 2152, 2154, 2156,
2158, 2160, 2162, 2164, 2166, 2168, 2170, 2172, 2174, 2176, 2178,
2180, 2182, 2184, 2186, 2188, 2190}, {3000, 3003, 3006, 3009, 3012,
3015, 3018, 3021, 3024, 3027, 3030, 3033, 3036, 3039, 3042, 3045,
3048, 3051, 3054, 3057, 3060, 3063, 3066, 3069, 3072, 3075, 3078,
3081, 3084, 3087, 3090, 3093, 3096, 3099, 3102, 3105, 3108, 3111,
3114, 3117, 3120, 3123, 3126, 3129, 3132, 3135, 3138, 3141, 3144,
3147, 3150, 3153, 3156, 3159, 3162, 3165, 3168, 3171, 3174, 3177,
3180, 3183, 3186, 3189, 3192, 3195, 3198, 3201, 3204, 3207, 3210,
3213, 3216, 3219, 3222, 3225, 3228, 3231, 3234, 3237, 3240, 3243,
3246, 3249, 3252, 3255, 3258, 3261, 3264, 3267, 3270, 3273, 3276,
3279, 3282, 3285}, {4000, 4004, 4008, 4012, 4016, 4020, 4024, 4028,
4032, 4036, 4040, 4044, 4048, 4052, 4056, 4060, 4064, 4068, 4072,
4076, 4080, 4084, 4088, 4092, 4096, 4100, 4104, 4108, 4112, 4116,
4120, 4124, 4128, 4132, 4136, 4140, 4144, 4148, 4152, 4156, 4160,
4164, 4168, 4172, 4176, 4180, 4184, 4188, 4192, 4196, 4200, 4204,
4208, 4212, 4216, 4220, 4224, 4228, 4232, 4236, 4240, 4244, 4248,
4252, 4256, 4260, 4264, 4268, 4272, 4276, 4280, 4284, 4288, 4292,
4296, 4300, 4304, 4308, 4312, 4316, 4320, 4324, 4328, 4332, 4336,
4340, 4344, 4348, 4352, 4356, 4360, 4364, 4368, 4372, 4376, 4380}}
(gdb)
```

An individual array element can be viewed as follows:

```
(gdb) p poly_int_array[2]
$4 = {3000, 3003, 3006, 3009, 3012, 3015, 3018, 3021, 3024, 3027,
3030, 3033, 3036, 3039, 3042, 3045, 3048, 3051, 3054, 3057, 3060,
3063, 3066, 3069,3072, 3075, 3078, 3081, 3084, 3087, 3090, 3093,
3096, 3099, 3102, 3105, 3108, 3111, 3114, 3117, 3120, 3123, 3126,
3129, 3132, 3135, 3138, 3141, 3144, 3147, 3150, 3153, 3156, 3159,
3162, 3165, 3168, 3171, 3174, 3177, 3180, 3183, 3186, 3189, 3192,
3195, 3198, 3201, 3204, 3207, 3210, 3213, 3216, 3219, 3222, 3225,
3228, 3231, 3234, 3237, 3240, 3243, 3246, 3249, 3252, 3255, 3258,
3261, 3264, 3267, 3270, 3273, 3276, 3279, 3282, 3285}
(gdb)
```

The symbolic names of poly variables can also be passed to the `pex` command. It uses the address of the variable and displays the data accordingly.

The standard GDB `whatis` command displays the type and multiplicity of a variable:

```
(gdb) whatis poly_int_array
type = poly int [4]<96 PEs>
(gdb)
```

The information `<96 PEs>` describes how many elements the variable is visible over and the type includes the poly keyword.

7.4.6 Hardware threads

`csgdb` has extended the threading support in GDB to allow it to debug the threads supported by the hardware. After loading an application with multiple threads the debugger can see the state of all threads in the system.

The state of the threads can be seen by using the `info threads` command:

```
(gdb) info threads
* 8 Software Thread 7  0x02003b18 in _start7 ()
  7 Software Thread 6  _start6 () at thread_test.is:68
  6 Software Thread 5  _start5 () at thread_test.is:87
  5 Software Thread 4  _start4 () at thread_test.is:102
  4 Software Thread 3  _start3 () at thread_test.is:117
  3 Software Thread 2  _start2 () at thread_test.is:132
  2 Software Thread 1  _start1 () at thread_test.is:147
  1 Software Thread 0  _start () at thread_test.is:162
0x02003b18 in _start7 ()
(gdb)
```

The currently executing thread is marked with `*`.

Each thread has an identifier assigned to it by `csgdb` and these are used to select which thread to view. The software thread number is displayed after the GDB identifier. In the example above, the currently executing thread has the GDB identifier 8 and is software thread 7.

The `thread` command is used to select a thread.

```
(gdb) thread 2
[Switching to thread 2 (Software Thread 1)]#0  _start1 () at
thread_test.is:147
147    sem.wait SEM_SIG6
(gdb) list
142    sem.wait SEM_THREAD_FINISH
143
144_start1::
145.global _start1
146
147    sem.wait SEM_SIG6
148    mov  32:m2, 0
149_testloop6::
150.global _testloop6
151    j.ifn 32:m2, _testloop6
(gdb)
```

All commands are applied to the currently selected thread unless otherwise specified. For example, commands can be executed on all threads in the following way:

```
(gdb) thread apply all x/i $pc

Thread 8 (Software Thread 7):
0x2003b18 <_start7>:sem.put         77              4

Thread 7 (Software Thread 6):
0x200312c <_start6>:mov             16:m2           0x20

Thread 6 (Software Thread 5):
0x200317c <_start5>:sem.select      36

Thread 5 (Software Thread 4):
0x20031b0 <_start4>:sem.select      37

Thread 4 (Software Thread 3):
0x20031e4 <_start3>:sem.select      38

Thread 3 (Software Thread 2):
0x2003218 <_start2>:sem.select      39

Thread 2 (Software Thread 1):
0x200324c <_start1>:sem.select      3A

Thread 1 (Software Thread 0):
0x2003280 <_start>:sem.select      3B
#0  0x02003b18 in _start7 ()
```

You can change the view of `csgdb` to either the software mapping of the threads (if you are debugging the software) or the hardware mapping (if you are debugging the hardware). To view the hardware mapping, use the command:

```
set print cs_hardware_thread_view on
```

When any of the thread commands are used with this option set, the debugger displays the hardware thread identifiers.

```
(gdb) info threads
* 8 Hardware Thread 0  0x02003b18 in _start7 ()
  7 Hardware Thread 1  _start6 () at thread_test.is:68
  6 Hardware Thread 2  _start5 () at thread_test.is:87
  5 Hardware Thread 3  _start4 () at thread_test.is:102
  4 Hardware Thread 4  _start3 () at thread_test.is:117
  3 Hardware Thread 5  _start2 () at thread_test.is:132
  2 Hardware Thread 6  _start1 () at thread_test.is:147
  1 Hardware Thread 7  _start () at thread_test.is:162
0x02003b18 in _start7 ()
```

To disable this mode and to view the software mapping, use the command:

```
set print cs_hardware_thread_view off
```

7.4.7 System register viewer

The debugger lets you view the system register present in the CSX device. The values and fields contained within them are presented in a form that can be clearly understood. To display this information, use the command `sysreg` which has been added to csgdb.

Getting help in csgdb

The `sysreg` command has limited online help which can be accessed with the `help` argument to `sysreg`.

```
(gdb) sysreg help

***** MTAP system register viewer help *****

Command  Arguments                           Description
-------   ---------                          -----------
list     {reg group}     | {reg full name}   List system register
information

display  {reg group}     | {reg full name}   Display system register
values
                         | {address}

set      {reg full name} | {address} {value} Write to system
registers
         {reg full name} | {bitfield}{value}

return   {reg full name} | {address} {var}   Return register value to
csgdb variable

(gdb)
```

The help option lists the other available options to the command and the arguments that go with them.

Listing system register information

Register groups are individual registers, which are linked together by being members of a particular part of the hardware. The `list` option lets you view information about register groups, registers contained within the groups and the bit field information for individual registers. For example, to get a list of all register groups use the `list` option with no arguments.

```
(gdb) sysreg list

System register group list :

Group Name
----------
CCBRS
CCBRS_P0
CCBRS_P1
ISU
ISU_GIU
ISU_GSU
ISU_IG
LMI
LMI_DMA
LMI_DMA_AEU
LMI_LMICOM
LMI_LMIRIF
LMI_LMISRV
MTAP
MTAP_AC
MTAP_AC_DB
MTAP_AC_DB_CM
MTAP_AC_IT
MTAP_AC_MS
MTAP_GPIOC0
MTAP_GPIOC0_GPIOC
MTAP_GPIOE0
MTAP_GPIOE0_GPIOE
MTAP_TSC
MTAP_TSC_ICACHE
MTAP_TSC_ICACHE_IBUFFER
MTAP_TSC_LSU
MTAP_TSC_SCHED
MTAP_TSC_SEM
MTAP_TSC_TP
MTAP_TSC_TP_DP
MTAP_TSC_TP_TPREG
SYS

(gdb)
```

This command lists all the available register groups that are visible to the debugger.

Viewing information about a register group

You can view the contents of the register groups themselves by passing the name of the group with the `list` argument. The register group names are displayed when you use the `list` argument on its own.

For example, to display the contents of the `MTAP_TSC_SCHED` group, enter the following command:

```
(gdb) sysreg list MTAP_TSC_SCHED

System register list for group MTAP_TSC_SCHED :

Register Name
-------------
CONTROL
STATUS
SWITCH_THREAD

(gdb)
```

This lists the register names that are contained within the group.

Listing the information about a specific register

The `list` option also lets you display information about a specific register and by passing the full register name (in the format `group name`) along with the `list` argument.

For example, to view the information for the `STATUS` register of the `MTAP_TSC_SCHED` group:

```
(gdb) sysreg list MTAP_TSC_SCHED STATUS

System register definition
--------------------------
Name :          STATUS
Group :         MTAP_TSC_SCHED
Description :   Status of each thread
Reset Value :   255
Address :       0x102

Bit Fields
----------
Name :  READY
First : 0
Last :  7
Width : 8

Name :  THREAD
First : 16
Last :  18
Width : 3

Name :  YIELD
First : 8
Last :  15
Width : 8

(gdb)
```

This command lists the definition and bit field information for the requested register.

Displaying system register values

As well as displaying the information regarding the make up of each of the groups and registers, it is possible to display the values contained within them. The values can be displayed at a group level or also at an individual register level to allow the bit-field values to be displayed. This is done by using the `display` argument to the `sysreg` command.

Displaying the values of a register group

The values of all registers contained within a register group can be displayed using the `display` argument with a valid register group name. For example:

```
(gdb) sysreg display MTAP_TSC_SCHED

System register display for group MTAP_TSC_SCHED :

Register Name                   Value
-------------                   -----
CONTROL                         0x8
STATUS                          0x70000
SWITCH_THREAD                   0x7

(gdb)
```

Displaying the value of an individual register

The value of a register can be displayed by passing a valid register name or hex address with the `display` argument. For example:

```
(gdb) sysreg display MTAP_TSC_SCHED STATUS

System register display for MTAP_TSC_SCHED_STATUS :

Value : 0x70000 0b00000000000001110000000000000000

Bit Fields                      Value
----------                      -----
READY                           0x0
THREAD                          0x7
YIELD                           0x0

(gdb)
```

Returning a register value to a GDB variable

The `return` option lets you store the value of a register in a GDB variable for use in a script.

The following example prints the value of register `MTAP_TSC_TPREG_REGISTER_R1` through the GDB variable `$regval`:

```
(gdb) sysreg return MTAP_TSC_TPREG_REGISTER_R1 regval
(gdb) print $regval
```

Writing to registers

The `set` option lets you write values to system registers.

Full register names or hex addresses can be specified. As well as writing to whole registers, valid bit field names can be specified when only part of a register requires writing to.

```
(gdb) set MTAP_TSC_TPREG_REGISTER_R1 123
(gdb) set 06700A84 123
```

7.4.8 TSC semaphore viewer

Semaphores are used to synchronize code running on the CSX processor and the host. These semaphores are in the Thread Sequence Controller (TSC) of the CSX processor. The debugger is able to display information about the TSC semaphores. The command, `semaphores`, has been added to csgdb to let you view the semaphore information. The command can also be shortened to `sem`.

Getting help in csgdb

The `semaphores` command has limited online help which can be accessed with the `help` argument to `semaphores`.

```
(gdb) sem help

***** TSC semaphore viewer help *****

Use help {command} for more detailed command specific instruction.

Command    Arguments                       Description
-------    ---------                       -----------
display    {semaphore} | all | allval      Display all semaphore
information
value      {semaphore} | all | allval      Display the current
semaphore value(s)
nonzero    {semaphore} | all | allnon      Display the current
nonzero status(s)
interrupt  {semaphore} | all | allint      Display the current
interrupt enable status(s)
overflow   {semaphore} | all | allovr      Display the current
overflow status
thread     {thread} | all                 Display the current thread
/ semaphore use

(gdb)
```

Displaying semaphore information

Using the `semaphores` command with the display option lists all information about a particular set of semaphores. The arguments to this command can be an individual semaphore, all semaphores or all semaphores which currently have a value. Use the `all` argument to list the information. For example, to display information about all TSC semaphores:

```
(gdb) sem display all

Semaphore    Value    NonZero    Interrupt    Overflow
---------    -----    -------    ---------    --------
0            0        0          0            0
1            0        0          0            0
2            0        0          0            0
3            0        0          0            0
4            0        0          0            0
...
...
...
123          0        0          0            0
124          0        0          0            0
125          0        0          0            0
126          0        0          0            0
127          0        0          1            0
```

There are 128 semaphores and this command lists all the information about all of them.

Listing information for all semaphores with a current value

The `semaphores` command with the `display` argument can be used to list information about only those semaphores with a value. This is done by passing the `allval` argument to the command.

```
(gdb) sem display allval

Semaphore     Value    NonZero     Interrupt     Overflow
---------     -----    -------     ---------     --------
30            3        1           0             0
34            2        1           0             0
36            1        1           0             0
39            4        1           0             0
45            1        1           0             0
55            2        1           0             0
56            1        1           0             0
68            1        1           0             0
119           4        1           0             0
```

Listing semaphore information for an individual semaphore

To limit the information displayed, the debugger can list information for an individual semaphore. This is done by passing the semaphore number to the `semaphores display` command.

```
(gdb) sem display 34

Semaphore     Value    NonZero     Interrupt     Overflow
---------     -----    -------     ---------     --------
34            2        1           0             0
```

Displaying only the values of semaphores

The following examples show the use of the `value` argument to the `semaphores` command. Use the options as follows:

- `all` displays the current value of all semaphores.
- `allval` displays the values for the semaphores which have a value greater than 0.
- A semaphore number displays the information for just that numbered semaphore.

```
(gdb) sem value all

Semaphore           Value
---------           -----
0                   0
1                   0
2                   0
3                   0
4                   0
...
...
...
123                 0
124                 0
125                 0
126                 0
127                 0
```

```
(gdb) sem value allval

Semaphore           Value
---------           -----
30                  3
34                  2
36                  1
39                  4
45                  1
55                  2
56                  1
68                  1
119                 4

(gdb) sem value 30

Semaphore           Value
---------           -----
30                  3
```

Displaying only the nonzero status of the semaphores

The debugger can list the nonzero status of each of the semaphores. This is done by passing the `nonzero` option to the `semaphores` command. The arguments that work with the `nonzero` option are:

- `all` to list the nonzero fields for all semaphores.
- `allnon` to list just those with values in the nonzero field.
- An individual semaphore number.

```
(gdb) sem nonzero all

Semaphore           NonZero
---------           -------
0                   1
1                   1
2                   1
3                   1
4                   1
...
...
...
123                 1
124                 1
125                 1
126                 1
127                 0

(gdb) sem nonzero allnon
```

```
Semaphore          NonZero
---------          -------
0                  1
1                  1
2                  1
3                  1
4                  1
...
...
...
122                1
123                1
124                1
125                1
126                1

(gdb) sem nonzero 125

Semaphore          NonZero
---------          -------
125                1
```

Displaying the interrupt enable status of the semaphores

It is possible to list the interrupt enable status of each of the semaphores. This is done by passing the `interrupt` option to the `semaphores` command. The arguments that work with the `interrupt` option are:

- `all` to list the interrupt fields for all semaphores.
- `allint` to list just those with values in the interrupt field.
- An individual semaphore number.

```
(gdb) sem interrupt all

Semaphore          Interrupt
---------          ---------
0                  0
1                  0
2                  0
3                  0
4                  0
...
...
...
123                0
124                0
125                0
126                0
127                1

(gdb) sem interrupt allint

Semaphore          Interrupt
---------          ---------
127                1

(gdb) sem interrupt 120

Semaphore          Interrupt
---------          ---------
120                0
```

Displaying the overflow status of the semaphores

The debugger can display the overflow status of each of the semaphores. This is done by passing the `overflow` option to the `semaphores` command. The arguments that work with the `overflow` option are:

- `all` to list the overflow fields for all semaphores.
- `allovr` to list just those with values in the overflow field.
- An individual semaphore number.

```
(gdb) sem overflow all

Semaphore          Overflow
---------          --------
0                  0
1                  0
2                  0
3                  0
4                  0
...
...
...
123                0
124                0
125                0
126                0
127                0

(gdb) sem overflow allovr

Semaphore          Overflow
---------          --------
10                 1
18                 1
123                1

(gdb) sem overflow 20

Semaphore          Overflow
---------          --------
20                 0
```

Displaying the current thread / semaphore usage

It is also possible to view the semaphore usage for the TSC threads so that you can see which semaphore number is currently selected. This is done using the `thread` argument to the `semaphores` command. The `thread` argument takes sub options of either `all` or a thread number to specify what to display.

```
(gdb) sem thread all

Thread          Semaphore
------          ---------
0               10
1               23
2               43
3               101
4               102
5               32
6               22
7               25

(gdb) sem thread 1

Thread          Semaphore
------          ---------
1               23

(gdb) sem thread 2

Thread          Semaphore
------          ---------
2               43
```

7.5 Registers

Table 19 shows the register mapping for the debugger and assembly language.

Debugger register name	Assembler register name	Description
`$pc`	n/a	Program counter
`$pred`	n/a	Predicates register
`$pestat`	n/a	Full PE status register
`$ret`	n/a	Return register
`$status`	n/a	Nonfloating point PE status
`$enable`	n/a	Enable state (all levels)
`$fpadd`	n/a	PE floating point add status
`$fpmul`	n/a	PE floating point mul status
`$enabled`	n/a	PE enabled register
`$numenb`	n/a	Number of enabled PE’s
`$numpes`	n/a	Number of PE’s
`$0m2 ... $62m2`	`0:m2 ... 62:m2`	2 byte mono registers
`$0m4 ... $60m4`	`0:m4 ... 60:m4`	4 byte mono registers
`$0m8 ... $56m8`	`0:m8 ... 56:m8`	8 byte mono registers
`$0p1 ... $127p1`	`0:p1 ... 127:p1`	1 byte poly registers
`$0p2 ... $126p2`	`0:p2 ... 126:p2`	2 byte poly registers
`$0p4 ... $124p4`	`0:p4 ... 124:p4`	4 byte poly registers
`$0p8 ... $120p8`	`0:p8 ... 120:p8`	8 byte poly registers
`$0p16 ... $112p16`	`0:p16 ... 112:p16`	4 byte poly vector registers
`$0p32 ... $96p32`	`0:p32 ... 96:p32`	8 byte poly vector registers

Table 19. Mapping between debugger and assembly language registers

7.6 Using DDD

As `csgdb` is a port of the GDB debugger for the CSX architecture, it is possible to use the standard Linux DDD graphical user interface (GUI). This is not provided as part of the SDK but can be used if installed. The DDD GUI comes as standard on most Linux systems. For Windows, you need to have the cygwin tools installed.

You can start DDD by using `csgdb` as follows:

```
> ddd -debugger csgdb [executable-file]
```

Once it has been started you must connect `csgdb` to the target as described in *Section 7.4.1: Connect command and options on page 67*.

After this you can set a breakpoint and select **[Run]** in DDD. You can then debug the application using the GUI front end.

8 Simulators reference

The SDK includes a simulation environment for the CSX processor. Two levels of simulator are provided: a higher-level instruction set simulator, `isim`, and a cycle-accurate simulator, `casim`, which more exactly mimics the behavior of the hardware.

`isim` is a high level model of a CSX processor which executes the same instructions as, and behaves functionally identically to, the real hardware but does not accurately represent the timing of that behavior.

`casim` is a low level model of the CSX processor which exactly mimics the instruction execution and functionality of the hardware with near cycle accuracy. `casim` is specifically intended for fine-grain (e.g. inner loop) code optimisation and for detailed code profiling with the ClearSpeed Visual Profiler (see *[5]: ClearSpeed Visual Profiler User Guide* for more details).

8.1 Invoking the simulator

The simulators (`isim` or `casim)` need to be run concurrently with the host program (`csgdb`, `csrun` or a host application). Typically these are run in separate command shell windows so that the output from each can be seen.

Note: the simulator itself must be started before a program is loaded.

To run a simulator, the command is:

```
isim [option]*
or
casim [option]*
```

These will start the simulators for the current default processor configuration.

Note: The simulators do not take the name of the program to be executed as a command-line argument. Instead, the executable is loaded into the simulator by a program running on the host (in a separate command-shell window), for example:

```
csreset --sim -A
csrun --sim some.csx
```

or via the debugger using the command:

```
connect --sim
```

The command-line option `--sim` (or `-s`) is required to direct host programs to connect to the simulator.

8.2 Command-line options

As well as the standard command-line options (see *Section 1.2.3: Generic options on page 14*), the simulator has a set of specific command-line options. These are summarized in *Table 20* (`isim`) and *Table 21* (`casim`).

8.2.1 Command line options for isim

Long name	Short name	Valid values	Description
`--profile`	`-p`	*filename*	Specifies the file that profiling information will be written to
`--csx`	`-c`	*filename*	Specifies the file which provides extra information about the program that is being profiled
`--quiet`	`-q`		Suppress the display of cycle counts while the simulator is running
`--max-cycle`		*integer*	Specifies an upper limit to the simulation speed.
`--strict-mem-alignment`			Enforces checking of memory alignment, register alignment or both
`--strict-reg-alignment`			
`--strict-alignment`			
`--mem-warn`			Enable memory warnings e.g. poly out of bounds and uninitiated mono reads
`--display-while-idle`			Update cycle counters while idling
`--instance`	`-i`	*integer*	Instance number of simulator.
`--ram-size`	`-r`	*integer*	DRAM size in MBytes (default 512 MB)
`--processor-type`			Defines processor type as CSX600 or CSX700

Table 20. Summary of `isim` command-line options

The command-line options may be specified in any order.

```
-p filename
--profile filename
```

The `-p` option enables profiling in the simulator and specifies the filename that profiling data is to be written to. See Section *Section 8.5: Profiling on page 96* for more information.

Note: This profile information is not compatible with the ClearSpeed Visual Profiler.

```
-c filename
--csx filename
```

The `--csx` option can be used in conjunction with the profiling option to provide the simulator with the name of the file being simulated so it can extract more detailed profiling information.

```
-q
--quiet
```

This option turns off the display of the cycle count while the simulator is running. This may be useful if the verbose option is used.

```
--max-cycle integer
```

This limits the speed of simulation to the specified number of cycles per second. This can improve the accuracy of profiling based on sampling the instruction pointer at regular intervals.

```
--strict-alignment
--strict-mem-alignment
--strict-reg-alignment
```

These options enable checking of the alignment of poly data in the simulator. Alignment of memory, registers or both can be checked. This only checks poly alignment as the architecture does not support nonaligned accesses to mono memory or registers. A mis-aligned access causes a simulator error. See section *Section 8.4: Errors on page 96*.

It is recommended that alignment checking is enabled when testing code.

```
--mem-warn
```

Enables warning for potential memory access errors. Useful when testing code.

```
--display-while-idle
```

Displays the cycle count when the simulator is idling (it is normally only displayed when busy, unless disabled completely with `--quiet`). This may be useful when timing execution of multiple applications.

```
-i integer
--instance integer
```

Specify the instance number of this simulator. This allows the host tools (for example `csreset`, `csrun`) to identify multiple simulators by their instance number. See *Section 8.3: Simulating multiple CSX processors on page 95*.

```
-r integer
--ram-size integer
```

Specify DRAM size in MBytes. The default is the 512 MB.

```
--processor-type
```

Specifies simulated processor type as either csx600 or csx700. The default (if the option is not used) is CSX700. Code generated by the SDK is compatible with both processors. The only known exception is that code written for the CSX600 using non-ECC memory instructions (with the compiler option `--no-poly-ecc` or the assembler pragma `non_ecc_st` on) will not run on the CSX700.

8.2.2 Command line options for casim

Long name	Short name	Valid values	Description
`--instance`	`-i`	*integer*	Instance number of simulator
`--quiet`	`-q`		Suppress the display of cycle counts while the simulator is running
`--slow`	`-s`		Disable 'fast mode'

Table 21. Summary of `casim` command-line options

Long name	Short name	Valid values	Description
`--trace`	`-T`	*`filename`*	Enable profiling trace information output to file.
`--processor-type`			Defines processor type as CSX600 or CSX700

Table 21. Summary of `casim` command-line options (Continued)

`-i` ***`integer`***
`--instance` ***`integer`***

Specify the instance number of this simulator. This allows the host tools (for example `csreset` or `csrun`) to identify multiple simulators by their instance number. See *Section 8.3: Simulating multiple CSX processors on page 95*.

`-q`
`--quiet`

This option turns off the display of the cycle count while the simulator is running. This may be useful if the verbose option is used.

`--slow`
`-s`

Normally `casim` runs in “fast mode” where as much cycle-accurate behavior as possible is disabled when the processor is idle. This means, for example, that the performance counters are disabled when no code is running. If it is important for the performance counters to be cycle accurate when idling then the `--slow` option can be used. This may be important when simulating multiple CSX processor cores if one of them could be idle while the others are running.

`-trace` ***`filename`***
`-T` ***`filename`***

This enables profile trace information output to the file *`filename`*. The profile trace file can be read by the ClearSpeed Visual Profiler to give details of the timing of instruction pipelining and issue. See *Section 8.5: Profiling on page 96*.

`--processor-type`

Specifies simulated processor type as either csx600 or csx700. The default (if the option is not used) is CSX700. Code generated by the SDK is compatible with both processors. The only known exception is that code written for the CSX600 using non-ECC memory instructions (with the compiler option `--no-poly-ecc` or the assembler pragma `non_ecc_st` on) will not run on the CSX700.

8.3 Simulating multiple CSX processors

When simulating multiboard systems, each simulator can be thought of as a single PCI board containing two processors. Individual boards or simulators are distinguished by their zero-based *instance numbers.* The host application can also be parametrized with an instance number so that unique simulator-application communication mappings can be established.

For example, two simulators could be started as follows (in separate command shells):

```
isim -i 1
isim -i 2
```

Then the corresponding host applications would run as shown below:

```
csreset --sim -i 1
csreset --sim -i 2
csrun --sim -i 1 ./first.csx
csrun --sim -i 2 ./second.csx
```

Note that the `--sim` option tells the host tool to communicate with a simulator, instead of a board.

8.4 Errors

If `isim` tries to execute an instruction which it does not understand, or is unable to complete an instruction correctly, it will stop and display an error message along with the program counter of the instruction it was attempting to execute. The simulator will continue running and can load and run further programs. It is only the code currently being simulated that will halt.

If `casim` executes an illegal instruction or an instruction with illegal or out-of-bounds operands, it will issue a warning message and continue execution of the program as would occur on the hardware. Depending on the nature of the instruction, it may be ignored or it may trigger a series of further error or warning messages if the processor state has been adversely affected. This is useful in debugging code, for example, where illegal memory addresses have been generated, which would cause real hardware to hang.

8.5 Profiling

`casim` is a cycle-accurate simulator (or near cycle-accurate, as some small differences between `casim` and real hardware do exist). It has been designed to work in conjunction with ClearSpeed Visual Profiler in two ways:

1. The first is directly, via the built-in monitor ports accessible from the host, in the same manner as that possible with real hardware (the process for connecting profiler to hardware or a simulator is described in *[5]: ClearSpeed Visual Profiler User Guide*).
2. The second is by enabling the production of extended profile trace data, dumped to a file that the profiler can read. Using this second method, much more detail about instruction issue and pipelining is available form `casim` than is available by connecting directly to hardware. This process is described in the next section.

8.5.1 Profiler trace file production on casim

`casim` has been designed to output profiling trace information that can be read by the ClearSpeed Visual Profiler. The trace file contains detailed instruction issue and pipelining information allowing the programmer to analyse inefficiencies in the code execution and to optimize the overlap of I/O and compute to achieve maximum application performance.

Much more detailed information is available form the `casim` trace file than is available by directly connecting the profiler to the hardware.

Tracing is enabled by the `--trace` (`-T`) command-line option. This takes a parameter which specifies the file the trace information is to be written to. For example:

```
casim -T my_trace.dat
```

This will create a file named `my_trace.dat` and output profile tracing information to it, when enabled.

Once enabled the output of trace information to the file is controlled by special instructions inserted into executable code via the debugger connected to the simulation. This allows the user to control the portion of code to be profiled. See *[5]: ClearSpeed Visual Profiler User Guide* for details.

The resulting trace file is read by the ClearSpeed Visual Profiler to produce a detailed graphical representation of the progress of instruction pipes. The file is not intended to be read manually. However, for reference, an example of the trace file output format is shown in *Figure 9*, with a key shown in *Table 22*.

```
C    0x6503a
TS    0    0x00000014    7
C      0x6503b
I2   0       0x00200000    7
I1    0      0x00000011    7
I0    0      0x881c0945    7    0x2013184
TS    0      0x00000010    7
M      0     0xb08d0200    0x1
A      0         0xb08d0000
L      0             0xa6180102    0x2
```

Figure 9.`casim` profile trace file format

Event	**Code**	**Fields**			
Cycle count	C	`cycle_count`			
TSC stall flag info	TS	`processor_id`	stall info bit field	thread	
Opcode in **INST0** with PC	I0	`processor_id`	opcode	thread	pc
Opcode in **INST1**	I1	`processor_id`	opcode	thread	
Opcode in **INST2**	I2	`processor_id`	opcode	thread	
Opcode in AC preprocessing	A	`processor_id`	opcode		
Opcode in microcode issue	M	`processor_id`	opcode	count	
Opcode in load/store issue	L	`processor_id`	opcode	count	
Opcode in PIO controller issue	P	`processor_id`	opcode	count	

Table 22. `casim` trace file key

The cycle count (C) line is output every cycle. The `count` field for M, L and P codes gives the number of cycles that these multi-cycle opcodes have been in the issue stage.

The TSC stall flag (TS) is output whenever there is a stall. The format of the stall info bit field field of the TS trace message is shown in *Table 23*.

stall info bit field value	Stall flag	Description
1 (bit 0)	FULL	Down-stream controller issue pipe is full (a normal condition when the controller is busy).
2 (bit 1)	SEM	Semaphore unit is busy (should be a very short stall).
4 (bit 2)	READY	From scheduler: this bit is reset when instruction pipeline is stalled due to other flags, e.g. FULL or if scheduler is waiting on a semaphore.
8 (bit 3)	LOAD_STORE	Mono load-store stall (try doing bigger loads and stalls to amortize cost).
16 (bit 4)	ICACHE_MISS	Four cycles if buffer miss only, more if a full Icache miss.
32 (bit 5)	INST0_ALUOP	Mono ALU is stalled due to latency of consecutive semaphore select operations
64 (bit 6)	MULTI-CYCLE-ALUOP	Multi-cycle mono ALU op, for example, mul, mulfp, and so on.
128 (bit 7)	IBAU	not used
256 (bit 8)	WRITE-RESULT	Writing a result register is not bypassed so a stall is required.

Table 23. `casim` profile trace TSC stall event key

8.6 Instruction profiling on isim

As isim is not cycle-accurate, accurate profiling as described above for casim is not possible. However, isim does accurately model instruction execution and the facility exists to profile this, allowing reasonable estimates to be made of code performance.

Note: This profile information is not the same as the trace information generated by `casim` and is not compatible with the ClearSpeed Visual Profiler.

To run a program on `isim` with profiling enabled, the `--profile` (`-p`) command-line option should be used. This indicates the output file to which the profiling results are written. For example:

```
isim -p prof.vpr
```

This will create a file named `prof.vpr` (in the directory where `isim` is invoked) and output profiling information to it. This information is text based and is suitable for loading into a spreadsheet for analysis, as all the fields are tab separated. An example of the output is shown in *Figure 10*.

```
Tsc     Ac                                            Pio       Thread
Instruction
...
1        Non                                          Non       1
2018c70     add    32:m2, 32:m2, 0x80
1        8                                      Non       1         2018c74
st     32:m2, 0:p32
1        8                                      Non       1         2018c78
```

Figure 10.Example isim profiling information

The first three fields are the number of cycles the instruction takes to execute in the TSC (mono processor), AC (Array Controller), and PIO (Programmed I/O controller). “Non” indicates that the instruction is not executed on that controller. The fourth field is the thread ID and the remaining fields are the program counter, the instruction name and its arguments.

If the `--csx` option is used, the output will include more information, as shown in *Figure 11*.

```
Tsc     Ac     Pio    Thread  Instruction

...
  _async_redirect
1      1      Non                   1       2006530  st       0:m4     32:m16
135    async_io_asm.is
1      1      Non    1       2006534 sem.select       77       139
async_io_asm.is
1      1      Non    1       2006538 sem.wait.selected        139
async_io_asm.is
1      1      Non    1       200653C mono.immed       0x3040   141
```

Figure 11.Extended isim profiling information

This format includes the following extra fields: labels from the source file and the line number and file name (last two fields) of the source file that the code was created from.

9 Archiver

This archiver program combines several object files into a ClearSpeed library file. It takes the place of the GNU archiver, `ar`, or the Microsoft `lib` program. Some libraries are provided as part of the SDK, these can be found in the `lib` directory of the SDK installation. The conventional extension for these files is `.csa`.

9.1 Invoking the archiver

The archiver takes a list of object files and generates an output library file or archive. The library name must be specified by using the `-o` option. The linker command is:

```
arcs [option]* -o lib_file input_files
```

For example, the following command will combine the object files `foo.cso` and `bar.cso` to generate the archive file `foo.csa` in the same directory:

```
arcs -o foo.csa foo.cso bar.cso
```

9.2 Command-line options

As well as the common command-line options defined in *Chapter 1: SDK overview*, the compiler has its own set of specific options. These are summarized in *Table 24*.

Long name	Short name	Valid values	Description
`--output`	-o	`lib_name`	The name of the library file to be created
--extract	-x		Extracts object files from the archive.
--toc	-t		Displays the contents of the archive.

Table 24. Standard command-line options

`-o` ***`library`***
`--output` ***`library`***

Specifies the output file name for the library. This option must be used to specify the library file name. One or more object files must also be specified.

`--extract`
`-x`

Extracts object files contained in the archive and puts them in the current directory.

`--toc`
`-t`

Displays the contents of the archive file.

10 Object file dump

The object dump tool, `csdump`, is a useful utility for inspecting the contents of object files. It is similar to the standard unix `objdump` program. The standard `objdump` can be used with ClearSpeed object files as they are based on the ELF standard. However, `csdump` adds some features of specific relevance to ClearSpeed object files.

10.1 Invoking csdump

The object dump tool takes an object file and displays information about the contents. All the output from `csdump` is sent to standard output, unless otherwise specified. The command line is:

```
csdump [option]* file_name
```

If invoked without any options, `csdump` generates a full dump of the file, dividing it into sections and, where applicable, disassembling the code. If the relocation section is present in the file, the relocations are overlaid onto the disassembly. Both object and executable files can be inspected with `csdump`.

10.2 Command-line options

As well as the standard command-line options (see section *Section 1.2.3: Generic options on page 14*) there are a set of specific command-line options for csdump. These are summarized in *Table 25*.

Long name	Short name	Valid values	Description
`--disasm`	`-d`	*none*	Dumps disassembled object code
`--ipconf`	`-i`	*none*	Displays the configuration information contained in the file
`--line`	`-l`	*none*	Generates a dump of line information in a human readable form
`--memdump`	`-m`	*none*	Generates a raw ASCII dump of all the loadable segments, together with entry point info
`--nm`	`-n`	*none*	Display information about symbols (in the style of `nm`)
`--segments`	`-s`	*none*	Displays the segment addresses and sizes
`--thread`	`-t`	*none*	Display thread information

Table 25. Summary of `csdump` command-line options

Only a single option and a single object file can be given to the `csdump` command. With no options, the command does a full dump of the object file contents.

`-d`
`--disasm`

Generates a disassembly listing of the object code.

-m
--memdump

This is an advanced option used for generation of a raw ASCII dump of the loadable segments of the file. It will only work with executable files.

Sample output is shown in *Figure 12*.

```
_start 0x0
MONO 0x00000000 0x00031f94
0x10
0x00
0x40
....
```

Figure 12.ASCII dump format

The first few lines of the output contain the information on the entry points. In our case, we have dumped a single threaded application, hence only the `_start` symbol and its address were printed.

The rest of the output consists of sequences of bytes, each headed by the single line description of how to interpret the data. The line starts with keyword `MONO` or `POLY`, the address where the bytes should be loaded and the length of the byte sequence.

-n
--nm

This option prints information about the symbols in the object file.

Sample output is shown in *Figure 13*.

```
00000000 ?
00000040 B __FRAME_BEGIN_MONO__
00000040 B __FRAME_BEGIN_POLY__
00000000 B __monotempspace
00000000 B __polytempspace
00000924 T _mono_mandelbrot.cn_ISLABEL_0
00001540 T _mono_mandelbrot.cn_ISLABEL_1
000007bc T _mono_mandelbrot.cn_MIRLAB_0
00000870 T _mono_mandelbrot.cn_MIRLAB_3
00000d20 T _mono_mandelbrot.cn_MIRLAB_END_0
00000ca8 T _mono_mandelbrot.cn_MIRLAB_END_3
00000020 A _ret_addr_save
00000f64 T _start
0000000c A _temp_reg_save_mono
00000000 A _temp_reg_save_poly
000004d8 T calcres
00000000 U dprint_mono_memory
00000000 T terminate
```

Figure 13.Symbol information output

For each symbol, `csdump` prints the value, an indication of the type and the symbol name. The type flags are explained in *Table 26*.

Symbol type	Description
`T`	Symbol is defined in `.text` section
`D`	Symbol is defined in an initialized data section
`B`	Symbol is defined in an uninitialized data section
`A`	An absolute symbol
`U`	An undefined or external symbol
`?`	Type of symbol is unknown or architecture specific

Table 26. Symbol-type flags

`-i`
`--ipconf`

Displays the configuration information contained in the file. This defines the attributes of the target processor. Only object files for compatible processors can be linked together into an executable. An executable can only be loaded and run on a compatible target.

`-s`
`--segments`

Displays the segment addresses and sizes. This option will work only for executable files.

An example output is shown in *Figure 14*.

```
+-----------------------------------------------------------
| inx  file_addr  file_sz    mem_addr   mem_size   type
|    0 0x402030e8 0x00031f94 0x00000000 0x00031f94 mono
| 0001 0x4023507c 0x00000c40 0x00000000 0x00000c40 poly
```

Figure 14.Segment information output

The explanation of the fields is the same as for maps generated by the linker. See *Chapter 6: Linker reference*.

`-t`
`--thread`

Displays information about threads in the object code.

An example output is shown in *Figure 15*.

```
+--------------------------------------------------------
---
| inx  thread_id  entry      mono SP    poly SP
|    0 0x00000000 0x80000000 0x80002580 0x00000068
| 0001 0x00000001 0x800001d0 0x8000267f 0x00000167
```

Figure 15.Thread information output

For each thread in the object file, the following information is printed:

- `inx`: an internal index number
- `thread_id`: the thread number (0 is the highest priority thread)
- `entry`: the start address (entry point) of the thread
- `mono SP`: the stack pointer in mono memory
- `poly SP`: the stack pointer in poly memory

`-l`
`--line`

Prints the source line information contained in the file in a readable form.

The first column is the sequence number of the record (starting from 0), the second gives the line number (in hexadecimal), the third column is the size of the code associated with this line, next is the address in the `.text` section where the matching instruction can be found, and finally the last column gives the file name from which the code originated.

Sample output can be seen in *Figure 16*.

```
+-----------------------------------------------------------
| inx  line       address    span       module
|    0 0x00000006 0x00000000 0x00000008 sort.cn
| 0001 0x00000009 0x00000008 0x00000124 sort.cn
| 0002 0x0000000a 0x0000012c 0x000000f0 sort.cn
| 0003 0x0000000b 0x0000021c 0x00000108 sort.cn
| 0004 0x0000000c 0x00000324 0x00001780 sort.cn
| 0006 0x0000001b 0x00001aa4 0x0000000c stdio_asm.s
| 0007 0x0000001c 0x00001ab0 0x0000000a stdio_asm.s
```

Figure 16.Line number information output

11 The C^n language

The **C^n** language is strongly based on ANSI C (*[8]: The C Programming Language*). It is assumed that you are an experienced C programmer, as the focus of this document is to introduce and explain the differences between **C^n** and C, and not to act as a C reference manual. For information on compiling **C^n** code, see *Chapter 2: Building programs*. For information about the standard **C^n** libraries, see *[2]: The C^n Standard Library Reference Manual*.

11.1 Summary of differences from ANSI C

New keywords: The keywords `mono` and `poly` are used to support the parallel data processing features of the CSX processor.

C++ extensions: C++ style comments (`//...`) are supported.

Other extensions: The break and continue statements can be used with a label to control which loop they apply to**.**

11.2 Glossary of terms

In order to avoid confusion a number of terms are defined here:

- **Basic type:** A variable which stores a single object (for example, a char, an int, a float).
- **Derived type:** Types derived (possibly recursively) from basic types, such as arrays, structures, unions or pointers. These types may hold several objects of the basic type.
- **Mono variable:** A variable that has one instance. This can be of basic or derived type. A mono basic type stores a single object in mono memory. As with basic types, mono derived types hold a collection of objects in mono memory.
- **Poly variable:** A variable that has many instances with, typically, different data values on each of the Processing Elements (PE). This can be of basic or derived type. A poly basic type stores a single object in each of the PE memory blocks. A poly derived type holds a collection of objects in the memory of each PE.
- **Domain/Multiplicity:** These terms are used to denote that an object exists in either mono or poly space. If an object is in the poly domain, then it has poly multiplicity and resides in poly memory. Objects, expressions and statements can, and do, all have a multiplicity.

  An expression can also be described as being in the mono or poly domain: this is defined as the domain of the result.

  Additionally, statements with controlling expressions are said to be in the domain of the conditional expression, for example:

  ```
  poly int i;
  if (i == 7) {
      /* do some work */
  }
  ```

  In the above example, the `if` statement is in the poly domain because the conditional expression resolves to a poly value. This is also known as a *poly conditional*.

11.3 Comments

C*ⁿ* supports both the standard C block comments (`/* ... */`) and C++ style line comments (`// ...`).

11.4 Data types

11.4.1 Basic types

The **C*ⁿ*** language supports the following basic types:

- `char`, `unsigned char`, `signed char`
- `short`, `unsigned short`, `signed short`
- `int`, `unsigned int`, `signed int`
- `long`, `unsigned long`, `signed long`
- `float`, `double`, `long double`

If `char`, `short`, `int` or `long` is specified alone, then it defaults to its `signed` alternative.

The sizes of these basic types are shown in *Table 42*.

11.4.2 Derived types

The **C*ⁿ*** language supports the following derived types:

- `struct`
- `union`
- array
- pointer

These are exactly the same as for ANSI C, and should cause no problems for C programmers.

11.5 Mono and poly types

The **C*ⁿ*** language introduces two extra keywords that can be used in declarations. These extra keywords are part of the declaration specifier for declarators *[10]: ISO/IEC 9899: Programming Languages – C*. These new keywords are called *multiplicity specifiers*. The multiplicity specifiers allow you to specify the domain in which the declaration will exist.

The new keywords are:

- `mono` – the object exists in the mono domain (one instance).
- `poly` – the object exists in the poly domain (many instances).

The default multiplicity is mono: wherever a multiplicity specifier could be used, there will be an implicit mono, unless an explicit poly is used.

11.5.1 Basic types

The basic types and the multiplicity specifier can be used together to produce declarations. Some sample declarations follow:

```
poly int counter; //a different instance of ’counter’ exists on each
PE

mono unsigned char initial; //a single instance of ’initial’ exists
in mono memory

unsigned long tval; // implicit mono multiplicity

poly unsigned long p_tval;
```

11.5.2 Pointer declaration

Pointers are more complicated than basic types. Pointer declarations consist of a base type and a pointer. The declaration on the left of the `*` represents the base type (the type of the object that the pointer points to). The declaration on the right of the `*` represents the pointer object itself.

The possible combinations should be familiar to most C programmers as it is possible to make either of these entities constant. For instance:

```
const int * const foo; /* const pointer to const int */
int * const bar;       /* const pointer to nonconst int */
const int * bing;      /* nonconst pointer to const int */
```

The *constness* applies to the pointer or the pointer’s base type depending on which side of the asterisk the `const` is situated.

The rules for the multiplicity specifier are similar to the rules for `const`. For example:

```
poly int * poly frodo;    /* poly pointer to poly int */
int * poly bilbo;         /* poly pointer to mono int */
poly int * blurgle;       /* mono pointer to poly int */
```

Note: The position of the multiplicity specifier in relation to the asterisk. Use of `const` or a multiplicity specifier to the left hand side of an asterisk applies to the object being pointed to. A `const` or multiplicity specifier to the right hand side of an asterisk relates to the pointer itself.

The four different ways of declaring pointers with a multiplicity specifier are as follows:

- Mono pointer to mono object (for example, `mono int * mono`, or just `int *`).
- Mono pointer to poly object (for example, `poly int * mono`, or just `poly int *`).
- Poly pointer to mono object (for example, `mono int * poly`, or just `int * poly`).
- Poly pointer to poly object (for example, `poly int * poly`).

These pointers are used to access memory (similar to C). However, how these pointers represent memory can be confusing.

The following figures are given to help visualize how these different pointer types work:

- *Figure 17* shows how `int *` (that is, `mono int * mono`) can be visualized.
- *Figure 18* shows how `poly int * mono` and `mono int * poly` can be visualized.
- *Figure 19* shows how `poly int * poly` can be visualized.

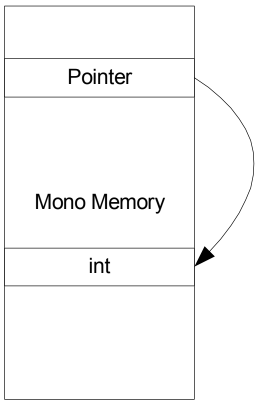


Figure 17.Representation of mono int * mono

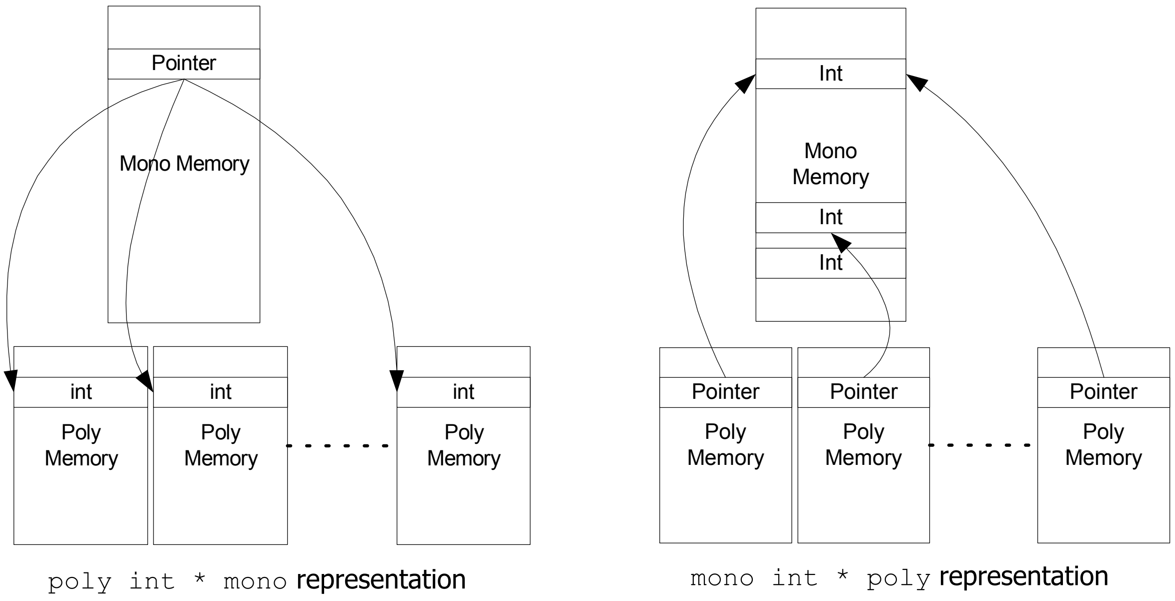


Figure 18.Representations of poly int * mono and mono int * poly

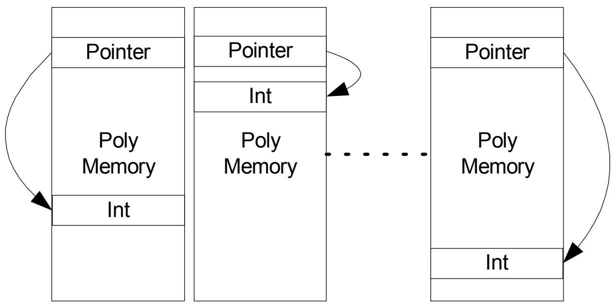


Figure 19.Representation of poly int * poly

Although all these pointer types generally behave as expected, see the comments about de-referencing in *Section 11.6: Assignment on page 112*.

More complex pointer types

As with normal C pointers, it is also possible to insert the const specifier on either side of the asterisk resulting in 16 different types of pointers.

Pointer declarations can be chained together, as in C, to give pointers to pointers to objects, and higher order pointers as well. For example:

```
/* mono pointer to const poly pointer to mono pointer to poly int */
poly int * * poly const * foo;
```

This is displayed graphically in *Figure 20*.

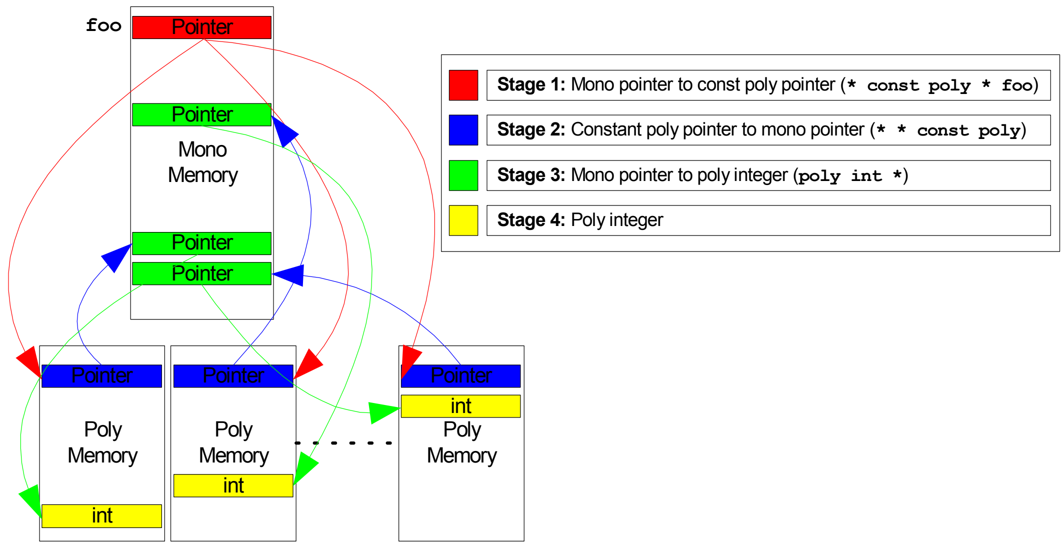

foo
Pointer
Pointer
Mono Memory
Pointer
Pointer
Pointer
Poly Memory
int
Pointer
Poly Memory
int
Pointer
int
Poly Memory
Stage 1: Mono pointer to const poly pointer (* const poly * foo)
Stage 2: Constant poly pointer to mono pointer (* * const poly)
Stage 3: Mono pointer to poly integer (poly int *)
Stage 4: Poly integer

Figure 20.Representation of poly int * * poly const * foo

Reading the pointer declaration from right to left, the first pointer is a mono pointer to a const poly pointer. This is represented in Stage 1.

- Stage 1 shows that the mono pointer points to the same location in poly memory on each PE.
- Stage 2 shows the const poly pointer to a mono pointer. Each pointer in poly memory can potentially point to a different location in mono space.
- Stage 3 shows the mono pointer pointed to in stage 2 pointing back into poly memory, but this time, as the mono pointer can be different for each PE, it can point to different locations in poly memory.
- Stage 4, finally, is the actual value being pointed to in poly memory.

11.5.3 Array types

The syntax for declaring an array in **C^n** is similar to the syntax in C. It is possible to use the multiplicity specifier in an array declaration. Consider the following:

```
poly int array[60];
```

The poly specifier only applies to the *base type* of the array (the type of the elements of the array). This example will reserve a space in each instance of poly memory for 60 ints, the address of this memory will be at the same location in each PE. By looking at *Figure 18* you can see that the array is in effect a `poly int * mono`. It is not possible to create a `poly int * poly` using array notation.

Multi-dimensional arrays are supported in **C^n** in exactly the same way as for ANSI C.

There are some additional restrictions when dealing with arrays, specifically array subscripting (see *Section 11.6*).

11.5.4 Struct and union types

This section applies to both structs and unions. Wherever a struct is described, a union can be substituted.

The C language distinguishes between the declaration and definition of objects. A *declaration* is where an object type is specified but no object of that type is created, for example, a struct declaration. A *definition* is where an object of a particular type is created, that is, memory is actually reserved for the object, for example, a variable definition.

Structs and unions match their C equivalents, the only difference being the type of objects one can declare inside a struct declaration.

Multiplicity within structs

Standard C allows any variable declaration that is valid outside a struct declaration to appear inside it, with the exception of storage class specifiers. **C^n** has the additional restriction that multiplicity specifiers cannot be included for objects created inside the struct. The reason for this is that the struct, at the point of declaration is not actually allocated space in memory: it is not until an object of that struct is created that memory is allocated. Therefore declaring a poly definition inside a struct, then defining an instance of that struct in the mono domain will result in contradictory multiplicity specifications.

For example, the following declarations and definitions are legal:

```
struct _A { /* define a struct */
    int a;
    char b;
    float c;
};

poly struct _A foo; /* define foo to be poly struct_A */
```

The struct declaration just declares the contents of the struct, not where that memory resides. At the time of object definition, the compiler resolves where memory should be allocated for the object.

It should be clear from this explanation that the following code is *invalid*:

```
struct _B { /* define a struct */
    poly int a;      /* illegal use of multiplicity */
    mono char b;     /* illegal use of multiplicity */
    poly float c;    /* illegal use of multiplicity */
};

poly struct _B bar;  /* in which domain should bar.b exist? */
mono struct _B bing; /* where would bing.a and bing.c get created? */
```

Multiplicity of pointers

Only the object being declared inside a struct is prohibited from having a multiplicity specifier. When pointers were described, it was suggested that you think of pointers as two parts: one the pointer being created, the other the base type of the pointer. Multiplicity can therefore be used on the base type of pointers, but not on the pointer itself. It can be seen that if no multiplicity specifiers were allowed anywhere inside a struct or union, it would be impossible to declare a pointer to poly data inside a struct. In the following example, all declarations are legal **C^n**:

```
union _C { /* define a union */
    poly int * a;
    mono int * poly * b;
};

poly union _C fred;
mono union _C barney;
```

In the declaration of `fred`, the identifier `a` is declared as a poly pointer to a poly int (`poly int * poly`) and `b` is declared as a poly pointer to a poly pointer to a mono int (`mono int * poly * poly`).

In the declaration of `barney`, `a` is declared as a mono pointer to a poly int (`poly int * mono`) and `b` is declared as a mono pointer to a poly pointer to a mono int (`mono int * poly * mono`).

Multiplicity of arrays versus pointers

In the case of an array definition inside a struct or union, the base type of the array cannot carry a multiplicity specifier. The multiplicity specified for an object of the struct or union type defines the multiplicity of the fields. This is one instance where arrays and pointers are not interchangeable.

For example:

```
union _E {
    poly int * a;
    int b[256];
    int * c;
};

mono union _E betty;
poly union _E wilma;
```

In the declaration of `betty`, the field's of the struct have the following types:

- `a` is defined as a mono pointer to a poly int (`poly int * mono`)
- `b` is defined as a mono int array (`mono int [256]`)
- `c` is defined as a mono pointer to a mono int (`mono int * mono`)

As would be expected, the fields `b` and `c` have equivalent pointer types.

In the definition of `wilma`, the fields are created as follows:

- `a` is defined as a poly pointer to a poly int (`poly int * poly`)
- `b` is defined as a poly int array (`poly int [256]`)
- `c` is defined as a poly pointer to a mono int (`mono int * poly`)

In this case, if `wilma.b` is used without a subscript, that is as a pointer, it has the type mono pointer to poly int (`poly int * mono`) which is not the same type as either `wilma.a` or `wilma.c`.

11.5.5 Typedefs

As with ANSI C, **C^n** supports typedef. Typedefs allow you to define your own types. Similarly to structs and unions, typedefs cannot include a multiplicity specifier. They can, however, use multiplicity to define the base type of a pointer. For instance:

```
typedef poly int p_int;   /* illegal use of multiplicity specifier */
typedef poly int * p_ptr; /* p_ptr is a pointer to a poly int */
typedef mono int * m_ptr; /* m_ptr is a pointer to a mono int */

p_ptr a;                  /* poly int * mono a */
poly p_ptr a;             /* poly int * poly a */
m_ptr a;                  /* mono int * mono a */
poly m_ptr a;             /* mono int * poly a */
```

The reason typedefs cannot contain a multiplicity specifier for the object being defined is the same as for struct and union. The typedef defines a type not an object, and multiplicity specifiers can only be used when an object is being created.

11.6 Assignment

Assigning within a domain (poly to poly, or mono to mono) is the simplest case and these assignments are always legal and have the obvious behavior.

A mono value can also be assigned to a poly variable. In this case the same value is copied to every instance of the variable on each PE, for example:

```
mono int x;
poly int px;

px = x;
```

After this operation, every PE's `px` will contain the value of the mono variable `x`.

However, it is not obvious what should happen when assigning a poly to a mono – that is when taking data from the multiple instances of the poly variable and storing it in the single mono variable. Therefore direct assignment from the poly domain to mono is not allowed in **C*ⁿ***.

There are however, many instances when it is useful to transfer data from poly memory to mono space and so the standard **C*ⁿ*** libraries contain a well defined suite of functions for data transfer between mono and poly memory.

The standard **C*ⁿ*** libraries also include reduction operations which allow multiple values from a poly variable to be combined, in various ways, into a single mono value.

11.6.1 Pointer dereferencing

Note that certain **C*ⁿ*** statements, if they were to be allowed, would require an implicit poly to mono assignment. The compiler does not currently support such implicit transfers, for efficiency reasons. One such operation is de-referencing a `mono char * poly` pointer (see *Figure 18*). Attempting to dereference such a pointer will result in a poly object, but the data is stored in the mono domain and would therefore need to be copied to poly space.

This also relates to arrays because it would seem possible to create a conventional, mono, array, then attempt to access it using a poly variable as the index. This may seem a useful feature but, again, because it implicitly dereferences a `mono * poly` pointer it is not allowed.

The compiler will report any attempt to dereference a `mono * poly` pointer as an error. The desired result can be achieved using the standard libraries.

11.7 Expressions

C*ⁿ* supports all the same operators as C. However, some expressions have slightly different behavior depending on the multiplicity of their operands. For details of the operators in **C*ⁿ***, see *Section 11.16*.

Mono and poly variables can usually be used interchangeably in expressions. The only difficulty is expressions that result in an assignment (see *Section 11.6*). It is perfectly valid to add a poly and a mono, to subtract them, or to perform any other operation. However, the result of any expression containing a poly and a mono object is invariably poly, and a poly object can only be assigned to another poly object.

Therefore, an expression can mix mono and poly variables as long as the expression does not result in a poly value being assigned to a mono value. Mono values will be promoted to poly in mixed expressions. For example:

```
poly int x;
int y;
x = x + y;
```

In the above expression, `y` will be promoted to a poly type before being added to (every instance of) `x`.

The conditional operator, `?:`, behaves similarly to an `if...else` statement and therefore conforms to the same rules with respect to execution of mono or poly expressions inside a mono or poly conditional, see *Section 11.8.2*.

11.7.1 Casting

Note: when casting a poly variable to another type, the cast must include the poly specifier. For example:

```
poly int k;
poly float value;

k=2;
value=(poly float) k;
```

11.8 Flow Control

The **C^n** language supports the same basic flow control statements as ANSI C with some minor additions. The basic flow control constructs are:

- `if` statement
- `if...else` statement
- `for` loop
- `while` loop
- `do...while` loop
- `switch` statements
- goto

Each of these flow control statements uses expressions for loop or branch control. The complication in **C^n** is that these expressions can be of mono or poly domain.

The important point here is that there is a single instruction stream to be executed by all (mono and poly) processing elements. This means that mono and poly conditional constructs behave differently:

- A mono expression for the condition affects *all* mono and poly processing elements and so it is handled in the normal way, that is, by using jumps around code which is not executed (or which is executed multiple times).
- A poly condition only affects the poly execution unit and, importantly, on some of the PEs the expression may be true and false on others. This has two implications: firstly mono statements are executed regardless of the result of the poly condition. Secondly, the PEs require a mechanism to allow some of them to skip certain instructions – this is the enable state described below.

Note: A mono condition is an expression containing only mono variables. If any component of the conditional expression is poly, then the whole expression is poly.

Additional statements that implement flow control are:

- `break` statements
- `continue` statements
- `return` statements

11.8.1 Poly flow control

Each PE contains an *enable state*. This tells the PE whether it is "switched on" or not (whether it should execute instructions or not). For example, you may wish to only perform processing on PEs with an even PE number. The following piece of **C*ⁿ*** code would perform this operation:

```
poly int penum = get_penum(); /* use Cn standard library function */
if (penum % 2 == 0)
{
    // do some processing here
}
```

The descriptions of the `if` and `if...else` statements are used below in order to explain poly flow control in detail. The principles also apply to loop constructs.

11.8.2 If statements

`if` statements in **C^n** have the same form as ANSI C. The format is repeated here for clarity:

```
if (expression) {statement-list}
```

As described above, *expression* can be mono or poly.

Mono if

A mono `if` statement is exactly the same as a conventional ANSI C `if` statement.

In the mono `if` statement, if *expression* is false, *statement-list* will be skipped entirely and execution will continue after the `if` statement.

Poly if

In the case of a poly `if`, *expression* can be true on some PEs and false on others. This is where the PE enable state comes in: all the PEs for which the condition is false are disabled for the duration of the `if` statement. The *statement-list* will then be executed, but any poly statements will only have an effect on the PEs that are enabled. Even if all PEs are switched off by *expression*, the *statement-list* will still get executed, but all poly statements will do nothing. This has the side effect that all mono statements inside a poly conditional will get executed irrespective of the expression controlling the `if`. *Effectively, a poly condition is invisible to any mono code inside that* `if` *statement.*

For example:

```
poly int penum = get_penum();
poly int foo = 0;
mono int bar;

if (penum % 2) { // all odd numbered PEs
    foo = penum * 10;
    bar = 1;
}
```

At the end of the above code fragment, `foo` will contain the value 0 on all even PEs and be the PE number times ten on all odd numbered PEs, `bar` will be 1. It may be worth noting that, although the *condition* is invisible to the mono statements, they are still within a compound statement block (with all the implications for variable scope that this implies).

The following example may help to stress the point about mono statements in a poly `if`.

```
poly int foo = 0;
mono int bar = 0;

if (foo) {
    bar = 1;
}
```

Note: Note that `bar` will have the value 1 at the end of this code, even though every single PE was disabled for the `if` statement. As described above, the mono statements will execute irrespective of any poly conditionals.

`if` statements can be nested just as in C. Nested poly `if` statements behave as would be expected: poly statements are only executed on PEs where *all* the nested conditional expressions evaluated to true.

If...else statements

The `if...else` statement in ***Cⁿ*** is similar to the ANSI C version. The format is repeated here for clarity.

```
if (expression) {if-statement-list} else {else-statement-list}
```

A poly `if...else` works by enabling all the PEs that match the conditional expression, and disabling all the others. For the `else` clause, the enable state of all the PEs is inverted: those PEs that were enabled by the condition are disabled and vice-versa. Note that any PEs which were disabled *before* the `if` will still be disabled for the *`else-statement-list`*.

`if...else` statements follow the same rules as `if` statements with respect to poly and mono conditionals. The only thing to note here is that an `if...else` statement with a poly condition will be executed with some PEs enabled for the *`if-statement-list`* and the remainder enabled for the *`else-statement-list`*. However, all mono statements inside *both* the `if` part and the `else` part of the statement will get executed, regardless of the condition.

For example:

```
poly int penum = get_penum();
mono int foo, bar;

if (penum % 2) { // executed on all odd PEs
    foo = 1;
} else { // executed on all even PEs
    foo = 2;
    bar = 2;
}
```

At the end of this code fragment, both `foo` and `bar` will be set to 2 (`foo` will initially have been set to 1 and then this is overwritten by the second assignment). Even if the second branch had all PEs disabled, all the mono statements would still get executed.

The example in *Table 27* may help visualize what happens. The first column shows the code which is relevant to the mono execution unit, the second column shows only the statements that affect poly data.

Mono view of code	Poly view of code
~~poly int penum = get_penum();~~	poly int penum = get_penum();
~~poly int p1, p2;~~	poly int p1, p2;
mono int m1, m2;	mono int m1, m2;
...	...
~~if (penum % 2) {~~	if (penum % 2) {
m1 += 1;	~~m1 += 1;~~
~~p1 = 0;~~	p1 = 0;
if (m1 > 10) {	if (m1 > 10) {
m2 = 10;	~~m2 = 10;~~
~~p2 = 10;~~	p2 = 10;
} else {	} else {
m2 = 0;	~~m2 = 0;~~
~~p2 = 0;~~	p2 = 0;
}	}
~~} else {~~	} else {
m1 = 0;	~~m1 = 0;~~
~~p1 = 1;~~	p1 = 1;
~~}~~	}

Table 27. Mono statements in poly conditionals

As can be seen, in the *mono view* the mono execution unit takes no notice of any poly statements, including the poly conditionals. The state at the end of this code is that `m1` is set to the value 0, but the value of `m2` is either 0 or 10, depending on the initial value of `m1`.

In the *poly view*, the only relevant mono statements are conditionals because their outcome can affect which poly code is executed, all other mono statements are ignored. At the end of this code fragment, the value of `p1` is 0 on odd-numbered PEs and 1 on the others. The value of `p2` is dependent on the initial value of `m1`.

Note that, although the poly conditional execution does not affect the mono code, the *block structure* of the code is still relevant. So, for example, any declarations within the braces of a conditional statement will be local to that block. For example:

```
poly int p = get_penum();
mono int m = 17;

if ( p % 2 ) {
    mono int m; // creates a new instance of m inside this scope.
    m = 21;     // assign a value (unconditionally)
}

// m at this point will have the value 17
```

11.8.3 Switch statements

Switch statements are supported in **C^n**, as long as the expression is mono. They provide the same functionality as ANSI C.

A pragma can be used before a switch statement to force the compiler to generate a jump table. This may improve performance in some cases. See *Section 11.10.3: Generating jump tables for switch statements on page 125*.

11.8.4 For, while and do...while loops

Due to the similarity of these constructs, the main points will be described together.

A loop with a poly control expression (a *poly loop*) will execute as long as the condition is true on *any* PE. In other words, the loop will terminate when the loop condition is false on *every* PE. Before the loop terminates, any PEs that evaluate the condition as false will be disabled for all the remaining iterations. These PEs will no longer participate in the remainder of the loop. When all PEs have evaluated the expression as false, the loop will be terminated.

Analogously to `if` statements, mono statements inside the loop will get executed on every iteration. Unlike `if` statements, if all PEs are disabled after evaluating the condition, the loop will terminate immediately so even the mono statements will not be executed. In other words, a poly loop can iterate zero times.

Consider the following piece of code:

```
poly int i;
mono int max_loop_count  = 0;
poly int this_loop_count = 0;

...  /* i is set in this code, value may be different on every PE */
while (i > 0) {
    i--;                /* Decrement poly loop control */
    max_loop_count++;   /* Increment mono loop_count: every time */
    this_loop_count++;  /* Increment poly loop_count: only while i >
0 */
}
```

At the end of this code, each PE will have a different value of `this_loop_count`, reflecting the number of iterations on that PE (the initial value of `i`). The value of `max_loop_count` will depend on the largest value of `i` across all PEs. In this case, `max_loop_count` may be a useful value since it informs you the total number of iterations the loop went through.

Break and continue

`break` and `continue` are used with loops to control the flow of the program.

An alternative to goto

`goto` statements can sometimes be useful in ANSI C, for example to handle errors in deeply nested loops. Similar behavior can be achieved in **C^n** as the `break` and `continue` statements have been extended to allow their use with labels. In **C^n**, label declarations are allowed only before keywords which start a loop construct (`for`, `while` and `do`). The `break` and `continue` statements in **C^n** can specify an optional label. This allows the program to break out of heavily nested loops. For instance, consider this example (for simplicity, assume all variables are mono):

```
L1: for (i = 0; i < 10000; i++) {
L2:     while(j > 100) {    /* execution continues here after
continue L2 */
L3:         do {
                ...
                if (foo == 0) {
                    break L1;
                }
                ...
                if (bar == 0) {
                    continue L2;
                }
                ...
            } while (a != b);
        }
    }
    /* execution continues here after break L1 */
```

In the above example, the statement `break L1` will break out of the outermost `for` loop, meaning execution will continue after the first `for` loop. The `continue L2` statement will cause the next iteration of the `while` loop to be executed. This gives nearly all of the flexibility of `goto`, but in a more structured way.

The `break` and `continue` statements are part of the loop control, just as much as the loop condition is. They are therefore treated as either mono or poly statements depending on the domain of the loop condition. Their precise behavior therefore varies depending on whether the loop condition is a mono or poly expression. With a labelled `break` or `continue`, the domain of the statement is determined by the loop it is controlling rather than the innermost loop it is within.

Goto

Goto statements can sometimes be useful and **C^n** allows for the use of goto in all contexts other than when the branch would cross a poly condition level boundary. For instance, consider the following example:

```
#include <stdio.h>

int main(void)
{
        poly int x = 10;

        printf("A\n");
labelA:
        if (x) {
                goto labelD;
                printf("poly if\n");
labelD:
                printf("D\n");
        }

        printf("B\n");
        goto labelC;
labelB:
        printf("C\n");
labelC:

        return 0;
}
```

The above example prints the output:

```
A
D
B
```

Changing the line `goto labelD;` to `goto labelB;` is not allowed as the branch would then cross a poly condition level boundary, expressed by the poly `if`.

Mono loops

The behavior of mono `break` and `continue` statements is exactly as in standard C: the code will exit the loop at the `break` statement and no further code inside the loop will be executed. The `continue` statement causes the next iteration of the loop to begin immediately.

In a mono loop, `break` and `continue` are mono statements. This means that they are executed even if they are within a poly conditional, for example (see *Table 27*).

For example, consider the following code where `i` is a mono variable and `foo` is poly:

```
for (i = 0; i < 10000; i++) {
    if (foo == 0) {
        break;
    }
    ...
}
```

This loop will terminate immediately because the mono `break` is executed unconditionally within the poly `if`.

Poly loops

In a poly loop, the loop control statements are treated as poly statements. They therefore behave as expected for poly code: the PEs which execute them either stop executing code in the loop (`break`) or are disabled unto the start of the next loop iteration (`continue`).

To understand this behavior remember that PEs cannot execute jumps. The only way to handle these statements is to disable the PEs. In the case of `break`, the PEs are disabled until the loop terminates. In this way, the PEs which execute the `break` will no longer participate in the loop. In the case of `continue`, the PEs are disabled for the current iteration. In this way, the PEs which execute the `continue` will not participate in this iteration but they will re-evaluate the loop condition.

The result of this is that some PEs can stop executing the code in the loop while others continue to iterate. Similarly some PEs can stop executing the current iteration while others continue. This preserves the semantics of `break` and `continue` for poly processing.

If all PEs are disabled after the `break` statement then the loop will terminate at the end of the current iteration.

Any PEs which do not execute the `break` or `continue` will carry on executing the loop code. Similarly, any mono code in the loop, after the `break` or `continue`, will always be executed at least once.

The following sections describe the behavior of poly `break` and `continue` in more detail.

Poly break

A poly `break` works by immediately disabling all PEs which execute it. Any other PEs (and any mono code) execute until the end of the current iteration. If, at this point, all PEs are disabled then the loop will terminate, otherwise the enabled PEs will continue to iterate until all are disabled (either by the loop condition or a `break`).

Consider first, the simple example below where `foo` is a poly variable:

```
while (foo < 100) {
    if (bar == 0) {
        break;
    }
    ... mono code
    ... poly code
}
```

In this case, the `break` statement will disable all PEs that execute it (if `bar` is a mono expression then this will be all PEs). Note that some PEs may already be disabled, either because they have reached the loop termination condition or because they have previously executed the `break`.

The processor continues executing the code after the `break`. The following poly statements will not be executed by the PEs which are disabled. Any following mono statements will be executed.

When the processor gets to the end of the iteration, the loop condition is evaluated and the enable state of the PEs is checked. If all PEs are disabled, iteration of the loop will be terminated. This means that if all PEs execute the `break`, the following mono code will be executed once before the loop exits.

With a labelled `break`, the domain of the statement is determined by the loop it is controlling. Otherwise, the same principle applies: each loop being exited ‘unwinds’ as described above.

Consider the following example where `i`, `j`, `a` and `b` are all poly variables:

```
L1: for (i = 0; i < 10000; i++) {
L2:     while(j > 100) {
L3:         do {
                ...
                if (foo == bar) {
                    break L2;
                }
                ... L3 mono code
                ... L3 poly code
            } while (a != b);
            ... L2 mono code
            ... L2 poly code
        }
        // execution continues here for PEs that execute break L2
        ...
    }
```

In this case, the code indicated as "`L3 poly code`" and "`L2 poly code`" will be ignored by PEs that execute the `break L2` statement and the code marked as "`L3 mono code`" and "`L2 mono code`" will be executed.

Poly continue

A poly `continue` works by immediately disabling all PEs which execute it *for the remainder of the current iteration only*. The current loop iteration then runs to completion. Any PEs which were disabled by the `continue` will be re-enabled and then the loop condition will be re-evaluated.

The effect of this is that the PEs which execute the `continue` will cease to execute code in the loop until the loop condition is re-evaluated. The other PEs will execute the whole of the remainder of the code in the loop. As before, any mono code in the loop will be executed unconditionally.

Consider the example below where `foo` is a poly variable:

```
while (foo < 100) {
    if (bar == 0) {
        continue;
    }
    ... mono code
    ... poly code
}
```

In this case, the `continue` statement will disable all PEs that execute it – if `bar` is a mono expression then this will be all PEs. Note that some PEs may already be disabled because they have reached the loop termination condition.

The processor continues executing the code after the `continue`. The following poly statements will not be executed by the PEs which are disabled. Any following mono statements will be executed.

When the processor gets to the end of the loop, those PEs which were disabled by the continue will be re-enabled. The loop condition is then evaluated and the loop execution continues.

11.9 Functions

Functions are fundamentally the same in **C^n** as they are in ANSI C.

11.9.1 Function multiplicity

Multiplicity specifiers can be used to specify the return type of a function as well as the types of any arguments. Return types of functions can be of mono or poly domain. The `void` return type can also be either mono or poly. The domain of the function is defined by the return type.

11.9.2 Returning from functions

As with ANSI C, a function which specifies a return type other than `void` must have a return statement somewhere in the function. It should have one per control flow branch through the function.

Mono functions

A return in a mono function behaves exactly as expected: the function returns control to the calling code at that point.

Poly functions

A return statement in a poly function works by disabling the PEs. Note that the function does not actually return control to the calling code until the end of the function body is reached (because program control flow is a mono operation). This means that any *mono* code after the return statement will be executed.

A conditional return will disable those PEs which execute it. These PEs will remain disabled until the end of the function. Other PEs will execute the rest of the code in the function. When the function returns, all PEs have their enable state restored to what it was on entry.

Consider the following example:

```
poly int bar(poly int p1, p2) {
    if (p1) {
        if (p2) {
           return -1;  // disable appropriate PEs and save the return
value of -1
        } else {
           return 0; // disable appropriate PEs and save the return
value of 0
        }
    }
    ...  (1)
    return 0; // PEs which are still enabled save 0 as a return value
and are disabled
    ...  (2)
} /* return saved poly values here */
```

In this case, all PEs for which the condition `p1` is true will return a value (either 0 or -1, depending on `p2`). These PEs will be disabled until the end of the function. All other PEs will continue to execute the rest of the poly code in the function. Therefore, poly code at (1) in this function will be executed by those PEs which have not already specified a return value of 1 or -1. This is followed by an unconditional return so any poly code at (2) will not be executed. All mono code in the function will always be executed.

11.10 Pragmas

The section outlines the currently supported set of CSX specific pragmas.

11.10.1 Including assembler macros in C^n

The CSX processor instruction set is split between actual instructions and macros provided as part of the SDK in assembler header files. As with C-style macros, these instructions cannot be accessed without first including the correct header in the assembler source. If these instructions are to be accessed from assembly functions within **C^n** code (see *Section 11.11: Inline assembler on page 128*) the header must be included.

To include a particular assembly header in a piece of **C^n** source code, the assembly include pragma must be used:

```
#pragma asm_inc <file.inc>
```

or

```
#pragma asm_inc "file.inc"
```

11.10.2 Forcing the alignment of identifiers

The CSX ABI, described in Section *Section 13.3: Data representation and allocation on page 158*, defines the alignment of data objects for the CSX processor. The compiler will produce data aligned to these requirements by default. However, it is sometimes useful to be able to override these default settings. The alignment pragma is used to do this for a specific variable:

```
#pragma align integer
```

The scope of the align pragma is the variable declaration which immediately follows it. The `integer` parameter defines the alignment in bytes for the variable. This value can be expressed in decimal or hexadecimal using the normal C notation.

The following example forces the variable `i` to be allocated in poly memory at an address which is a multiple of 32 bytes. The pragma has no effect on the alignment of `j`.

```
#pragma align 0x20
poly int i[200];
int j[100];
```

Note: The **C^n** pragma for specifying the alignment of variables (`#pragma align`) can only be used with static (global) variables. Specifying this pragma before a local variable allocated on the stack will have no effect.

11.10.3 Generating jump tables for switch statements

The compiler normally treats switch statements (*Section 11.8.3: Switch statements on page 118*) as a series of conditional branch statements. In some cases, depending on the size of the switch statement and the nature of the cases, it may be more efficient to generate a jump table.

The switch pragma can be used to do this for an individual switch statement:

```
#pragma switch jumptable
switch(program[pc])
{
```

The compiled code can then be checked for changes in code size and speed.

The pragma should appear immediately before the switch statement which is to be translated as a jump table.

11.10.4 Unrolling loops

There are a number of pragmas available which can be used to influence the behavior of the loop unroller. Each of these pragmas should be placed immediately before the loop to be affected.

```
#pragma loop no unroll
```

This can be used to prevent the loop from being unrolled.

```
#pragma loop unroll(nr)
```

This can be used to request a loop to be unrolled a certain number of times. The parameter `nr` should be a positive integral value. See also *Section 4.4.34: Loop unrolling on page 51*.

```
#pragma loop maxunroll(nr)
```

This pragma sets a limit on the number of times the loop will be unrolled. Set immediately before the loop you want to affect. The parameter `nr` should be a positive integral value indicating the maximum unroll factor for the following loop.

11.10.5 Moving code to on-chip memory

It is often important to run performance-critical code from the fast on-chip SRAM rather than external DRAM. While it is possible to have the linker place *all* code in on-chip memory this is not always practical due to space limitations. You may want to specify particular, performance-critical functions to be placed in on-chip memory. The `hot` pragma provides a tool for achieving this. This pragma takes a bracketed list of function names, all of which must be defined in the current compilation unit:

```
#pragma hot (f1, ..., fn)
```

The scope of the hot pragma is the current compilation unit. Each function in the list will be placed in on-chip memory by the linker while all other functions will be placed in DRAM.

The following example forces the functions `foo` and `bar` to be placed in on-chip memory, but leaves main in DRAM (the default):

```
#pragma hot (foo,bar)

int bar(void) {... }

int foo(void) { ... }

int main(void)
{
    ...

    for (...)
        foo() + bar();

    ...

    return 0;
}
```

11.10.6 Setting stack sizes

A pragma can be used to set the size of statically allocated stacks for each thread, as follows:

```
#pragma static_stack(mono|poly, size, thread)
```

The first argument defines whether a mono or poly stack size is being defined. The second argument specifies the stack size in bytes. The third argument specifies the thread number for which the stack size is being set.

See *Section 12.1: Stack allocation on page 150* for more details on the use of dynamic and static stacks.

11.10.7 Controlling inlining functions

The following pragmas control inlining function definitions.

`#pragma inline`

This pragma should be placed immediately before the definition of a procedure. It is a request for the following function to be inlined, but doesn't guarantee inlining. The behavior when marking functions for inlining using this pragma is not the same as when the inline keyword is used. Using the inline pragma does not affect whether or not a function is generated in its own right. This does mean, however, that you may need to use the static keyword to avoid multiple symbol definitions where an inline function is defined in a header file and included in multiple source files within a project.

The inline pragma can be used with on/off placed after it, for example:

```
#pragma inline on
```

The effect of this is to mark all functions declared after the pragma with an inline pragma, until a `#pragma inline off` is seen.

`#pragma inlinecalls`

This pragma can be placed before a function call site to indicate that the called function (or functions) within the succeeding statement should be inlined. This pragma can also be turned 'on' or 'off' in the same way as the inline pragma.

`#pragma noinline`

This pragma can be placed immediately before a function definition and will ensure that the function is not inlined, even at –O3 and above when auto-inlining is enabled.

`#pragma forceinline`

This pragma is again placed just before a function definition and indicates that the function will always be inlined. This overcomes the inlining rules above, except for those rules that affect functional correctness (varags, recursive functions and computed gotos).

11.11 Inline assembler

Inline assembly code in ***C**^n^* is defined using a similar syntax to functions and, as such, must be named. A consequence of this is that they cannot be defined within basic blocks.

An inline assembly sequence can be defined using the ***C**^n^* keyword `__asm`. These keywords are storage class specifiers and therefore cannot be combined with `static` or `extern`. The prototype of the assembly function can, however, be specified as `static` or `extern`, but it cannot use the `__asm` keyword. The `__asm` keyword can only be attached to function definitions. A function with storage class `__asm` must have a function body and cannot consist solely of a function prototype. Such a function is referred to as an assembly function.

The assembly code starts at the first character after the opening brace of the body of the assembly function and ends with the last character before the matching closing brace.

11.11.1 Enable state

Any changes to the enable state within an assembly function must be completely contained within that function. The enable state must be restored to its original state when the assembly function exits. In other words, the enable state when the assembly function exits must be the same as it was at the entry to the function.

For example, code such as the following is not allowed (although the compiler does not check for this):

```
__asm void poly_if_on_arg(poly char a)
{
    @[
            .poly;
    ]
    cmp ${a}, 0 ;
    if.nzero ;
}
```

The compiler cannot tell that the assembly function has changed the enable state and so it may perform some incorrect optimizations.

Either perform such conditional code entirely in inline assembly or entirely in Cn, not a mixture of both.

11.11.2 Use of variables within assembler code

Parameters to an assembly function and locally-defined variables (variables defined within the assembly function) can be referenced in the assembly code using their symbolic names with the `@{variable}` syntax. This allows register allocation to be performed by the compiler.

A number of operand modifiers are provided to change and constrain the way that operands are interpreted by both the compiler and, in some cases, the assembler.

The following is a simple example of an assembly function implementing single-precision floating-point add. Note the use of `@{}` to specify the return value of the function.

```
__asm mono float __addf(mono float x, mono float y)
{
    add @{}f, @{x}f, @{y}f;
}
```

This could be called from the **C^n** code as follows:

```
int main(void)
{
    float y = __addf(10.0, 20.0);
    return (int)y;
}
```

Byte selection operators

To use only the least significant or most significant bytes of an operand, the `.lsbytes` and `.msbytes` operators are provided. The format of these is as follows:

```
.lsbytes ( variable_name, number_of_bytes );
.msbytes ( variable_name, number_of_bytes );
```

Any number of bytes can be specified. If the number of bytes specified is greater than the size of the operand, the operator is ignored. An example of using these is shown below:

```
__asm mono char __add(mono char x, mono int y)
{
  add @{}, @{x}, .lsbytes(@{y}, 2);
}
```

The `.lsbytes` operator in this example is used to extract the least significant byte of `y` in order to add it to `x`, a 2-byte value (as registers on in mono are a minimum of 2 bytes in size). The actual byte that gets chosen is dependant upon the endianness of the target platform. For a wider discussion on these and other assembly directives along with more detailed examples, see *Chapter 14: Assembly language*.

11.11.3 Specifying constraints on register use

The compiler manages register allocation for variables used in inline assembly. To allow the compiler to do this correctly, you must ensure you fully specify the usage of registers and memory. Failure to do this may cause hard-to-track-down problems. In many cases, these will not cause compilation warnings or errors, which makes them particularly troublesome.

The use of registers, and other restrictions, are specified by a set of constraint directives (*Section 11.11.4: Constraint directives on page 131*).

There are some registers which can be written to without any additional constraints being specified:

- the result register (`@{}`)
- scratch registers (defined with the `.scratch` directive)

There are some restrictions on these registers, as described below. If you unsure of the rules, then it is better to specify a `.interfere` directive to be safe.

Writing to the result register

If any part of the result register is written before a read or write of another register, then it is necessary to add an explicit *interference* clause to the inline assembly code. This is because the compiler assumes that the result register is written after all other registers. If this is not the case then the compiler may incorrectly allocate the result register.

For example:

```
int __asm invalid1(int x, int y)
{
   add @{}, @{x}, @{x};
   add @{}, @{},  @{y};
}
```

This example is incorrect because the register allocator may decide that the optimal allocation is to assign the result register and `y` to the same register, which would cause the first add instruction to overwrite argument `y` and make the second add use the wrong value.

This is fixed in the following way:

```
int __asm valid1(int x, int y)
{
   @[
         .interfere (x,) (y,)
   ]
   add @{}, @{x}, @{x} ;
   add @{}, @{},  @{y} ;
}
```

Note: The result register is specified by a blank in the interference pair.

The same rule applies to interference between scratch registers and the result register. Scratch registers automatically interfere with each other and argument registers, but not with the result register, so any writes to the result register before reading or writing a scratch register will require a directive to specify interference between the result and scratch registers.

Writing to argument registers

To write to argument registers, a `.clobber` directive is required to inform the compiler that those registers are written to.

For example, this code modifies the argument `y`:

```
int __asm invalid2(int x, int y)
{
   add @{y}, @{y}, @{x};
   add @{},  @{y}, @{x};
}
```

This should include a `.clobber` directive as shown:

```
int __asm valid2(int x, int y)
{
   @[
         .clobber y
         .interfere (x, y)
   ]
   add @{y}, @{y}, @{x};
   add @{},  @{y}, @{x};
}
```

The additional `.interfere` directive is also required because in this case we are expecting to be able to read the value of `x` after `y` is written in the first add instruction, so they cannot be stored in the same register.

Writing to other registers

When writing to other registers, you must add a `.write` directive to show that you are writing a register which is not otherwise specified as an argument (`.clobber` should be used here), the result or a scratch. For example:

```
.write 8:m2;
```

Using .nobarrier

For some inline assembly sections (those which do not use swazzle or vector operations), it is possible to specify the `.nobarrier` directive to allow the scheduler more freedom in moving items past the inline assembly block.

When this is used, you must specify whether the inline assembly section reads or writes memory (`.read .memory` or `.write .memory`), as well as the other register-related directives. This allows the scheduler to have enough information about the content of the inline assembly block to ensure correct scheduling around it.

11.11.4 Constraint directives

Constraints on the use of variables and other properties of the assembly function can be defined using the `@[`*`constraints`*`]` directive. Multiple constraints can be listed, one per line, within the brackets.

`.scratch` ***`name`*** **`[,`** ***`name`*** **`]*`**

This is followed by a list of names separated by commas. This directive declares new objects of type `scratch` that can be used in the assembly code, in other words the directive simply introduces new symbols that can be referenced with the assembler body. Applying additional constraints, as given below, allows scratch symbols to be used as symbolic references to particular classes of registers, and so on. The following example defines symbols `y` and `x` to be scratch:

```
@[
   .scratch x, y
]
```

It is possible for the compiler to allocate scratch registers (declared using `.scratch`) to the same registers that are used as return registers (denoted `@{}` in the assembly code). If any part of the return register is written before a read of a scratch or operand register, you should declare an explicit interference (see *Section 11.11.3: Specifying constraints on register use on page 129*). This avoids the scratch or operand register being overlapped with the return register. Scratch registers automatically interfere with one another so it is not necessary to specify them in an interfere directive.

`.restrict [`*`variable`*`:`*`register_class`*`]*`

This directive is followed by a list of register restrictions (possibly empty) separated by commas. This directive allows you to restrict a symbol to a register class. For example, if the symbol `piX` is a 4-byte poly value, its use should be restricted to the poly registers `0:p4`, `4:p4` and so on, the `pdreg` class. A register restriction consists of a variable followed by a colon followed by a register class.

The set of register classes are defined as follows:

`mwreg`, `mdreg` and `mddreg` are 2, 4, and 8-byte mono registers, respectively

`preg`, `pwreg`, `pdreg` and `pddreg` are 1, 2, 4, and 8-byte poly registers, respectively

`pfvecreg` and `pdvecreg` are 4x4-byte and 4x8-byte poly vector registers, respectively, and

`p2fvecreg` and `p2dvecreg` are 2x4-byte and 2x8-byte poly vector registers, respectively

For example, consider the following assembler function which, given a mono unsigned short as an argument, adds the constant value 0x1000 and returns the result. The `restrict` directive is used to constrain the temporary register used to hold the constant 0x1000 to a 2-byte mono register `mwreg`, as follows:

```
 __asm mono unsigned short__add1000(mono unsigned short x)
{
  @[
    .scratch temp
    .restrict temp:mwreg
  ]
         mov @{temp}, 0x1000;
         add @{}, @{x}, @{temp};
}
```

Optionally, an *explicit* restriction can be added. This requests the compiler to allocate the restricted variable to a particular set of registers within the specified register class. Such an explicit restriction consists of a list of registers separated by commas and surrounded by angle brackets. In the above example, rather than just restricting `temp` to the register class `mwreg`*,* it could be allocated to the mono return register (`8:m2`) by using the expression:

```
.restrict temp:mwreg <8:m2>
```

The full set of registers for each register type is defined in *Table 28*.

`0:m2`, `2:m2` ... `62:m2`	the set of 2-byte mono registers
`0:m4`, `4:m4`, ... `60:m4`	the set of 4-byte mono registers
`0:m8`, `8:m8`, ... 56:m8	the set of 8-byte mono registers
`0:p1`, `1:p1`, ... `127:p1`	the set of 1-byte poly registers
`0:p2`, `2:p2`, ... `126:p2`	the set of 2-byte poly registers
`0:p4`, `4:p4`, ... `124:p4`	the set of 4-byte poly registers
`0:p8`, `8:p8`, ... `120p8`	the set of 8-byte poly registers

Table 28. Register range definitions

`0:p4f[4], 16:p4f[4], ... 112:p4f[4]`	the set of 4x4-byte poly registers
`0:p8f[4], 32:p8f[4], ... 96:p8f[4]`	the set of 4x8-byte poly registers

Table 28. Register range definitions (Continued)

You can also specify predefined register sets (shown in *Table 29*) by using the following syntax:

```
.restrict temp:preg <registerset>
```

In addition, you can specify a range of registers by using a dash:

```
.restrict temp:preg <startreg-endreg>
```

For example, to restrict the register class `preg` to all registers between `reg1` and `reg20` inclusive, use the expression:

```
.restrict temp:preg <reg1-reg20>
```

To specify multiple ranges, registers and sets, separate them by using commas:

```
.restrict temp:preg <pregs_lo, 127:p1, 70:p1-72:p1>
```

Register sets	Register ranges
`pregs_even`	all even-numbered 1-byte registers (`0:p1, 2:p1, 4:p1 ...`)
`pregs_odd`	all odd-numbered 1-byte registers (`1:p1, 3:p1, 5:p1 ...`)
`pregs_lo`	all 1-byte registers up to 64 bytes into the register file (`0:p1-63:p1`)
`pwregs_lo`	all 2-byte registers up to 64 bytes into the register file (`0:p2-62:p2`)
`pdregs_lo`	all 4-byte registers up to 64 bytes into the register file (`0:p4-60:p4`)
`pddregs_lo`	all 8-byte registers up to 64 bytes into the register file (`0:p8-56:p8`)
`pregs_8bytealigned`	8-byte aligned 1-byte registers (`0:p1, 8:p1, 16:p1 ...`)
`pwregs_8bytealigned`	8-byte aligned 2-byte registers (`0:p2, 8:p2, 16:p2 ...`)
`pdregs_8bytealigned`	8-byte aligned 4-byte registers (`0:p4, 8:p4, 16:p4 ...`)
`mwregs_8bytealigned`	8-byte aligned 2-byte mono registers (`0:m2, 8:m2, 16:m2 ...`)
`mdregs_8bytealigned`	8-byte aligned 4-byte mono registers (`0:m4, 8:m4, 16:m4 ...`)

Table 29. Ranges for predefined register sets

.change

This is followed by a list of register ranges separated by commas. This list defines registers that are modified by the assembly code. For example, the following code uses the mono register `32:m2` for scratch calculation:

```
__asm mono short calc(void)
{
   @[
         .change 32:m2
   ]
   mov 32:m2, 0x100;
   add 32:m2, 32:m2, 32:m2;
   mov @{}, 32:m2;
}
```

.unique

This specifies that *all* objects should be placed in different registers. Any symbols locally defined using the `.scratch` directive, passed as parameters or the result register, will not share registers.

For example, the following code uses `.unique` to force a, b, x, y and the result into non-overlapping registers:

```
__asm poly short test(mono short x, mono short y)
{
   @[
         .scratch a, b
         .restrict a:pwreg, b:pwreg
         .unique
   ]
   mov @{a}, @{x};
   mov @{b}, @{y};
   add @{}, @{a}, @{b};
}
```

.clobber

This is followed by a, possibly empty, list of function parameters. This informs the compiler that the parameter values are changed by the assembly function. Normally parameters are assumed not to be changed by the assembly code. For example, the following code uses parameter `x` as a temporary variable for doing a simple calculation before adding the result to `y`:

```
#pragma asm_inc <arith.inc>
__asm mono short addDbl(mono short x, mono short y)
{
   @[
         .clobber x
   ]
   add @{x}, @{x}, @{x};
   add @{}, @{y}, @{x};
}
```

.target
.prefer

These can be followed by a function parameter object. The `.target` directive specifies that the parameter and the return value of the assembler function *must* use the same register. The `.prefer` directive specifies that it is preferable to use the same register but not required. For example, consider the following assembler function which adds `y` to `x`, returning the result in the register assigned to `x`:

```
__asm mono short adds(mono short x, mono short y)
{
   @[
         .target x
   ]

   add @{x}, @{x}, @{y};
}
```

.interfere

This directive is followed by a, possibly empty, list of object pairs separated by commas. An object pair consists of two object identifiers separated by a comma and enclosed by parentheses. This directive specifies that the two symbols in a pair should not be placed in the same register. This is particularly useful in assembler instructions that cannot have operands in the same registers.

The following example casts its first argument (double) down to a float, storing the result in its second argument which is also used as the return register. The *interfere* directive is used to capture the constraint that the double and float registers cannot overlap.

```
#pragma asm_inc <shift.inc>
__asm mono float castDblToFlt(mono double in, mono float out)
{
   @[
         .target out
         .interfere (in, out)
   ]
   cast @{out}, @{in};
}
```

.read
.write

These are followed by a, possibly empty, list of register ranges separated by commas. These directives are used to tell the compiler which registers are read and written, respectively. Register ranges are defined in *Table 28*. The following example reads from mono registers `16:m2` and `18:m2` and writes to mono register `8:m2`:

```
__asm mono short addS (void)
{
   @[
         .read 16:m2, 18:m2;
         .write 8:m2;
   ]
         add 8:m2, 16:m2, 18:m2;
}
```

.read .memory
.write .memory

These directives are used to tell the compiler that an inline assembly block has a side-effect on memory, to give more accurate scheduling dependencies. The following example shows the directive in use where a global is loaded from memory:

```
#pragma asm_inc <ldst.inc>
__asm poly short read_from_global(void)
{
    @[
        .read .memory
        .write 8:p2;
    ]
    ld 8:p2, some_global;
}
```

.barrier

This directive prevents the instruction scheduler from moving instructions across the assembly code function. This is applied by default, to make the scheduler compatible with "older" versions of inline assembly (where dependency directives have not been specified).

.nobarrier

This directive disables the default `.barrier` directive. This allows the compiler to schedule instructions around the block. If you are sure that there are no hidden dependencies, you can place a `.nobarrier` directive on the inline assembly block to disable the default `.barrier`.

.poly

This directive should be used by any block of inline assembly which uses poly code. The compiler uses this information to determine if there are any conditional assignments inside the inline assembly block, and it will extend the live-ranges of poly variables across that block to avoid unnecessary moves or spills of poly registers which may otherwise occur after that block.

11.11.5 Inline assembly example

The following **C*n*** program defines a mono `memcpy` function using assembly code and uses a selection of the directives described in *Section 11.11.4: Constraint directives on page 131*:

```
#include <dprint.h>

__asm void * __memcpy(void * dest, const void * src, int n)
{
  @[
    .target         dest
    .clobber        n, src
    .scratch        tmp
    .restrict       tmp:mwreg
  ]

.LL_loop::
   cmp  .lsbytes(@{n},2), 0;
   cmpc .msbytes(@{n},2), 0;

   j.if.zero .LL_complete;

   ld   .lsbytes(@{tmp}, 1), @{src};
   st   @{dest}, .lsbytes(@{tmp},1);

   add  .lsbytes(@{src},2), .lsbytes(@{src},2), 1;
   addc .msbytes(@{src},2), .msbytes(@{src},2), 0;

   add  .lsbytes(@{dest},2), .lsbytes(@{dest},2), 1;
   addc .lsbytes(@{dest},2), .lsbytes(@{dest},2), 0;

   sub  .lsbytes(@{n},2), .lsbytes(@{n},2), 1;
   subc .msbytes(@{n},2), .msbytes(@{n},2), 0;

   j .LL_loop;

.LL_complete::
}


#define LENGTH 10

int main(void)
{
    char dst[LENGTH] = "987654321";
    char src[LENGTH] = "123456789";

    __memcpy(dst, src, LENGTH);

    dprint_mono(STRING, dst);

    return 0;
}
```

11.12 Vector intrinsics

Vectors define a group of poly values which are operated on together. The purpose of vector operations is to make better use of internal pipelines and allow greater throughput of operations.

Note: Each of these vector types is a two or four-element vector on every PE. This is distinct from the poly keyword which could be interpreted as a 96-element vector across the PE array.

It is important to note that vectors are *poly* types. Mono vectors are not supported.

Support for the vector instruction set from within ***C^n*** is provided through the addition of new data types combined with a set of intrinsic functions that map directly to corresponding instructions. For example, the following vector function:

```
__cs_vadd_scalar()
```

implements the instruction:

```
vector.add.scalar
```

For more information on the corresponding instructions, refer to *[1]: CSX600 Instruction Set Reference Manual*.

The vector data types are:

`__FVECTOR`	4 x poly single-precision floating-point elements
`__DVECTOR`	4 x poly double-precision floating-point elements
`__SIVECTOR`	4 x poly signed integer elements
`__UIVECTOR`	4 x poly unsigned integer elements
`__SSVECTOR`	4 x poly signed short integer elements
`__USVECTOR`	4 x poly unsigned short integer elements
`__F2VECTOR`	2 x poly single-precision floating-point elements
`__D2VECTOR`	2 x poly double-precision floating-point elements

This includes a range of integer vector types to allow casting from integer values to floating point elements and back again.

The instruction set does not provide instructions for working with these additional integer types. They can only be accessed from ***C^n*** and they are provided to allow straightforward casting between the different types.

Note: The compiler does not provide any intrinsics for the two-element vector types. They are, however, useful in inline assembler, for example when operating on complex numbers.

Values of these types can be defined in ***C^n*** as follows:

```
    __FVECTOR  vacc = {0.0, 0.0, 0.0, 0.0};
```

Overloading the array initialization syntax allows vectors to be initialized with constant values.

Vector assignment and the loading and storing from arrays are supported as normal. For example, the following piece of code loads four vectors from a poly array of single precision floats:

```
        poly float V[BUFFERSIZE];
        __FVECTOR  v0;
        __FVECTOR  v1;
        __FVECTOR  v2;
        __FVECTOR  v3;
        poly float *v   = &V[0];

    v0            = *((__FVECTOR *)v);
    v1            = *((__FVECTOR *)(v+4));
        v2        = *((__FVECTOR *)(v+8));
        v3        = *((__FVECTOR *)(v+12));
```

Unlike other types in **C^n**, such as int and float, the standard arithmetic operators are not supported. A set of built-in operations is provided instead. To square the vector `v0`, from the example above, and add the result to an accumulator `vacc`*,* the following vector function can be used:

```
  vacc = __cs_vmulacc(vacc, v0,v0);
```

It is important to note that this call maps directly to the vector instruction set, as defined in the *[1]: CSX600 Instruction Set Reference Manual* and does not have the overhead of a function call.

A more complete example of using vector instructions from **C^n** can be found in: `examples/sdk/cn_vector/square.cn` in the SDK install directory.

11.13 Operator overloading

Unless specified, all operands and return value must have the same vector type.

Where the operands are a vector type and a scalar type, the scalar type must match the element type of the vector (float for __FVECTOR, double for __DVECTOR, for example), if mono scalar types are used, the scalar will be promoted to poly prior to the operation.

The actual set of operators, assignments and casts is as follows:

Operator	Supported vectors	Result type	Description
`vector1+vector2`	_FVECTOR, _DVECTOR	vector	Adds corresponding elements of the operand vectors producing a vector result
`vector1 + scalar` or `scalar + vector2`	_FVECTOR, _DVECTOR	vector	Adds the scalar to each element of vector1, producing a vector result
`vector1 += vector2`	_FVECTOR, _DVECTOR	vector	Adds corresponding elements of vector1 and vector2 assigning the resulting vector to vector1
`vector1 += vector`	_FVECTOR, _DVECTOR	vector	Adds the scalar to each element of vector1, assigning the result to vector1
`vector1 - vector2`	_FVECTOR, _DVECTOR	vector	Subtracts the corresponding elements of vector2 from those of vector1, producing a vector result

Table 30. Arithmetic operators

Operator	Supported vectors	Result type	Description
`vector1 - scalar`	_FVECTOR, _DVECTOR	vector	Subtracts the scalar from each element of vector1, producing a vector result
`scalar - vector1`	_FVECTOR, _DVECTOR	vector	Subtracts each element of vector1 from the scalar producing a vector result
`vector -= scalar`	_FVECTOR, _DVECTOR	vector	Subtracts the scalar from each element of vector1, the result of each subtraction being placed in the corresponding element of vector1
`vector1 * scalar or scalar * vector1`	_FVECTOR, _DVECTOR	vector	Multiplies each element of vector1 by the scalar producing a vector result
`vector1 *= vector2`	_FVECTOR, _DVECTOR	vector	Multiplies the corresponding elements of vector1 and vector2 assigning the resulting vector to vector1
`vector1 *= scalar`	_FVECTOR, _DVECTOR	vector	Multiplies each element of vector1 by the scalar assigning the vector result to vector1

Table 30. Arithmetic operators

Operator	Supported types	Result type	Description
`(_FVECTOR)vector1`	_DVECTOR, _SIVECTOR, _UIVECTOR, _SSVECTOR, _USVECTOR	_FVECTOR	Casts the elements of vector1 to float, assigning each cast to the corresponding element of the result vector
`(_FVECTOR)scalar`	Any scalar type	_FVECTOR	Casts the scalar to float and then assigns the resulting value to each element of the result factor
`(_DVECTOR)vector1`	_DVECTOR, _SIVECTOR, _UIVECTOR, _SSVECTOR, _USVECTOR	_DVECTOR	Casts the elements of vector1 to double, assigning each cast to the corresponding element of the result vector
`(_DVECTOR)scalar`	Any scalar type	_DVECTOR	Casts the scalar to double and then assigns the resulting value to each element of the result vector
`(_SIVECTOR)vector1`	_FVECTOR, _DVECTOR	_SIVECTOR	Casts each element of vector1 to signed int, producing a vector result
`(_UIVECTOR)vector1`	_FVECTOR, _DVECTOR	_UIVECTOR	Casts each element of vector1 to unsigned int, producing a vector result
`(_SSVECTOR)vector1`	_FVECTOR, _DVECTOR	_SSVECTOR	Casts each element of vector1 to signed short, producing a vector result
`(_USVECTOR)vector1`	_FVECTOR, _DVECTOR	_USVECTOR	Casts each element of vector1 to unsigned short, producing a vector result

Table 31. Type cast operators

In *Table 32*, substitute one of the following operators for [cmp]:

<, <=, >, >=, ==, !=

Operator	Supported types	Result type	Description
`vector1 [cmp] vector2`	_FVECTOR, _DVECTOR	poly int	Each element of vector1 is compared to the corresponding element of vector2, the result value is a logical AND of all comparison results

Table 32. Comparison operators

Operator	Supported types	Result type	Description
`vector1[i]`	_FVECTOR, _DVECTOR	scalar	Returns the i'th element of vector1, where 0 <= i <=3 and must be a constant

Table 33. Array indexing

11.14 Supported intrinsics

Overloading is used so that you can create multiple functions with the same name but different parameters. With function loading you do not have to remember multiple function names for the same operation on different types of arguments. For example, the following call to the vector function will produce code for either the single- or double-precision vector `add`:

```
vrs = __cs_vadd(v0, v1);
```

The full set of intrinsics exist for both single precision and double precision, each sharing the same overloaded function name. For example:

```
extern __FVECTOR   __cs_vadd(__FVECTOR x,

__FVECTOR y);
```

Calls the single-precision version.

```
extern __DVECTOR   __cs_vadd(__DVECTOR x,

__DVECTOR y);
```

Calls the double-precision version.

For simplicity, only the single-precision versions are described. One exception to this is the cast operations which do not have overloaded variants because they explicitly move between types.

11.14.1 Arithmetic operations

The following list of vector intrinsics cover the arithmetic instructions of the instruction set. All the operations discussed in this section are element-by-element operations on the components of the supplied vectors:

```
extern __FVECTOR __cs_vadd(__FVECTOR x,
                                                         __FVECTOR y);
```

Adds the elements of vector `x` to the corresponding elements of vector `y` and returns the result.

```
extern __FVECTOR  __cs_vadd_scalar(__FVECTOR x,

poly float y);
```

Adds the scalar `y` to each of the elements of vector `x` and returns the resulting vector.

```
extern __FVECTOR  __cs_vsub(__FVECTOR x,
                                                         __FVECTOR y);
```

Subtracts the corresponding elements of vector `y` from each of the elements of vector `x` and returns the resulting vector.

```
extern __FVECTOR  __cs_vsub_scalar(__FVECTOR x,
                                  poly float y);
```

Subtracts the scalar `y` from each of the elements of vector `x` and returns the resulting vector.

```
xtern __FVECTOR   __cs_displace(poly float x,
                                  __FVECTOR y);
```

Subtracts each element of the vector `y` from the scalar `x` and returns the resulting vector.

```
extern __FVECTOR  __cs_vmul(__FVECTOR x,
                              __FVECTOR y);
```

Multiplies the elements of vector `x` by the corresponding elements of vector `y` and returns the result.

```
extern __FVECTOR  __cs_vmul_scalar(__FVECTOR x,
                                  poly float y);
```

Multiplies the elements of the vector `x` by the scalar `y` and returns the result.

```
extern __FVECTOR  __cs_vmulacc (__FVECTOR z,
                               __FVECTOR x,
                               __FVECTOR y);
```

Multiplies the elements of vector `x` by the corresponding elements of vector `y` and adds the result to `z`, returning z. (Note that the register allocated to z will correspond to that returned by the call.)

```
extern __FVECTOR __cs_vmulacc_scalar (__FVECTOR z,
                                     __FVECTOR x,
                                     poly float y);
```

Multiplies the elements of `x` by the scalar `y` and adds the result to `z`, returning `z`. (Note that the register allocated to z will correspond to that returned by the call.)

```
extern __FVECTOR  __cs_vmulnegacc(__FVECTOR z,
                                 __FVECTOR x,
                                 __FVECTOR y);
```

Multiplies the elements of vector `x` by the corresponding elements of vector `y` and subtracts the result from `z`, returning `z`. (Note that the register allocated to z will correspond to that returned by the call.)

```
extern __FVECTOR __cs_vmulnegacc_scalar(__FVECTOR z,
                                       __FVECTOR x,
                                       poly float y);
```

Multiplies the elements of `x` by the scalar `y` and subtracts the result from `z`, returning z.

(Note that the register allocated to z will correspond to that returned by the call.)

```
extern __FVECTOR   __cs_vaddmul    (__FVECTOR z,
                                    __FVECTOR x,
                                    __FVECTOR y);
```

Adds the elements of vector `x` to the corresponding elements of vector `y` and multiplies the result with `z`, returning z. (Note that the register allocated to z will correspond to that returned by the call.)

```
extern __FVECTOR   __cs_vaddmul_scalar(__FVECTOR z,
                                       __FVECTOR x,
                                       poly float y);
```

Adds the elements of `x` to the scalar `y` and multiplies the result by `z`, returning `z`. (Note that the register allocated to z will correspond to that returned by the call.)

```
extern __FVECTOR   __cs_vsubmul(__FVECTOR z,
                                __FVECTOR x,
                                __FVECTOR y);
```

Subtracts the elements of vector `x` from the corresponding elements of vector `y` and multiplies the result by `z`, returning `z`. (Note that the register allocated to z will correspond to that returned by the call.)

```
extern __FVECTOR __cs_vsubmul_scalar(__FVECTOR z,
                                     __FVECTOR x,
                                     poly float y);
```

Subtracts the elements of `x` from the scalar `y` and multiplies the result by `z`, returning `z`. (Note that the register allocated to z will correspond to that returned by the call.)

```
extern __FVECTOR   __cs_vneg(__FVECTOR x);
```

Negates the elements of vector `x` and returns the resulting vector.

11.14.2 Cast operations

The following list of vector intrinsics allow you to translate between the different vector types supported by **C*^{n}***:

```
extern __FVECTOR __cs_vcast_uif(__UIVECTOR);
```

Casts the unsigned-integer vector to a vector whose elements are floating point.

```
extern __UIVECTOR __cs_vcast_fui(__FVECTOR);
```

Casts the floating-point vector to a vector whose elements are unsigned integer.

```
extern __FVECTOR __cs_vcast_sif(__SIVECTOR);
```

Casts the signed-integer vector to a vector whose elements are floating point.

```
extern __SIVECTOR __cs_vcast_fsi(__FVECTOR);
```

Casts the floating-point vector to a vector whose elements are signed integer.

```
extern __FVECTOR __cs_vcast_usf(__USVECTOR);
```

Casts the unsigned-short vector to a vector whose elements are floating point.

```
extern __USVECTOR __cs_vcast_fus(__FVECTOR);
```

Casts the floating-point vector to a vector whose elements are unsigned short.

```
extern __FVECTOR __cs_vcast_ssf(__SSVECTOR);
```

Casts the signed-short vector to a vector whose elements are floating point.

```
extern __SSVECTOR __cs_vcast_fss(__FVECTOR);
```

Casts the floating-point vector to a vector whose elements are signed short.

Note: The corresponding double-precision definitions have been omitted because they are the same as the single precision version, modulo the type. By replacing '`f`' with '`d`', you can cast from an unsigned integer to a vector of double elements with the form `__cs_vcast_uid`.

There are two casting operations to transform between the two different types:

```
extern __DVECTOR __cs_vcast_fd(__FVECTOR);
```

Casts the single-precision floating-point vector to a vector whose elements are double-precision floating-point.

```
extern __FVECTOR __cs_vcast_df(__DVECTOR);
```

Cast the double-precision floating-point vector to a vector whose elements are single-precision floating-point.

11.14.3 Reduce operations

The following two functions provide alternative methods of combining the elements of a single vector to produce a scalar, that is, the reduction is from a poly vector to a "normal" poly variable (scalar):

```
extern poly float __cs_vreduce_add(__FVECTOR x);
```

Adds the elements of vector `x` to produce a scalar result.

```
extern poly float __cs_vreduce_mul(__FVECTOR x,
                                   __FVECTOR y);
```

Multiplies the elements of vector `x` by the corresponding elements of vector `y` then adds the results to produce a scalar result.

11.14.4 Selection operations

The following method is provided to access individual elements of a vector:

```
extern poly float __cs_vindex(__FVECTOR v,
                              const unsigned short i);
```

Returns the *ith* element of the vector `v`, where 0 <= `i` <= 3. If `i` is out of range, the behavior is undefined.

11.14.5 Constructor operations

The final set of vector functions provide for the construction of vectors from a set of scalar values:

```
extern __FVECTOR __cs_vmconstructor(mono float a,
                                    mono float b,
                                    mono float c,
                                    mono float d);
```

Constructs the vector `{a, b, c, d}` and returns the result.

```
extern __DVECTOR __cs_vmconstructor(mono double a,
                                    mono double b,
                                    mono double c,
                                    mono double d);
```

Constructs the vector `{a, b, c, d}` and returns the result.

```
extern __FVECTOR __cs_vpconstructor(poly float a,
                                    poly float b,
                                    poly float c,
                                    poly float d);
```

Constructs the vector `{a, b, c, d}` and returns the result.

```
extern __DVECTOR __cs_vpconstructor(poly double a,
                                    poly double b,
                                    poly double c,
                                    poly double d);
```

Constructs the vector `{a, b, c, d}` and returns the result.

11.15 Reserved keywords

Table 34 shows the keywords reserved by the **C^n** compiler.

`...`	`do`	`int`	`struct`
`__asm`	`double`	`long`	`switch`
`asm`	`else`	`mono`	`typedef`
`auto`	`enum`	`poly`	`union`
`break`	`extern`	`register`	`unsigned`
`case`	`float`	`return`	`volatile`
`char`	`for`	`short`	`while`
`const`	`goto`	`signed`	

Table 34. Reserved keywords in C^n

`continue`	`if`	`sizeof`	
`default`	`inline`	`static`	

Table 34. Reserved keywords in C^n

11.16 Supported operators

This section describes the operators supported in **C^n**. These are identical to standard C.

11.16.1 Unary operators

`+`	unary plus
`-`	unary minus
`~`	ones compliment
`!`	logical not
`&`	address of
`*`	dereference
`++`	post or pre increment
`--`	post or pre decrement

Table 35. Unary operators in C^n

11.16.2 Binary operators

`*`	multiply	`<=`	less than or equal to
`/`	divide	`>=`	greater than or equal to
`+`	plus	`==`	equivalent
`-`	minus	`!=`	not equivalent to
`%`	modulus	`&`	bitwise AND
`<<`	shift left	`^`	bitwise XOR
`>>`	shift right	`|`	bitwise OR
`<`	less than	`&&`	logical AND
`>`	greater than	`||`	logical OR

Table 36. Binary operators in C^n

11.16.3 Assignment operators

`=`	simple assignment
`*=`	multiply and assign
`/=`	divide and assign
`+=`	add and assign
`-=`	subtract and assign
`%=`	modulo and assign
`<<=`	left shift and assign
`>>=`	right shift and assign
`&=`	AND and assign
`^=`	XOR and assign
`|=`	OR and assign

Table 37. Assignment operators in C^n

11.16.4 Miscellaneous operators

`.`	struct accessor
`->`	pointer to struct accessor
`? :`	conditional operator
`[]`	array subscript
`,`	expression separator

Table 38. Miscellaneous operators in C^n

11.16.5 Operator precedence

Table 39 shows operator precedence. All operators within each group have the same precedence.

Highest precedence

`.`	member selection
`->`	member selection
`()`	function call
`[]`	array subscript
`!`	logical not
`~`	ones complement
`++`	increment
`--`	decrement
`-`	unary minus
`+`	unary plus
`&`	address of
`*`	dereference
`sizeof()`	size of
`*`	multiplication
`/`	division
`%`	modulo
`+`	addition
`-`	subtraction
`<<`	shift left
`>>`	shift right
`<`	less than
`<=`	less than or equal
`>`	greater than
`>=`	greater or equal
`==`	equal
`!=`	not equal
`&`	bitwise AND
`^`	bitwise XOR
`|`	bitwise OR
`&&`	logical AND
`||`	logical OR
`=`	simple assignment
`+=`	add and assign
`-=`	subtract and assign
`*=`	multiply and assign
`/=`	divide and assign
`%=`	modulo and assign
`&=`	AND and assign
`|=`	OR and assign
`^=`	XOR and assign
`<<=`	shift left and assign
`>>=`	shift right and assign
`? :`	conditional expression
`,`	comma

Lowest precedence

Table 39. Precedence table for C^n operators

12 Memory use

This chapter describes some of the options available in the SDK for managing the use of meory by the CSX processor.

12.1 Stack allocation

Each thread executing in a program will probably require a mono and a poly stack.

In the 3.0 release, stacks are automatically created for the main execution thread (thread 0) and these stacks are dynamically sized. As the program runs, more stack space will be used, up to the limit of available memory. Run-time stack checking can be enabled to ensure that the stack usage does not exceed available memory.

Thread 7 is used by the asynchronous memcpy functions. Mono and poly stacks of zero size are allocated for this thread.

No thread is defined for threads 1 to 6. It is the programmers responsibility to define stacks for these threads if they are used.

If you use any other threads in your program then you must allocate mono and poly stacks for each thread. Normally, these stacks will be assigned fixed sizes and allocated statically.

One mono stack and one poly stack can be defined to be managed dynamically. By default, these are allocated to thread 0. If you wish to assign a dynamic stack to another thread then you must first assign a static stack for thread 0. To define a dynamic stack for a thread, you should set the stack size to -1. This will convert the stack to a dynamic stack(1). If you define two threads with dynamic stacks in the same domain (that is, two mono or two poly dynamic stacks) this will cause a run-time error.

12.1.1 Stack size definition

By default, the mono and poly stacks for the main execution thread (thread 0) are dynamically sized, up to the maximum available memory. If a size is specified for these stacks then they will become static, with a fixed size.

In many cases, the use of a dynamic stack for the main execution thread in the 3.0 release may remove the need to explicitly specify the size of the stacks.

In the previous SDK releases, stacks had to be creating by defining an appropriate symbol, typically by creating an assembler source code file containing the necessary definitions and then linking this with your program.

With this release, the size of statically allocated stacks can be defined in a number of different ways. You can use whichever method is most convenient for your application and development process.

The size of the stacks can be specified in any compilation unit making up an executable. However, any particular stack must only be specified once.

1. This does not work with the C^n pragma described below.

Command line options

The compiler has a set of command line options for specifying the sizes of the stacks for each thread. See *Section 2.4.3: Compiler options on page 22* for details.

The command line options are of the form:

```
--set-mono-stack-size-thread-n size
--set-poly-stack-size-thread-n size
```

Where `n` is the thread number that a stack is being defined for and `size` is the size of the stack in bytes.

C^n pragmas

A C^n pragma is also provided for setting the stack size, as follows:

```
#pragma static_stack(mono|poly, size, thread)
```

The first argument defines whether a mono or poly stack size is being defined. The second argument specifies the stack size in bytes. The third argument specifies the thread number for which the stack size is being set.

Note: This pragma does not accept -1 as a stack size to define a dynamically allocated stacks: use one of the other methods for this.

Assembly code

Note: The other methods of specifying the stack size all map on to this underlying mechanism by causing the compiler to emit the necessary directives to define the stacks.

The mechanism for specifying the size of stacks in assembler code has changed. Instead of defining the stacks in the mono and poly bss sections using the `.fill` command, you now use the `.set` directive to specify the size of the stack you need. The runtime allocates this space when the executable is loaded.

For example, previously you would have included code similar to the following fragment in your program:

```
.section .mono.bss
__FRAME_BEGIN_MONO__3::
.global __FRAME_BEGIN_MONO__3
.fill 1024, 1, 0x0
```

This creates a 1 KB mono stack frame for thread 3 in the mono bss section.

The new method of declaring this is to use a `.set` command as shown below:

```
.set __FRAME_BEGIN_MONO__3, 1024
.global __FRAME_BEGIN_MONO__3
```

This will cause the runtime to allocate an area of this size for the stack at load time and assign all necessary pointers to this point. All stacks, both mono and poly, can be declared in this manner.

Note: The same symbols are used to define the stack sizes as were previously used to define the start address of the stack. Therefore, your program will fail to run correctly if you do not change, or remove, the old code for specifying stack sizes.

12.2 Stack checking

This release also includes support for run-time checking of stack usage. There are two types of checks that can be performed: a static, compile time, check on the maximum size of any functions stack frame; secondly, a run-time check that the program does not run past the end of the available memory.

12.2.1 Run-time stack checking

The option `dynamic-stack-check` turns on run-time checking of mono and poly stack usage for all threads. This causes the compiler to add code the entry point of every function to check that the function’s stack frames will not cause the stacks to overrun available memory. This can have a significant performance penalty and so is turned off by default. This option should only be used when developing or debugging software.

For statically allocated stacks, this checks that the mono and poly stack frames for a function will not exceed the size specified for the stack.

For dynamically allocated stacks, this checks that the mono and poly stack frames for a function will not cause the stack to grow beyond the available memory. For the mono stack this means that the stack will not overrun the heap (which grows from the top of memory). For the poly stack, it checks that the stack will not grow past the end of poly memory.

If these checks fail then the runtime will display a warning on the console when that function is called.

12.2.2 Stack frame size checking

The compler can also check (at compile time) that the stack frame for any function does not exceed a given size. This is a simple test that does affect performance and gives some confidence that stack usage is not grossly excessive. This check can be turned on using the compiler command line options `check-mono-frame` and `check-poly-frame`.

The default limits for stack frame sizes are 64 KB for mono and 3 KB for poly. These limits can be changed with the command line options `check-mono-frame-size` and `check-poly-frame-size`.

If this check fails, then the compiler will generate a warning. You can cause the compiler to report an error when the check fails by using the `error-mono-frame` or `error-poly-frame` options.

12.3 Support for ECC memory

Future ClearSpeed processors will include memory with error correcting codes (ECC) for greater reliability. This applies to both the on-chip SRAM and the poly memory (in addition to the current ECC support for external DRAM). The use of ECC memory introduces some constraints on the way that memory can be accessed. Stores to memory which are the same width as the ECC word are not affected. Stores which are narrower than this need to perform a read-modify-write of the whole word to avoid causing an ECC error.

Support for ECC memory in future products is being introduced in this release of the SDK to avoid future compatibility changes.

On-chip SRAM memory will have 32-bit ECC and so a simple store must be 32 bits wide. If you wish to write 16-bit data or a single byte to this memory then you will have to read the 32-bit word from memory, modify the bytes to be written and write the whole word back.

Poly memory will have 16-bit ECC. The poly load and store instructions have been modified to perform a read-modify-write cycle for all one-byte stores. These instruction will therefore be slower in this release. All poly one-byte stores now also require additional temporary registers in order to perform this read modify write logic. *Table 40* lists the temporary registers required.

Store type	Sub type	Mono temporary registers	Poly temporary registers	Non-ECC	ECC
Store	Immediate address	2	3	2	13
	Immediate address, mono offset	2	3	1	12
	Mono address, no offset	2	3	1	12
	Mono address, with offset	2	3	1	12
	Poly address, no offset	0	5	2	17
	Poly address, with offset	0	5	2	17
Indexed store	Immediate address	0	5	1	17
	Mono address, no offset	0	5	1	16
	Mono address, with offset	0	5	1	18
Forced store	Immediate address	2	4	2	19
	Immediate address, mono offset	2	4	1	19
	Mono address, no offset	2	4	1	18
	Mono address, with offset	2	4	1	19
	Poly address, no offset	0	6	2	23
	Poly address, with offset	0	6	2	23
Forced indexed store	Immediate address	0	6	2	23
	Mono address, no offset	0	6	1	22
	Mono address, with offset	0	6	1	24

Table 40. Temporaries required

If you are writing code which will *only* be run on a processor without ECC poly memory, then it is possible to make the tools use the old single-byte store instructions. These do not do a read-modify-write and so are faster.

You can force the compiler to use the non-ECC store instructions using the `cscn` command line option `--no-poly-ecc`.

You can make the assembler use the old style store instructions by inserting the following pragma at the top of your assembler source code file.

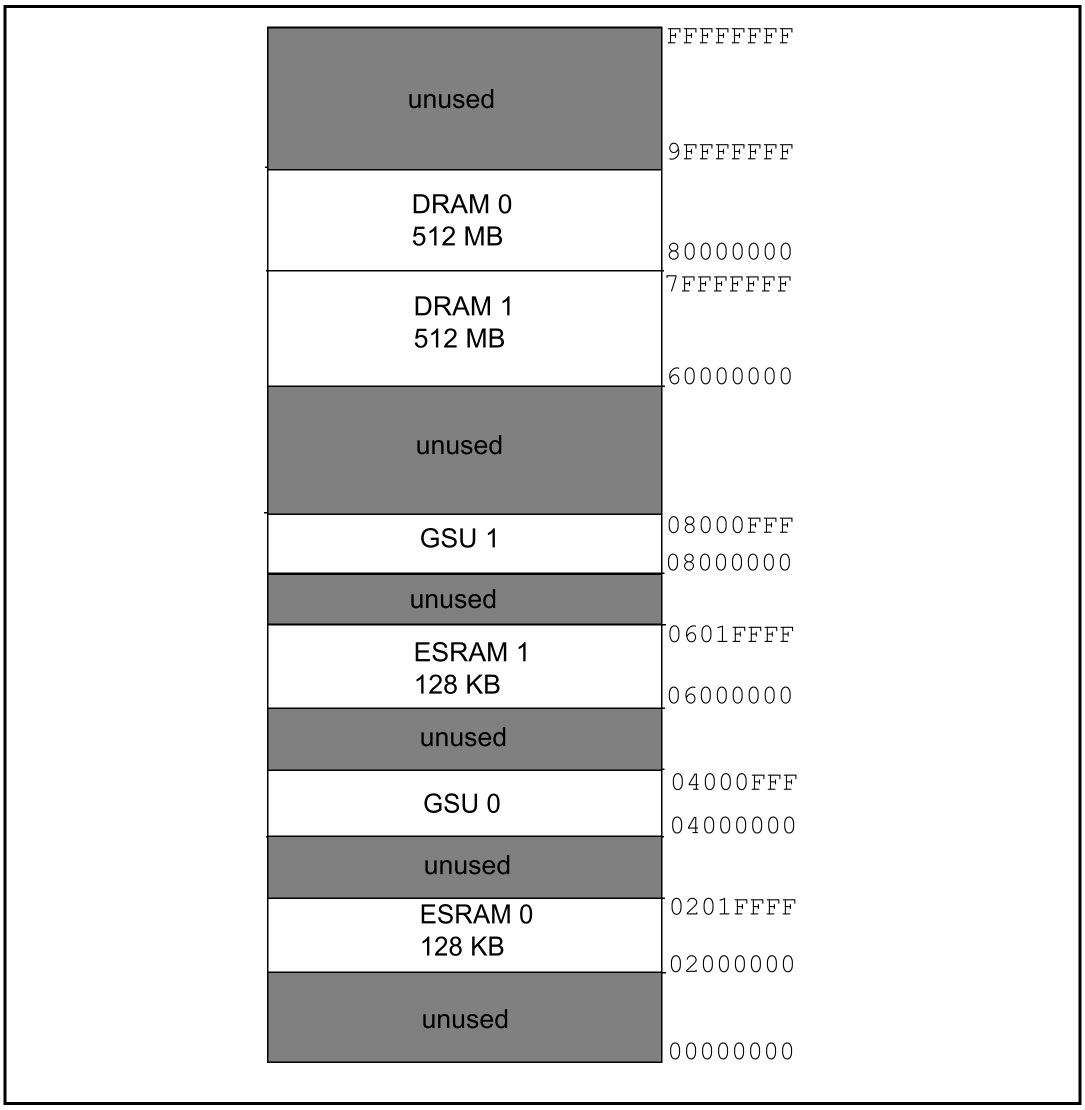
```
.pragma non_ecc_st on
```

12.4 Advance card memory map

This section describes the memory map used by the Advance accelerator cards.

Each processor on the Advance X620 and Advance e620 cards has 512 MBytes of DDR2-400 DRAM directly connected. The DRAM is 72 bits wide, including 8 bits of error correcting code (ECC). This allows correction of single-bit errors and detection of most multiple-bit errors.

The memory map, shown in *Figure 12.4.1: Host memory map on page 154*, is as seen by the onboard processors (not the host). This depicts how the various memory areas and memory mapped registers are addressed. The memory for each processor consists of embedded (on-chip) SRAM and external DDR2 SDRAM. These are shown in the diagram as ESRAM 0 and ESRAM 1 and DRAM 0 and DRAM 1 (for processor 0 and 1 respectively) The Global Semaphore Unit (GSU) registers are memory mapped and shown as GSU 0 and GSU 1.



12.4.1 Host memory map

The Advance accelerator's memory map has three regions: the standard PCI configuration space which describes the capabilities of the card and two base address register (BAR) regions for access to the card features. The BARs are both 64-bit address type. Each of these three regions is described in the following sections.

BAR0

BAR0 is 1 MByte in size and maps all the control registers of the Advance accelerator. The FPGA will have 32-bit registers as shown in *Table 41*

Offset	Name	Access	Description
80000	Version	Read only	Version information for the FPGA.
80100	Reset	Read write	bit 0: reset core. One shot. Write 1 to reset all of the system except the PCI interface. bit 1: reset front. One shot. Write 1 to reset the PCI halfbridge and dma. The PCI bus interface can only be reset from the PCI bus or power up. The hardware writes these bits to 0 almost immediately as the system is reset.
80200	Timestamp	Read only	Date and time of build in seconds since 1970-01-01 00:
80300	DMA Diagnostics 1	Read only	Internal use only.
80400	Error Address	Read only	Address of transaction in error. (Timeout/unexpe
80500	Error Status	Read only	Status of transaction in error. bit 0: unexpected flag. bit 1: time out flag. bit 2,3: dmabar: 00=bar 0, 001=bar 1, 10=dma, 11=arggh bit 4..15: amount outstanding/ extra information. bit 16..27: destination ID
80600	Error Control	Read write	bit 0..15: time out preset: 1 = enable the timeout error. bit 16: discard enable: 1 = enable the unexpected response error. bit 17: reset. One shot. Write 1 to reenable the error checking. The system stops updating the address and status registers on the first error. The hardware will write this bit to 0 almost immediately as the subsystem is reset.
80700	Interrupt serviced	Read write	bit 0: eoi. One shot. Write 1 at the end of the interrupt service routine. The hardware will write this bit to 0 almost immediately as the MSI subsystem is primed.
80800	GP Store	Read write	General purpose register for use by software.
80900	BAR2 Page	Read write	Contains bits 56 to 25 of the clear connect address for accesses through BAR1.
80a00	AEU table switch	Read write	bit 0: select map. 0 = 512 Mbyte, 1 = 2048 Mbyte.

Offset	Name	Access	Description
80c00	DMA Diagnostics 2	Read only	Internal use only.
80d00	DMA Diagnostics 3	Read only	Internal use only.
80e00	PVCI address	Read write	This register contains the address to be used for the next PVCI transaction.
80f00	PVCI data	Read write	Reading this register initiates a PVCI read of the address in the address register and the result is read. Writing this register initiates a PVCI write of the data to the address in the address register.

Table 41. FPGA 32-bit registers

BAR2

BAR2 is 32 MByte in size and provides a relocatable window into the physical memory on the Advance accelerator, see also 12.4.1 The location of the window is controlled by register address `0x80900` in BAR0.

13 Application binary interface

This chapter describes the Application Binary Interface (ABI) for the ClearSpeed tool chain. The following definitions apply in the text that follows:

- **Byte** = 8 bits.
- **Word** = 16 bits.
- **Double Word** = 32 bits.
- **Quad Word** = 64 bits.

13.1 Overview of the ABI

An ABI is the set of rules that software must obey in order to interact with other compiled components.

The ABI defines a set of runtime interfaces between compiled software components, or software components that must interact with other ABI compliant software. An ABI differs from an Application Programming Interface (API) in that an API is a build time interface that is usually defined as a set of prototypes of library functions.

The ABI also defines a system level interface for compiled programs. The purpose of the ABI is to provide a set of rules that enable the object files and libraries to be shared across various development environments and languages and the executables to be loaded and executed.

Note: The ABI is a convention only, but it is necessary for compatibility with the ClearSpeed SDK.

13.2 Process startup

An application depends on a loader to set up and run the program on a target device or simulator. A loader calls the program entry point recorded in the object file. By default, this is the symbol `_start` defined in the **C*ⁿ*** runtime library. The SDK tools use this symbol as the place to start execution when code is loaded and run.

The initialization tasks performed by the operating system on program loading include:

- Booting the processor (loading the program into memory, initializing the processor's control registers, and so on).
- Allocating mono memory for the mono variable stack and poly memory for the poly variable stack (the sizes of the stacks are provided by the object file).
- Initializing the `mono_sp` and `poly_sp` registers to set up the mono and poly stack pointers respectively; these are both mono registers.
- Starting the execution of the application.

See *[7]: ClearSpeed CSX600 Hardware Programming Manual* for details of the startup process.

13.2.1 Multithreaded code

In order to support multithreaded code, entry points are defined for each thread. These are `_start`, `_start1`, . . . `_start7`, that correspond to the number of threads supported by the processor. The default entry point, `_start`, corresponds to the lowest priority thread. The entry point `_start7` corresponds to thread 0, the highest priority.

The standard entry point is the lowest priority thread because some threads used in the system have to operate at a higher priority (for example, debug and async I/O) consequently it is convenient to default user programs to lower priority threads; a user can specify higher priority threads if necessary. See *[7]: ClearSpeed CSX600 Hardware Programming Manual* for greater detail.

13.2.2 Program termination

When a program terminates normally, it returns control to the runtime system. The exit code is contained in the mono return register and is the exit value of the program. This is usually zero to indicate normal termination.

13.3 Data representation and allocation

The text that follows describes how various types of data are stored in memory.

The ABI assumes that data is stored in the endianness (see *Section 13.7: Endianness on page 175*) chosen for the processor. Consequently, where data is shared with another device with different endianness, one device reorders the bytes to compensate.

13.3.1 Data types

The sizes and alignment of supported data types are described in the text that follows.

Scalar types

Table 42 shows the size and alignment of scalar and vector types in memory.

Note: Scalar types in registers and memory must be naturally aligned, for example, a value of type `int` is 4-byte aligned in memory and in registers that are a multiple of four bytes. Mono characters are naturally aligned to one byte in memory and are stored in mono registers that are at least 2-byte aligned.

Type		Size (bytes)	Alignment (bytes)

Integer	`char`
	`signed char`
	`unsigned char`
		1	1

	`short`
	`signed short`
	`unsigned short`
		2	2

	`int`
	`signed int`
	`unsigned int`
	`long`
	`signed long`
	`unsigned long`
		4	4

	`enum`	4	4
Pointer[a]	`poly` *`any type`* `* any multiplicity specifier`	2	2

	`any type` `* any multiplicity specifier`
	`mono` *`any type`* `* any multiplicity specifier`
		4	4

Floating point	`float`	4	4

	`double`
	`double long`
		8	8

Single precision floating point vector	`__FVECTOR`	16	16
Double precision floating point vector	`__DVECTOR`	32	32
[a] any type = int, float and so on.			

Table 42. Size and alignment of basic data types

Aggregate types

Aggregate types include structures, unions and arrays. The rules the compiler uses are:

- The alignment of an entire aggregate object uses the alignment of its largest component.
- Padding is used where it is necessary for structures and unions to meet the alignment requirements. The contents of the padding are undefined.
- No reordering of unions or structures is carried out to better pack the structure (which would be in breach of the C standard).
- An array uses the same alignment as its elements.
- The size of an array is always a multiple of the base type alignment.

The key points are:

- The alignment of a structure or union follows the alignment of the most coarsely aligned member.
- Each member is aligned to its own alignment at the lowest available offset. Padding is used where required.
- Bit fields are packed within the base type so that minimum space is used, maintaining order and not crossing type boundaries.

Typical alignments are illustrated in *Figure 21* to *Figure 25*.

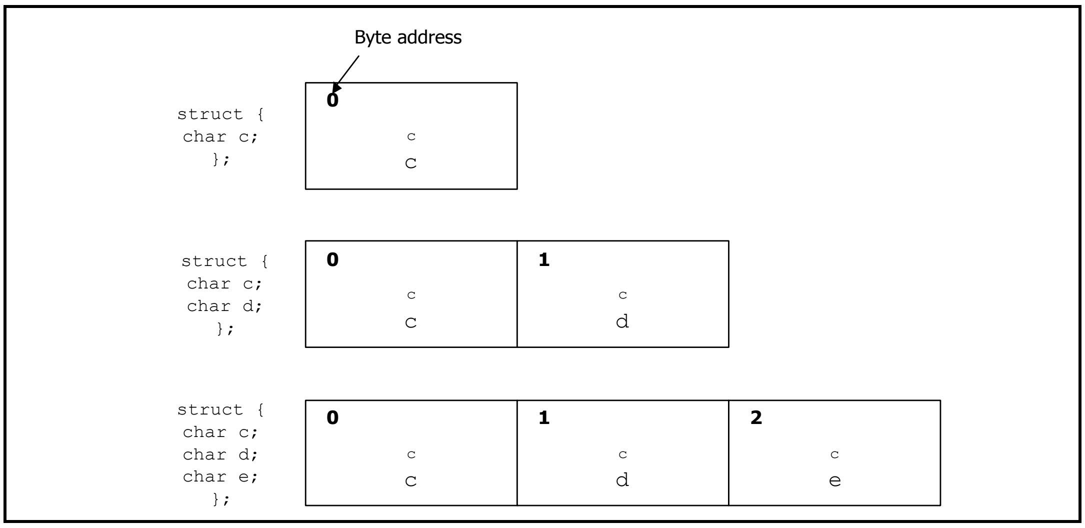


Figure 21.Structures smaller than a word

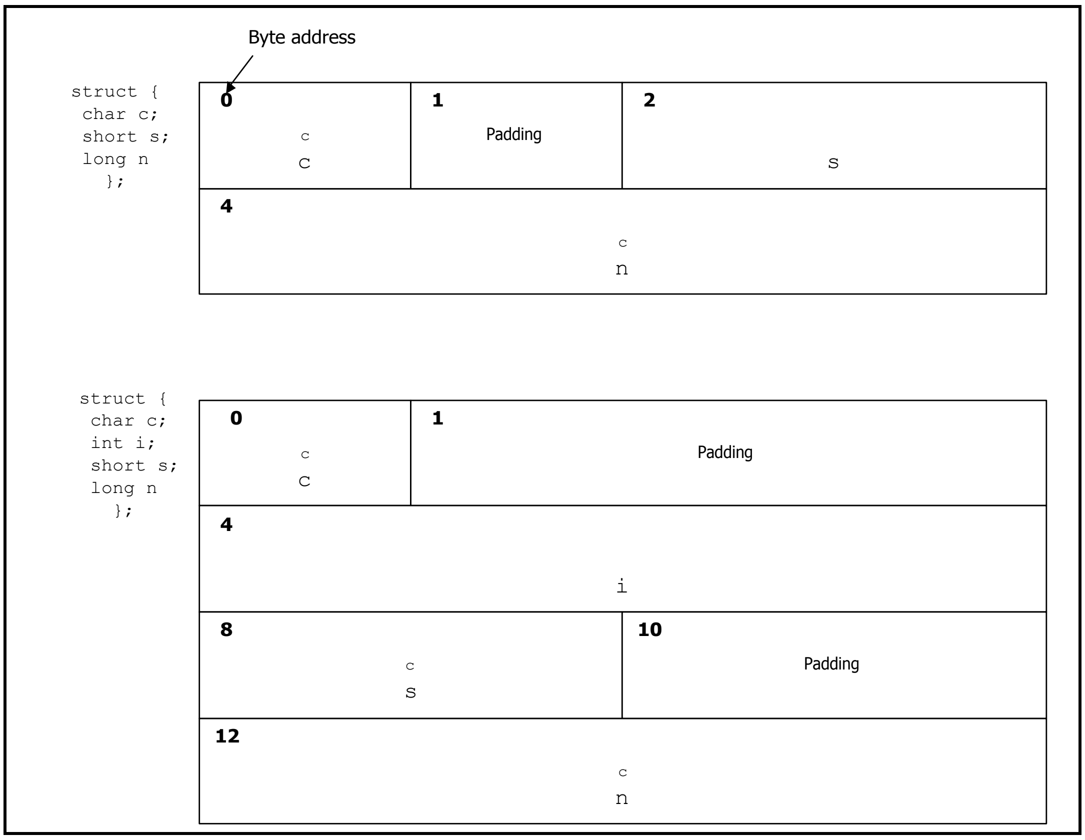


Figure 22.Structures larger than a word

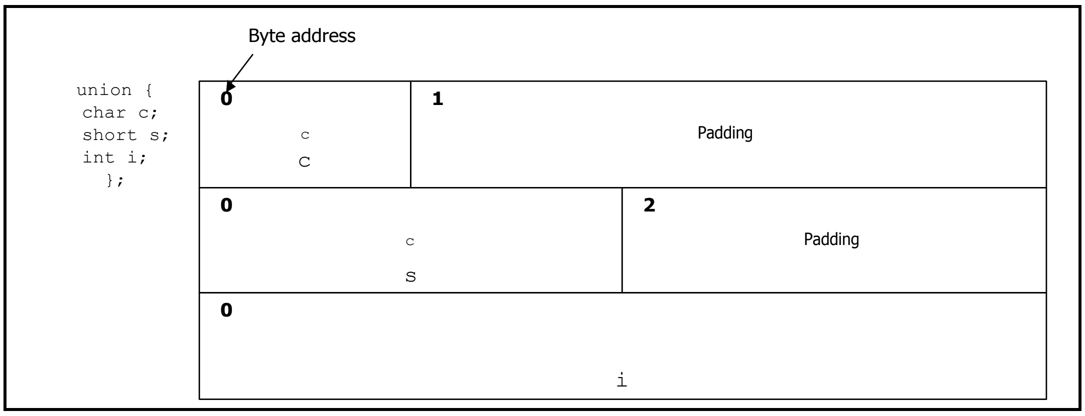


Figure 23.Union allocation

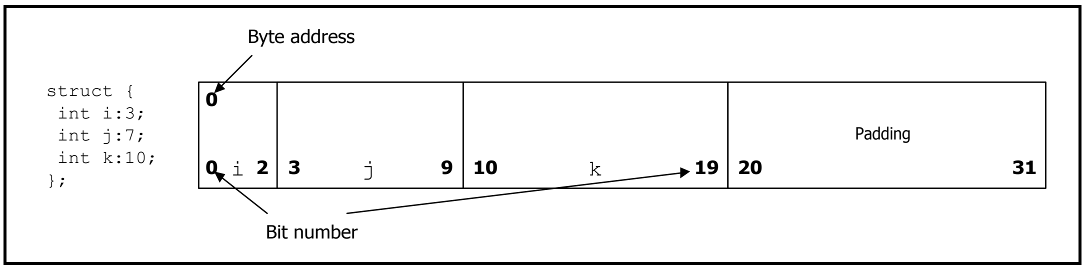


Figure 24.Bit fields: LSB to MSB allocation

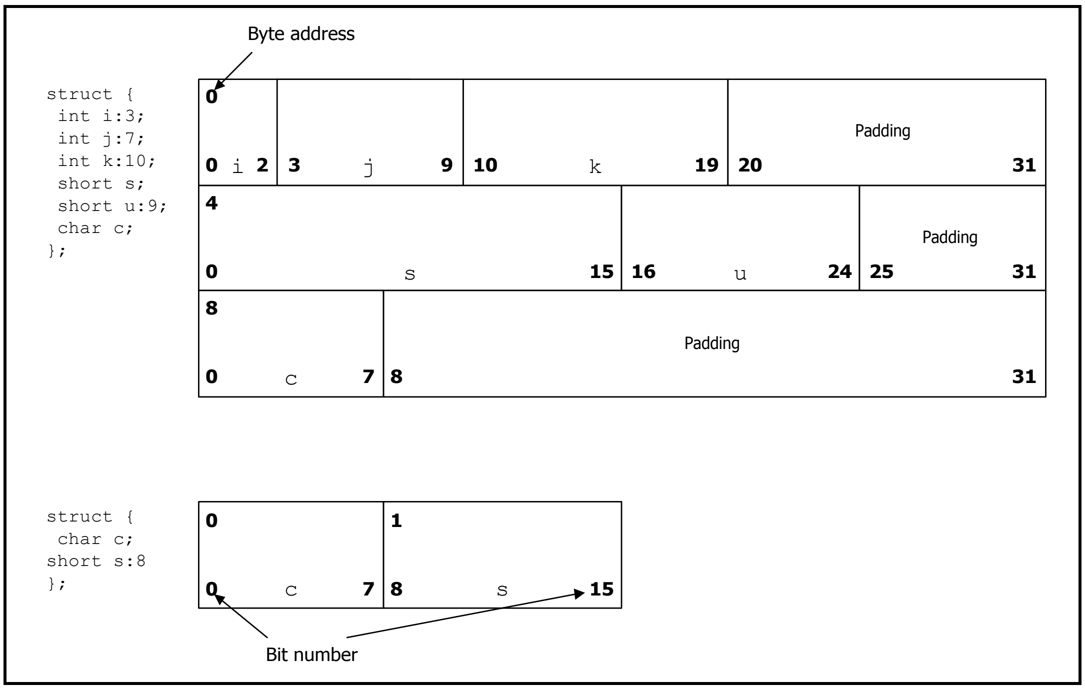


Figure 25.Bit fields: boundary alignment

Enumeration types

Enumeration types are allocated as 4-byte unsigned integer values and are thus 4-byte aligned and restricted to the range 0 - 2^32-1.

13.3.2 Memory model

There are two separate memory spaces accessible in the processor architecture: mono memory (for example, external DRAM attached through the memory interface) and poly memory. Poly memory is distributed across processing elements (PE), and is private to each PE. The memory architecture is described in *[6]: CSX600 Core Architecture Manual*.

Mono load and store instructions transfer data between mono memory and the mono register file. Poly loads and stores move data between poly memory and the poly register file on the same PE.

Data is transferred between the mono and poly memory spaces using Programmed I/O (PIO). For details of the PIO function, see *[8]: The C Programming Language*. This functionality is exposed to the **C*ⁿ*** programmer by variants of the standard `memcpy` function.

The ABI reserves some words of poly memory as illustrated in *Figure 26*.

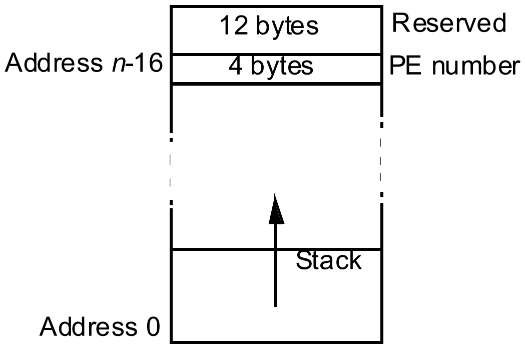


Figure 26.Reserved poly memory locations for a PE with *n* bytes of memory

13.3.3 Register model

The general register assignment is listed in *Table 44* and *Table 43*.

Three operand instructions (for example, `add r1, r2, r3`) that use poly registers greater than 64 (the upper half of the register file) are required to have an alignment of 2, which implies that they are even and must be of size 2 bytes or greater. So any register argument, r, to a three operand poly instruction must obey:

```
all (r <64) or (r modulo 2 = 0 with size (r) >= 2)
```

Register Number	ABI Name	Use
0. . . 3	`mono_sp`[a]	The base address for accessing the mono stack in mono memory.
4. . . 5	`poly_sp`[a]	The base address for accessing poly stack in poly memory.
6. . . 7	*`Reserved`*	These registers are reserved for future use.
8. . . 15	**V0 - V7**	Used for expression evaluation and returning values from function calls. Should never be used for values that need to persist across function calls.
16. . . 31	**A0 - A15**	Used for passing the arguments to functions. If the number or size of function arguments exceeds the storage provided by these registers, the remaining parameters are passed on the stack, starting at address 0 relative to the start of the stack frame. Values are preserved across function calls. Callee saves.
32. . . *59*	**T39 - T***59*	Working registers. Values are preserved across function calls. Callee saves.
60. . . 63	**T60-T63**	Working registers. Values are not preserved across function calls. Caller saves.
[a] Caller is responsible for setting the `mono_sp` and `poly_sp` registers prior to a function call. The loader sets the initial values of these registers.		

Table 43. Mono register assignment

Register Number	ABI Name	Use
0. . . 7	**v0 - v7**	Used for expression evaluation and returning integer and pointer values from function calls. Should never be used for values that need to persist across function calls.
8. . . 23	**a0 - a15**	Used for passing the arguments to functions. If the number or size of function arguments exceeds the storage provided by these registers, the remaining parameters are passed on the stack, starting at address 0 relative to the start of the stack frame. Values are preserved across function calls. Callee saves.
24. . 123	**t0 - t***123*	Working registers. Values are preserved across function calls. Callee saves.
124. 127	**t124-t***127*	Working registers. Values are not preserved across function calls. Caller saves.
It is the callee's responsibility to preserve all registers for disabled PEs. All registers for disabled PEs must be preserved across function calls.		

Table 44. Poly register assignment

Packing

Function parameters passed in registers are packed as tightly as alignment constraints allow. For example, consider the function prototype:

```
f (int, short, int, short)
```

and a corresponding call to the function f:

```
f (a, b, c, d)
```

The arguments are of different sizes, so the possibility exists to utilize register space more efficiently. The arguments are passed to the function as illustrated in *Figure 27*. The argument d appears before c because it requires only 2-byte alignment, so the packing algorithm uses the first free location that is 2 bytes in size and alignment.

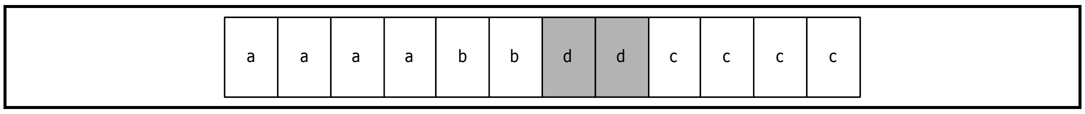


Figure 27.Register packing

The packing algorithm operates as follows:

1. Take the first argument and assign it to either the first mono or first poly argument register, depending on its type.
2. Take the second argument and place this in the first free argument register, associated with its type and if this is not the first argument register the next free register must have the correct alignment for the argument in question.
3. This may introduce a gap.
4. While there are still remaining arguments take the next one and find the next free argument register, with correct type, that has the correct alignment, this may be between previously allocated arguments (in the gap mentioned above).
5. Repeat until all the arguments are allocated. If there are more arguments than parameter registers, they must be pushed on to the stack.

13.4 Calling functions

The text that follows describes how functions are called, parameters passed and values returned. The general procedure for calling a function is outlined first.

13.4.1 Calling sequence

Preparation for call:

1. The caller stores parameter values in the parameter registers (`a` and `A` registers) packing as appropriate. It is the responsibility of the caller to spill to the stack the contents of the parameter registers, if necessary, before new values are stored in them.
2. Where appropriate, the caller stores the outstanding parameters at the aligned address beyond the current end of its stack frame, packing as appropriate.
3. If the callee returns an object larger than the return value size, the caller places a pointer in the return registers to the storage location where the returned object should be placed.

Procedure call:

1. The caller resets the stack pointer values in the `mono_sp` and `poly_sp` mono registers to beyond its stack frame.
2. Caller jumps to the subroutine being called using `j.sub`, which stores the return address in the return address register.

Procedure entry:

1. The callee saves the return address, if necessary. In all cases when the callee is not a leaf function, it must save the return address.
2. The callee saves the user predicate register, if necessary.
3. The callee saves the parameter registers (**a** and **A**) and the workspace registers (**t** and **T**), if they are modified by the function.
4. The callee saves the state of the enable stack, if the enable stack is changed.
5. The function body is executed.

Procedure exit:

1. The callee stores the return value either to an address pointed to by a register (**v** and **V** registers) or returns value in **v** or **V**.
2. The callee restores the saved registers.
3. The callee restores the user predicates.
4. The callee restores the enable state.
5. If the callee is a leaf function, it jumps to the address given in the mono return address register using the `return` instruction.
6. If the callee is not a leaf function, it must restore the saved return address and jump to this value, either directly using the `jump` instruction or by restoring the return register and jump using the `return` instruction.

Procedure return:

1. The caller restores the previous values of the `mono_sp` and `poly_sp` registers.

An example of a function call

Calling code

```
#include <asm_header. inc>
                     // function that will be called
.global pe_fraction
                     // Define names for registers
#define a0 8:p4u
_main::
.global _main                         // Save poly register used
 st _poly_sp, a0, 0 // Preserve return address
 mono.result.get 60:m2,3
 mono.result.get 62:m2,2
 st  _mono_sp,60:m4,0 //Get number of this PE
 penum a0                                 // Prepare for call
                     // Add offsets to the stack pointers
                     // to allocate new stack frames
                     // allocate new mono stack frame
 add _mono_sp, _mono_sp, 16 //Allocate new poly stack frame
 add _poly_sp, _poly_sp, 16
                                                            //Call:
jump to function entry point
 j.sub  pe_fraction;                                        // return
here

//Subtract offsets from stack
                                                            //
pointers to free stack frame
 sub _mono_sp, _mono_sp, 16
 sub _poly_sp, _poly_sp, 16
                                                            //Print
out result
                                                            //pass
result as parameter
 mov a0, _poly_ret_val:p4f

//Allocate new stack frames
 add _mono_sp, _mono_sp, 16
 add _poly_sp, _poly_sp, 16
                                                            //Call
print function
 mov 16:m4, _CN_LIBEXT_DPRINT_DEC_FORMAT1_CN_LIBEXT_FLOAT_TYPE
 set. varargs 8:p4
 .setmonotemp 28,4
 call.varargs dprint_poly
                                                            //Restore
stack frames
 sub _mono_sp, _mono_sp, 16
 sub _poly_sp, _poly_sp, 16
                                                            //Restore
poly register used
 ld  a0, _poly_sp, 0
                                                            //Restore
return address
 ld  60:m4,_mono_sp,0
 j  60:m4
```

Called code

```
                                                            //Define
names for registers
#define t0 20:p4f
#define t1 24:p4f
#define a0 8:p4u
.section .text
.global pe_fraction
                                                            //A
simple function to convert the
                                                            // PE
number parameter to a fraction
pe_fraction::
                     // Preserve poly registers used
 st _poly_sp, t0, 4
 st _poly_sp, t1, 8
                                             // convert parameter to
float
 cast t0, a0
                     // get number of PEs as a float
 cast t1, _num_pes
                                             // ratio of PE number to
total PEs
 div _poly_ret_val:p4f, t0, t1
                                             // Restore poly register
used
 ld t0, _poly_sp, 4
 ld t1, _poly_sp, 8
                                             // return to calling
code
 return
```

13.4.2 Call stack

The arrangement of stack frames in memory is illustrated in *Figure 28* (this is convention only, a function is not necessarily required to implement a stack like this to maintain ABI compliance). The stack pointers are the mono registers `mono_sp` and `poly_sp`. The stack pointers hold the address of the base of the stack frame. A function accesses the contents of its stack frame at positive offsets from the stack pointers.

On entry to a function, both the mono stack and the poly stack are aligned to 16 byte boundaries.

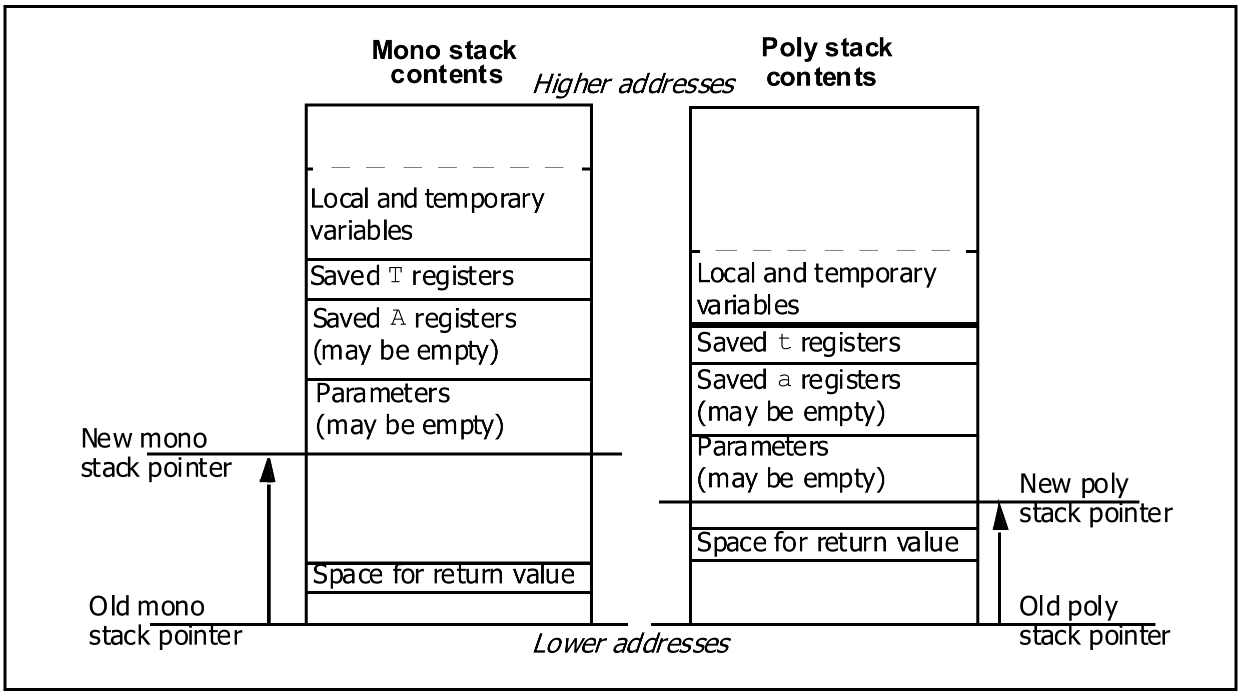


Figure 28.Stack frame layout in mono and poly memory

13.4.3 Variable allocation and parameter passing

Passing parameters to regular functions is described in the text that follows. In *Figure 28* and in the text that follows, upper case letters (**A** or **T**) refer to mono registers and lower case letters (**a** or **t**) refer to poly registers, refer to *Table 44* and *Table 43*.

1. Static and global variables are allocated at the top of the memory range. They are initialized by loading `mono.data` and `poly.data` segments of the Executable and Linkable Format (ELF) loadable file.
2. The register file is logically divided into three ranges: return values, parameter space and workspace; this is illustrated in *Table 44*.
3. The parameters to functions are placed in the parameter space of the register file, starting at registers **a0** and **A0**.
4. When the number of **a** or **A** registers is insufficient, the remaining parameters are passed on the stack. Parameters are placed on the stack in the order they are declared and with the alignment defined in *Table 42*. Padding may be inserted between parameters to maintain alignment. This should be taken into account when calculating the stack frame size.
5. Structures can be passed in the register file. However, if the entire structure does not fit into the register file, the structure must not be split, instead it should be passed entirely in the memory.

6. The callee must save and restore any workspace and parameter registers that it uses.
7. Functions return a result by placing the value in the **v** (or **V**) registers. If the object being returned is larger than 8 bytes then, on entry to the function, the **v** registers contain a pointer to the memory location (typically allocated on the caller's stack frame) where the result should be written.

13.4.4 Functions with variable number of parameters

Any initial fixed parameters follow precisely the same pattern as normal function calls with all prototyped parameters passed in registers if possible. All variable parameters are pushed on to the appropriate stacks; mono parameters are pushed on to the mono stack and poly parameters are pushed on to the poly stack. An array of `void mono * mono` and `void poly * mono` pointers is constructed pointing to each of the parameters in order and is stored on the mono stack. Finally, a pointer to the array of pointers is passed as the final mono argument to the particular function, either in a parameter register, if free, or on the mono stack, as for standard mono parameters.

The arrangement of the stack frames for variable parameter functions is illustrated in *Figure 29*.

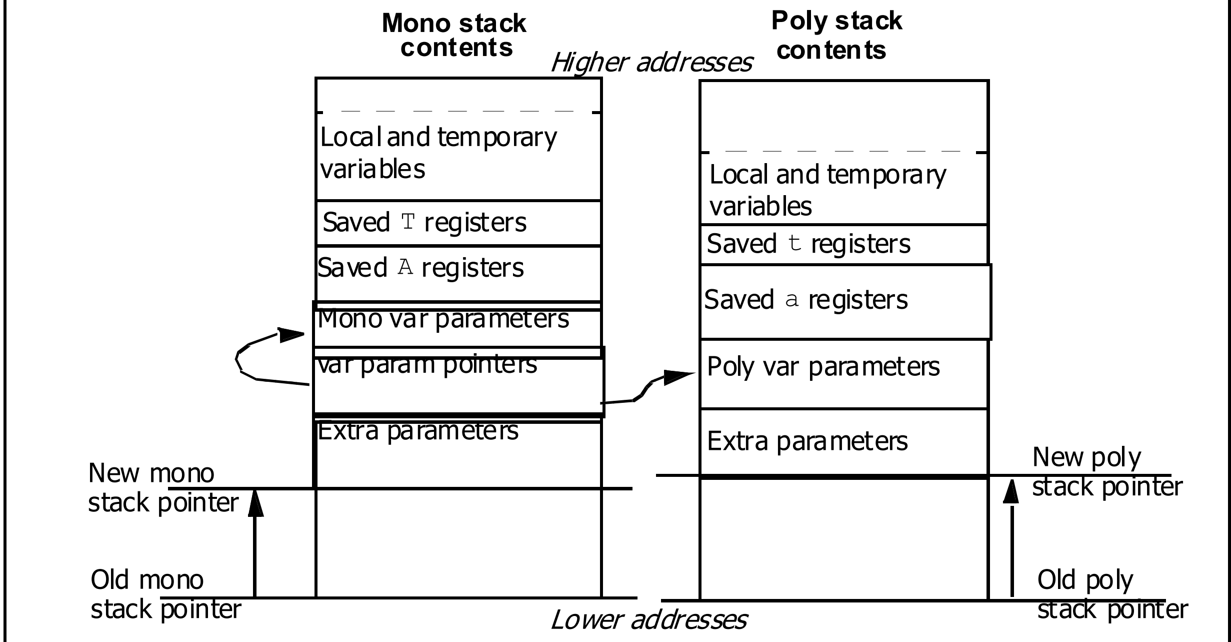


Figure 29.Layout of the stack frames for variable parameter functions

An example of calling a **C*ⁿ*** function follows:

```
#include <macro_includes.inc>
#include <dprint_defs.h>

#define PENUMS 24:p4
#define PENUMS_F 24:p4f
#define TOT_PES 28:p4
#define TOT_PES_F 28:p4f
#define RESULT 32:p4f
#define RESULT_D 32:p8f

.global my_function    ;
     // External function that will be called

.section .text

main::
.global main
.type main, @function

   st   _poly_sp, 56:p8, 0;
   st   _poly_sp, 8:p8,  8;
   st              _poly_sp, 24:p4, 16 ; //save poly registers to be
used.
   st              _poly_sp, 28:p4, 20 ;
   st              _poly_sp, 32:p8, 24 ;


   return.get 60:m4u;
   st              _mono_sp, 60:m4u, 0;//save return address
```

```
 // Convert PE number to a number in range 0 to 1
       penum  PENUMS;                      // get number of this PE

       cast   PENUMS_F, PENUMS;                    // convert to
float

       mov         TOT_PES, _num_pes

       cast        TOT_PES_F, TOT_PES;// get total number of pe's in
float format

       div         RESULT, PENUMS_F, TOT_PES_F;                //
ratio

       cast        RESULT_D, RESULT;// sinp takes a double so cast
float into double

       mov         8:p8f, RESULT_D ;// put parameter in correct
register

   // Call sinp() function
   // add offsets to the stack frame pointers, to allocate new stack
frames
         add _mono_sp, _mono_sp, 16; // allocate new mono stack
frame
         add _poly_sp, _poly_sp, 32;  // allocate new poly stack
frame


       j.sub      my_function;

   // Subtract offsets from stack frame pointers to free stack frame
            sub   _mono_sp, _mono_sp, 16;
            sub   _poly_sp, _poly_sp, 32;

            mov  8:p8f, 0:p8f; // put return result in passing
register.

   // Call print_result function
   // add offsets to the stack frame pointers, to allocate new stack
frames
   add       _poly_sp, _poly_sp, 32;  // allocate new poly stack
frame
   add       _mono_sp, _mono_sp, 16; // allocate new mono stack frame

   j.sub print_result;

   // Subtract offsets from stack frame pointers to free stack frame
   sub   _mono_sp, _mono_sp, 16;
   sub   _poly_sp, _poly_sp, 32;

   mov       8:m4, 0         ;    // return value of 0

   ld   56:p8, _poly_sp, 0;
   ld   8:p8, _poly_sp, 8;//restore poly registers
   ld   24:p4, _poly_sp, 16 ;
   ld   28:p4, _poly_sp, 20 ;
   ld   32:p8, _poly_sp, 24 ;

   ld   60:m4u, _mono_sp, 0; // restore return address and jump
   j    60:m4u    ;
```

```
print_result::
.global print_result

    mov 16:m4, _CN_LIBEXT_DPRINT_DEC_FORMAT |
_CN_LIBEXT_DPRINT_FLOAT_TYPE ; // output decimal float
   .setpolytemp 56, 8
   set.varargs 8:p8f;// put parameter
   .setmonotemp 60, 4
   call.varargs dprint_poly;// call dprint

         return
```

The **Cⁿ** function that is called from the code is:

```
extern poly double my_function(poly double x) {
return (3*x);
}
```

13.4.5 Status and predicate bits

The status flags are not guaranteed to be preserved across a function call. However, the user predicate state must be preserved. It is the responsibility of the callee to save the state if the predicates are modified. For more information on how to save and restore the state, see *[1]: CSX600 Instruction Set Reference Manual*.

13.4.6 Enable state

Functions must preserve the entire state of the enable stack.

The convention used by the compiler is that, on entry to a function that may change the enable state, the enable stack is saved at the start of the function and restored when the function exits.

By convention, all code should use up to five levels of enable state in a function before saving and restoring this nesting, giving an indefinite amount of enable state to the user. This leaves two levels for assembler instructions.

Note that some macro instructions make use of the enable stack. This is documented in the *[1]: CSX600 Instruction Set Reference Manual* and must be taken into account when calculating the enable stack usage. For more information on saving and restoring the enable state, see *[1]: CSX600 Instruction Set Reference Manual* for details.

13.5 Poly scratch memory

A small amount of poly memory, 128 bytes, is reserved as scratch memory for the PIO memory transfer routines defined in the standard library. This memory is also reused by the debugger for reading and writing poly registers.

The start address for this memory is defined by the global symbol `_poly_io_queue_scratch_space`.

13.6 Semaphores

The TSC provides 128 semaphores which are manipulated by instructions such as `sem.put` and `sem.wait`, see *[1]: CSX600 Instruction Set Reference Manual* for details. Restrictions applied by the ABI on the use of the semaphores are listed in Table 45..

Semaphore number	Usage
0 to 94 inclusive	For programmer use.
95 to 127	Reserved for use by libraries at run time.

Table 45. Semaphore usage restrictions

13.7 Endianness

Endianness defines the way that data is stored in memory, that is, the order of bytes in memory for multi byte objects. This is illustrated in *Figure 30*.

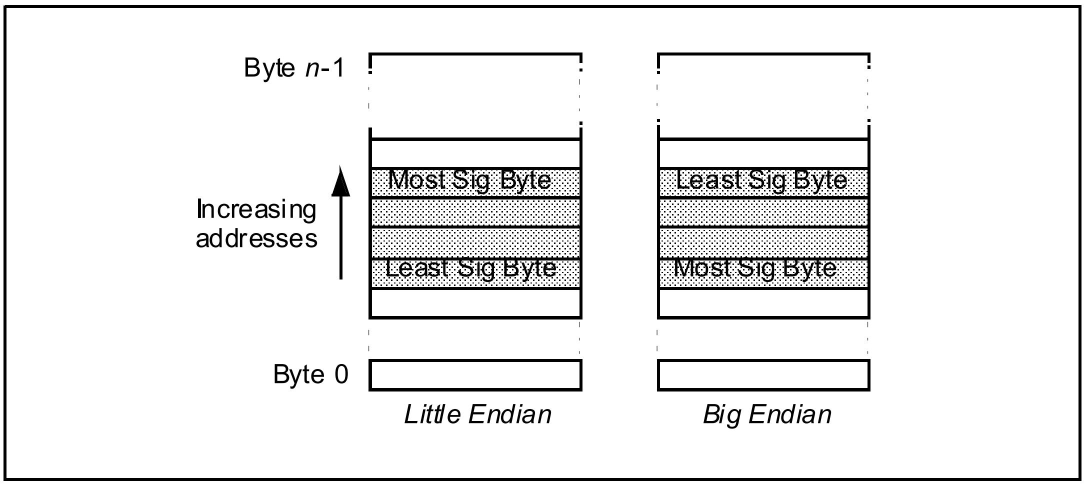


Figure 30.Layout of 4 byte value in memory

Because it is designed to be integrated in a variety of embedded systems, the processor is implemented as a bi-endian architecture; it can switch between big and little-endian.

In little-endian mode, the processor stores the least significant byte of a multibyte object at the lowest memory address. In big-endian mode, the processor stores the least significant byte of a multibyte object at the highest memory address.

These two ways of storing data in memory are illustrated for 2- and 4-byte objects in *Figure 31*.

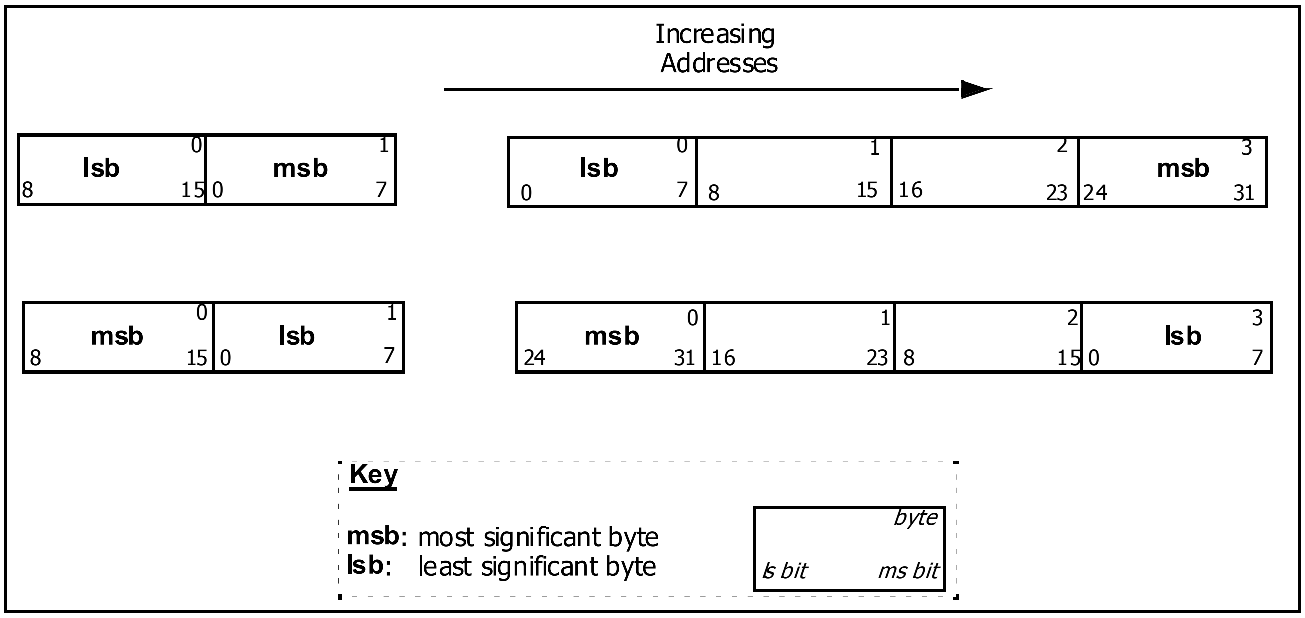


Figure 31.Big and little endian values in memory

The normal mode is little endian. The control registers that switch between big and little endian are listed in the Register Map chapter of *[6]: CSX600 Core Architecture Manual*.

13.8 Debugging information format

The SDK uses the Debug With Arbitrary Record Format (DWARF 2. 0) standard for representing debugging information. An outline of the extensions to the DWARF format and how the DWARF virtual registers are mapped on to the hardware registers is described in the text that follows.

13.8.1 DWARF extensions

The following extensions to DWARF provide support for the poly type and the **Cⁿ** language in general.

Custom tags

```
DW_TAG_ClearSpeed_Base = (0x4200)
DW_TAG_CS_mono_type = (DW_TAG_ClearSpeed_Base )
DW_TAG_CS_poly_type = (DW_TAG_ClearSpeed_Base+1)
DW_TAG_CS_null_type = (DW_TAG_ClearSpeed_Base+2)
```

Source languages

```
DW_LANG_ClearSpeed_Base = (0x9000)
DW_LANG_CS_Cn =(DW_LANG_ClearSpeed_Base )
DW_LANG_CS_Vis =(DW_LANG_ClearSpeed_Base+1)
```

Base type encoding

```
DW_ATE_ClearSpeed_Base = (DW_ATE_lo_user)
DW_ATE_CS_double    = (DW_ATE_ClearSpeed_Base )
DW_ATE_CS_unsigned_short = (DW_ATE_ClearSpeed_Base+1)
DW_ATE_CS_signed_short = (DW_ATE_ClearSpeed_Base+2)
```

Location operation registers

```
DW_OP_ClearSpeed_Base = (DW_OP_lo_user)
DW_OP_mono_regx   = (DW_OP_ClearSpeed_Base )
DW_OP_poly_regx   = (DW_OP_ClearSpeed_Base+1)
```

Custom attributes

```
DW_AT_ClearSpeed_Base = (0x3000)
DW_AT_CS_mono_frame_base = (DW_AT_ClearSpeed_Base )
DW_AT_CS_poly_frame_base = (DW_AT_ClearSpeed_Base+1)
```

13.8.2 DWARF virtual register mapping

The DWARF standard requires that a mapping is defined from DWARF specific mapping of numbers and virtual registers on to the actual registers of the architecture. The mapping is described in the text that follows.

The mapping is split as follows:

- DW_OP_reg0, DW_OP_reg1, . . . , DW_OP_reg31

  The `DW_OP_regn` operations encode the names of up to 32 registers, numbered from 0 to 31, inclusive. The object address is in register `n`.
- `DW_OP_regx`

  The `DW_OP_regx` operation has a single unsigned LEB 128 literal operand that encodes the name of a register.

One of the key concepts in the DWARF standard is to provide areas to compress commonly used values because the debug information can be large. This is the idea behind the 32 register mappings described above. However, the processor has many registers, including the virtual mapping of 2, 4, and 8 registers on to the actual 2 and 1-byte register files, so the use of these 32 registers is fairly unimportant. Therefore, the thirty two 4-byte poly registers are mapped to these as follows:

```
DW_OP_reg0 -> 0:p4
DW_OP_reg1 -> 4:p4
. . .
DW_OP_reg31 -> 124:p4
```

The following defines a `DW_OP_regx` for each of base registers and for each of the virtual registers, repeating the definition of 4-byte poly registers to keep everything orthogonal. The first five registers represent the state that either the caller or callee must save if they want to use these registers, as described in *13.3.3: Register model*. Some of these are implicit registers which are not given symbolic names, but must be represented explicitly in DWARF, thus describing what has really been saved and restored.

```
DW_OP_regx 0 -> CFA
DW_OP_regx 1 -> program counter (pc)
DW_OP_regx 2 -> predicates
DW_OP_regx 3 -> enable state (enable state)
DW_OP_regx 4 -> return rule
DW_OP_regx 5 -> return register (ret)
DW_OP_regx 6 -> not used
DW_OP_regx 7 -> not used
DW_OP_regx 8 -> not used
DW_OP_regx 9 -> not used
```

2-byte mono registers

```
DW_OP_regx 10 -> 0:m2
DW_OP_regx 11 -> 2:m2
. . .
DW_OP_regx 41 -> 62:m2
```

4-byte mono registers

```
DW_OP_regx 42 -> 0:m4
DW_OP_regx 43 -> 4:m4
. . .
DW_OP_regx 57 -> 60:m4
```

8-byte mono registers

```
DW_OP_regx 58 -> 0:m8
DW_OP_regx 59 -> 8:m8
. . .
DW_OP_regx 65 -> 56:m8
```

1-byte poly registers

```
DW_OP_regx 66 -> 0:p1
DW_OP_regx 67 -> 1:p1
. . .
DW_OP_regx 193 -> 127:p1
```

2-byte poly registers

```
DW_OP_regx 194 -> 0:p2
DW_OP_regx 195 -> 2:p2
. . .
DW_OP_regx 257 -> 126:p2
```

4-byte poly registers

```
DW_OP_regx 258 -> 0:p4
DW_OP_regx 259 -> 4:p4
. . .
DW_OP_regx 289 -> 124:p4
```

8-byte poly registers

```
DW_OP_regx 290 -> 0:p8
DW_OP_regx 291 -> 8:p8
. . .
DW_OP_regx 305 -> 120:p8
```

16-byte poly registers

```
DW_OP_regx 306 -> 0:p16
DW_OP_regx 307 -> 16:p16
. . .
DW_OP_regx 313 -> 112:p16
```

32-byte poly registers

```
DW_OP_regx 314 -> 0:p32
DW_OP_regx 315 -> 32:p32
. . .
DW_OP_regx 317 -> 96:p32
```

14 Assembly language

This chapter describes the assembly language and directives that are used in the source code for the assembler. See the *[1]: CSX600 Instruction Set Reference Manual* for details of the instruction set.

Chapter 2: Building programs, has information on how to assemble source files. It will also be helpful to read the *Chapter 6: Linker reference* for more detail on some concepts.

14.1 Overview

The assembler reads a source file and translates the contents into an object file. The textual input to the assembler consists of *labels*, *instructions* and *directives*.

- **Labels** are used to provide meaningful names for locations in the program and other values.
- **Instructions** are translated into executable op-codes in the output file.
- **Directives** are used primarily for creating or manipulating data, defining symbols and controlling the overall object file structure.

Each of these components are described in more detail in later sections.

14.2 Basic syntax

Each source line can consist of a number of components:

- A label (optional)
- An instruction or directive
- Zero or more arguments for the instruction or directive
- Comments

Note: The assembler requires line endings to be in the standard format for that system. That is, line feed for Linux, carriage return and line feed for Windows.

14.2.1 Labels

Labels provide symbolic names for locations in the program: addresses of subroutines or data. Labels can be defined on either a line by themselves or preceding an instruction. Labels can contain letters, numbers and underscores. Labels have to start with a letter, underscore or, in special cases, a dot (.). For more information, see section *Section 14.3.2: Symbols on page 182*. The definition of a label is terminated with a double colon. For example:

```
exp_fct_start::
```

14.2.2 Instructions

An instruction consists of a mnemonic followed by a number (zero or more) of comma-separated operands. The instruction is terminated with a semicolon or new line. Multiple instructions can appear on one line, separated by semicolons.

```
ld 0:m2, x_value;  add 0:p2, 0:p2, 0:m2;
```

14.2.3 Directives

Directives start with a dot to distinguish them from instructions. A directive may be followed by a number of comma separated parameters. Only one directive can appear on a line.

```
.byte 42
```

14.2.4 Comments

The remainder of any line following "//" is comment text and is ignored. For example:

```
add 0:p2, 0:p2, 0:m2    // add mono register 0-1 to poly registers 0-
1,
                                                                    //
putting result in poly registers 0-1
```

14.2.5 Literals

Numeric values can be expressed in decimal, octal, hexadecimal or floating point notation. Octal and hexadecimal numbers are represented with the C syntax, for example, `0177` (octal) and `0x1234` (hex). The type (integer or floating point) can be deduced from the syntax of the number. Floating-point values are single precision (32 bit) by default. Double precision (64 bit) floating-point values are indicated by appending `:8`. For example, `3.5` is assumed to be a 32-bit value, `3.5:8` is a 64-bit float.

Character literals enclosed in single quotes can be used as integer values. All the string escape sequences described below can be used.

Strings are enclosed in double quotes. A double quote can be included in a string by prefixing it with a back slash:

```
.string "A \"quoted\" string."
```

A new line character can be included in a string with the `\n` escape sequence.

Table 46 lists the other escape sequences recognized by the assembler.

`\"`	Double quote: **"**
`\'`	Single quote: **'**
`\?`	Question mark: **?**
`\\`	Backslash: \
`\a`	Bell (ASCII code 7)
`\b`	Backspace (ASCII code 8)
`\f`	Form feed (ASCII code 12)
`\n`	New line (ASCII code 10)
`\r`	Return (ASCII code 13)
`\t`	Tab (ASCII code 9)
`\v`	Vertical feed (ASCII code 11)

Table 46. Escape sequences in strings

`\0`*octal-digits*	Character with octal code *octal-digits*
`\x`*hex-digits*	Character with hexadecimal code *hex-digits*

Table 46. Escape sequences in strings

14.3 Sections and symbols

As well as the instructions and data, the object file generated from the source contains information about *sections* and *symbols*.

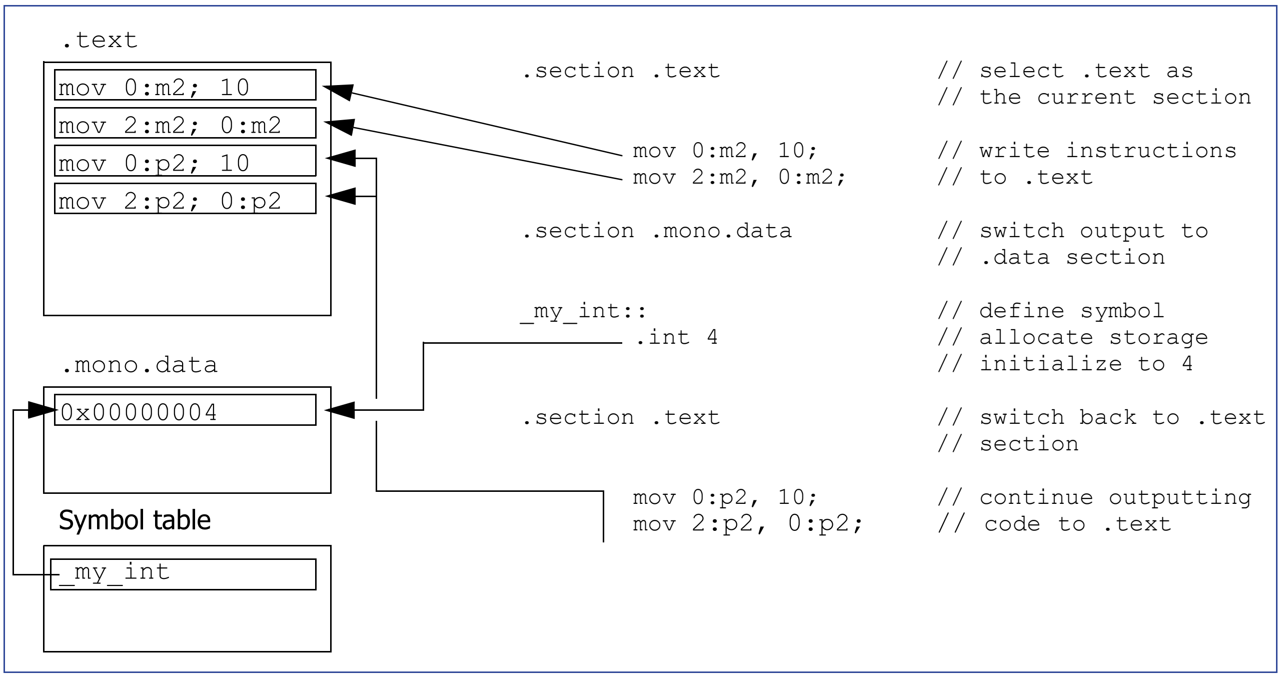
14.3.1 Sections

The assembler organizes the data in an assembled program into named sections of related information – code, data, debug information, and so on. In the final stages of processing, these are transformed into an executable code image by the linker.

The standard sections are:

`.text`	stores the code corresponding to the instructions in the input file.
`.poly.data`	contains initialized poly variables and other poly data.
`.mono.data`	contains initialized mono variables and other mono data.
`.poly.bss`	reserves storage for undefined poly data. On loading will be initialized to 0.
`.mono.bss`	reserves storage for undefined mono data. On loading will be initialized to 0.

The assembler maintains a *location counter* for each section. This holds the next offset in that section where information from the source file will be stored. The location counter will be adjusted each time data or code is stored in a section and can also be manipulated explicitly by directives such as `.align`. Each time the `.section` directive is used, the assembler will append subsequent data or instructions to the newly selected section. This is illustrated in *Figure 32*.



```
.section .text              // select .text as
                            // the current section

        mov 0:m2, 10;       // write instructions
        mov 2:m2, 0:m2;     // to .text

.section .mono.data         // switch output to
                            // .data section

_my_int::                   // define symbol
        .int 4              // allocate storage
                            // initialize to 4

.section .text              // switch back to .text
                            // section

        mov 0:p2, 10;       // continue outputting
        mov 2:p2, 0:p2;     //  code to .text
```

Figure 32.Textual input and memory organization

14.3.2 Symbols

Labels and named data objects (strings, integers, bytes, and so on) are referred to as symbols. The assembler maintains a relationship between the symbol name, its value, storage location (for data objects) and the section in which they were defined. Symbols can be divided into the following categories:

- *Local.* All symbols explicitly created in the input file are assumed to be *local*. Local symbols can only be referenced in the source file where they are defined. It is not an error if, at link time, multiple local symbols with the same name are encountered in different files.
- *Global. Symbols can be made visible to other source files by declaring them as global.* Global symbols must have unique names not only in the context of the file in which they were defined, but all the files constituting the final executable.
- *External.* Any symbol that has been referenced in the input file, and for which the definition has not been found is defined as *external*. The value of this symbol will not be known until the object file is linked with another file that defines a value for the symbol.
- *Internal. Internal symbols* are a special case of local symbol. They use a specific syntax for their names: they must begin with `.LL`. Internal symbols are never placed in the file's symbol table and so are not visible to the debugger. Internal symbols can be used for determining size of objects, for example, structures or functions, performing local jumps, and so on.

Figure 33 demonstrates uses of the various types of symbols.

```
.section .text                  // switch to text (code) section

.LL_exp_fct_start::             // internal symbol marks the start
                                // of the function, we will use it
                                // to compute the size of the
                                // function body

_exported_function::            // define the function entry point
.global _exported_function      // make it global (exported)
   .... instructions ....
   return;

.LL_exp_fct_end::               // internal symbol marks the end
                                // of the function, we can now
                                // calculate the size of the symbol

.size _exported_function , .LL_exp_fct_end - .LL_exp_fct_start
.type _exported_function, @function

.section .mono.data             // switch to mono data section

_local_int::                    // symbol will be in the symbol table
   .int 0xFF                    // and will be visible to the debugger
                                // it is a local symbol however and
                                // will not be visible to the linker
                                // or the loader

_global_int::                   // a global symbol
   .int 0xAA
.global _global_int

.LL_internal_short::            // an internal symbol, scope
   .short 0x00                  // restricted to the current file
```

Figure 33.Symbol types

In addition to the above categories, symbols can also be categorized as:

- *Absolute symbols*, where the value is a constant and will not change during linking.
- *Relocatable symbols*, where the symbol represents a location in the code or data sections which is unknown or not fixed when the code is assembled. The absolute location will not be determined until the code is linked.

Symbol arithmetic

The assembler provides support for *constant folding* and symbol arithmetic. An expression using only literal values and absolute symbols, whose values are known, will be fully evaluated to produce a constant value. For instance:

```
.set myval, 1*2-3;
mov a_label-2:m2u, 36:m2u;
```

For a description of the `.set` directive, see page 189.

Expressions can use the operators shown in *Table 47*. Expressions involving relocatable symbols, or symbols whose values are not known, can only use addition and subtraction. The following rules must be observed:

1. Two absolute(1) values can be added or subtracted, the result is an absolute value.
2. An absolute value can be added to or subtracted from a relocatable symbol, the result is a relocatable symbol.
3. Two relocatable symbols can be subtracted, the result is an absolute value. In this case, the two symbols must be defined in the same file so their relative values are known when the file is assembled.

The operations are not commutative and the relocatable symbol must be the first operand.

`+ - * / %`	unary plus unary minus multiplication division modulo	Highest precedence
`+ -`	addition subtraction	
`<< >>`	shift left shift right	

`< <= >=`
`> == !=`
	less than
	less than or equal
	greater than or equal
	greater than
	equal to
	not equal to	

`&`	bit-wise and	
`^`	bit-wise xor	
`|`	bit-wise or	
`&& ||`	logical and logical or	Lowest precedence

Table 47. Operators and precedence

14.4 Instructions

Instructions are made up of a mnemonic and zero or more operands. Instructions allow a mixture of *mono*, *poly* and *immediate* operands. Some instructions are executed on many processing elements in the poly execution unit, others only on the mono execution unit. Where an instruction is executed is usually determined by multiplicity of the operand.. This is fully explained in the *[1]: CSX600 Instruction Set Reference Manual*.

The assembler is a *macro* assembler. This means that instructions in the source file may be assembled into one or more instructions on the target architecture. Moreover, some instructions may require temporary mono or poly registers for work space. Temporary registers are not passed in as part of each instruction. Instead, assembler directives are used to reserve

1. Here 'absolute' refers to either an absolute symbol or a constant literal.

register space to use as work space (see the descriptions of the `.setmonotemp` and `.setpolytemp` directives on page 190).

14.4.1 Instruction mnemonics

Instruction mnemonics describe the operation to be performed. Instruction names are alphabetic, with dots separating the fields of an instruction name. For example, a subset of the compare instructions have the form `cmp.`*`cond`*, where the condition code, *`cond`*, is `eq` for 'compare equal', `gt` for 'compare greater than', and so on.

There is not a one-to-one mapping between mnemonics and machine instructions: the assembler uses the operand types to determine which op-code should be generated. For example, the `add` mnemonic can generate different instruction op-codes depending on whether the operands are integer or floating point, mono or poly.

See the *[1]: CSX600 Instruction Set Reference Manual* for details of the instruction mnemonics.

14.4.2 Operands

Operands have the form *value*:*specifiers*, where the ":" and the specifiers are optional components. The *value* can be a numeric literal or a label. The value specifies a register or a literal value, depending on the specifier. The specifiers are four fields after the colon: *domain*, *size*, *type and vector size*. The specifiers must appear in this order. Domain is either `m`, `p` or `i` for mono, poly or immediate. *Size* is normally 1 to 8 (bytes). T*ype* is `u`, `s` or `f` for unsigned integer, signed integer or float respectively. The vector size is for specific instructions which take vector arguments. These indicate a contiguous grouping of *vector size* elements of width *size* in the mono or poly register file. Square brackets are used to indicate the vector size.

Note that for some operations involving data movement the size field can be up to 64 bytes.

The operand structure is shown in *Figure 34*.

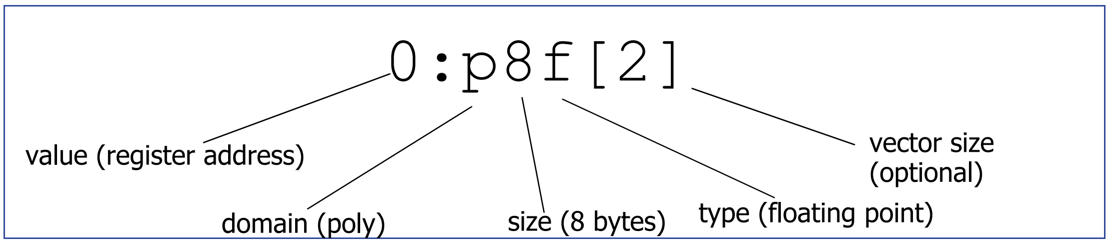


Figure 34.An illustration of the fields for an instruction operand

The example above indicates two double-precision floating-point (8-byte) values in the poly register file starting at location 0.

The value field may be any of the following:

- numeric literal
- label
- absolute symbol
- variable

The value field can be interpreted as either a register or an immediate, depending on the domain specifier.

If the domain is mono or poly, then the value field is considered to be a register address. Note that this specifies a byte index into the register file of the appropriate domain. For example, if there are 32 16-bit mono registers, the address will be in the range 0–63.

The default domain is immediate. If the width of an immediate or label is not specified, it is assumed to be 4 bytes.

It is possible to use arithmetic expressions to generate the value field for both registers and immediates.

For example:

```
mov 0:m2, 10+23    // Moves 33 into 2-byte mono registers 0
mov 10+2:m2, 1     // Moves 1 into 2-byte mono register 12
```

Specifiers may be omitted in some cases. The defaults are:

- *domain* = immediate
- *type* = unsigned for registers
- *width* = 1 for registers
- *width* = 4 for immediates.

However, explicitly qualifying all arguments can provide some extra error checking.

There are also some functions which can be used on operands to select the least significant or most significant bytes. These functions are `.lsbytes` and `.msbytes`. These are documented under the description of macro instructions in *Section : Operand functions on page 196*. For example, `.lsbytes(.LL_mylabel, 2)` would return the two least significant bytes of the label `.LL_mylabel`.

The instruction set document defines any constraints on the use of the operands for each instruction.

Predefined operands

There are a number of predefined named operands which can be used where a regular operand would be used in an instruction. These are defined by the configuration file (see *Chapter 1: SDK overview*, for more information). Most of these are part of the ABI which is needed to interact with compiled code (see *Chapter 13: Application binary interface*). *Table 48* lists the predefined operands.

Name	Description	Type[(a)]
`_mono_sp`	Mono stack pointer	R (m4u)
`_poly_sp`	Poly stack pointer	R (m2u)
`_num_pes`	Number of poly processing elements (PEs)	I
`_poly_memory_size`	Size of memory (in bytes) in each PE	I
`_mono_temp_start`	Start address of mono temporary registers	I
`_mono_temp_size`	Size (in bytes) allocated for mono temporary registers	I

Table 48. Predefined operands

Name	Description	Type[a]
`_poly_temp_start`	Start address of poly temporary registers	I
`_poly_temp_size`	Size (in bytes) allocated for poly temporary registers	I
`_mono_ret_val`	Address of register used for mono return value from a function	I
`_mono_ret_val_size`	Size (in bytes) of register used for mono return value from a function	I
`_poly_ret_val`	Address of register used for poly return value from a function	I
`_poly_ret_val_size`	Size (in bytes) of register used for poly return value from a function	I
`_num_pio`	Number of channels of PIO	I
`_mono_stack_size`	Memory reserved for mono stack (in bytes)	I
`_poly_stack_size`	Memory reserved for poly stack (in bytes)	I

`_sem_print`
`_sem_print_ex`
`_reserved_sem_bank_0`
`_reserved_sem_bank_1`
`_reserved_sem_bank_2`
`_reserved_sem_bank_3`
	Reserved semaphores	I

Table 48. Predefined operands

a. R = register
I = immediate

The predefined operands may be either registers or immediate values. These are shown in the table as R or I, respectively. For registers the appropriate specifiers are also shown. Some of the immediate operands are to be used as the *addresses* of registers. These should be used with specifiers, to define their domain, type and width.

Figure 35 shows some example instructions.

```
mov _mono_sp, 20                   // Move 20 into mono_sp, defined as a register
add _poly_ret_val:p1, 4:p1, 8:p1  // poly_ret_val is defined as an immediate value, sc
                                   // add specifiers to turn it into a register

add 0:p2, 0:p2, 0:m2               // add mono register 0-1 to poly registers 0-1,
                                   // putting result in poly registers 0-1
mul 4:m4, 0:m2, 23                 // multiply mono register 0-1 by 23 (unsigned),
                                   // putting result in mono registers 4-7
mul 4:p4s, 8:p2s, 12:p2u           // multiply poly registers 8-9 by poly register 12
                                   //  (signed x unsigned)
```

Figure 35.Example instructions

Endianness and registers

In a little-endian configuration of the processor, the least significant byte of a 2-byte (or larger) register, will be the lowest byte address. For example, if `0:m2` holds the number `0x1234` then, for the little endian case, byte 0 (`0:m1`) contains `0x34` (the least significant byte) and byte 1 (`1:m1`) contains `0x12` (the most significant byte).

Conversely, in a big endian system `0:m1` would contain `0x12` (the most significant byte) and `1:m1` would contain `0x34`.

14.5 Directives

Directives provide means of emitting data, setting or changing symbol parameters and creating the structure of an executable file. All directive names start with dot.

In the following descriptions, *`italics`* indicate parameters to the directives and square brackets, `[]`, indicate optional components, `*` indicates parameters that can be repeated.

`.alias` *`alias { instruction [, instruction] }`*

See the description of macro definitions in *Section 14.6.1: Matching macros against instructions on page 193*.

`.align` *`alignment [, value]`*

Advances the current value of the location counter in the current section to the required alignment in bytes. For example, `.align 8` advances the location counter until it is a multiple of 8. The second expression (also absolute) is the value to be stored in the padding bytes. If the `value` is omitted, the padding bytes are zero.

Data should be naturally aligned. It is advisable to specify a `.align` directive before emitting any data with an increased data width than was previously specified.

`.ascii "`*`text`*`" [, "`*`text`*`"]*`

Emits a string constant into the current section.

`.asciz "`*`text`*`" [, "`*`text`*`"]*`
`.string "`*`text`*`" [, "`*`text`*`"]*`

Emits a string constant into the current section. A null, '\0', character is automatically appended to terminate the string.

```
.byte   const [, const]*
.double const [, const]*
.float  const [, const]*
.int    const [, const]*
.short   const [, const]*
```

Emit a numeric constant into the current section. The parameter expression can be an absolute expression as defined on page 183. The expression for `.byte`, `.int`, and `.short` has to be an integer value. These directives do not do any padding to maintain alignment. The byte sequence representing the value will be put in the object file at the current location. Use the `.align` directive to maintain alignment if necessary.

`.fill` *`repeat, size, value`*

This directive emits *`repeat`* copies of *`size`* bytes taken from the *`value`*. The parameters *`repeat`*, *`size`* and `value` are absolute expressions. *`repeat`* may be zero or more. *`size`* may be zero or more but if it is more than eight, then it is truncated to eight – behavior compatible with other assemblers. The contents of the value that `.fill` emits is taken from an eight-byte number. The highest order four bytes are zero. The lowest order four bytes are the bytes in *`value`* rendered in the byte order of the target that the code is generated for. The fill bytes are taken from the lowest order *`size`* bytes of this number.

`.global` *`name`*

This directive makes the symbol *`name`* global, that is, it is stored in the symbol table and is visible to the linker and other object files. If the symbol is defined in the current file, its value is made available to other object files that are linked with the object file. Global symbols must be defined in one of the object files that are linked to create an executable file. Global symbols cannot be defined in multiple files.

`.pragma` ***`pragma_name state`***

This directive switches *`pragma_name`* to be on or off. *`state`* is either `on` or `off`. The following *`pragma_names`* are available for use:

- `alignment_unknown`

  This directive, if set to `on`, forces the instruction set to emit 1-byte load stores. This is only advised when absolutely necessary.
- `DEBUG_ON`

  This directive, if set to `on`, informs the instruction set that it is being run in debug mode. That is, it makes sure that the vector instructions flush after each instruction.
- `no_pipeline_nops`

  This directive, if set to `on`, will stop mass inserting `nops` into the instruction stream and should only be used when you know that there are no hazards present.
- `suppress_vector_flush`

  This directive, if set to `on`, stops the instruction set automatically flushing the vector pipelines.

`.section` ***`name`*** `[,` ***`parameter`***`]*`

This directive creates a new section or sets the named section as the current section. All further directives and instructions will append data to this section until another `.section` directive changes the current section.

Section names can consist only of alphanumeric characters, underscore and the dot. Use of spaces is not allowed. It is traditional to start section names with a dot. Sections are also described by a number of parameters that determine their alignment constraints, storage requirements, and so on. The object file format conforms to the ELF file format specification *[9]: Executable and Linkable Format (ELF)* and the standard section names defined there are recognized.

The names of data sections are prefixed with `.mono` and `.poly` to denote their multiplicity. Such compound section names, for example `.poly.bss`, are automatically and correctly identified by the assembler as, in this case, `.bss` type.

When defining custom sections, where default values are not accessible, you need to specify section parameters directly, in the optional ***`parameter`*** field of the directive, with a comma separated list of parameters. The allowed parameters are: `@write`, `@alloc` and `@progbits`. The meaning of the parameters is defined in the ELF standard.

`.set` ***`symbol`***`,` ***`value`***

Creates, or updates, the value of an existing absolute symbol. Values of absolute symbols can be set multiple times. The most recently assigned value is used when the symbol is referenced.

The `.set` directive can also be used to create symbols representing operands. For instance:

```
    .set temp_op, 32:m4u;
```

When these labels are subsequently used, you can override the specifiers. For instance:

```
    mov temp_op:m2u, 36:m2u;
```

Note: The predefined operands described *on page 186* can also be overridden in this way.

`.setmonotemp [.perm]` ***`startreg, regsize`***
`.setpolytemp [.perm]` ***`startreg, regsize`***

Specifies which mono and poly registers are used as temporary storage in the following instruction. The *`startreg`* parameter specifies the start address (as a byte offset) in the register file. The *`regsize`* parameter defines the number of bytes to be reserved as temporaries. The instruction set documentation defines the number of temporary registers required by each predefined macro provided by ClearSpeed.

Normally, the temporary registers are only available for one instruction following the directive. Each macro instruction which requires temporary registers should be preceded by a directive to allocate the appropriate number of registers. The following example sets the top four bytes of the mono register file as temporaries for the following floating point add:

```
.setmonotemp 60, 4
add  8:m4f, 8:m4f, 3.141
```

Although it is less efficient in register use, it is possible to use the optional `.perm` argument to make permanent allocations of temporary registers. Consider, for example:

```
.section .text
.setpolytemp .perm 60, 4
.setmonotemp .perm 60, 4
```

This allocates four bytes from register 60 in the mono and poly register files for use as temporary registers by *all* following macros. The contents of these registers will not be preserved across any macro instructions that use temporaries. It is your responsibility to ensure that these registers do not contain any data.

`.size` ***`symbol, size`***

Changes the size of the symbol. If this directive appears prior to the symbol being created then a symbol with the given name and with all properties set to default values, will be constructed.

`.type` ***`symbol, type`***

Sets the type of the symbol. The possible type values are: `@object` and `@function`. This directive can appear anywhere in the source. The logic for creating symbols follows that of the `.size` directive.

14.5.1 CFI directives

Each time a program performs a function call, information about the call is generated. That information includes the location of the call in the program, the arguments of the call, and the local variables of the function being called. The data is saved in two regions of memory (call stacks), one for mono state and the other for poly, as described in *Chapter 13: Application binary interface*. A debugger needs to be able to generate a stack trace from the current program counter and to look at values from anywhere in the chain. Information about registers saved in the stack are recorded using the DWARF debugging information format.

The DWARF 2.0 standard defines the section `.debug_frame` that is used to store the CFI information.

Entries are of two forms:

- **A Common Information Entry** (CIE) holds information that is shared among many Frame Descriptors and includes the following information:

  `code_alignment_factor`

  `data_alignment_factor`

  These are used to multiply address for code and data respectively. For the processor, these values are set to 16 and 1.

  `return_address_register`

  A constant that indicates which column in the rule table represents the return address of the function.

- **A Frame Description Entry** (FDE) contains at least the following fields:

  `CIE_pointer`

  This is an offset from the start of the `.debug_frame` section to a particular CIE.

  `initial_location`

  An addressing-unit sized constant indicating the first program address associated with this entry.

  Note: The program addresses are always mono so it does not need to have two types of FDE.

CFI instructions

A sequence of DWARF CFI instructions describe the movement of registers. This sequence is the actual heart of the DWARF CFI and describes the movement of registers to and from the mono and poly stack and between themselves.

Section 13.8: Debugging information format on page 176 defines a mapping between DWARF virtual registers and the actual hardware registers of the processor that are exposed to you and captured by the ABI.

CFI directives

This section defines the CFI directives which are supported by the assembler and may be used directly by the assembler programmer.

`.cfi_startprologue`

This directive can be inserted at the start of each function. It tells the assembler to emit initial CFI instructions for the function.

`.cfi_endepilogue`

This directive can be inserted at the end of each function. It tells the assembler to emit the appropriate structures (CIE, FDE) and relocations for the CFI generated after a call to `.cfi_startprologue`.

`.cfi_def_mono_cfa` ***`reg,imm`***

This directive can be used to set a rule for computing the mono CFA from this address onwards, until the CFA is defined by another directive. The directive changes the rule for calculating the CFA to use register *`reg`* and offset *`imm`*.

`.cfi_def_mono_cfa_register` *`reg`*

This directive changes the rule for calculating the mono CFA to use register *`reg`*. The offset remains the same.

`.cfi_def_mono_cfa_offset` *`imm`*

This directive changes the rule for calculating the mono CFA to use offset *`imm`*. The register remains the same.

`.cfi_adjust_mono_cfa_offset` *`imm`*

Similar to the previous directive but *`imm`* is a relative value that will be added to current offset instead of an absolute value as in `.cfi_def_mono_cfa_offset`.

`.cfi_def_poly_cfa` *`reg,imm`*

This directive can be used to set a rule for computing the poly CFA from this address onwards, until the CFA is defined by another directive. The directive changes the rule for calculating the CFA to use register *`reg`* and offset *`imm`*.

`.cfi_def_poly_cfa_register` *`reg`*

This directive changes the rule for calculating the poly CFA to use the register *`reg`*. The offset remains the same.

`.cfi_def_poly_cfa_offset` *`imm`*

This directive changes the rule for calculating the poly CFA to use the offset *`imm`*. The register remains the same.

`.cfi_adjust_poly_cfa_offset` *`imm`*

Like the previous one but *`imm`* is a relative value that will be added to the current offset instead of an absolute value as in `.cfi_def_poly_cfa_offset`.

`.cfi_offset` *`reg,imm`*

The final directive is a single rule for both poly and mono and should be used to generate a rule saying that the register *`reg`* is saved at offset *`imm`* from the particular CFA.

`.cfi_retsave` *`imm`*

This directive can be used to generate a rule saying that the link register (see *Chapter 13: Application binary interface*) is saved at offset *`imm`* from the particular CFA.

`.cfi_def_restore reg`

This directive can be used to generate a rule saying that `reg` has been restored and the last save rule, for `reg`, can be discarded.

14.6 Macros

A macro allows a mapping from a single macro instruction name onto a sequence of instructions. Macros can be defined at any point in the assembly file and then used within the text sections. The assembler provides a sophisticated mechanism for macros which allows one from a number of different macros to be selected using not only the name but also by matching the number and types of the operands. A single macro can match a wide variety of operands. For example, it is possible to define an `add` macro which will match both mono and poly operands. If multiple macros match the same source code instruction, the first one defined which matches will be selected.

Defined macros can currently only expand to instructions, local labels (ones defined with `.LL_`) or other macros. They cannot define assembly directives such as `.fill` or `.float`. They are therefore only appropriate for use in the `.text` section.

The basic syntax for defining a macro is as follows:

```
.define macro_name(macro_parameters)
constraints
pragmas
{
    macro_statements
}
```

The format of *`macro_parameters`*, *`constraints`*, *`pragmas`* and *`macro_statements`* is defined below.

A simple example would be:

```
.define fred(dst:p2, src:i)
.constraint src < 128;
{
     jim dst, src;
     bob dst, src;
}
```

In this case, when the assembler encounters the instruction `fred` in the source code, with a second operand with a value less than 128, it will substitute it with the two instructions `jim` and `bob`.

If the value of the second operand is greater than or equal to 128, it will report an error.

14.6.1 Matching macros against instructions

A macro definition will match against an instruction if it matches against the name, the macro parameters and satisfies any particular constraints and pragmas for the macro.

An instruction in the source code will be matched by a macro if it meets the following conditions:

- If it has the same name.
- If the operands are compatible with the macro parameters.
- If it satisfies any constraints defined for the macro.

If more than one macro matches an instruction, the first one will match.

Macro name

The macro name must start with a letter or underscore, but can also contain numbers, for example, `fred_jim2`. These names will be matched directly against the names of instructions in the assembler source code. It is also possible for a macro name to map onto several different instruction names using the `.alias` directive.

`.alias macro_name { [, alias] }`

This directive defines one or more aliases for a macro name. An instruction matching any of the aliases will be substituted by the macro definition.

For example:

```
.alias ld_st { load, store }
.define ld_st {
   ... body of macro definition
}
```

Any occurrence of the instruction names `load` or `store` in the assembly source will be matched by the macro `ld_st` and replaced with the macro definition.

Macro parameters

A macro can have zero or more comma-separated macro parameters. Each of these parameters will be matched against each of the operands of an instruction, in order. Every parameter must match an operand for an instruction to match the macro. The number of parameters in the macro and the number of operands in the instruction must be the same.

A parameter can define specifiers for an operand, for example domain or width, which are matched against the source operands. Any specifier which is not defined is 'wildcarded' and will match operands with any value for that specifier. For example, if the domain is not defined, then an operand of any domain could match (provided that the other specifiers match). For domain and type, multiple specifiers can be defined to match either mono or poly, or both unsigned and signed.

The vector size is assumed to be one but it can use : [ ] to wildcard.

Parameter syntax is similar to that for instruction operands, except that a name is used in place of the value part and specifiers can be omitted or used multiple times. For example, `dst:mp4us` would match any operand which is either mono or poly, width 4 and is either unsigned or signed. For this example, both `32:p4s` or `40:m4u` would match but `36` (an immediate), `32:m4f` (a float) or `40:p2s` (width 2) would not. Note that the (otherwise rarely used) `i` specifier is used to match an immediate, for example `dst:i`. In addition to these standard domains, `l` can be used to match a label, for example `dst:l`. If no specifiers are used to define a match, the '`:`' should be omitted.

Although most parameters will be named and match any value, it is possible to use a fixed value instead of a name to limit matching to a particular operand, for example, `lsl(dst:p4u, src0:p4u, 1)` would match instruction `lsl` with four-byte unsigned poly operands for `dst` and `src0`, but *only* the immediate value 1 for the final parameter.

The named parameters can be referenced by macro statements in the body of the macro or by constraint directives. The values of parameters can also be modified in the macro body.

Macro constraints

Constraints provide a way of further limiting which instructions a macro will match. This is done by defining an expression which must be nonzero for the macro to match. This expression can reference macro parameters or global symbols defined by a `.set` directive. Macro expressions are described in more detailed below but, for example, comparative operators such as < produce a nonzero result if they are true. Examples of constraint expressions are:

```
.constraint macro_expression;
src1 < 50 or .width(src0) == 2.
```

Multiple constraints can be defined and an instruction must match *all* of them to match the macro.

Macro pragmas

Inside the macro definition, the `.pragma` directive names pragmas which must be turned on (using the `.pragma` directive, see page 189) for the macro to be used. They are of the form:

```
.pragma pragma_name;
```

The pragma name can be any mixture of letters, underscore and numbers, as long as it starts with a letter or underscore. There may be multiple pragmas, all of which must be satisfied for the macro to be matched.

14.6.2 Macro body definition

The main body of the macro consists of one or more macro statements and label declarations. A macro statement consists of a name and zero or more macro expressions. The name can be an instruction name or an internal macro statement (such as `.print` or `.set`). Each expression is evaluated to generate an operand.

Macro statements are defined as follows:

```
name macro_expressions;
```

All macro statements are terminated by a semicolon.

Statements can be conditional. This is controlled by the `.if`, `.else` or `.endif` macro statements. Conditional `.if` statements can be nested to a depth of up to 64. These are explained in more detail below.

Label declarations must start with `.LL_` and be suffixed with `::`. For example:

```
.LL_local_label::
```

These labels can only be referenced within the body of the macro.

Macro expressions

The expressions in a macro statement are separated by commas, in the same way as instruction operands, for example `mov dst, src`. Each macro expression evaluates to a single operand. Expressions consist of:

- Operands (see page 185)
- Macro parameters (see page 194)
- Variables (page 195)
- Operand functions (page 196)

Variables

Variables are defined within a macro using the `.set` directive. Variables defined in this way have the scope of the macro they are defined in. Symbols (see *Section 14.3.2: Symbols on page 182*) defined globally can also be used as variables in a macro by preceding the symbol name with `@`.

Operators

Operators are used in expressions, such as `32+4`. These operators work on the value component of an operand (32 in this example). The nonvalue component of the generated operand will be based on the first operand of the operation. For example, `32:p4 + 4` results in `36:p4`.

Operators are either arithmetic operators (`+`, `-`, `*`, `/`, `%`), bit-wise operators (`&`, `|`, `<<`, `>>`) or relational operators (`<`, `<=`, `==`, `!=`, `>`, `>=`, `||`, `&&`). These operators should be familiar to anyone who uses C. Indeed the precedence of these operators is the same as C. Precedence of operators and their meaning is shown in *Table 47 on page 184*. Operators of the same precedence are grouped together with the highest precedence grouped first. Precedence can be altered by bracketing expressions. The sub-expression within the brackets will be evaluated before being used by other operators. For example, (32+4)*8 would do the addition first and then the multiplication.

When an operator has two operands, they will be assumed to be 64-bit signed integers unless the first operand is an immediate floating-point value. In this case, the second operand will be promoted to the same type.Comparison operators such as < will evaluate to 1 if the comparison is true, or 0 if it is false. For example, `32 < 36` will evaluate to 1 and `32 > 40` will evaluate to 0. The result of a logical 'and' (`&&`) will be 1 if *both* the operands are nonzero. The result of logical or (`||`) will 1 if *either* of the operands are nonzero.

Operand functions

These are functions which can only be used inside a macro definition. The arguments to these functions are expressions, these are evaluated to generate operands before being passed to the function. For example, `.width(.setwidth(32:p2s, 4))` will generate the operand `32:p4s` (from the `.setwidth` function) and then return the value 4.

`.getelement(`***`exp1, exp2`***`)`

Returns a single element of a vector register of *exp1*, where *exp2* is the index, ranging from `0-3`. If *`exp2`* is outside of the range, that is, *exp2* < `0` or *exp2* > `3`, an error is reported.

For example:

```
.getelement(32:p4[4], 1) returns 36:p4 for little-endian targets
.getelement(48:p4[4], 10) reports an error
```

`.flatten(`***`exp`***`)`

Returns an operand that is the flattened version of a vector register *exp*. The flattened operand has size equal to the base size multiplied by the vector size of the vector operand.

For example:

```
.flatten(32:p4[4]) returns 32:p16
.flatten(32:p8[4]) returns 32:p32
```

`.vectorize(`***`exp1, exp2)`***

Returns an operand that is a vectorized version of *exp1*, with vector size *exp2*. The operand size of the vector will be the width of *exp1* divided by *exp2.*

For example:

```
.vectorize(32:p16, 4) returns 32:p4[4]
.vectorize(32:p32, 2) returns 32:p16[2]fm
```

`.lsbytes(`***`exp1, exp2`***`)`

Returns the least significant width *w* bytes of *`exp1`*, where *w* is the value component of `exp2`. If `exp2` is less than the minimum domain width for the domain of *`exp1`* (2 for mono, otherwise 1), the returned operand rounds to zero.

For example:

```
.lsbytes(32:p4, 1) returns 32:p1 for little-endian targets
.lsbytes(40:m8, 2) returns 40:m2 for little-endian targets
.lsbytes(32:p4, 1) returns 35:p1 for big-endian targets
.lsbytes(40:m8, 2) returns 46:m2 for big-endian targets
```

`.lshalf(`***`exp`***`)`

Returns the least significant *w* bytes of *`exp`*, where *w* is `.width(`*`exp`*`)/2` (rounded down). If *w* is less than the minimum domain width for the domain (2 for mono, otherwise 1), it rounds to zero width.

For example:

```
.lshalf(32:p4) returns 32:p2 for little-endian targets
.lshalf(40:m8) returns 40:m4 for little-endian targets
.lshalf(32:p4) returns 34:p2 for big-endian targets
.lshalf(40:m8) returns 44:m4 for big-endian targets
```

`.lshead(`***`exp`***`)`

Returns the least significant `min_domain_width` bytes of *`exp`*, where `min_domain_width` is 1 if *`exp`* is poly or immediate and 2 if it is mono.

For example:

```
.lshead(32:p4) returns 32:p1 for little-endian targets
.lshead(40:m4) returns 40:m2 for little-endian targets
.lshead(32:p4) returns 35:p1 for big-endian targets
.lshead(40:m4) returns 42:m2 for big-endian targets
```

`.lstail(`***`exp`***`)`

Returns the least significant *w* bytes of *`exp`*, where *w* is `(.width(`*`exp`*`) - min_domain_width)` where `min_domain_width` is 1 if *`exp`* is poly or immediate, and 2 if it is mono.

For example:

```
.lstail(32:p4) returns 32:p3 for little-endian targets
.lstail(40:m8) returns 40:m6 for little-endian targets
.lstail(32:p4) returns 33:p3 for big-endian targets
.lstail(40:m8) returns 42:m6 for big-endian targets
```

`.max(`***`exp1,exp2`***`)`

Returns `exp1` if the value component of `exp1` is greater than or equal to the value component of `exp2`, otherwise returns `exp2`.

`.min(`***`exp1, exp2`***`)`

Returns `exp1` if the value component of `exp1` is less than or equal to the value component of `exp2`, otherwise returns `exp2`.

`.msbytes(`***`exp1, exp2`***`)`

Returns the most significant width `w` bytes of `exp1`, where `w` is the value component of `exp2`. If `exp2` is less than the minimum domain width for that domain (2 for mono, otherwise 1), the returned operand rounds to zero width.

For example:

```
.msbytes(32:p4, 1) returns 35:p1 for little-endian targets
.msbytes(40:m8, 2) returns 46:m2 for little-endian targets
.msbytes(32:p4, 1) returns 32:p1 for big-endian targets
.msbytes(40:m8, 2) returns 40:m2 for big-endian targets
```

`.mshalf(`***`exp`***`)`

Returns the most significant width `w` bytes of `exp`, where `w` is the total width of `exp`/2 (rounded down). If `w` is less than the minimum domain width for that domain (2 for mono, otherwise 1), it rounds to zero width.

For example:

```
.mshalf(32:p4) returns 34:p2 for little-endian targets
.mshalf(40:m8) returns 44:m4 for little-endian targets
.mshalf(32:p4) returns 32:p2 for big-endian targets
.mshalf(40:m8) returns 40:m4 for big-endian targets
```

`.mshead(`***`exp`***`)`

Returns the most significant `min_domain_width` bytes of *`exp`*, where `min_domain_width` is 1 if it is poly or immediate and 2 if is mono.

For example:

```
.mshead (32:p4) returns 35:p1 for little-endian targets
.mshead(40:m4)  returns 42:m2 for little-endian targets
.mshead (32:p4) returns 32:p1 for big-endian targets
.mshead(40:m4)  returns 40:m2 for big-endian targets
```

`.mstail(`***`exp`***`)`

Returns the most significant width w bytes of `exp`, where w is the total width of `exp` - `min_domain_width`. `min_domain_width` is 1 if it is poly or immediate and 2 if is mono.

For example:

```
.mstail(32:p4) returns 33:p3 for little-endian targets
.mstail(40:m8) returns 42:m6 for little-endian targets
.mstail(32:p4) returns 32:p3 for big-endian targets
.mstail(40:m8) returns 40:m6 for big-endian targets
```

`.overlap(`***`exp1, exp2`***`)`

Returns 1 if `exp1` and `exp2` are both mono or both poly and the operands overlap.

For example:

```
.overlap(32:p4, 34:p4)  returns 1
.overlap (32:p4, 40:p4) returns 0
.overlap (32:p4, 32:m4) returns 0
```

`.setfloat(`***`exp`***`)`

Returns an operand which is the same as *`exp`*, but with type float.

For example:

```
.setfloat(32:p4s) returns 32:p4f.
```

`.setimmediate(`***`exp`***`)`

Returns an operand which is the same as *`exp`*, but with domain immediate.

For example:

```
.setimmediate(32:p4s) returns 32.
```

`.setmono(`***`exp`***`)`

Returns an operand which is the same as *`exp`*, but with domain mono.

For example:

```
.setmono(32:p4s) returns 32:m4s.
```

`.setpoly(`***`exp`***`)`

Returns an operand which is the same as *`exp`*, but with domain poly.

For example:

```
.setpoly(32:m4s) returns 32:p4s.
```

`.setsigned(`***`exp`***`)`

Returns an operand which is the same as *`exp`*, but with type signed.

For example:

```
.setsigned(32:p2u) returns 32:p2s.
```

`.setunsigned(`***`exp`***`)`

Returns an operand which is the same as *`exp`*, but with type unsigned.

For example:

```
.setunsigned(32:p2s) returns 32:p2u.
```

`.setwidth(`***`exp1, exp2`***`)`

Returns an operand which is the same as `exp1`, but with width specified by `exp2`.

For example:

```
    .setwidth(32:p4, 2) returns 32:p2.
```

`.width(`*`exp`*`)`

Returns the width of *`exp`* in bytes (immediates default to a width of four bytes).

Internal macro statements

These are statements for controlling the expansion of a macro. They can only be used within a macro definition.

`.error` ***`error_args`***

This produces an error which will be output along with the file and line number of the instruction which ultimately matched this macro. The comma separated argument list, `error_args`, differs from most statements in that it can include quoted strings as arguments and these can be used interchangeably with expressions. It can take any number of arguments which are concatenated to generate an error message.

For example:

```
  .error "operand 0 must be poly (", dst, ")\n"
```

`.if` ***`exp`***
`.else`
`.endif`

These statements control conditional expansion of a macro. If *`exp`* is nonzero, then following lines, until the next `.else` or `.endif`, will be included in the macro expansion. Conditional statements can be nested, but only up to a maximum depth of 64 (including any called macros).

`.print` ***`print_args`***

This outputs text and evaluated expressions to the standard output. This can be useful for debugging. The comma-separated argument list, *`print_args`*, differs from most statements in that it can include quoted strings as arguments and these can be used interchangeably with expressions. It can have any number of arguments which are concatenated to generate the displayed message.

For example:

```
  .print "dst = ", dst, "\n"
```

`.set` ***`var, expression`***

The `.set` directive (see page 189) behaves slightly differently inside a macro. It is used to set a variable, *`var`*, to be the operand generated by *`expression`*. Variables defined within a macro are local to that macro definition. Symbols defined globally can be accessed by preceding the name with `@`.

For example: `.set local_var, 32:p4u` sets the value of a variable accessible only within the current macro

`.set @global_var, 32:p4u` sets the value of a symbol

Variables are described in more detail on page 195. Symbols are described on page 182.

`.temp [.align] *var*, *expression*`

This creates a variable, *`var`*, with type based on the value *`expression`*. That is, *`var`* will have the same width, domain, and type as *`expression`*. Before a macro using `.temp` is called, you need to set up sufficient temporary storage space in the mono or poly registers for all the variables allocated by `.temp` directives. The directives used to allocate temporary storage (`.setmonotemp` and `.setpolytemp`) are described on page 190.

If the variable needs to be aligned, the keyword `.align` should appear after `.temp`. For example, `.temp .align t, 32:m4u` will cause the variable to be aligned to its width.

14.6.3 Standard header files

There are a number of header files which define the standard macro instructions. To simplify using these, a file called `macro_includes.inc` is provided to include all the macro definition files. This can be included in an assembler source file with the line:

```
#include <macro_includes.inc>
```

14.7 Instruction set extension library

The poly instructions for the CSX processor are implemented in microcode. To make effective use of the available microcode a limited number of instructions are included in the base instruction set. Some less frequently used and application specific instructions are available in an instruction set extension library.

The instructions described in the "complex instructions" section of the *Instruction Set Reference Manual* and a number of more complex "swazzle" instructions have been moved to the new extension library. If you use these instructions in your program, you will need to do the following:

1. Add a call to the function `__cn_extension_ucode()` to your program to initialize the instruction set extension library. This must be done before using any of the instructions in this set.
2. When compiling your program, use the command line option with `cscn`:
   ```
   --use-add-ucode cn_ucode_extension
   ```
   This informs the assembler and linker about the new instructions in the library.

See the *[1]: CSX600 Instruction Set Reference Manual* for information on the additional instructions included in this library.

15 Bibliography

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