

TSIM2 Simulator User's Manual

ERC32/LEON2/LEON3/LEON4

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1 Introduction

1.1 General

TSIM is a generic SPARC* architecture simulator capable of emulating ERC32- and LEON-based computer systems.

TSIM provides several unique features:

- Accurate and cycle-true emulation of ERC32 and LEON2/3/4 processors
- Superior performance: +30 MIPS on high-end PC (AMD64@2.4 GHz)
- Accelerated simulation during processor standby mode
- Standalone operation or remote connection to GNU debugger (gdb)
- 64-bit time for unlimited simulation periods
- Instruction trace buffer
- EDAC emulation (ERC32)
- MMU emulation (LEON2/3/4)
- SDRAM emulation (LEON2/3/4)
- Local scratch-pad RAM (LEON3/4)
- Loadable modules to include user-defined I/O devices
- Non-intrusive execution time profiling
- Code coverage monitoring
- Dual-processor synchronisation
- Stack backtrace with symbolic information
- Check-pointing capability to save and restore complete simulator state
- Also provided as library to be included in larger simulator frameworks
- Pre-defined simulation modules for AT697, UT699, and AT7913 can be provided separately

1.2 Supported platforms and system requirements

TSIM supports the following platforms: solaris-2.8, linux, linux-x64, Windows 2K/XP, and Windows 2K/XP with Cygwin unix emulation.

1.3 Obtaining TSIM

The primary site for TSIM is <http://www.gaisler.com/>, where the latest version of TSIM can be ordered and evaluation versions downloaded.

1.4 Problem reports

Please send problem reports or comments to tsim@gaisler.com.

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2 Installation

2.1 General

TSIM is distributed as a tar-file (e.g. `tsim-erc32-2.0.13.tar.gz`) with the following contents:

<code>doc</code>	TSIM documentation
<code>samples</code>	Sample programs
<code>iomod</code>	Example I/O module
<code>tsim/cygwin</code>	TSIM binary for cygwin
<code>tsim/linux</code>	TSIM binary for linux
<code>tsim/linux-x64</code>	TSIM binary for linux-x64
<code>tsim/solaris</code>	TSIM binary for solaris
<code>tsim/win32</code>	TSIM binary for native windows
<code>tlib/cygwin</code>	TSIM library for cygwin
<code>tlib/linux</code>	TSIM library for linux
<code>tlib/linux-x64</code>	TSIM library for linux-x64
<code>tlib/solaris</code>	TSIM library for solaris
<code>tlib/win32</code>	TSIM library for native windows

The tar-file can be installed at any location with the following command:

```
gunzip -c tsim-erc32-2.0.21.tar.gz | tar xf -
```

2.2 License installation

TSIM is licensed using a HASP USB hardware key. Before use, a device driver for the key must be installed. The latest drivers can be found at www.aladdin.com or www.gaisler.com. See *appendix A* for installation of device drivers under Windows and Linux platforms.

3 Operation

3.1 Overview

TSIM can operate in two modes: standalone and attached to gdb. In standalone mode, ERC32 or LEON applications can be loaded and simulated using a command line interface. A number of commands are available to examine data, insert breakpoints and advance simulation. When attached to gdb, TSIM acts as a remote gdb target, and applications are loaded and debugged through gdb (or a gdb front-end such as ddd).

3.2 Starting TSIM

TSIM is started as follows on a command line:

tsim-erc32 [*options*] [*input_files*]

tsim-leon [*options*] [*input_files*]

tsim-leon3 [*options*] [*input_files*]

tsim-leon4 [*options*] [*input_files*]

The following command line options are supported by TSIM:

-ahbm *ahb_module*

Use *ahb_module* as loadable AHB module rather than the default *ahb.so* (LEON only). If multiple **-ahbm** switches are specified up to 16 AHB modules can be loaded. The environmental variable TSIM_MODULE_PATH can be set to a ':' separated (';' in WIN32) list of search paths.

-at697e Configure caches according to the Atmel AT697E device (LEON2 only).

-banks *ram_banks*

Sets how many ram banks (1 - 4) the ram is divided on. Default is 1. (LEON only).

-bopt Enables idle-loop optimisation (see text).

-bp Enables emulation of LEON3/4 branch prediction

-c file Reads commands from *file* and executes them at startup.

-cfg file Reads extra configuration options from *file*.

-cfgreg_and *and_mask*, **-cfgreg_or** *or_mask*

LEON2 only: Patch the Leon Configuration Register (0x80000024). The new value will be: $(reg \& \textit{and_mask}) \mid \textit{or_mask}$.

-cpm *cp_module*

Use *cp_module* as loadable co-processor module file name (LEON). The environmental variable TSIM_MODULE_PATH can be set to a ':' separated (';' in WIN32) list of search paths.

-cas

When running a VXWORKS SMP image the SPARCV9 "casa" instruction is used. The option **-cas** enables this instruction (LEON3/4 only).

-dcsiz *size* Defines the set-size (kbytes) of the LEON dcache. Allowed values are 1 - 64 in binary steps. Default is 4 kbytes.

-dlock Enable data cache line locking. Default is disabled. (LEON only).

-dlram *addr size*

Allocates *size* Kbytes of local dcache scratchpad memory at address *addr*. (LEON3/4)

- dlsiz** *size* Sets the line size of the LEON data cache (in bytes). Allowed values are 8, 16 or 32. Default is 16.
- drepl** *repl* Sets the replacement algorithm for the LEON data cache. Allowed values are *rnd* (default) for random replacement, *lru* for the least-recently-used replacement algorithm and *lrr* for least-recently-replaced replacement algorithm.
- dsets** *sets* Defines the number of sets in the LEON data cache. Allowed values are 1 - 4.
- ext** *nr* Enable extended irq ctrl with extended irq number *nr* (LEON3 only)
- fast_uart** Run UARTs at infinite speed, rather than with correct (slow) baud rate.
- fpm** *fp_module*
 Use *fp_module* as loadable FPU module rather than the default fp.so (LEON only). The enviromental variable TSIM_MODULE_PATH can be set to a ':' separated (',' in WIN32) list of search paths.
- freq** *system_clock*
 Sets the simulated system clock (MHz). Will affect UART timing and performance statistics. Default is 14 for ERC32 and 50 for LEON.
- gdb** Listen for GDB connection directly at start-up.
- gr702rc** Set cache parameters to emulate the GR702RC device.
- grfpu** Emulate the GRFPU floating point unit, rather then Meiko or GRFPU-lite (LEON only).
- hwbp** Use TSIM hardware breakpoints for gdb breakpoints.
- icsiz** *size* Defines the set-size (kbytes) of the LEON icache. Allowed values are 1 - 64 in binary steps.
- ift** Generate illegal instruction trap on IFLUSH. Emulates the IFT input on the ERC32 processor.
- ilock** Enable instruction cache line locking. Default is disabled.
- ilram** *addr size*
 Allocates *size* bytes of local icache scratchpad memory at address *addr*. (LEON3)
- ilsiz** *size* Sets the line size of the LEON instruction cache (in bytes). Allowed values are 8, 16 or 32.
- iom** *io_module*
 Use *io_module* as loadable I/O module rather than the default io.so. The enviromental variable TSIM_MODULE_PATH can be set to a ':' separated (',' in WIN32) list of search paths.
- irepl** *repl* Sets the replacement algorithm for the LEON instruction cache. Allowed values are *rnd* (default) for random replacement, *lru* for the least-recently-used replacement algorithm and *lrr* for least-recently-replaced replacement algorithm.
- isets** *sets* Defines the number of sets in the LEON instruction cache. Allowed values are 1(default) - 4.
- iwde** Set the IWDE input to 1. Default is 0. (TSC695E only)
- l2wsiz** *size* Enable emulation of L2 cache (LEON3/4 only) with *size* Kbytes. The *size* must be binary aligned (e.g. 16, 32, 64 ...).
- logfile** *filename*
 Logs the console output to *filename*. If *filename* is preceded by '+' output is append.
- mflat** This switch should be used when the application software has been compiled with the gcc -mflat option, and debugging with gdb is done.
- mmu** Adds MMU support (LEON only).

- nb** Do not break on error exeptions when debugging through GDB
- nfp** Disables the FPU to emulate system without FP hardware. Any FP instruction will generate an FP disabled trap.
- nomac** Disable LEON MAC instruction. (LEON only).
- noreadline** Disable loading and use of libreadline.(soldll).
- nosram** Disable sram on startup. SDRAM will appear at 0x40000000 (LEON only).
- nothreads** Disable threads support.
- notimers** Disable the LEON timer unit.
- nouart** Disable emulation of UARTs. All access to UART registers will be routed to the I/O module.
- nov8** Disable SPARC V8 MUL/DIV instructions (LEON only).
- nrtimersval** Adds upport for more than 2 timers. Value *val* can be in the range of 2 - 8. See also switch -*sametimerirq*. Default: 2 (LEON3/4 only).
- nwin win** Defines the number of register windows in the processor. The default is 8. Only applicabale to LEON3/4.
- port portnum**
Use *portnum* for gdb communication (port 1234 is default)
- pr** Enable profiling.
- ram ram_size**
Sets the amount of simulated RAM (kbyte). Default is 4096.
- rest file_name**
Restore saved state from *file_name.tss*. See *section 3.8 - Check-pointing*
- rom rom_size**
Sets the amount of simulated ROM (kbyte). Default is 2048.
- rom8, -rom16**
By default, the prom area at reset time is considered to be 32-bit. Specifying -rom8 or -rom16 will initialise the memory width field in the memory configuration register to 8- or 16-bits. The only visible difference is in the instruction timing.
- rtems ver** Override autodetected RTEMS version for thread support. *ver* should be 46 or 48.
- sametimerirq** Force all timer irq to be 8. Works together with switch -*nrtimers*. Default: sepearate irqs for each timer starting from 8. (LEON3 only)
- sdram sdram_size**
Sets the amount of simulated SDRAM (mbyte). Default is 0. (LEON only)
- sdbanks [1|2]**
Sets the sdram banks. This parameter is used to calculate the used sdram in conjunction with the *mcfg2.sdramsize* field. The actually used sdram at runtime is *sdbanks*mcfg2.sdramsize*. Default:1 (LEON only)
- sym file** Read symbols from *file*. Useful for self-extracting applications
- timer32** Use 32 bit timers instead of 24 bit. (LEON2 only)
- tsc691** Emulate the TSC691 device, rather than TSC695
- tsc695e** Obsolete. TSIM/ERC32 now always emulates the TSC695 device rather that the early ERC32 chip-set.

-uart[1,2] device

By default, UART1 is connected to stdin/stdout and UART2 is disconnected. This switch can be used to connect the uarts to other devices. E.g., ‘-uart1 /dev/ptypc’ will attach UART1 to ptypc. On linux ‘-uart1 /dev/ptmx’ can be used in which case the pseudo terminal slave’s name to use will be printed. If you use minicom to connect to the uart then use minicom’s *-p <pseudo terminal>* option. On windows use *\\.com1*, *\\.com2* etc. to access the serial ports. The serial port settings can be adjusted by doubleclicking the “Ports (COM and LPT)” entry in controlpanel->system->hardware->devicemanager. Use the “Port Setting” tab in the dialog that pops up.

-ut699 Set parameters to emulate the UT699 device.

-wdfreqfreq Specify the frequency of the watchdog clock. (ERC32 only)

input_files Executable files to be loaded into memory. The input file is loaded into the emulated memory according to the entry point for each segment. Recognized formats are elf32, aout and records.

Command line options can also be specified in the file .tsimcfg in the home directory. This file will be read at startup and the contents will be appended to the command line.

3.3 Standalone mode commands

TSIM dynamically loads libreadline.so if available on the host system, this will provide command history and completion with the tab-key. If libreadline.so is not found a simpler commandline will be used with no history and poor editing capabilities.

If the file .tsimrc exists in the home directory, it will be used as a batch file and the commands in it will be executed at startup.

Below is a description of commands that are recognized by the simulator when used in standalone mode:

batch file Execute a batch file of TSIM commands.

+bp, break address
Adds an breakpoint at *address*.

bp, break Prints all breakpoints and watchpoints

-bp, del[num]
Deletes breakpoint/watchpoint *num*. If *num* is omitted, all breakpoints and watchpoints are deleted.

bt Print backtrace

cont [count/time]
Continue execution at present position. See the **go** command for how to specify count or time.

coverage [enable | disable | gcc | save [file_name] | print address <len>]
Code coverage control. Coverage can be enabled, disabled, saved to a file or printed to the console.

dis [addr] [count]
Disassemble *[count]* instructions at address *[addr]*. Default values for count is 16 and *addr* is the program counter address.

echo string Print <string> to the simulator window.

edac [clear | cerr | merr <address>]
Insert EDAC errors, or clear EDAC checksums (ERC32 only)

- event** Print events in the event queue. Only user-inserted events are printed.
- flush** [*all* | *icache* | *dcache* | *addr*] Flush the LEON caches. Specifying *all* will flush both the icache and dcache. Specifying *icache* or *dcache* will flush the respective cache. Specifying *addr* will flush the corresponding line in both caches.
- float** Prints the FPU registers
- gdb** Listen for gdb connection.
- go** [*address*] [*count/time*] The **go** command will set pc to *address* and npc to *address* + 4, and resume execution. No other initialisation will be done. If *address* is not given, the default load address will be assumed. If a *count* is specified, execution will stop after the specified number of instructions. If a *time* is given, execution will continue until *time* is reached (relative to the current time). The time can be given in micro-seconds, milliseconds, seconds, minutes, hours or days by adding 'us', 'ms', 's', 'min', 'h' or 'd' to the time expression. Example: go 0x40000000 400 ms. **Note:** for the **go** command, if the *count/time* parameter is given, *address* must be specified.
- help** Print a small help menu for the TSIM commands.
- hist** [*length*] Enable the instruction trace buffer. The *length* last executed instructions will be placed in the trace buffer. A **hist** command without *length* will display the trace buffer. Specifying a zero trace length will disable the trace buffer.
- icache, dcache** Dumps the contents of tag and data cache memories (LEON only).
- inc** *time* Increment simulator time without executing instructions. Time is given in the same format as for the **go** command. Event queue is evaluated during the advancement of time.
- leon** Display LEON peripherals registers.
- load** *files* Load *files* into simulator memory.
- l2cache** Display contents of L2 cache
- mp** <1|2> Synchronize two TSIM instances. See manual for details.
- mec** Display ERC32 MEC registers.
- mem** [*addr*] [*count*] Display memory at *addr* for *count* bytes. Same default values as for **dis**. Unimplemented registers are displayed as zero.
- vmem** [*vaddr*] [*count*] Same as **mem** but does a MMU translation on *vaddr* first (LEON only).
- mmu** Display the MMU registers (LEON only).
- quit** Exits the simulator.
- perf** [*reset*] The **perf** command will display various execution statistics. A 'perf reset' command will reset the statistics. This can be used if statistics shall be calculated only over a part of the program. The **run** and **reset** command also resets the statistic information.
- prof** [0|1] [*stime*] Enable ('prof 1') or disable ('prof 0') profiling. Without parameters, profiling information is printed. Default sampling period is 1000 clock cycles, but can be changed by specifying *stime*.

- reg** [*reg_name value*]
 Prints and sets the IU registers in the current register window. **reg** without parameters prints the IU registers. **reg** *reg_name value* sets the corresponding register to *value*. Valid register names are psr, tbr, wim, y, g1-g7, o0-o7 and l0-l7. To view the other register windows, use **reg** *wn*, where *n* is 0 - 7.
- reset**
 Performs a power-on reset. This command is equal to **run** 0.
- restore** *file*
 Restore simulator state from *file*.
- run** [*addr*] [*count/time*]
 Resets the simulator and starts execution from address *addr*, the default is 0. The event queue is emptied but any set breakpoints remain. See the **go** command on how to specify the time or count.
- save** <*file*>
 Save simulator state *file*.
- step**
 Equal to **trace** 1.
- sym** [*file*]
 Load symbol table from *file*. If *file* is omitted, prints current (.text) symbols.
- version**
 Prints the TSIM version and build date.
- walk** *address* [*iswriteisidlissu*]*
 If the MMU is enabled printout a table walk for the given address. The flags *iswrite*, *isid* and *issu* are specifying the context: *iswrite* for a write access (default read), *isid* for a icache access (default dcache), *issu* for a supervisor access (default user).
- watch** *address*
 Adds a watchpoint at *address*.
- wmem**, **wmemh**, **wmemb**<*address*> <*value*>
 Write a word, half-word or byte directly to simulated memory.
- xwmem** <*asi*> *address*> <*value*>
 Write a word to simulated memory using ASI=*asi*. Applicable to LEON3.

Typing a 'Ctrl-C' will interrupt a running simulator. Short forms of the commands are allowed, e.g **c**, **co**, or **con**, are all interpreted as **cont**.

3.4 Symbolic debug information

TSIM will automatically extract (.text) symbol information from elf-files. The symbols can be used where an address is expected:

```
tsim> bre main
breakpoint 3 at 0x020012f0: main
tsim> dis strcmp 5
02002c04 84120009 or      %o0, %o1, %g2
02002c08 8088a003 andcc   %g2, 0x3, %g0
02002c0c 3280001a bne,a    0x02002c74
02002c10 c64a0000 ldsb    [%o0], %g3
02002c14 c6020000 ld      [%o0], %g3
```

The **sym** command can be used to display all symbols, or to read in symbols from an alternate (elf) file:

```
tsim> sym /opt/rtems/src/examples/samples/dhry
read 234 symbols
tsim> sym
0x02000000 L _text_start
0x02000000 L _trap_table
0x02000000 L text_start
0x02000000 L start
0x0200102c L _window_overflow
```

```
0x02001084 L _window_underflow
0x020010dc L _fpdis
0x02001a4c T Proc_3
```

Reading symbols from alternate files is necessary when debugging self-extracting applications, such as boot-proms created with mkprom or linux/uClinux.

3.5 Breakpoints and watchpoints

TSIM supports execution breakpoints and write data watchpoints. In standalone mode, hardware breakpoints are always used and no instrumentation of memory is made. When using the gdb interface, the gdb 'break' command normally uses software breakpoints by overwriting the breakpoint address with a 'ta 1' instruction. Hardware breakpoints can be inserted by using the gdb 'hbreak' command or by starting tsim with -hwbp, which will force the use of hardware breakpoints also for the gdb 'break' command. Data write watchpoints are inserted using the 'watch' command. A watchpoint can only cover one word address, block watchpoints are not available.

3.6 Profiling

The profiling function calculates the amount of execution time spent in each subroutine of the simulated program. This is made without intervention or instrumentation of the code by periodically sample the execution point and the associated call tree. Cycles in the call graph are properly handled, as well as sections of the code where no stack is available (e.g. trap handlers). The profiling information is printed as a list sorted on highest execution time ration. Profiling is enabled through the **prof 1** command. The sampling period is by default 1000 clocks which typically provides the best compromise between accuracy and performance. Other sampling periods can also be set through the **prof 1 n** command. Profiling can be disabled through the **prof 0** command. Below is an example profiling the dhrystone benchmark:

```
bash$tsim-erc32 /opt/rtems/src/examples/samples/dhry
tsim> pro 1
profiling enabled, sample period 1000
tsim> go
resuming at 0x02000000
Execution starts, 200000 runs through Dhrystone
Stopped at time 23375862 (1.670e+00 s)
tsim> pro

function      samples      ratio(%)
start         36144        100.00
_start        36144        100.00
main           36134         99.97
Proc_1         10476         28.98
Func_2          9885         27.34
strcmp          8161         22.57
Proc_8          2641          7.30
.div            2097          5.80
Proc_6          1412          3.90
Proc_3          1321          3.65
Proc_2          1187          3.28
.umul           1092          3.02
Func_1           777          2.14
Proc_7           772          2.13
Proc_4           731          2.02
Proc_5           453          1.25
Func_3           227          0.62
printf           8           0.02
vfprintf        8           0.02
_vfprintf_r      8           0.02

tsim>
```

3.7 Code coverage

To aid software verification, the professional version of TSIM includes support for code coverage. When enabled, code coverage keeps a record for each 32-bit word in the emulated memory and monitors whether the location has been read, written or executed. The coverage function is controlled by the coverage command:

```
coverage enable          enable coverage
coverage disable        disable coverage
coverage save [filename] write coverage data to file (file name optional)
coverage print address [len] print coverage data to console, starting at address
coverage gcc exec-file [src-file] print source code with back-annotated coverage information
coverage clear          reset coverage data
```

The coverage data for each 32-bit word of memory consists of a 5-bit field, with bit0 (lsb) indicating that the word has been executed, bit1 indicating that the word has been written, and bit2 that the word has been read. Bit3 and bit4 indicates the presence of a branch instruction; if bit3 is set then the branch was taken while bit4 is set if the branch was not taken.

As an example, a coverage data of 0x6 would indicate that the word has been read and written, while 0x1 would indicate that the word has been executed. When the coverage data is printed to the console or save to a file, it is presented for one block of 32 words (128 bytes) per line:

```
tsim> cov print start
02000000 : 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0
02000080 : 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02000100 : 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02000180 : 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

When the code coverage is saved to file, only blocks with at least one coverage field set are written to the file. Block that have all the coverage fields set to zero are not saved in order to decrease the file size. Note that only the internally emulated memory (prom and ram) are subject for code coverage, any memory emulated in the user's I/O module must be handled by a user-defined coverage function.

When coverage is enabled, disassembly will include an extra column after the address, indicating the coverage data. This makes it easier to analyse which instructions has not been executed:

```
tsim> di start

02000000 1 a0100000 clr      %l0
02000004 1 29008004 sethi   %hi(0x2001000), %l4
02000008 1 81c52000 jmp      %l4
0200000c 1 01000000 nop
02000010 0 91d02000 ta        0x0
02000014 0 01000000 nop
02000018 0 01000000 nop
```

The coverage data is not saved or restored during check-pointing operations. When enabled, the coverage function reduces the simulation performance of about 30%. When disabled, the coverage function does not impact simulation performance. Individual coverage fields can be read and written using the TSIM function interface using the `tsim_coverage()` call (see "Function interface" on page 43). Enabling and disabling the coverage functionality from the function interface should be done using `tsim_cmd()`.

Coverage information can also be back-annotated to the source code of applications compiled with gcc (sparc-rtems-gcc). The command '**coverage gcc exec-file src-file**' will produce a file called *src-file.cov* where each executable line is either marked with the line number (if it has been executed), or '#####' if it has not been executed. The exec-file is the binary file which has been executed by TSIM, while the src-file is (one of) the source files. Note that the binary file must have been compiled by sparc-rtems-gcc with debugging enabled in STABS format (-gstabs). Also, the RCC cross-compiler must be installed on the host and in the execution path. TSIM uses the RCC tools (sparc-rtems-objdump) to extract the debug information from the binary.

The example below shows an example of the command and annotated source code:

```
tsim> coverage gcc stanford stanford.c
coverage for stanford.c: 95.4%
tsim> q
$ cat stanford.c.cov
.
.

642      kount = 0;
643      if (Fit (0, m))
644          n = Place (0, m);
        else
#####      printf ("Error1 in Puzzle\n");
647      if (!Trial (n))
#####      printf ("Error2 in Puzzle.\n");
649      else if (kount != 2005)
#####      printf ("Error3 in Puzzle.\n");
        };
```

The example above shows that there are three executable lines which have not been executed. Note when the code is compiled with optimisation (-O or O2), some lines which seem to have executable code might be marked as not executable. This is because the optimisation process has either removed them or merged them with other lines.

3.8 Check-pointing

The **professional** version of TSIM can save and restore its complete state, allowing to resume simulation from a saved check-point. Saving the state is done with the **save** command:

```
tsim> save file_name
```

The state is saved to *file_name*.tss. To restore the state, use the **restore** command:

```
tsim> restore file_name
```

The state will be restored from *file_name*.tss. Restore directly at startup can be performed with the '**-rest *file_name***' command line switch.

Note that TSIM command line options are not stored (such as alternate UART devices, etc.).

Note that AT697, UT699 and GR7913 simulation modules do not support check-pointing.

3.9 Performance

TSIM is highly optimised, and capable of simulating ERC32 systems faster than realtime. On high-end Athlon processors, TSIM achieves more than 1 MIPS / 100 MHz (cpu frequency of host). Enabling various debugging features such as watchpoints, profiling and code coverage can however reduce the simulation performance with up to 40%.

3.10 Backtrace

The **bt** command will display the current call backtrace and associated stack pointer;

```
tsim> bt
      %pc          %sp
#0  0x0200190c    0x023ffcc8 Proc_1 + 0xf0
#1  0x02001520    0x023ffd38 main + 0x230
#2  0x02001208    0x023ffe00 _start + 0x60
#3  0x02001014    0x023ffe40 start + 0x1014
```


3.11 Connecting to gdb

TSIM can act as a remote target for gdb, allowing symbolic debugging of target applications. To initiate gdb communication, start the simulator with the **-gdb** switch or use the TSIM **gdb** command:

```
bash-2.04$ ./tsim -gdb
```

```
TSIM/LEON - remote SPARC simulator, build 2001.01.10 (demo version)
serial port A on stdin/stdout
allocated 4096 K RAM memory
allocated 2048 K ROM memory
gdb interface: using port 1234
```

Then, start gdb in a different window and connect to TSIM using the extended-remote protocol:

```
bash-2.04$ sparc-rtems-gdb t4.exe

(gdb) tar extended-remote localhost:1234
Remote debugging using localhost:1234
0x0 in ?? ()
(gdb)
```

To load and start the application, use the gdb **load** and **cont** command.

```
(gdb) load
Loading section .text, size 0x14e50 lma 0x40000000
Start address 0x40000000 , load size 87184
Transfer rate: 697472 bits/sec, 278 bytes/write.
(gdb) cont
Continuing
```

To interrupt simulation, Ctrl-C can be typed in both gdb and TSIM windows. The program can be restarted using the gdb **run** command but a **load** has first to be executed to reload the program image into the simulator:

```
(gdb) load
Loading section .text, size 0x14e50 lma 0x40000000
Loading section .data, size 0x640 lma 0x40014e50
Start address 0x40000000 , load size 87184
Transfer rate: 697472 bits/sec, 278 bytes/write.
(gdb) run
The program being debugged has been started already.
Start it from the beginning? (y or n) y
Starting program: /home/jgais/src/gnc/t4.exe
```

If gdb is detached using the **detach** command, the simulator returns to the command prompt, and the program can be debugged using the standard TSIM commands. The simulator can also be re-attached to gdb by issuing the **gdb** command to the simulator (and the **target** command to gdb). While attached, normal TSIM commands can be executed using the gdb **monitor** command. Output from the TSIM commands is then displayed in the gdb console.

TSIM translates SPARC traps into (unix) signals which are properly communicated to gdb. If the application encounters a fatal trap, simulation will be stopped exactly on the failing instruction. The target memory and register values can then be examined in gdb to determine the error cause.

Profiling an application executed from gdb is possible if the symbol table is loaded in TSIM before execution is started. gdb does not download the symbol information to TSIM, so the symbol table should be loaded using the monitor command:

```
(gdb) monitor sym t4.exe
read 158 symbols
```

When an application that has been compiled using the gcc **-mflat** option is debugged through gdb, TSIM should be started with **-mflat** in order to generate the correct stack frames to gdb.

3.12 Thread support

TSIM has thread support for the RTEMS operating system. Additional OS support will be added to future versions. The GDB interface of TSIM is also thread aware and the related GDB commands are described later.

3.12.1 TSIM thread commands

thread info - lists all known threads. The currently running thread is marked with an asterisk.

```
grlib> thread info
```

Name	Type	Id	Prio	Ticks	Entry point	PC	State
Int.	internal	0x09010001	255	138	_CPU_Thread_Idle_body	0x4002f760 _Thread_Dispatch + 0x11c	READY
UI1	classic	0x0a010001	120	290	Init	0x4002f760 _Thread_Dispatch + 0x11c	READY
ntwk	classic	0x0a010002	100	11	rtems_bsdnet_schedneti	0x4002f760 _Thread_Dispatch + 0x11c	READY
DCrx	classic	0x0a010003	100	2	rtems_bsdnet_schedneti	0x4002f760 _Thread_Dispatch + 0x11c	Wevnt
DCTx	classic	0x0a010004	100	4	rtems_bsdnet_schedneti	0x4002f760 _Thread_Dispatch + 0x11c	Wevnt
FTPa	classic	0x0a010005	10	1	split_command	0x4002f760 _Thread_Dispatch + 0x11c	Wevnt
FTPD	classic	0x0a010006	10	1	split_command	0x4002f760 _Thread_Dispatch + 0x11c	Wevnt
* HTPD	classic	0x0a010007	40	79	rtems_initialize_webse	0x40001b60 console_outbyte_polled + 0x34	READY

thread bt <id> - do a backtrace of a thread.

Backtrace of inactive thread:

```
grlib> thread bt 0x0a010003
```

```

%pc
#0  0x4002f760  _Thread_Dispatch + 0x11c
#1  0x40013ed8  rtems_event_receive + 0x88
#2  0x40027824  rtems_bsdnet_event_receive + 0x18
#3  0x4000b664  websFooter + 0x484
#4  0x40027708  rtems_bsdnet_schednetisr + 0x158
```

A backtrace of the current thread (equivalent to normal bt command):

```
grlib> thread bt 0x0a010007
```

```

%pc      %sp
#0  0x40001b60  0x43fea130  console_outbyte_polled + 0x34
#1  0x400017fc  0x43fea130  console_write_support + 0x18
#2  0x4002dde8  0x43fea198  rtems_termios_puts + 0x128
#3  0x4002df60  0x43fea200  rtems_termios_puts + 0x2a0
#4  0x4002dfe8  0x43fea270  rtems_termios_write + 0x70
#5  0x400180a4  0x43fea2d8  rtems_io_write + 0x48
#6  0x4004eb98  0x43fea340  device_write + 0x2c
#7  0x40036ee4  0x43fea3c0  write + 0x90
#8  0x4001118c  0x43fea428  trace + 0x38
#9  0x4000518c  0x43fea498  websOpenListen + 0x108
#10 0x40004fb4  0x43fea500  websOpenServer + 0xc0
#11 0x40004b0c  0x43fea578  rtems_initialize_webserver + 0x204
#12 0x40004978  0x43fea770  rtems_initialize_webserver + 0x70
#13 0x40053380  0x43fea7d8  _Thread_Handler + 0x10c
#14 0x40053268  0x43fea840  __res_mkquery + 0x2c8
```

3.12.2 GDB thread commands

TSIM needs the symbolic information of the image that is being debugged to be able to check for thread information. Therefore the symbols need to be read from the image using the **sym** command before issuing the **gdb** command.

When a program running in GDB stops TSIM reports which thread it is in. The command **info threads** can be used in GDB to list all known threads.

```
Program received signal SIGINT, Interrupt.
[Switching to Thread 167837703]

0x40001b5c in console_outbyte_polled (port=0, ch=113 'q') at ../../../../../../rtems-4.6.5/c/src/lib/libbsp/sparc/leon3/console/debugputs.c:38
38      while ( (LEON3_Console_Uart[LEON3_Cpu_Index+port]->status & LEON_REG_UART_STATUS_THE)
== 0 );

(gdb) info threads

  8 Thread 167837702 (FTPD Wevnt) 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
  7 Thread 167837701 (FTPa Wevnt) 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
  6 Thread 167837700 (DCTX Wevnt) 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
  5 Thread 167837699 (DCRx Wevnt) 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
  4 Thread 167837698 (ntwk ready) 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
  3 Thread 167837697 (UI1 ready) 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
  2 Thread 151060481 (Int. ready) 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
* 1 Thread 167837703 (HTPD ready) 0x40001b5c in console_outbyte_polled (port=0, ch=113 'q')
  at ../../../../../../rtems-4.6.5/c/src/lib/libbsp/sparc/leon3/console/debugputs.c:38
```

Using the **thread** command a specified thread can be selected:

```
(gdb) thread 8

[Switching to thread 8 (Thread 167837702)]#0 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
109      _Context_Switch( &executing->Registers, &their->Registers );
```

Then a backtrace of the selected thread can be printed using the **bt** command:

```
(gdb) bt

#0 0x4002f760 in _Thread_Dispatch () at ../../../../../../rtems-4.6.5/cpukit/score/src/threaddispatch.c:109
#1 0x40013ee0 in rtems_event_receive (event_in=33554432, option_set=0, ticks=0, event_out=0x43fecc14)
  at ../../../../../../leon3/lib/include/rtems/score/thread.inl:205
#2 0x4002782c in rtems_bsdnet_event_receive (event_in=33554432, option_set=2, ticks=0, event_out=0x43fecc14)
  at ../../../../../../rtems-4.6.5/cpukit/libnetworking/rtems/rtems_glue.c:641
#3 0x40027548 in socnnsleep (so=0x43f0cd70) at ../../../../../../rtems-4.6.5/cpukit/libnetworking/rtems/rtems_glue.c:465
#4 0x40029118 in accept (s=3, name=0x43feccf0, namelen=0x43feccec) at ../../../../../../rtems-4.6.5/cpukit/libnetworking/rtems/rtems_syscall.c:215
#5 0x40004028 in daemon () at ../../../../../../rtems-4.6.5/c/src/libnetworking/rtems_servers/ftpd.c:1925
#6 0x40053388 in _Thread_Handler () at ../../../../../../rtems-4.6.5/cpukit/score/src/threadhandler.c:123
#7 0x40053270 in __res_mkquery (op=0, dname=0x0, class=0, type=0, data=0x0, datalen=0, newrr_in=0x0, buf=0x0, buflen=0)
  at ../../../../../../rtems-4.6.5/cpukit/libnetworking/libc/res_mkquery.c:199
```

It is possible to use the **frame** command to select a stack frame of interest and examine the registers using the **info registers** command. Note that the **info registers** command only can see the following registers for an inactive task: g0-g7, i0-i7, o0-o7, pc and psr. The other registers will be displayed as 0:

```
(gdb) frame 5

#5  0x40004028 in daemon () at ../../../../../../rtems-4.6.5/c/src/libnetworking/rtems_servers/
ftpd.c:1925
1925      ss = accept(s, (struct sockaddr *)&addr, &addrLen);

(gdb) info reg

g0          0x0      0
g1          0x0      0
g2          0xffffffff -1
g3          0x0      0
g4          0x0      0
g5          0x0      0
g6          0x0      0
g7          0x0      0
o0          0x3      3
o1          0x43feccf0 1140772080
o2          0x43feccec 1140772076
o3          0x0      0
o4          0xf3400e4  -213909276
o5          0x4007cc00 1074252800
sp          0x43fecc88  0x43fecc88
o7          0x40004020 1073758240
i0          0x0      0
i1          0x4007ce88 1074253448
i2          0x4007ce88 1074253448
i3          0x400048fc 1073760508
i4          0x43feccf0 1140772080
i5          0x3      3
i6          0x1      1
i7          0x0      0
i8          0x0      0
i9          0x0      0
i10         0x0      0
i11         0x40003f94 1073758100
i12         0x0      0
i13         0x43ffaafc8 1140830152
i14         0x0      0
i15         0x4007cd40 1074253120
fp          0x43feccd08 0x43feccd08
i17         0x40053380 1074082688
y           0x0      0
psr         0xf3400e0  -213909280
wim         0x0      0
tbr         0x0      0
pc          0x40004028 0x40004028 <daemon+148>
npc         0x4000402c 0x4000402c <daemon+152>
fsr         0x0      0
csr         0x0      0
```

It is not supported to set thread specific breakpoints. All breakpoints are global and stops the execution of all threads. It is not possible to change the value of registers other than those of the current thread.

4 Emulation characteristics

4.1 Common behaviour

4.1.1 Timing

The TSIM simulator is cycle-true, i.e. a simulator time is maintained and incremented according processor instruction timing and memory latency. Tracing using the **trace** command will display the current simulator time in the left column. This time indicates when the instruction is fetched. Cache misses, waitstates or data dependencies will delay the following fetch according to the incurred delay.

4.1.2 UARTs

If the baudrate register is written by the application software, the UARTs will operate with correct timing. If the baudrate is left at the default value, or if the **-fast_uart** switch was used, the UARTs operate at infinite speed. This means that the transmitter holding register always is empty and a transmitter empty interrupt is generated directly after each write to the transmitter data register. The receivers can never overflow or generate errors.

Note that with correct UART timing, it is possible that the last character of a program is not displayed on the console. This can happen if the program forces the processor in error mode, thereby terminating the simulation, before the last character has been shifted out from the transmitter shift register. To avoid this, an application should poll the UART status register and not force the processor in error mode before the transmitter shift registers are empty. The real hardware does not exhibit this problem since the UARTs continue to operate even when the processor is halted.

4.1.3 Floating point unit (FPU)

The simulator maps floating-point operations on the hosts floating point capabilities. This means that accuracy and generation of IEEE exceptions is host dependent and will not always be identical to the actual ERC32/LEON hardware. The simulator implements (to some extent) data-dependant execution timing as in the real MEKIO FPU (ERC32/LEON2). For LEON3/4, the **-grfpu** switch will enable emulation of the GRFPU instruction timing.

4.1.4 Delayed write to special registers

The SPARC architecture defines that a write to the special registers (**%psr**, **%wim**, **%tbr**, **%fsr**, **%y**) may have up to 3 delay cycles, meaning that up to 3 of the instructions following a special register write might not 'see' the newly written value due to pipeline effects. While ERC32 and LEON have between 2 and 3 delay cycles, TSIM has 0. This does not affect simulation accuracy or timing as long as the SPARC ABI recommendations are followed that each special register write must always be followed by three NOP. If the three NOP are left out, the software might fail on real hardware while still executing 'correctly' on the simulator.

4.1.5 Idle-loop optimisation

To minimise power consumption, LEON and ERC32 applications will typically place the processor in power-down mode when the idle task is scheduled in the operation system. In power-down mode, TSIM increments the event queue without executing any instructions, thereby significantly improving simulation performance. However, some (poorly written) code might use a busy loop (BA 0) instead of triggering power-down mode. The **-bopt** switch will enable a detection mechanism which will identify such behaviour and optimise the simulation as if the power-down mode was entered.

4.1.6 Custom instruction emulation

TSIM/LEON allows the emulation of custom (non-SPARC) instructions. A handler for non-standard instruction can be installed using the `tsim_ext_ins()` callback function (see "Function interface" on page 43). The function handler is called each time an instruction is encountered that would cause an unimplemented instruc-

tion trap. The handler is passed the opcode and all processor registers in a pointer, allowing it to decode and emulate a custom instruction, and update the processor state.

The definition for the custom instruction handler is:

```
int myhandler (struct ins_interface *r);
```

The pointer **r* is a structure containing the current instruction opcode and processor state:

```
struct ins_interface {
    uint32    psr;    /* Processor status registers */
    uint32    tbr;    /* Trap base register */
    uint32    wim;    /* Window maks register */
    uint32    g[8];   /* Global registers */
    uint32    r[128]; /* Windowed register file */
    uint32    y;      /* Y register */
    uint32    pc;     /* Program counter */
    uint32    npc;    /* Next program counter */
    uint32    inst;   /* Current instruction */
    uint32    icnt;   /* Clock cycles in curr inst */
    uint32    asr17;
    uint32    asr18;
};
```

SPARC uses an overlapping windowed register file, and accessing registers must be done using the current window pointer (*%psr[4:0]*). To access registers *%r8 - %r31* in the current window, use:

```
cwp = r->psr & 7;
regval = r->r[((cwp << 4) + RS1) % (nwindows * 16)];
```

Note that global registers (*%r0 - %r7*) should always be accessed by *r->g[RS1]*;

The return value of the custom handler indicates which trap the emulated instruction has generated, or 0 if no trap was caused. If the handler could not decode the instruction, 2 should be returned to cause an unimplemented instruction trap.

The number of clocks consumed by the instruction should be returned in *r->icnt*; This value is by default 1, which corresponds to a fully pipelined instruction without data interlock. The handler should not increment the *%pc* or *%npc* registers, as this is done by TSIM.

4.2 ERC32 specific emulation

4.2.1 Processor emulation

TSIM/ERC32 emulates the behaviour of the TSC695 processor from Atmel by default. The parallel execution between the IU and FPU is modelled, as well as stalls due to operand dependencies (IU & FPU). Starting TSIM with the **-tsc691** will enable TSC691 emulation (3-chip ERC32).

4.2.2 MEC emulation

The following list outlines the implemented MEC registers:

Register	Address	Status
MEC control register	0x01f80000	implemented
Software reset register	0x01f80004	implemented
Power-down register	0x01f80008	implemented
Memory configuration register	0x01f80010	partly implemented
IO configuration register	0x01f80014	implemented
Waitstate configuration register	0x01f80018	implemented
Access protection base register 1	0x01f80020	implemented
Access protection end register 1	0x01f80024	implemented
Access protection base register 2	0x01f80028	implemented
Access protection end register 2	0x01f8002c	implemented
Interrupt shape register	0x01f80044	implemented
Interrupt pending register	0x01f80048	implemented
Interrupt mask register	0x01f8004c	implemented
Interrupt clear register	0x01f80050	implemented
Interrupt force register	0x01f80054	implemented
Watchdog acknowledge register	0x01f80060	implemented
Watchdog trap door register	0x01f80064	implemented
RTC counter register	0x01f80080	implemented
RTC counter program register	0x01f80080	implemented
RTC scaler register	0x01f80084	implemented
RTC scaler program register	0x01f80084	implemented
GPT counter register	0x01f80088	implemented
GPT counter program register	0x01f80088	implemented
GPT scaler register	0x01f8008c	implemented
GPT scaler program register	0x01f8008c	implemented
Timer control register	0x01f80098	implemented
System fault status register	0x01f800A0	implemented
First failing address register	0x01f800A4	implemented
GPI configuration register	0x01f800A8	I/O module callback
GPI data register	0x01f800AC	I/O module callback
Error and reset status register	0x01f800B0	implemented
Test control register	0x01f800D0	implemented
UART A RX/TX register	0x01f800E0	implemented
UART B RX/TX register	0x01f800E4	implemented
UART status register	0x01f800E8	implemented

The MEC registers can be displayed with the **mec** command, or using **mem** ('mem 0x1f80000 256'). The registers can also be written using **wmem** (e.g. 'wmem 0x1f80000 0x1234'). When written, care has to be taken not to write an unimplemented register bit with '1', or a MEC parity error will occur.

4.2.3 Interrupt controller

Internal interrupts are generated as defined in the MEC specification. All 15 interrupts can be tested via the interrupt force register. External interrupts can be generated through loadable modules.

4.2.4 Watchdog

The watchdog timer operate as defined in the MEC specification. The frequency of the watchdog clock can be specified using the **-wdfreq** switch. The frequency is specified in MHz.

4.2.5 Power-down mode

The power-down register (0x01f800008) is implemented as in the specification. A Ctrl-C in the simulator window will exit the power-down mode. In power-down mode, the simulator skips time until the next event in the event queue, thereby significantly increasing the simulation speed.

4.2.6 Memory emulation

The amount of simulated memory is configured through the **-ram** and **-rom** switches. The ram size can be between 256 kbytes and 32 Mbyte, the rom size between 128 kbyte and 4 Mbyte. Access to unimplemented MEC registers or non-existing memory will result in a memory exception trap.

The memory configuration register is used to decode the simulated memory. The fields RSIZ and PSIZ are used to set RAM and ROM size, the remaining fields are not used. NOTE: after reset, the MEC is set to decode 128 kbytes of ROM and 256 kbytes of RAM. The memory configuration register has to be updated to reflect the available memory. The waitstate configuration register is used to generate waitstates. This register must also be updated with the correct configuration after reset.

4.2.7 EDAC operation

The EDAC operation of ERC32 is implemented on the simulated RAM area (0x2000000 - 0x2FFFFFFF). The ERC32 Test Control Register can be used to enable the EDAC test mode and insert EDAC errors to test the operation of the EDAC. The **edac** command can be used to monitor the number of errors in the memory, to insert new errors, or clear all errors. To see the current memory status, use the **edac** command without parameters:

```
tsim> edac
ram error count : 2
0x20000000 : MERR
0x20000040 : CERR
```

TSIM keeps track of the number of errors currently present, and reports the total error count, the address of each error, and its type. The errors can either be correctable (CERR) or non-correctable (MERR). To insert an error using the edac command, do '**edac cerr addr**' or '**edac merr addr**' :

```
tsim> edac cerr 0x2000000
correctable error at 0x2000000
tsim> edac
ram error count : 1
0x20000000 : CERR
```

To remove all injected errors, do **edac clear**. When accessing a location with an EDAC error, the behaviour of TSIM is identical to the real hardware. A correctable error will trigger interrupt 1, while un-correctable errors will cause a memory exception. The operation of the FSFR and FAR registers are fully implemented.

NOTE: the EDAC operation affect simulator performance *when there are inserted errors in the memory*. To obtain maximum simulation performance, any diagnostic software should remove all inserted errors after having performed an EDAC test.

4.2.8 Extended RAM and I/O areas

TSIM allows emulation of user defined I/O devices through loadable modules. EDAC emulation of extended RAM areas is not supported.

4.2.9 SYSAB signal

TSIM emulates changes in the SYSAB output by calling the command() callback in the I/O module with either “sysab 0” or “sysab 1” on each change of SYSAB.

4.2.10 EXTINTACK signal

TSIM emulates assertion of the EXTINTACK output by calling the command() callback in the I/O module with “extintack” on each assertion. Note that EXTINTACK is only asserted for one external interrupt as programmed in the MEC interrupt shape register.

4.2.11 IWDE signal

The **TSC695E** processor input signal can be controlled by the -iwde switch at start-up. If the switch is given, the IWDE signal will be high, and the internal watchdog enabled. If -iwde is not given, IWDE will be low and the internal watchdog will be disabled. Note that the simulator must start in TSC695E-mode using the -tsc695e switch, for this option to take effect.

4.3 LEON2 specific emulation

4.3.1 Processor

The LEON2 version of TSIM emulates the behavior of the LEON2 VHDL model. The (optional) MMU can be emulated using the *-mmu* switch.

4.3.2 Cache memories

The evaluation version of LEON implements 2*4kbyte caches, with 16 bytes per line. The commercial TSIM version can emulate any permissible cache configuration using the *-icsize*, *-ilsize*, *-dcsiz*e and *-dlsize* options. Allowed sizes are 1 - 64 kbyte with 8 - 32 bytes/line. The characteristics of the leon multi-set caches (as of leon2-1.0.8) can be emulated using the *-isets*, *-dsets*, *-irepl*, *-drelp*, *-ilock* and *-dlock* options. Diagnostic cache reads/writes are implemented. The simulator commands **icache** and **dcache** can be used to display cache contents. Starting TSIM with *-at697e* will configure that caches according to the Atmel AT697E device.

4.3.3 LEON peripherals registers

The LEON peripherals registers can be displayed with the **leon** command, or using **mem** ('mem 0x80000000 256'). The registers can also be written using **wmem** (e.g. 'wmem 0x80000000 0x1234').

4.3.4 Interrupt controller

External interrupts are not implemented, so the I/O port interrupt register has no function. Internal interrupts are generated as defined in the LEON specification. All 15 interrupts can also be generated from the user-defined I/O module using the *set_irq()* callback.

4.3.5 Power-down mode

The power-down register 0x80000018) is implemented as in the specification. A Ctrl-C in the simulator window will exit the power-down mode. In power-down mode, the simulator skips time until the next event in the event queue, thereby significantly increasing the simulation speed.

4.3.6 Memory emulation

The memory configuration registers 1/2 are used to decode the simulated memory. The memory configuration registers has to be programmed by software to reflect the available memory, and the number and size of the memory banks. The waitstates fields must also be programmed with the correct configuration after reset. Both SRAM and SDRAM can be emulated.

Using the **-banks** option, it is possible to set over how many ram banks the external SRAM is divided in. Note that software compiled with BCC/RCC, and **not** run through mkprom must **not** use this option. For mkprom encapsulated programs, it is essential that the **same** ram size and bank number setting is used for both mkprom and TSIM.

The memory EDAC of LEON2-FT is not implemented.

4.3.7 SPARC V8 MUL/DIV/MAC instructions

TSIM/LEON optionally supports the SPARC V8 multiply, divide and MAC instruction. To correctly emulate LEON systems which do not implement these instructions, use the **-nomac** to disable the MAC instruction and/or **-nov8** to disable multiply and divide instructions.

4.3.8 DSU and hardware breakpoints

The LEON debug support unit (DSU) and the hardware watchpoints (%asr24 - %asr31) are not emulated.

4.4 LEON3 specific emulation

4.4.1 General

The LEON3 version of TSIM emulates the behavior of the LEON3MP template VHDL model distributed in the GRLIB-1.0 IP library. The system includes the following modules: LEON3 processor, APB bridge, IRQMP interrupt controller, LEON2 memory controller, GPTIMER timer unit with two 32-bit timers, two APBUART uarts. The AHB/APB plug&play information is provided at address 0xFFFFF000 - 0xFFFFFFFF (AHB) and 0x800FF000 - 0x800FFFFF (APB).

4.4.2 Processor

The instruction timing of the emulated LEON3 processor is modelled after LEON3 VHDL model in GRLIB IP library. The processor can be configured with 2 - 32 register windows using the *-nwin* switch. The MMU can be emulated using the *-mmu* switch. Local scratch pad ram can be added with the *-ilram* and *-dlram* switches.

4.4.3 Cache memories

The evaluation version of TSIM/LEON3 implements 2*4kbyte caches, with 16 bytes per line. The commercial TSIM version can emulate any permissible cache configuration using the *-icsize*, *-ilsize*, *-dcsiz*e and *-dlsize* options. Allowed sizes are 1 - 64 kbyte with 8 - 32 bytes/line. The characteristics of the leon multi-way caches can be emulated using the *-isets*, *-dssets*, *-irepl*, *-drepl*, *-ilock* and *-dlock* options. Diagnostic cache reads/writes are implemented. The simulator commands **icache** and **dcache** can be used to display cache contents.

4.4.4 Power-down mode

The LEON3 power-down function is implemented as in the specification. A Ctrl-C in the simulator window will exit the power-down mode. In power-down mode, the simulator skips time until the next event in the event queue, thereby significantly increasing the simulation speed.

4.4.5 LEON3 peripherals registers

The LEON3 peripherals registers can be displayed with the **leon** command, or using **mem** ('mem 0x80000000 256'). The registers can also be written using **wmem** (e.g. 'wmem 0x80000000 0x1234').

4.4.6 Interrupt controller

The IRQMP interrupt controller is fully emulated as described in the GRLIB IP Manual. The IRQMP registers are mapped at address 0x80000200. All 15 interrupts can also be generated from the user-defined I/O module using the `set_irq()` callback.

4.4.7 Memory emulation

The LEON2 memory controller is emulated in the LEON3 version of TSIM. The memory configuration registers 1/2 are used to decode the simulated memory. The memory configuration registers has to be programmed by software to reflect the available memory, and the number and size of the memory banks. The waitstates fields must also be programmed with the correct configuration after reset. Both SRAM and SDRAM can be emulated.

Using the **-banks** option, it is possible to set over how many ram banks the external SRAM is divided in. Note that software compiled with BCC/RCC, and **not** run through mkprom must **not** use this option. For mkprom encapsulated programs, it is essential that the **same** ram size and bank number setting is used for both mkprom and TSIM.

4.4.8 CASA instruction

The SPARCV9 “casa” command is implemented if the **-cas** switch is given. The “casa” instruction is used in VXWORKS SMP multiprocessing to synchronize using a lock free protocol.

4.4.9 SPARC V8 MUL/DIV/MAC instructions

TSIM/LEON3 optionally supports the SPARC V8 multiply, divide and MAC instruction. To correctly emulate LEON systems which do not implement these instructions, use the **-nomac** to disable the MAC instruction and/or **-nov8** to disable multiply and divide instructions.

4.4.10 DSU and hardware breakpoints

The LEON debug support unit (DSU) and the hardware watchpoints (%asr24 - %asr31) are not emulated.

4.5 LEON4 specific emulation

4.5.1 General

The LEON4 version of TSIM emulates the behavior of the LEON4MP template VHDL model distributed in the GRLIB-1.0.x IP library. The system includes the following modules: LEON4 processor, APB bridge, IRQMP interrupt controller, LEON2 memory controller, L2 cache, GPTIMER timer unit with two 32-bit timers, two APBUART uarts. The AHB/APB plug&play information is provided at address 0xFFFFF000 - 0xFFFFFFFF (AHB) and 0x800FF000 - 0x800FFFFF (APB).

4.5.2 Processor

The instruction timing of the emulated LEON4 processor is modelled after LEON4 VHDL model in GRLIB IP library. The processor can be configured with 2 - 32 register windows using the *-nwin* switch. The MMU can be emulated using the *-mmu* switch. Local scratch pad ram can be added with the *-ilram* and *-dlram* switches.

4.5.3 L1 Cache memories

The evaluation version of TSIM/LEON4 implements 2*4kbyte caches, with 16 bytes per line. The commercial TSIM version can emulate any permissible cache configuration using the *-icsize*, *-ilsize*, *-dcsiz*e and *-dlsiz*e options. Allowed sizes are 1 - 64 kbyte with 8 - 32 bytes/line. The characteristics of the leon multi-set caches can be emulated using the *-isets*, *-dssets*, *-irepl*, *-drepl*, *-ilock* and *-dlock* options. Diagnostic cache reads/writes are implemented. The simulator commands **icache** and **dcache** can be used to display cache contents.

4.5.4 L2 Cache memory

The LEON4 L2 cache is emulated, and placed between the memory controller and AHB bus. Both the PROM and SRAM/SDRAM areas are cached in the L2. The size of the L2 cache is default 64 Kbyte, but can be configured to any (binary aligned) size using the *-l2wsiz*e switch at start-up. Setting the size to 0 will disable the L2 cache. The L2 cache is implemented with one way and 32 bytes/line. The contents of the L2 cache can be displayed with the **l2cache** command.

4.5.5 Power-down mode

The LEON4 power-down function is implemented as in the specification. A Ctrl-C in the simulator window will exit the power-down mode. In power-down mode, the simulator skips time until the next event in the event queue, thereby significantly increasing the simulation speed.

4.5.6 LEON4 peripherals registers

The LEON4 peripherals registers can be displayed with the **leon** command, or using **mem** ('mem 0x80000000 256'). The registers can also be written using **wmem** (e.g. 'wmem 0x80000000 0x1234').

4.5.7 Interrupt controller

The IRQMP interrupt controller is fully emulated as described in the GRLIB IP Manual. The IRQMP registers are mapped at address 0x80000200. All 15 interrupts can also be generated from the user-defined I/O module using the `set_irq()` callback.

4.5.8 Memory emulation

The LEON2 memory controller is emulated in the LEON4 version of TSIM. The memory configuration registers 1/2 are used to decode the simulated memory. The memory configuration registers has to be programmed by software to reflect the available memory, and the number and size of the memory banks. The waitstates fields must also be programmed with the correct configuration after reset. Both SRAM and SDRAM can be emulated.

Using the **-banks** option, it is possible to set over how many ram banks the external SRAM is divided in. Note that software compiled with BCC/RCC, and **not** run through mkprom must **not** use this option. For mkprom encapsulated programs, it is essential that the **same** ram size and bank number setting is used for both mkprom and TSIM.

4.5.9 CASA instruction

The SPARCV9 “casa” command is implemented if the **-cas** switch is given. The “casa” instruction is used in VXWORKS SMP multiprocessing to synchronize using a lock free protocol.

4.5.10 SPARC V8 MUL/DIV/MAC instructions

TSIM/LEON4 optionally supports the SPARC V8 multiply, divide and MAC instruction. To correctly emulate LEON systems which do not implement these instructions, use the **-nomac** to disable the MAC instruction and/or **-nov8** to disable multiply and divide instructions.

4.5.11 GRFPU emulation

By default, TSIM-LEON4 emulates the GRFPU-Lite FPU. If the simulator is started with **-grfpu**, the fully pipelined GRFPU is emulated. Due to the complexity of the GRFPU, the instruction timing is approximated and might show some discrepancies compared to the real hardware.

4.5.12 DSU and hardware breakpoints

The LEON debug support unit (DSU) and the hardware watchpoints (%asr24 - %asr31) are not emulated.

5 Loadable modules

5.1 TSIM I/O emulation interface

User-defined I/O devices can be loaded into the simulator through the use of loadable modules. As the real processor, the simulator primarily interacts with the emulated device through read and write requests, while the emulated device can optionally generate interrupts and DMA requests. This is implemented through the module interface described below. The interface is made up of two parts; one that is exported by TSIM and defines TSIM functions and data structures that can be used by the I/O device; and one that is exported by the I/O device and allows TSIM to access the I/O device. Address decoding of the I/O devices is straight-forward: all access that do not map on the internally emulated memory and control registers are forwarded to the I/O module.

TSIM exports two structures: `simif` and `ioif`. The `simif` structure defines functions and data structures belonging to the simulator core, while `ioif` defines functions provided by system (ERC32/LEON) emulation. At start-up, TSIM searches for 'io.so' in the current directory, but the location of the module can be specified using the **-iom** switch. Note that the module must be compiled to be position-independent, i.e. with the **-fPIC** switch (gcc). The win32 version of TSIM loads `io.dll` instead of `io.so`. See the `iomod` directory in the TSIM distribution for an example `io.c` and how to build the `.so` and `.dll` modules. The environmental variable `TSIM_MODULE_PATH` can be set to a ':' separated (',' in WIN32) list of search paths.

5.1.1 simif structure

The `simif` structure is defined in `sim.h`:

```
struct sim_options {
    int phys_ram;
    int phys_sdram;
    int phys_rom;
    double freq;
    double wdfreq;
};
struct sim_interface {
    struct sim_options *options; /* tsim command-line options */
    uint64 *simtime; /* current simulator time */
    void (*event)(void (*cfunc)(), uint32 arg, uint64 offset);
    void (*stop_event)(void (*cfunc)());
    int *irl; /* interrupt request level */
    void (*sys_reset)(); /* reset processor */
    void (*sim_stop)(); /* stop simulation */
    /* Following entries for LEON2 only. LEON3 modules should ignore them */
    char *args; /* concatenated argv */
    void (*stop_event_arg)(void (*cfunc)(), int arg, int op);
};
struct sim_interface simif; /* exported simulator functions */
```

The elements in the structure has the following meaning:

```
struct sim_options *options;
```

Contains some tsim startup options. `options.freq` defines the clock frequency of the emulated processor and can be used to correlate the simulator time to the real time.

```
uint64 *simtime;
```

Contains the current simulator time. Time is counted in clock cycles since start of simulation. To calculate the elapsed real time, divide `simtime` with `options.freq`.

```
void (*event)(void (*cfunc)(), int arg, uint64 offset);
```

TSIM maintains an event queue to emulate time-dependant functions. The `event()` function inserts an event in the event queue. An event consists of a function to be called when the event expires, an argument with which the function is called, and an offset (relative the current time) defining when the event should expire. NOTE:

the `event()` function may NOT be called from a signal handler installed by the I/O module, but only from `event()` callbacks or at start of simulation. The event queue can hold a maximum of 2048 events.

```
void (*stop_event)(void (*cfunc)());
```

`stop_event()` will remove all events from the event queue which has the calling function equal to `cfunc()`. NOTE: the `stop_event()` function may NOT be called from a signal handler installed by the I/O module.

```
int *irl;
```

Current IU interrupt level. Should not be used by I/O functions unless they explicitly monitor these lines.

```
void (*sys_reset)();
```

Performs a system reset. Should only be used if the I/O device is capable of driving the reset input.

```
void (*sim_stop)();
```

Stops current simulation. Can be used for debugging purposes if manual intervention is needed after a certain event.

```
char *args;
```

LEON2 only: Arguments supplied when starting `tsim`. The arguments are concatenated as a single string.

```
void (*stop_event_arg)(void (*cfunc)(), int arg, int op);
```

LEON2 only: Similar to `stop_event()` but differentiates between 2 events with same `cfunc` but with different `arg` given when inserted into the event queue via `event()`. Used when simulating multiple instances of an entity. Parameter `op` should be 1 to enable the `arg` check.

5.1.2 ioif structure

`ioif` is defined in `sim.h`:

```
struct io_interface {
    void (*set_irq)(int irq, int level);
    int (*dma_read)(uint32 addr, uint32 *data, int num);
    int (*dma_write)(uint32 addr, uint32 *data, int num);
};
extern struct io_interface ioif; /* exported processor interface */
```

The elements of the structure have the following meaning:

```
void (*set_irq)(int irq, int level);
```

ERC32 use: drive the external MEC interrupt signal. Valid interrupts are 0 - 5 (corresponding to MEC external interrupt 0 - 4, and EWDINT) and valid levels are 0 or 1. Note that the MEC interrupt shape register controls how and when processor interrupts are actually generated. When `-nouart` has been used, MEC interrupts 4, 5 and 7 can be generated by calling `set_irq()` with irq 6, 7 and 9 (level is not used in this case).

LEON use: set the interrupt pending bit for interrupt `irq`. Valid values on `irq` is 1 - 15. Care should be taken not to set interrupts used by the LEON emulated peripherals. Note that the LEON interrupt control register controls how and when processor interrupts are actually generated. Note that level is not used with LEON.

```
int (*dma_read)(uint32 addr, uint32 *data, int num);
int (*dma_write)(uint32 addr, uint32 *data, int num);
```

Performs DMA transactions to/from the emulated processor memory. Only 32-bit word transfers are allowed, and the address must be word aligned. On bus error, 1 is returned, otherwise 0. For ERC32, the DMA transfer uses the external DMA interface. For LEON, DMA takes place on the AMBA AHB bus.

5.1.3 Structure to be provided by I/O device

io.h defines the structure to be provided by the emulated I/O device:

```
struct io_subsystem {
    void (*io_init)(struct sim_interface sif, struct io_interface iif); /* start-up */
    void (*io_exit)(); /* called once on exit */
    void (*io_reset)(); /* called on processor reset */
    void (*io_restart)(); /* called on simulator restart */
    int (*io_read)(unsigned int addr, int *data, int *ws);
    int (*io_write)(unsigned int addr, int *data, int *ws, int size);
    char *(*get_io_ptr)(unsigned int addr, int size);
    void (*command)(char * cmd); /* I/O specific commands */
    void (*sigio)(); /* called when SIGIO occurs */
    void (*save)(char *fname); /* save simulation state */
    void (*restore)(char *fname); /* restore simulation state */
};
extern struct io_subsystem *iosystem; /* imported I/O emulation functions */
```

The elements of the structure have the following meanings:

```
void (*io_init)(struct sim_interface sif, struct io_interface iif);
```

Called once on simulator startup. Set to NULL if unused.

```
void (*io_exit)();
```

Called once on simulator exit. Set to NULL if unused.

```
void (*io_reset)();
```

Called every time the processor is reset (i.e also startup). Set to NULL if unused.

```
void (*io_restart)();
```

Called every time the simulator is restarted (simtime set to zero). Set to NULL if unused.

```
int (*io_read)(unsigned int addr, int *data, int *ws);
```

Processor read call. The processor always reads one full 32-bit word from addr. The data should be returned in *data, the number of waitstates should be returned in *ws. If the access would fail (illegal address etc.), 1 should be returned, on success 0.

```
int (*io_write)(unsigned int addr, int *data, int *ws, int size);
```

Processor write call. The size of the written data is indicated in size: 0 = byte, 1 = half-word, 2 = word, 3 = doubleword. The address is provided in addr, and is always aligned with respect to the size of the written data. The number of waitstates should be returned in *ws. If the access would fail (illegal address etc.), 1 should be returned, on success 0.

```
char * (*get_io_ptr)(unsigned int addr, int size);
```

TSIM can access emulated memory in the I/O device in two ways: either through the io_read/io_write functions or directly through a memory pointer. get_io_ptr() is called with the target address and transfer size (in bytes), and should return a character pointer to the emulated memory array if the address and size is within the range of the emulated memory. If outside the range, -1 should be returned. Set to NULL if not used.

```
int (*command)(char * cmd);
```

The I/O module can optionally receive command-line commands. A command is first sent to the AHB and I/O modules, and if not recognised, the to TSIM. command() is called with the full command string in *cmd. Should return 1 if the command is recognized, otherwise 0. TSIM/ERC32 also calls this callback when the SYSAV bit in the ERSR register changes. The commands “sysav 0” and “sysav 1” are then issued. When TSIM commands are issued through the gdb ‘monitor’ command, a return value of 0 or 1 will result in an

‘OK’ response to the gdb command. A return value > 1 will send the value itself as the gdb response. A return value < 1 will truncate the lsb 8 bits and send them back as a gdb error response: ‘Enn’.

```
void (*sigio)();
```

Not used as of tsim-1.2, kept for compatibility reasons.

```
void (*save)(char *fname);
```

The save() function is called when save command is issued in the simulator. The I/O module should save any required state which is needed to completely restore the state at a later stage. *fname points to the base file name which is used by TSIM. TSIM saves its internal state to fname.tss. It is suggested that the I/O module save its state to fname.ios. Note that any events placed in the event queue by the I/O module will be saved (and restored) by TSIM.

```
void (*restore)(char *fname);
```

The restore() function is called when restore command is issued in the simulator. The I/O module should restore any required state to resume operation from a saved check-point. *fname points to the base file name which is used by TSIM. TSIM restores its internal state from fname.tss.

5.1.4 Cygwin specific io_init()

Due to problems of resolving cross-referenced symbols in the module loading when using Cygwin, the io_init() routine in the I/O module must initialise a local copy of simif and ioif. This is done by providing the following io_init() routine:

```
static void io_init(struct sim_interface sif, struct io_interface iif)
{
#ifdef __CYGWIN32__
/* Do not remove, needed when compiling on Cygwin! */
    simif = sif;
    ioif = iif;
#endif
/* additional init code goes here */
};
```

The same method is also used in the AHB and FPU/CP modules.

5.2 LEON AHB emulation interface

In addition to the above described I/O modules, TSIM also allows emulation of the LEON2/3 processor core with a completely user-defined memory and I/O architecture. By loading an AHB module (ahb.so), the internal memory emulation is disabled. The emulated processor core communicates with the AHB module using an interface similar to the AHB master interface in the real LEON VHDL model. The AHB module can then emulate the complete AHB bus and all attached units.

The AHB module interface is made up of two parts; one that is exported by TSIM and defines TSIM functions and data structures that can be used by the AHB module; and one that is exported by the AHB module and allows TSIM to access the emulated AHB devices.

At start-up, TSIM searches for 'ahb.so' in the current directory, but the location of the module can be specified using the **-ahbm** switch. Note that the module must be compiled to be position-independent, i.e. with the **-fpic** switch (gcc). The win32 version of TSIM loads ahb.dll instead of ahb.so. See the iomod directory in the TSIM distribution for an example ahb.c and how to build the .so /.dll modules. The environmental variable TSIM_MODULE_PATH can be set to a ':' separated (',' in WIN32) list of search paths.

5.2.1 procif structure

TSIM exports one structure for AHB emulation: procif. The procif structure defines a few functions giving access to the processor emulation and cache behaviour. The procif structure is defined in tsim.h:

```
struct proc_interface {
    void (*set_irl)(int level); /* generate external interrupt */
    void (*cache_snoop)(uint32 addr);
    void (*cctrl)(uint32 *data, uint32 read);
    /* Following entries for LEON2 only. LEON3 modules should ignore them (init 0) */
    void (*set_irl_level)(int level, int set);
    void (*set_irq)(uint32 irq, uint32 level); /* generate external interrupt */
};
extern struct proc_interface procif;
```

The elements in the structure have the following meaning:

```
void (*set_irl)(int level);
```

Set the current interrupt level (iui.irl in VHDL model). Allowed values are 0 - 15, with 0 meaning no pending interrupt. Once the interrupt level is set, it will remain until it is changed by a new call to set_irl(). The modules interrupt callback routine should typically reset the interrupt level to avoid new interrupts.

```
void (*cache_snoop)(uint32 addr);
```

The cache_snoop() function emulates the data cache snooping of the processor. The tags to the given address will be checked, and if a match is detected the corresponding cacheline will be flushed (= the tag will be cleared).

```
void (*cctrl)(uint32 *data, uint32 read);
```

Read and write the cache control register (CCR). The CCR is attached to the APB bus in the LEON2 VHDL model, and this function can be called by the AHB module to read and write the register. If read = 1, the CCR value is returned in *data, else the value of *data is written to the CCR. The cctrl() function is only needed for LEON2 emulation, since LEON3 accesses the cache controller through a separate ASI load/store instruction.

```
void (*power_down)();
```

The LEON processor enters power down-mode when called. Only applicable to LEON2.

```
void (*set_irl_level)(int level, int set);
```

LEON2 only: Callback *set_irl_level* can be used to emulate level triggered interrupts. Parameter *set* should be 1 to activate the interrupt level specified in parameter *level* or 0 to reset it. The interrupt level will remain

active after it is set until it is reset again. Multiple calls can be made with different *level* parameters in which case the highest level is used.

```
void (*set_irq)(uint32 irq, uint32 level);
```

LEON2 only: set the interrupt pending bit for interrupt irq. Valid values on irq is 1 - 15. Care should be taken not to set interrupts used by the LEON emulated peripherals. Note that the LEON interrupt control register controls how and when processor interrupts are actually generated.

5.2.2 Structure to be provided by AHB module

tsim.h defines the structure to be provided by the emulated AHB module:

```
struct ahb_access {
    uint32 address;
    uint32 *data;
    uint32 ws;
    uint32 rnum;
    uint32 wsize;
    uint32 cache;
};
struct pp_amba {
    int is_apb;
    unsigned int vendor, device, version, irq;
    struct {
        unsigned int addr, p, c, mask, type;
    } bars[4];
};
struct ahb_subsystem {
    void (*init)(); /* called once on start-up */
    void (*exit)(); /* called once on exit */
    void (*reset)(); /* called on processor reset */
    void (*restart)(); /* called on simulator restart */
    int (*read)(struct ahb_access *access);
    int (*write)(struct ahb_access *access);
    char *(*get_io_ptr)(unsigned int addr, int size);
    int (*command)(char *cmd); /* I/O specific commands */
    int (*sigio)(); /* called when SIGIO occurs */
    void (*save)(char *fname); /* save state */
    void (*restore)(char *fname); /* restore state */
    int (*intack)(int level); /* interrupt acknowledge */
    int (*plugandplay)(struct pp_amba **); /* LEON3 only: get plug and play
information */
    /* Following entries for LEON2 only. LEON3 modules should ignore them */
    int meminit; /* tell tsim weather to initialize mem */
    struct sim_interface *simif; /* initialized by tsim */
    unsigned char *(*get_mem_ptr_ws)(); /* initialized if meminit was set */
    void (*snoop)(unsigned int addr); /* initialized with cache snoop routine */
    struct io_interface *io; /* initialized by tsim */
    void (*dprint)(char *p); /* initialized by tsim */
};
extern struct ahb_subsystem *ahbsystem; /* imported AHB emulation functions */
```

The elements of the structure have the following meanings:

```
void (*init)(struct sim_interface sif, struct io_interface iif);
```

Called once on simulator startup. Set to NULL if unused.

```
void (*exit)();
```

Called once on simulator exit. Set to NULL if unused.

```
void (*reset)();
```

Called every time the processor is reset (i.e. also startup). Set to NULL if unused.

```
void (*restart)();
```

Called every time the simulator is restarted (simtime set to zero). Set to NULL if unused.

```
int (*read)(struct ahb_access *ahbacc);
```

Processor AHB read. The processor always reads one or more 32-bit words from the AHB bus. The ahb_access structure contains the access parameters: access.addr = read address; access.data = pointer to the first read data; access.ws = should return the number of AHB waitstates used for the complete access; access.rnum = number of words read (1 - 8); access.wsize = not used during read cycles; access.cache =

should return 1 if the access is cacheable, else 0. Return values: 0 = access succeeded; 1 = access failed, generate memory exception; -1 = undecoded area, continue to decode address (I/O module or LEON registers).

```
int (*write)(struct ahb_access *ahbacc);
```

Processor AHB write. The processor can write 1, 2, 4 or 8 bytes per access. The access parameters are as for read() with the following changes: access.data = pointer to first write data; access.rnum = not used; access.wsize = defines write size as follows: 0 = byte, 1 = half-word, 2 = word, 3 = double-word. Return values as for read()

```
char * (*get_io_ptr)(unsigned int addr, int size);
```

During file load operations and displaying of memory contents, TSIM will access emulated memory through a memory pointer. get_io_ptr() is called with the target address and transfer size (in bytes), and should return a character pointer to the emulated memory array if the address and size is within the range of the emulated memory. If outside the range, -1 should be returned. Set to NULL if not used.

```
int (*command)(char * cmd);
```

The AHB module can optionally receive command-line commands. A command is first sent to the AHB and I/O modules, and if not recognised, then to TSIM. command() is called with the full command string in *cmd. Should return 1 if the command is recognized, otherwise 0. When TSIM commands are issued through the gdb 'monitor' command, a return value of 0 or 1 will result in an 'OK' response to the gdb command. A return value > 1 will send the value itself as the gdb response. A return value < 1 will truncate the lsb 8 bits and send them back as a gdb error response: 'Enn'.

```
void (*save)(char *fname);
```

The save() function is called when save command is issued in the simulator. The AHB module should save any required state which is needed to completely restore the state at a later stage. *fname points to the base file name which is used by TSIM. TSIM save its internal state to fname.tss. It is suggested that the AHB module save its state to fname.ahs. Note that any events placed in the event queue by the AHB module will be saved (and restored) by TSIM.

```
void (*restore)(char * fname);
```

The restore() function is called when restore command is issued in the simulator. The AHB module should restore any required state to resume operation from a saved check-point. *fname points to the base file name which is used by TSIM. TSIM restores its internal state from fname.tss.

```
int (*intack)(int level);
```

intack() is called when the processor takes an interrupt trap (tt = 0x11 - 0x1f). The level of the taken interrupt is passed in level. This callback can be used to implement interrupt controllers. intack() should return 1 if the interrupt acknowledgement was handled by the AHB module, otherwise 0. If 0 is returned, the default LEON interrupt controller will receive the intack instead.

```
int (*plugandplay)(struct pp_amba **p);
```

Leon3 only: plugandplay() is called at startup. plugandplay() should return in *p* a static pointer to an array of structs of type pp_amba and return the number of entries in the array. The callback plugandplay() is used to add entries in the AHB and APB configuration space. Each struct pp_amba entry specifies an entry: If is_apb is set the entry will appear in the APB configuration space and only member bars[0] will be used. If is_apb is not set then the entry will appear in the AHB configuration space and bars[0-3] will be used. The members of the struct resemble the fields in a configuration space entries. The entry is mapped to the first free slot.

```
int meminit;
```

Leon2 only: The AHB module should initialize meminit with 1 if tsim should initialize and emulate ram/sdram/rom memory. Calls to read and write should return -1 (undecoded area) for the memory regions in

which case tsim will handle them. If *meminit* is left 0 the AHB module itself should emulate the memory address regions.

```
struct sim_interface *simif;
```

Leon2 only: Entry *simif* is initialized by tsim with the global struct *sim_interface* structure.

```
unsigned char *(*get_mem_ptr_ws) (unsigned int addr, int size, int *wws,
                                int *rws)
```

Leon2 only: If *meminit* was set to 1 tsim will initialize *get_mem_ptr_ws* with a callback that can be used to query a pointer to the host memory emulating LEON2's memory, along with waitstate information. Note that the host memory pointer returned is in the hosts byte order (normally little endian on a PC). The *size* parameter should be the length of the access (1 for byte, 2 for short, 4 for word and 8 for double word access). The *wws* and *rws* parameters will return the calculated write and read waitstates for a possible access.

```
void (*snoop) (unsigned int addr)
```

Leon2/3 only: The callback snoop is initialized by tsim and can be called to flush a cache line for address *addr*.

```
struct io_interface *io;
```

Leon2/3 only: Initialized with the I/O interface structure pointer.

```
void (*dprint)(char *);
```

Leon2/3 only: Initialized by tsim with a callback pointer to the debug output function.

5.2.3 Big versus little endianess

SPARC is conforms to the big endian byte ordering. This means that the most significant byte of a (half) word has lowest address. To execute efficiently on little-endian hosts (such as intel x86 PCs), emulated memory is organised on word basis with the bytes within a word arranged according the endianess of the host. Read cycles can then be performed without any conversion since SPARC always reads a full 32-bit word. During byte and half word writes, care must be taken to insert the written data properly into the emulated memory. On a byte-write to address 0, the written byte should be inserted at address 3, since this is the most significant byte according to little endian. Similarly, on a half-word write to bytes 0/1, bytes 2/3 should be written. For a complete example, see the prom emulation function in *io.c*.

5.3 TSIM/LEON co-processor emulation

5.3.1 FPU/CP interface

The professional version of TSIM/LEON can emulate a user-defined floating-point unit (FPU) and co-processor (CP). The FPU and CP are included into the simulator using loadable modules. To access the module, use the structure ‘cp_interface’ defined in io.h. The structure contains a number of functions and variables that must be provided by the emulated FPU/CP:

```
/* structure of function to be provided by an external co-processor */
struct cp_interface {
    void (*cp_init)(); /* called once on
start-up */
    void (*cp_exit)(); /* called once on
exit */
    void (*cp_reset)(); /* called on
processor reset */
    void (*cp_restart)(); /* called on
simulator restart */
    uint32 (*cp_reg)(int reg, uint32 data, int read);
    int (*cp_load)(int reg, uint32 data, int *hold);
    int (*cp_store)(int reg, uint32 *data, int *hold);
    int (*cp_exec)(uint32 pc, uint32 inst, int *hold);
    int (*cp_cc)(int *cc, int *hold); /* get condition codes */
    int *cp_status; /* unit status */
    void (*cp_print)(); /* print registers
*/
    int (*command)(char * cmd); /* CP specific
commands */
    int set_fsr(uint32 fsr); /* initialized by tsim */
};
extern struct cp_interface *cp; /* imported co-processor emulation functions */
```

5.3.2 Structure elements

```
void (*cp_init)(struct sim_interface sif, struct io_interface iif);
```

Called once on simulator startup. Set to NULL if not used.

```
void (*cp_exit)();
```

Called once on simulator exit. Set to NULL if not used.

```
void (*cp_reset)();
```

Called every time the processor is reset. Set to NULL if not used.

```
void (*cp_restart)();
```

Called every time the simulator is restarted. Set to NULL if not used.

```
uint32 (*cp_reg)(int reg, uint32 data, int read);
```

Used by the simulator to perform diagnostics read and write to the FPU/CP registers. Calling cp_reg() should not have any side-effects on the FPU/CP status. ‘reg’ indicates which register to access: 0-31 indicates %f0-%f31/%c0- %31, 34 indicates %fsr/%csr. ‘read’ indicates read or write access: read==0 indicates write access, read!=0 indicates read access. Written data is passed in ‘data’, the return value contains the read value on read accesses.

```
int (*cp_load)(int reg, uint32 data, int *hold);
```

Used to perform FPU/CP load instructions. ‘reg’ indicates which register to access: 0-31 indicates %f0-%f31/%c0- %31, 34 indicates %fsr/%csr. Loaded data is passed in ‘data’. If data dependency is emulated, the number of stall cycles should be return in *hold. The return value should be zero if no trap occurred or the trap

number if a trap did occur (0x8 for the FPU, 0x28 for CP). A trap can occur if the FPU/CP is in exception_pending mode when the load is executed.

```
int (*cp_store)(int reg, uint32 *data, int *hold);
```

Used to perform FPU/CP store instructions. 'reg' indicates which register to access: 0-31 indicates %f0-%f31/%c0-%c31, 32 indicates %fq/%cq, 34 indicates %fsr/%csr. Stored should be assigned to *data. During a STDFQ, the %pc should be assigned to data[0] while the instruction opcode to data[1]. If data dependency is emulated, the number of stall cycles should be return in *hold. The return value should be zero if no trap occurred or the trap number if a trap did occur (0x8 for the FPU, 0x28 for CP). A trap can occur if the FPU/CP is in exception_pending mode when the store is executed.

```
int (*cp_exec)(uint32 pc, uint32 inst, int *hold);
```

Execute FPU/CP instruction. The %pc is passed in 'pc' and the instruction opcode in 'inst'. If data dependency is emulated, the number of stall cycles should be return in *hold. The return value should be zero if no trap occurred or the trap number if a trap did occur (0x8 for the FPU, 0x28 for CP). A trap can occur if the FPU/CP is in exception_pending mode when a new FPU/CP instruction is executed.

```
int (*cp_cc)(int *cc, int *hold); /* get condition codes */
```

Read condition codes. Used by FBCC/CBCC instructions. The condition codes (0 - 3) should be returned in *cc. If data dependency is emulated, the number of stall cycles should be return in *hold. The return value should be zero if no trap occurred or the trap number if a trap did occur (0x8 for the FPU, 0x28 for CP). A trap can occur if the FPU/CP is in exception_pending mode when a FBCC/CBCC instruction is executed.

```
int *cp_status; /* unit status */
```

Should contain the FPU/CP execution status: 0 = execute_mode, 1 = exception_pending, 2 = exception_mode.

```
void (*cp_print)(); /* print registers */
```

Should print the FPU/CP registers to stdio.

```
int (*command)(char * cmd); /* CP specific commands */
```

User defined FPU/CP control commands. NOT YET IMPLEMENTED.

```
int (*set_fsr)(char * cmd); /* initialized by tsim */
```

This callback is initialized by tsim and can be called to set the FPU status register.

5.3.3 Attaching the FPU and CP

At startup the simulator tries to load two dynamic link libraries containing an external FPU or CP. The simulator looks for the file fp.so and cp.so in the current directory and in the search path defined by ldconfig. The location of the modules can also be defined using **-cpm** and **-fpm** switches. The enviromental variable TSIM_MODULE_PATH can be set to a ':' separated (',' in WIN32) list of search paths. Each library is searched for a pointer 'cp' that points to a cp_interface structure describing the co-processor. Below is an example from fp.c:

```
struct cp_interface test_fpu = {
    cp_init,          /* cp_init */
    NULL,             /* cp_exit */
    cp_init,          /* cp_reset */
    cp_init,          /* cp_restart */
    cp_reg,           /* cp_reg */
    cp_load,          /* cp_load */
    cp_store,         /* cp_store */
    fpmeiko,          /* cp_exec */
    cp_cc,            /* cp_cc */
    &fpregs.fpstate, /* cp_status */
}
```

```
    cp_print,          /* cp_print */  
    NULL              /* cp_command */  
};  
struct cp_interface *cp = &test_fpu; /* Attach pointer!! */
```

5.3.4 Big versus little endianness

SPARC conforms to the big-endian byte ordering. This means that the most significant byte of a (half) word has lowest address. To execute efficiently on little-endian hosts (such as intel x86 PCs), emulated register-file is organised on word basis with the bytes within a word arranged according to the endianness of the host. Double words are also in host order, and the read/write register functions must therefore invert the lsb of the register address when performing word access on little-endian hosts. See the file fp.c for examples (cp_load(), cp_store()).

5.3.5 Additional TSIM commands

float	Shows the registers of the FPU
cp	Shows the registers of the CP

5.3.6 Example FPU

The file fp.c contains a complete SPARC FPU using the co-processor interface. It can be used as a template for implementation of other co-processors. Note that data-dependency checking for correct timing is not implemented in this version (it is however implemented in the built-in version of TSIM).

6 TSIM library (TLIB)

6.1 Introduction

TSIM is also available as a library, allowing the simulator to be integrated in a larger simulation frame-work. The various TSIM commands and options are accessible through a simple function interface. I/O functions can be added, and use a similar interface to the loadable I/O modules described earlier.

6.2 Function interface

The following functions are provided to access TSIM features:

```
int tsim_init (char *option); /* initialise tsim with optional params. */
```

Initialize TSIM - must be called before any other TSIM function (except `tsim_set_diag()`) are used. The options string can contain any valid TSIM startup option (as used for the standalone simulator), with the exception that **no** filenames for files to be loaded into memory may be given. `tsim_init()` may only be called once, use the TSIM **reset** command to reset the simulator without exiting. `tsim_init()` will return 1 on success or 0 on failure.

```
int tsim_cmd (char *cmd); /* execute tsim command */
```

Execute TSIM command. Any valid TSIM command-line command may be given. The following return values are defined:

SIGINT	Simulation stopped due to interrupt
SIGHUP	Simulation stopped normally
SIGTRAP	Simulation stopped due to breakpoint hit
SIGSEGV	Simulation stopped due to processor in error mode
SIGTERM	Simulation stopped due to program termination

```
void tsim_exit (int val);
```

Should be called to cleanup TSIM internal state before main program exits.

```
void tsim_get_regs (unsigned int *regs);
```

Get SPARC registers. `regs` is a pointer to an array of integers, see `tsim.h` for how the various registers are indexed.

```
void tsim_set_regs (unsigned int *regs);
```

Set SPARC registers. `*regs` is a pointer to an array of integers, see `tsim.h` for how the various registers are indexed.

```
void tsim_disas(unsigned int addr, int num);
```

Disassemble memory. `addr` indicates which address to disassemble, `num` indicates how many instructions.

```
void tsim_set_diag (void (*cfunc)(char *));
```

Set console output function. By default, TSIM writes all diagnostics and console messages on `stdout`. `tsim_set_diag()` can be used to direct all output to a user defined routine. The user function is called with a single string parameter containing the message to be written.

```
void tsim_set_callback (void (*cfunc)(void));
```

Set the debug callback function. Calling `tsim_set_callback()` with a function pointer will cause TSIM to call the callback function after each executed instruction, **when the history is enabled**. History can be enabled with the `tsim_cmd()` function.

```
void tsim_gdb (unsigned char (*inchar)(), void (*outchar)(unsigned char c));
```

Controls the simulator using the gdb ‘extended-remote’ protocol. The `inchar` parameter is a pointer to a function that when called, returns next character from the gdb link. The `outchar` parameter is a pointer to a function that sends one character to the gdb link.

```
void tsim_read(unsigned int addr, unsigned int *data);
```

Performs a read from *addr*, returning the value in **data*. Only for diagnostic use.

```
void tsim_write(unsigned int addr, unsigned int data);
```

Performs a write to *addr*, with value *data*. Only for diagnostic use.

```
void tsim_stop_event(void (*cfunc)(), int arg, int op);
```

`tsim_stop_event()` can remove certain event depending on the setting of *arg* and *op*. If *op* = 0, all instance of the callback function *cfunc* will be removed. If *op* = 1, events with the argument = *arg* will be removed. If *op* = 2, only the first (earliest) of the events with the argument = *arg* will be removed. NOTE: the `stop_event()` function may NOT be called from a signal handler installed by the I/O module.

```
void tsim_inc_time(uint64);
```

`tsim_inc_time()` will increment the simulator time without executing any instructions. The event queue is evaluated during the advancement of time and the event callbacks are properly called. Can not be called from event handlers.

```
int tsim_trap(int (*trap)(int tt), void (*rett)());
```

`tsim_trap()` is used to install callback functions that are called every time the processor takes a trap or returns from a trap (RETT instruction). The `trap()` function is called with one argument (*tt*) that contains the SPARC trap number. If `tsim_trap()` returns with 0, execution will continue. A non-zero return value will stop simulation with the program counter pointing to the instruction that will cause the trap. The `rett()` function is called when the program counter points to the RETT instruction but before the instruction is executed. The callbacks are removed by calling `tsim_trap()` with a NULL arguments.

```
int tsim_cov_get(int start, int end, char *ptr);
```

`tsim_cov_get()` will return the coverage data for the address range $\geq start$ and $< end$. The coverage data will be written to a char array pointed to by **ptr*, starting at *ptr[0]*. One character per 32-bit word in the address range will be written. The user must assure that the char array is large enough to hold the coverage data.

```
int tsim_cov_set(int start, int end, char val);
```

`tsim_cov_set()` will fill the coverage data in the address range limited by *start* and *end* (see above for definition) with the value of *val*.

```
int tsim_ext_ins (int (*func) (struct ins_interface *r));
```

`tsim_ext_ins()` installs a handler for custom instructions. *func* is a pointer to an instruction emulation function as described in “Custom instruction emulation” on page 21. Calling `tsim_ext_ins()` with a NULL pointer will remove the handler.

```
int tsim_lastbp (int *addr)
```

When simulation stopped due to breakpoint or watchpoint hit (SIGTRAP), this function will return the address of the break/watchpoint in *addr. The function return value indicates the break cause; 0 = breakpoint, 1 = watchpoint.

6.3 I/O interface

The TSIM library uses the same I/O interface as the standalone simulator. Instead of loading a shared library containing the I/O module, the I/O module is linked with the main program. The I/O functions (and the main program) has the same access to the exported simulator interface (simif and ioif) as described in the loadable module interface. The TSIM library imports the I/O structure pointer, iosystem, which must be defined in the main program.

An example I/O module is provided in `tlib/<platform>/io.c`, which shows how to add a prom.

A second example I/O module is provided in `simple_io.c`. This module provides a simpler interface to attach I/O functions. The following interface is provided:

```
void tsim_set_ioread (void (*cfunc)(int address, int *data, int *ws));
```

This function is used to pass a pointer to a user function which is to be called by TSIM when an I/O **read** access is made. The user function is called with the address of the access, a pointer to where the read data should be returned, and a pointer to a waitstate variable that should be set to the number of waitstates that the access took.

```
void tsim_set_iowrite (void (*cfunc)(int address, int *data, int *ws, int size));
```

This function is used to pass a pointer to a user function which is to be called by TSIM when an I/O **write** access is made. The user function is called with the address of the access, a pointer to the data to be written, a pointer to a waitstate variable that should be set to the number of waitstates that the access took, and the size of the access (0=byte, 1=half-word, 2=word, 3=double-word).

6.4 UART handling

By default, the library is using the same UART handling as the standalone simulator. This means that the UARTs can be connected to the console, or any unix device (pseudo-ttys, pipes, fifos). If the UARTs are to be handled by the user's I/O emulation routines, `tsim_init()` should be called with '-nouart', which will disable all internal UART emulation. Any access to the UART register by an application will then be routed to the I/O module read/write functions.

6.5 Linking a TLIB application

Three sample application are provided, one that uses the simplified I/O interface (`app1.c`), and two that uses the standard loadable module interface (`app2` and `app3`). They are built by doing a 'make all' in the `tlib` directory. The win32 version of TSIM provides the library as a DLL, for all other platform a static library is provided (.a). Support for dynamic libraries on linux or solaris is not available.

6.6 Limitations

On Windows/cygwin hosts TSIM is not capable of reading UART A/B from the console, only writing is possible. If reading of UART A/B is necessary, the simulator should be started with `-nouart`, and emulation of the UARTs should be handled by the I/O module.

7 Aeroflex UT699 AHB module

7.1 Overview

This chapter describes the UT699 loadable AHB module for the TSIM2 simulator. The AHB module provides simulation models for the Ethernet, SpaceWire, PCI and CAN cores in the UT699 processor. For more information about this chip see the Aeroflex UT699 user manual.

The interfaces are modelled at packet/transaction/message level and provides an easy way to connect the simulated UT699 to a larger simulation framework.

The following files are delivered with the UT699 TSIM module:

File	Description
ut699/linux/ut699.so	UT699 AHB module for Linux
ut699/win32/ut699.dll	UT699 AHB module for Windows
Input	The input directory contains two examples of PCI user modules
ut699/examples/input/README.txt	Description of the user module examples
ut699/examples/input/Makefile	Makefile for building the user modules
ut699/examples/input/pci.c	PCI user module example that makes UT699 PCI initiator accesses
ut699/examples/input/pci_target.c	PCI user module example that makes UT699 PCI target accesses
ut699/examples/input/ut699inputprovider.h	Interface between the UT699 module and the user defined PCI module
ut699/examples/input/pci_input.h	UT699 PCI input provider definitions
ut699/examples/input/input.h	Generic input provider definitions
ut699/examples/input/tsim.h	TSIM interface definitions
ut699/examples/input/end.h	Defines the endian of the local machine
Test	The test directory contains tests that can be executed in TSIM
ut699/examples/test/README.txt	Description of the tests
ut699/examples/test/Makefile	Makefile for building the tests
ut699/examples/test/cansend.c	CAN transmission test
ut699/examples/test/canrec.c	CAN reception test
ut699/examples/test/pci.c	PCI interface test
ut699/examples/test/pcitest.h	Header file for PCI test

Table 1: Files delivered with the UT699 TSIM module

7.2 Loading the module

The module is loaded using the TSIM2 option -ahbm. All core specific options described in the following sections need to be surrounded by the options -designinput and -designinputend, e.g:

On Linux:

```
tsim-leon3 -ahbm ./ut699/linux/ut699.so
           -designinput ./ut699/examples/input/pci.so -designinputend
```

On Windows:

```
tsim-leon3 -ahbm ut699/win32/ut699.dll  
          -designinput ./ut699/examples/input/pci.dll -designinputend
```

7.3 Debugging

To enable printout of debug information the

```
-ut699_dbgon <flag>
```

switch can be used. Alternatively one can issue the “ut699_dbgon <flag>” command on the TSIM2 command line. The debug flags that are available are described for each core in the following sections.

7.4 10/100 Mbps Ethernet Media Access Controller interface

The Ethernet core simulation model is designed to accurately model the 10/100 Ethernet MAC available in the UT699. For core details and register specification please see the UT699 manual.

The following features are supported:

- Direct Memory Access
- Interrupts

7.4.1 Start up options

Switch	Description
-grethconnect host[:port]	Connect Ethernet core to packet server to specified server and TCP port. Default port is 2224.

Table 2: Ethernet core start up options

7.4.2 Commands

Switch	Description
greth_connect host[:port]	Connect Ethernet core to packet server to specified server and TCP port. Default port is 2224.
greth_status	Print Ethernet register status

Table 3: Ethernet core TSM commands

7.4.3 Debug flags

The following debug flags are available for the Ethernet interface. Use the them in conjunction with the ut699_dbgon command to enable different levels of debug information.

Flag	Trace
GAISLER_GRETH_ACC	GRETH accesses
GAISLER_GRETH_L1	GRETH accesses verbose
GAISLER_GRETH_TX	GRETH transmissions
GAISLER_GRETH_RX	GRETH reception
GAISLER_GRETH_RXPACKET	GRETH received packets
GAISLER_GRETH_RXCTRL	GRETH RX packet server protocol
GAISLER_GRETH_RXBDCTRL	GRETH RX buffer descriptors DMA
GAISLER_GRETH_TXCTRL	GRETH TX packet server protocol

Table 4: Ethernet debug flags

7.5 SpaceWire interface with RMAP support

The UT699 AHB module contains four SpaceWire cores which accurately model the four SpaceWire links available in the UT699. For core details and register specification please see the UT699 manual.

The following features are supported:

- Transmission and reception of SpaceWire packets
- Interrupts
- Time codes
- RMAP
- Modifying the link state

7.5.1 Start up options

Switch	Description
-grspwXconnect host:port	Connect GRPSW core X to packet server at specified server and port.
-grspwXserver port	Open a packet server for core X on specified port.
-grspw_normap	Disable the RMAP handler. RMAP packets will be stored to the DMA channel.
-grspw_rmap	Enable the RMAP handler. All RMAP packages will be simulated in hardware. Includes support for RMAP CRC. (Default)
-grspw_rmapcrc	Enable support for RMAP CRC. Performs RMAP CRC checks and calculations in hardware
-grspw_rxfreq freq	Set the RX frequency which is used to calculate receive performance.
-grspw_txfreq freq	Set the TX frequency which is used to calculate transmission performance.

Table 6: SpaceWire core start up options

X in the above options has the range 1-4.

7.5.2 Commands

Command	Description
grspwX_connect host:port	Connect GRSPW core X to packet server at specified server and TCP port.
grspwX_server port	Open a packet server for core X on specified TCP port.
grspw_status	Print status for all GRSPW cores.

Table 7: SpaceWire core TSIM commands

X in the above commands has the range 1-4.

7.5.3 Debug flags

The following debug flags are available for the SpaceWire interfaces. Use the them in conjunction with the `ut699_dbgon` command to enable different levels of debug information.

Flag	Trace
GAISLER_GRSPW_ACC	GRSPW accesses
GAISLER_GRSPW_RXPACKET	GRSPW received packets
GAISLER_GRSPW_RXCTRL	GRSPW rx protocol
GAISLER_GRSPW_TXPACKET	GRETH transmitted packets
GAISLER_GRSPW_TXCTRL	GRETH tx protocol

Table 8: SpaceWire debug flags

7.5.4 SpaceWire packet server

Each SpaceWire core can be configured independently as a packet server or client using either -grspwXserver or -grspwXconnect. TCP sockets are used for establishing the connections. When acting as a server the core can only accept a single connection.

For more flexibility, such as custom routing, an external packet server can be implemented using the protocol specified in the following sections. Each core should then be connected to that server.

7.5.5 SpaceWire packet server protocol

The protocol used to communicate with the packet server is described below. Three different types of packets are defined according to the table below.

Type	Value
Data	0
Time code	1
Modify link state	2

Table 9: Packet types

Note that all packets are prepended by a one word length field which specified the length of the coming packet including the header.

Data packet format:

31								0
0x0	LENGTH							
31:0	LENGTH, specifies length of packet including the header							

Header

31	16	15	8	7	5	4	1	0
0x4	RES	IPID=0	TYPE=0	RES	EEP			

Table 10: SpaceWire data packet

31:16	RES, reserved for future use
15:8	IPID, IP core ID, must equal 0 for SpaceWire
7:5	TYPE, packet type, 0 for data packets
4:1	RES, reserved for future use, must be set to 0
0	EEP, Error End of Packet. Set when the packet is truncated and terminated by an EEP.

Payload

0x8 -	SpaceWire packet
-------	------------------

Table 10: SpaceWire data packet

Time code packet format:

	31		0
0x0	LENGTH		
31:0	LENGTH, specifies length of packet including the header.		

Header

	31	16	15	8	7	5	4	0
0x4	RES		IPID=0		TYPE=1		RES	
31:16	RES, reserved for future use, must be set to 0							
15:8	IPID, IP core ID, must equal 0 for SpaceWire							
7:5	TYPE, packet type, 1 for time code packets							
4:0	RES, reserved for future use, must be set to 0							

Payload

	31	8	7	6	5	0
0x8			CT		CN	
31:8	RES, reserved for future use, must be set to 0					
7:6	CT, time control flags					
5:0	CN, value of time counter					

Table 11: SpaceWire time code packet

Link state packet format:

	31		0
0x0	LENGTH		
31:0	LENGTH, specifies length of packet including the header.		

Header

	31	15	8	7	5	4	3	2	0
0x4	RES	IPID=0		TYPE=2		RES		LS	
31:16	RES, reserved for future use, must be set to 0								

Table 12: SpaceWire link state packet

15:8	IPID, IP core ID, must equal 0 for SpaceWire		
7:5	TYPE, packet type, 2 for link state packets		
4:3	RES, reserved for future use, must be set to 0		
2:0	LS, Link State:	0	Error reset
		1	Error wait
		2	Ready
		3	Started
		4	Connecting
		5	Run

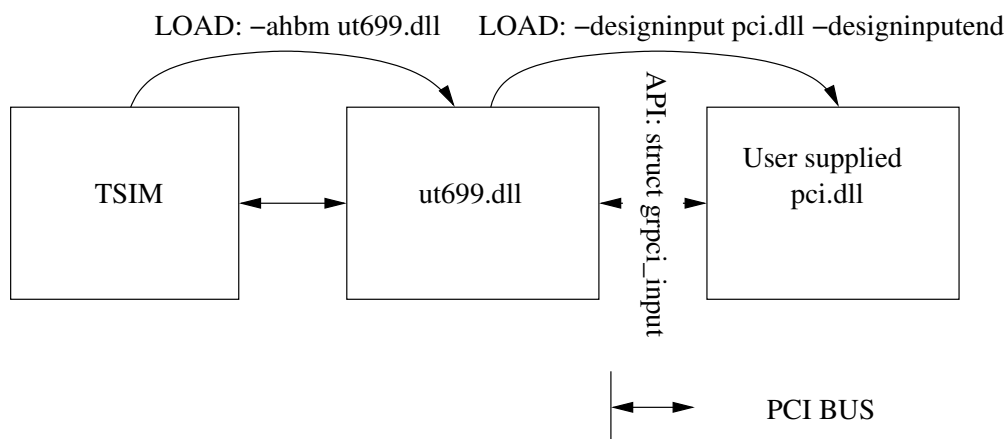
Table 12: SpaceWire link state packet

7.6 PCI initiator/target interface

The UT699 AHB module models the PCI core available in the UT699 ASIC. For core details and register specification please see the UT699 manual [UT699].

The PCI emulation is implemented by a two stage model:

1. The TSIM AHB module ut699.dll implements the PCI core itself
2. A user supplied dynamic library models the devices on the PCI bus.



To load a user supplied dynamic library use the following command line switch:

```
-designinput <pciexample> <switches> -designinputend
```

This will load a user supplied dynamic library “pciexample”. In addition the switches between -designinput and -designinputend are local switches only propagated to the user dynamic library “pciexample”.

7.6.1 Commands

pci_status Print status for the PCI core

7.6.2 Debug flags

The following debug flags are available for the PCI interface. Use the them in conjunction with the ut699_dbg command to enable different levels of debug information.

Flag	Trace
GAISLER_GRP_CI_ACC	AHB accesses to/from PCI core
GAISLER_GRP_CI_REGACC	GRPCI APB register accesses
GAISLER_GRP_CI_DMA_REGACC	PCIDMA APB register accesses
GAISLER_GRP_CI_DMA	GRPCI DMA accesses on the AHB bus
GAISLER_GRP_CI_TARGET_ACC	GRPCI target accesses

Table 13: PCI interface debug flags

Flag	Trace
GAISLER_GRP_CI_INIT	Print summary on startup

Table 13: PCI interface debug flags

7.6.3 User supplied dynamic library

The user supplied dynamic library should expose a public symbol `ut699inputsystem` of type `struct ut699_subsystem *`. The struct `ut699_subsystem` is defined as:

```
struct ut699_subsystem {
    void (*ut699_inp_setup) (int id, struct ut699_inp_layout *l, char **argv, int
    argc);
    void (*ut699_inp_restart) (int id, struct ut699_inp_layout *l);
    struct sim_interface *simif;
};
```

At initialization the callback `ut699_inp_setup` will be called once, supplied with a pointer to structure `struct ut699_inp_layout`.

```
struct ut699_inp_layout {
    struct grpci_input grpci;
};
```

The callback `ut699_inp_restart` will be called every time the simulator restarts and the PCI user module can access the global TSIM `sim_interface` structure through the `simif` member. See chapter 5 for more details.

The user supplied dynamic library should claim the `ut699_inp_layout.grpci` member of the structure by using the `INPUT_CLAIM(l->grpci)` macro (see the example below). `struct grpci_input` consists of callbacks that model the PCI bus (see the chapter PCI bus model API).

A typical user supplied dynamic library would look like this:

```
#include "tsim.h"
#include "inputprovider.h"

int pci_acc(struct grpci_input *ctrl, int cmd, unsigned int addr, unsigned int wsize,
            unsigned int *data, unsigned int *abort, unsigned int *ws) {
    ... BUS access implementation ...
}

static void ut699_inp_setup (int id, struct ut699_inp_layout *l, char **argv, int argc)
{
    printf("Entered PCI setup\n");

    if (INPUT_ISCLAIMED(l->grpci)) {
        printf("module user for PCI already allocated \n");
        return;
    }

    for(i = 0; i < argc; i++) {
        ... do argument processing ...
    }

    l->grpci.acc = pci_acc;

    ... do module setup ...

    printf("ut699_inp_setup: Claiming %s\n", l->grpci._b.name);
    INPUT_CLAIM(l->grpci);
    return;
}
```

```

}

static struct ut699_subsystem ut699_pci = {
    ut699_inp_setup, 0, 0
};

struct ut699_subsystem *ut699inputsystem = &ut699_pci;

```

A typical Makefile that would create a user supplied dynamic library pci.(dll|so) from pci.c would look like this:

```

M_DLL_FIX = $(if $(strip $(shell uname | grep MINGW32)),dll,so)
M_LIB      = $(if $(strip $(shell uname | grep MINGW32)),-lws2_32 -luser32 -lkernel32 -
    lwinmm,)
all:pci.$(M_DLL_FIX)

pci.$(M_DLL_FIX) : pci.o
$(CC) -shared -g pci.o -o pci.$(M_DLL_FIX) $(M_LIB)

pci.o: pci.c \
inputprovider.h
$(CC) -fPIC -c -g -O0 pci.c -o pci.o
clean:
-rm -f *.o *.so

```

7.6.4 PCI bus model API

The structure struct grpci_input models the PCI bus. It is defined as:

```

/* ut699 pci input provider */

struct grpci_input {
    struct input_inp _b;

    int (*acc)(struct grpci_input *ctrl, int cmd, unsigned int addr,
        unsigned int *data, unsigned int *abort, unsigned int *ws);

    int (*target_acc)(struct grpci_input *ctrl, int cmd, unsigned int addr,
        unsigned int *data, unsigned int *mexc);
};

```

The acc callback should be set by the PCI user module at startup. It is called by the UT699 module whenever it reads/writes as a PCI bus master.

Parameter	Description
cmd	Command to execute, see the PCI command table for details
addr	PCI address
data	Data buffer, fill for read commands, read for write commands
wsize	0: 8-bit access 1: 16-bit access, 2: 32-bit access, 3: 64-bit access. 64 bit is only used to model STD instructions to the GRPCI AHB slave
ws	Number of PCI clocks it shall to complete the transaction
abort	Set to 1 to generate target abort, 0 otherwise

Table 14: acc callback parameters

The return value of acc determines if the transaction terminates successfully (1) or with master abort (0).

The callback `target_acc` is installed by the UT699 AHB module. The PCI user dynamic library can call this function to initiate an access to the UT699 PCI target.

Parameter	Description
cmd	Command to execute, see the PCI command table for details. I/O cycles not support by UT699 target.
addr	PCI address
data	Data buffer, returned data for read commands, supply data for write commands
wsiz	0: 8-bit access 1: 16-bit access, 2: 32-bit access
mexc	0 if access is succesful, 1 in case of target abort

Table 15: target_acc parameters

If the address matched MEMBAR0, MEMBAR1 or CONFIG target_acc will return 1 otherwise 0.

7.7 CAN interface

The UT699 AHB module contains 2 CAN_OC cores which models the 2 CAN_OC cores available in the UT699. For core details and register specification please see the UT699 manual.

7.7.1 Start up options

Switch	Description
-can_ocXconnect host:port	Connect CAN_OC core X to packet server to specified server and TCP port.
-can_ocXserver port	Open a packet server for CAN_OC core X on specified TCP port.
-can_ocXack [0 1]	Specifies whether the CAN_OC core will wait for a acknowledgment packet on transmission. This option must be put after -can_ocXconnect.

Table 16: CAN core start up options

X in the above options is in the range 1 to 2.

7.7.2 Commands

Command	Description
can_ocXconnect host:port	Connect CAN_OC core X to packet server to specified server and TCP port.
can_ocXserver port	Open a packet server for CAN_OC core X on specified TCP port.
can_ocXack [0 1]	Specifies whether the CAN_OC core will wait for a acknowledgment packet on transmission. This command should only be issued after a connection has been established.

Table 17: CAN core TSIM commands

X in the above commands is in the range 1 to 2.

7.7.3 Debug flags

The following debug flags are available for the CAN interfaces. Use the them in conjunction with the ut699_dbgon command to enable different levels of debug information.

Flag	Trace
GAISLER_CAN_OC_ACC	CAN_OC register accesses
GAISLER_CAN_OC_RXPACKET	CAN_OC received messages
GAISLER_CAN_OC_TXPACKET	CAN_OC transmitted messages
GAISLER_CAN_OC_ACK	CAN_OC acknowledgements

Table 18: CAN debug flags

7.7.4 Packet server

Each CAN_OC core can be configured independently as a packet server or client using either -can_ocXserver or -can_ocXconnect. When acting as a server the core can only accept a single connection.

7.7.5 CAN packet server protocol

The protocol used to communicate with the packet server is described below. Four different types of packets are defined according to the table below.

Type	Value
Message	0x00
Error counter	0xFD
Acknowledge	0xFE
Acknowledge config	0xFF

Table 19: CAN packet types

CAN message packet format

Used to send and receive CAN messages.

31	0
0x0	LENGTH
31:0	LENGTH, specifies the length of the rest of the packet

CAN message									
Byte #	Description	Bits (MSB-LSB)							
		7	6	5	4	3	2	1	0
4	Protocol ID = 0	Prot ID 7-0							
5	Control	FF	RTR	-	-	DLC (max 8 bytes)			
6-9	ID (32 bit word in network byte order)	ID 10-0 (bits 31 - 11 ignored for standard frame format) ID 28-0 (bits 31-29 ignored for extended frame format)							
10-17	Data byte 1 - DLC	Data byte <i>n</i> 7-0							

Table 20: CAN message packet format

Error counter packet format

Used to write the RX and TX error counter of the modelled CAN interface.

31	0
0x0	LENGTH
31:0	LENGTH, specifies the length of the rest of the packet

Error counter packet

Table 21: Error counter packet format

Byte #	Field	Description
4	Packet type	Type of packet, 0xFD for error counter packets
5	Register	0 - RX error counter, 1 - TX error counter
6	Value	Value to write to error counter

Table 21: Error counter packet format

Acknowledge packet format

If the acknowledge function has been enabled through the start up option or command the CAN interface will wait for an acknowledge packet each time it transmits a message. To enable the CAN receiver to send acknowledge packets (either NAK or ACK) an acknowledge configuration packet must be sent. This is done automatically by the CAN interface when can_ocXack is issued.

31	0
0x0	LENGTH
31:0	LENGTH, specifies the length of the rest of the packet

Acknowledge packet

Byte #	Field	Description
4	Packet type	Type of packet, 0xFE for acknowledge packets
5	Ack payload	0 - No acknowledge, 1 - Acknowledge

Table 22: Acknowledge packet format

Acknowledge configuration packet format

This packet is used for enabling/disabling the transmission of acknowledge packets and their payload (ACK or NAK) by the CAN receiver. The CAN transmitter will always wait for an acknowledge if started with - can_ocXack or if the can_ocXack command has been issued.

31	0
0x0	LENGTH
31:0	LENGTH, specifies the length of the rest of the packet

Acknowledge configuration packet

Byte #	Field	Description	
4	Packet type	Type of packet, 0xFF for acknowledge configuration packets	
5	Ack configuration	bit 0	Unused
		bit 1	Ack packet enable, 1 - enabled, 0 - disabled
		bit 2	Set ack packet payload, 1 - ACK, 0 - NAK

Table 23: Acknowledge configuration packet format

8 Atmel AT697 PCI emulation

The PCI emulation is implemented as a AT697 AHB module that will process all accesses to memory region 0xa0000000 - 0xf0000000 (AHB slave mode) and the APB registers starting at 0x80000100.

The AT697 AHB module implements all registers of the PCI core. It will in turn load the PCI user modules that will implement the devices. The AT697 AHB module is supposed to be the PCI host. Both PCI Initiator and PCI Target mode are supported. The interface to the PCI user modules is implemented on bus level. Two callbacks model the PCI bus.

The following files are delivered with the AT697 TSIM module:

File	Description
at697/linux/at697.so	AT697 AHB module for Linux
at697/win32/at697.dll	AT697 AHB module for Windows
Input	The input directory contains two examples of PCI user modules
at697/examples/input/README.txt	Description of the user module examples
at697/examples/input/Makefile	Makefile for building the user modules
at697/examples/input/pci.c	PCI user module example that makes AT697 PCI initiator accesses
at697/examples/input/pci_target.c	PCI user module example that makes AT697 PCI target accesses
at697/examples/input/at697inputprovider.h	Interface between the AT697 module and the user defined PCI module
at697/examples/input/pci_input.h	AT697 PCI input provider definitions
at697/examples/input/input.h	Generic input provider definitions
at697/examples/input/tsim.h	TSIM interface definitions
at697/examples/input/end.h	Defines the endian of the local machine

Table 24: Files delivered with the AT697 TSIM module

8.1 Loading the module

The module is loaded using the TSIM2 option -ahbm. All core specific options described in the following sections need to be surrounded by the options -designinput and -designinputend, e.g:

On Linux:

```
tsim-leon -ahbm ./at697/linux/at697.so
          -designinput ./at697/examples/input/pci.so -designinputend
```

On Windows:

```
tsim-leon -ahbm ./at697/win32/at697.dll
          -designinput ./at697/examples/input/pci.dll -designinputend
```

This loads the AT697 AHB module ./at697.so which in turn loads the PCI user module ./pci.so. The PCI user module ./pci.so communicates with ./at697.so using the PCI user module interface, while ./at697.so communicates with TSIM via the AHB interface.

8.2 AT697 initiator mode

The PCI user module should supply one callback function *acc()*. The AT697 AHB module will call this function to emulate AHB slave mode accesses or DMA accesses that are forwarded via *acc()*. The *cmd* parameter determines which command to use. Configuration cycles have to be handled by the PCI user module.

8.3 AT697 target mode

The AT697 AHB module supplies one callback *target_acc()* to the PCI user modules to implement target mode accesses from the PCI bus to the AHB bus. The PCI user module should trigger access events itself by inserting itself into the event queue.

8.4 Definitions

```
#define ESA_PCI_SPACE_IO      0
#define ESA_PCI_SPACE_MEM    1
#define ESA_PCI_SPACE_CONFIG 2
#define ESA_PCI_SPACE_MEMPLINE 3

/* atc697 pci input provider */
struct esa_pci_input {
    struct input_inp _b;

    int (*acc)(struct esa_pci_input *ctrl, int cmd, unsigned int  addr, unsigned int
    *data, unsigned int *abort,unsigned int  *ws);

    int (*target_acc)(struct esa_pci_input *ctrl, int cmd, unsigned int addr, unsigned
    int *data, unsigned int *mexc);
};
```

8.4.1 PCI command table

```
0000:    "IRQ acknowledge",
0001:    "Special cycle",
0010:    "I/O Read",
0011:    "I/O Write",
0100:    "Reserved",
0101:    "Reserved",
0110:    "Memory Read",
0111:    "Memory Write",
1000:    "Reserved",
1001:    "Reserved",
1010:    "Configuration Read",
1011:    "Configuration Write",
1100:    "Memory Read Mutltiple",
1101:    "Dual Address Cycle",
1110:    "Memory Read Line",
1111:    "Memory Write And Invalidate"
```

8.5 Read/write function installed by PCI module

This function should be set by the PCI user module:

```
int (*acc)(struct esa_pci_input *ctrl, int cmd, unsigned int  addr, unsigned int *data,
    unsigned int *abort, unsigned int  *ws);
```

If set, the function is called by the AT697 AHB module whenever the PCI interface initiates a transaction. The function is called for AHB-slave mapped accesses as well as AHB-Master/APB DMA. The parameter *cmd*

specifies the command to execute, see chapter 8.4.1. Parameter *addr* specifies the address. The user module should return the read data in **data* for a read command or write the **data* on a write command and return the time to completion in **ws* as PCI clocks. A possible target abort should be returned in **abort*. The return value should be: 0: taken, 1: not taken (master abort)

8.6 Read/write function installed by AT697 module

The following function is installed by the AT697 AHB module:

```
int (*target_acc)(struct esa_pci_input *ctrl, int cmd, unsigned int addr, unsigned int
    *data, unsigned int *mexc);
```

The PCI user module can call this function to emulate a PCI target mode access to the AT697 AHB module. Parameter *cmd* specifies the command to execute, see chapter 8.4.1. The AT697 module is supposed to be the host and accesses to the configuration space is not supported. Parameter *addr* specifies the address. Parameter **data* should point to a memory location where to return the read data on a read command or point to the write data on a write command. Parameter **mexc* should point to a memory location where to return a possible error. If the call was hit by MEMBAR0, MEMBAR1 or IOBAR, *target_read()* will return 1 otherwise 0.

8.7 Registers

Table 25 contains a list of implemented and not implemented fields of the AT697F PCI Registers. Only register fields that are relevant for the emulated PCI module is implemented.

Table 25: PCI register support

Register	Implemented	Not implemented
PCIID1	device id, vendor id	
PCISC	stat 13, stat 12, stat 11, stat 7, stat 6 stat 5, stat 4, com2, com 1, com1	stat15 stat14 stat10_9 stat8 com10 com9 com8 com7 com6 com5 com4 com3
PCIID2	class code, revision id	
PCIBHDL	[bist, header type, latency timer, cache size] config-space only	
PCIMBAR1	base address, pref, type, msi	
PCIMBAR2	base address, pref, type, msi	
PCIIOBAR3	io base address, ms	
PCISID	subsystem id, svi	
PCICP	pointer	
PCILI	[max_lat min_gnt int_pin int_line] config-space-only	
PCIRT	[retry trdy] config-space-only	
PCICW		ben
PCISA	start address	
PCIW		ben
PCIDMA	wdcnt, com	b2b
PCIIS	act, xff, xfe, rfe	dmas, ss
PCIIC	mod, commsb	dwr, dww, perr
PCITPA	tpa1, tpa2	
PCITSC		errmem, xff, xfe, rfe, tms
PCIITE	dmaer, imier, tier	cmfer, imper, tbeer, tper, syser
PCIITP	dmaer, imier, tier	cmfer, imper, tbeer, tper, syser
PCIITF	dmaer, imier, tier, cmfer, imper, tbeer, tper, syser	
PCID	dat	
PCIBE	dat	
PCIDMAA	addr	
PCIA		p0, p1, p2, p3

8.8 Debug flags

The switch `-designdbgon flags` can be used to enable debug output. The possible values for *flags* are as follows:

Flag	Description
<i>ESAPCI_REGACC</i>	Trace accesses to the PCI registers
<i>ESAPCI_ACC</i>	Trace accesses to the PCI AHB-slave address space
<i>ESAPCI_DMA</i>	Trace DMA
<i>ESAPCI_IRQ</i>	Trace PCI IRQ

8.9 Commands

pci	Displays all PCI registers.
------------	-----------------------------

APPENDIX A: Installing HASP Device Driver

A.1 Installing HASP Device Driver

TSIM is licensed using a HASP USB hardware key. Before use, a device driver for the key must be installed. The latest drivers can be found at www.aladdin.com or www.gaisler.com. The installation is described below.

A.1.1 On a Windows NT/2000/XP host

The HASP device driver is installed using the installer HASPUserSetup.exe located in hasp/windows/driver directory on the GRMON CD. It will automatically install the required files.

Note: Administrator privileges are required to install the HASP device driver under Windows NT/2000/XP.

A.1.2 On a Linux host

The linux HASP driver consists of aksusbd daemon. It is contained in the hasp/linux/driver on the TSIM CD. The driver comes in form of RPM packages for Redhat and Suse linux distributions. The packages should be installed as follows:

Suse systems:

```
rpm -i aksusbd-suse-1.8.1-2.i386.rpm
```

Redhat systems:

```
rpm -i aksusbd-redhat-1.8.1-2.i386.rpm
```

The driver daemon can then be started by re-booting the most, or executing:

```
/etc/rc.d/init.d/aksusbd start
```

Note: All described action should be executed as root.

On other linux distributions, the driver daemon will have to be started manually. This can be done using the HDD_Linux_dinst.tar.gz, which also contains instruction on how to install and start the daemon. Note that you need to have usbfs or usbdevfs mounted on /proc/bus/usb before starting the daemon. This can be done in rc.local or similar:

```
mount -t usbfs none /proc/bus/usb
```

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