

BCC - Bare-C Cross-Compiler User's Manual

Version 1.0.36, April 2011

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1 Introduction

1.1 Scope

BCC is a cross-compiler for LEON2 and LEON3 processors. It is based on the GNU compiler tools and the Newlib standalone C-library. The cross-compiler system allows compilation of both tasking and non-tasking C and C++ applications. It supports hard and soft floating-point operations, as well as SPARC V8 multiply and divide instructions. BCC can also be used to compile the eCos kernel.

BCC consists of the following packages:

- GNU GCC C/C++ compiler v3.4.4, v4.4.2
- Newlib C-library v 1.13.1
- Low-level I/O routines for LEON2 and LEON3/4, including interrupt support
- uIP light-weight TCP/IP stack
- GDB debugger v6.4 with DDD and Insight Graphical front-end
- Mkprom prom-builder for LEON2/3
- Linux and Windows (MingW) hosts

1.2 Installation

1.2.1 Linux

BCC is provided as a bziped tar-file. It should be unpacked in the /opt directory of the host:

```
mkdir /opt
tar -C /opt -xjf sparc-elf-<version-number>.tar.bz2
```

After installation, add /opt/sparc-elf-<gcc-version-number>/bin to the PATH variable. This should be done by adding the following line to the file .profile in the home directory:

```
export PATH=/opt/sparc-elf-<gcc-version-number>/bin:$PATH
```

1.2.2 Windows

BCC for Windows is provided for native Windows (MinGW). It does not require any additional packages and can be run from a standard Command Prompt.

The native Windows version of BCC is packaged with zip. Use a tool like WinZip to uncompress it to a directory, e.g., C:\opt. Note: The directory should not contain spaces (or any other non-ASCII characters) as this will confuse the compiler.

To use the compiler the bin subdirectory, e.g., C:\opt\bin, must be added to the PATH environment variable. This can be done from the Control Panel:

```
System -> Advanced -> Environment Variables...
```

See <http://www.mingw.org/> for more information on MinGW and the optional MSYS environment.

1.3 Building from source

The source code for BCC is available from the Gaisler homepage www.gaisler.com. To build BCC from source you should:

- untar the source archive to <dir>
- issue “*cd <dir>;make download*”. This will download the original gcc, binutils and newlibc sources.
- issue “*cd <dir>; make install*”. This will untar all the downloaded original archives over the current sourcetree, preserving the LEON specific files.
- issue “*cd <dir>; make all*”. This will build the 4.4.2 and 3.4.4 toolchains. The default prefix is /opt.

1.4 Technical support

Technical support for BCC can be obtained from Aeroflex Gaisler AB by purchasing a technical support contract. Please contact sales@gaisler.com for details.

2 General development flow

2.1 Overview

Compilation and debugging of applications is typically done in the following steps:

1. Compile and link program with gcc
2. Debug program on a simulator or remote target
3. Create boot-prom for a standalone application

BCC supports both tasking and non-tasking C/C++ programs. Compiling and linking is done in the same manner as with a host-based gcc, and will not be explained here. The produced binaries will run on both LEON2 and LEON3/4 systems, without requiring any switches during compilation.

2.2 Gcc options

All gcc options are described in detail in the gcc manual. Some useful options are:

- -g generate debugging information - must be used for debugging with gdb
- -msoft-float emulate floating-point - must be used if no FPU exists in the system
- -mcpu=v8 generate SPARC V8 mul/div instructions - needs hardware multiply and divide
- -O2 or -O3 optimise code maximum performance and minimal code size
- -qsvt use the single-vector trap model
- -mtune=ut699sets UT699 specific parameters

Note that in GCC version 3.4.4 -mcpu=v8 was called -mv8 and -mflat was present:

- -mv8 generate SPARC V8 mul/div instructions - needs hardware multiply and divide
- -mflat do not use register windows (i.e. no save/restore instructions). This options is only available in gcc-3.4.4.

Ordinary C programs can be compiled without any particular switches to the compiler driver:

```
sparc-elf-gcc -msoft-float -g -O2 hello.c -o hello.exe
```

The default link address is start of RAM, i.e. 0x40000000 for LEON. Other link addresses can be specified through the -Ttext option (see gcc manual).

2.3 Floating-point considerations

If the targeted LEON processor has no floating-point hardware, then all applications must be compiled (and linked) with the -msoft-float option to enable floating-point emulation. When running the program on the TSIM simulator, the simulator should be started with the -nfp option (no floating-point) to disable the FPU.

2.4 LEON SPARC V8 instructions

Both LEON2 and LEON3 processors can be configured to implement the SPARC V8 multiply and divide instructions. The BCC compiler does by default not issue those instructions, but emulates them through a library. To enable generation of mul/div instruction, use the -mcpu=v8 switch during both compilation and linking. The v8 switch improves performance on compute-intensive applications and floating-point emulation.

LEON2 and LEON3 also supports multiply and accumulate (MAC). The compiler will never issue those instructions, they have to be coded in assembly. Note that the BCC assembler and other util-

ities are based on a modified version of GNU binutils-2.15 that supports the LEON MAC instructions.

2.5 Alternate register windows organization (only for GCC 3.X)

The compiler normally produces binaries that assumes that the target processor has 8 register windows. However, by compiling and linking with the **-mflat** switch, it is possible to produce binaries that will run on processors with only 2 register windows.

-mflat affect performance and code size. Using **-mflat**, the code size will increase with ~ 10%, and the performance will decrease with the same amount. When creating boot proms (see below), it is essential that the same **-mflat** parameter is given to `sparc-elf-mkprom`, as was used when the binary was compiled. Any miss-match will produce a faulty prom image.

2.6 Single vector trapping

When the vhd1 model is configured to support single vector trapping (svt) the `-qsvt` switch can be used with the linker to build an image that uses a dispatcher rather than a static trap table. The saving amounts to ~4k for the trap table, however trap handling will be slower. The image will try to enable svt on boot using `%asr17`.

2.7 Memory organization

The resulting executables are in elf format and have three main segments; text, data and bss. The text segment is by default at address 0x40000000 for LEON2 and LEON3, followed immediately by the data and bss segments. The stack starts at top-of-ram and extends downwards. The area between the end of bss and the bottom of the stack is used for the heap.

2.8 Creating LEON boot proms

To make a boot prom that will run from the prom on a standalone LEON target, use the `Mkprom2` utility available from the Aeroflex Gaisler website. It will create a compressed boot image that will load the application to the RAM, initiate various LEON registers, and finally start the application. `Mkprom2` will set all target dependent parameters, such as memory sizes, waitstates, baudrate, and system clock. The applications compiled with `sparc-elf-gcc` do not set these parameters themselves, and thus do not need to be re-linked for different board architectures.

Please see the `Mkprom2` manual for further information.

2.9 Newlib C-library

2.9.1 Stdio

BCC applications uses Newlib, which is a posix compatible C-library with full math support. However, no file or other I/O related functions will work, with the exception of I/O to `stdin`/`stdout`. `Stdin`/`stdout` are mapped on UART A, accessible via the usual `stdio` functions.

2.9.2 Time functions

The LEON timers are used to generate the system time. The function `clock()` will return the time expired in microseconds. The `gettimeofday()`, `time()` and `times()` can also be used to get the time. Before the time functions can be used, `leonbare_init_ticks()` should be called to start the LEON timers and install the timer interrupt handler:

```
#include <asm-leon/timer.h>
void leonbare_init_ticks();
```

This will initialize `Timer1` and `Timer2`. `Timer1` is used to generate ticks at 100Hz while `Timer2` is used to create high resolution timer events. `Timer1` ticks can be used by installing a ticker callback at

```
tickerhandler ticker_callback;
```

Timer2 timer events can be generated by initializing a struct `timerevent` structure and calling

```
#include <asm-leon/timer.h>
int addtimer(struct timerevent *e);
```

struct `timerevent` 'expire' field is the timeposition at which the event should be triggered. The current time can be retrieved using `int gettimeofday(struct timeval *tv, struct timezone *tz);`

2.9.3 Task switching

Task switching is supported by the functions:

```
#include <contextswitch.h>
int thread_setjmp(threadctx_t env, int val);
void thread_longjmp(threadctx_t env, int val);
```

`thread_longjmp()` will save the current register windows to the stack and jump to the stack previously saved by `thread_setjmp()` similar to `clib's setjmp` and `longjmp` construct. You can create your own scheduler by using a construct like:

```
void sched() {
    ...
    thread_longjmp(next());
}
...
if (!thread_setjmp(self()))
    sched();
...
```

2.9.4 Simple multi-tasking

Using the task switching primitives, a simple multi-tasking environment is supported by the functions:

```
#include <asm-leon/leonbare_kernel.h>
leonbare_thread_init();
leonbare_thread_create(struct leonbare_thread *thread1, char *stack1, int sizeof_stack1);
```

`leonbare_thread_init()` initializes and starts a simple scheduler, with `leonbare_thread_create()` you create and add a task to it. struct `leonbare_thread's` `th_func` member has to be initialized with the thread's entry function. The scheduler is a preemptive scheduler with `LEONBARE_RUNQ_NR` number of run queues. See `newlibc/libgloss/sparc_leon/kernel.c` for details.

2.9.5 Interrupt handling

Installing an interrupt handle is done by initializing member *handler* of a global variable *struct irqaction* and calling:

```
#include <asm-leon/irq.h>
void chained_catch_interrupt (int irq, struct irqaction *a );
```

where `irq` is the `irq` number (1 - 15). The supplied struct `irqaction` will be inserted in a list and therefore should be global.

The simple `void *catch_interrupt(void func(int irq), int irq);` is also supported which uses `chained_catch_interrupt` internally.

The source code for `libgloss` (`libleonbare.a`) can be found in the `src/libgloss` directory.

For systems using the extended LEON3 interrupt controller with support for up to 31 interrupts it is possible to use irq 1-31 with `catch_interrupt()` and `chained_catch_interrupt()`.

Low-level interrupt processing takes around 40 instructions to setting up the C environment for the interrupt handler, and another ~25 instruction to dispatch irq to the associated handler. If very fast processing is required, a custom lowlevel assembler irqroutine can be installed using:

```
#include <asm-leon/leon.h>
void lowlevelirqinstall(int irqnr,void (*handler)());
```

This will write instructions:

```
sethi    %hi(handler), %l4;
jmpl    %l4 + %lo(handler), %g0;
nop
```

at address `trampoline+0x100+(irqnr*16)`. The callers low-level interrupt routine has to ensure proper environment setup before calling a C routine. This includes saving volatile register, checking for invalid windows and avoiding nested irqs. An appropriate routine would be written in assembler.

In case of single (-qsvt) vector trap schemes you have to use the following function to insert a irq handler:

```
int svtlowlevelirqinstall(int trap,void (*handler)())
```

In case of -qsvt a table is used to dispatch the traps:

```
struct svt_trap_entry {
int start,end;
void (*func)(void);
};
extern struct svt_trap_entry trap_table[28];
```

Where *start* and *end* specify the range of traps that handler *func* should process. The last entry in the table should be {0,0,0}. You can modify the table by hand or use `svtlowlevelirqinstall` to install a interrupt handler for you. Note that the irq number is trap number + 0x10. The symbol `svt_trap_table_ext_end` marks the end of the trap dispatch table. To insert a trap handler in -qsvt mode you can use the function

```
int svtlowleveltrapinstall(int trap,void (*handler)());
```

`svtlowlevelirqinstall(irq,handler)` is equivalent to `svtlowleveltrapinstall(irq+0x10,handler)`.

```
Trap pre-amble
-----
1572 400001a0 ae10200a mov    10, %l7
1579 400001a4 a1480000 mov    %psr, %l0
1580 400001a8 108022fc ba    0x40008d98
1581 400001ac a7500000 mov    %wim, %l3

1582 40008d98 2d000004 sethi  %hi(0x1000), %l6
1587 40008d9c a02c0016 andn  %l0, %l6, %l0
1588 40008da0 2d100023 sethi  %hi(0x40008c00), %l6
1595 40008da4 ac15a1a8 or    %l6, 0x1a8, %l6
1596 40008da8 29100025 sethi  %hi(0x40009400), %l4

etraps.s save state
-----
1597 40008dac 81c52170 jmp    %l4 + 0x170
1599 40008db0 932de008 sll   %l7, 8, %o1
1606 40009570 aa27a138 sub   %fp, 312, %l5
1613 40009574 c2256074 st    %g1, [%l5 + 0x74]
1616 40009578 c43d6078 std   %g2, [%l5 + 0x78]
1620 4000957c c83d6080 std   %g4, [%l5 + 0x80]
1624 40009580 cc3d6088 std   %g6, [%l5 + 0x88]
1634 40009584 15100029 sethi  %hi(0x4000a400), %o2
1635 40009588 d602a050 ld    [%o2 + 0x50], %o3
1639 4000958c d6256134 st    %o3, [%l5 + 0x134]
```

```
1644 40009590 960560b0 add    %15, 176, %03
1651 40009594 d622a050 st     %03, [%02 + 0x50]
```

check for invalid window:

```
1654 40009598 a8102001 mov    1, %14
1655 4000959c a92d0010 sll   %14, %10, %14
1656 400095a0 808d0013 andcc %14, %13, %g0
1663 400095a4 02800013 be    0x400095f0
1664 400095a8 01000000 nop
1665 400095f0 81c5a008 jmp   %16 + 0x8
1673 400095f4 9c100015 mov   %15, %sp
```

back in irqtrap_fast.s:

check for nested_irq flag + set pil

```
1674 40008db0 932de008 sll   %17, 8, %01
1675 40008db4 92140009 or    %10, %01, %01
1676 40008db8 11100029 sethi %hi(0x4000a400), %00
1677 40008dbc 90122054 or    %00, 0x54, %00
1678 40008dc0 d0020000 ld    [%00], %00
1688 40008dc4 80a00008 cmp   %00
1691 40008dc8 22800002 be,a  0x40008dd0
1692 40008dcc 92126f00 or    %01, 0xf00, %01
1693 40008dd0 818a6020 mov   %01, 0x20, %psr
1700 40008dd4 01000000 nop
1701 40008dd8 01000000 nop
1702 40008ddc 01000000 nop
```

call routine catch_interrupt.c: handler_irq():

```
1703 40008de0 90100017 mov   %17, %00
1710 40008de4 40000028 call  0x40008e84
1711 40008de8 9203a0f0 add   %sp, 240, %01
1712 40008e84 9de3bf98 save  %sp, -104, %sp
1713 40008e88 03100029 sethi %hi(0x4000a400), %g1
1714 40008e8c 9b2e2002 sll   %i0, 2, %05
1715 40008e90 82106228 or    %g1, 0x228, %g1
1722 40008e94 e000400d ld    [%g1 + %05], %10
1723 40008e98 80a42000 cmp   %10
1726 40008e9c 02800018 be    0x40008efc
1727 40008ea0 a4102001 mov   1, %12
1734 40008ea4 10800007 ba    0x40008ec0
1735 40008ea8 da040000 ld    [%10], %05
1739 40008ec0 80a36000 cmp   %05
1748 40008ec4 02bffffa be    0x40008eac
1749 40008ec8 23100029 sethi %hi(0x4000a400), %11
1750 40008ecc c2046124 ld    [%11 + 0x124], %g1
1754 40008ed0 90100018 mov   %i0, %00
1761 40008ed4 80a06000 cmp   %g1
1762 40008ed8 12bffff5 bne   0x40008eac
1764 40008edc 94100019 mov   %i1, %02
1765 40008ee0 d2042008 ld    [%10 + 0x8], %01
1775 40008ee4 9fc34000 call  %05
1777 40008ee8 e4246124 st    %12, [%11 + 0x124]
```

-- installed irq handler

```
1780 40001260 9de3bf98 save  %sp, -104, %sp
```

2.9.6 Interrupt nesting

The variable

```
extern unsigned int nestedirq;
```

can be set to 1 if irq nesting is desired. By default it is set to 0. In case of 0 the PSR's PIL will be set to 15 (highest) to keep the irq processing uninterrupted. If nestedirq is set to 1 the PSR's PIL will be set to the incoming irq's level, therefore causing higher level irq's to interrupt the current irq processing.

2.9.7 Small binary

Newlib atexit() introduces a dependency to malloc() which will add ~10k extra code. If you want to avoid this you can link against libsmall.a (**-lsmall**). libsmall.a's atexit() supports only a static 32 exit-function entries. The c library newlib atexit() function is declared weak and can be overridden.

- **-lsmall** remove reference to malloc() by override Newlibc atexit().
-

2.9.8 Reentrancy

Newlibc is compiled with reentrancy. Locking is done by symbols calling `__st_pthread_mutex_xxx` that are defined in as weak symbols libleonbare.a and can be overloaded (see `<newlibsrc>/libgloss/sparc_leon/mutex.c`). libleonbare.a's symbols do nothing by default. Users can plug in their own locking functions here. The mutex definitions are placeholders that should be typecasted by the desired mutex type. The user also has to set `_impure_ptr` on a task switch to point to the thread locals.

2.9.9 AMBA plug and play

The options `-qambapp` can be given to enable plug and play scanning for UART, timer and irq-ctrl across AHB2AHB bridges. The default setup only scans the CPU bus configuration area at 0xfff00000.

2.10 FreeRTOS

The simple scheduling library FreeRTOS (www.freertos.org) is included in the BCC distribution. Please refer to the FreeRTOS documentation on the website for information on how to use the FreeRTOS API. The precompiled library libfreertos.a has been compiled using the configuration file supplied in `<installdir>/sparc-elf/include/freertos/FreeRTOSConfig.h`. To recompile it with another configuration goto `<installdir>/src/freertos/`, change `FreeRTOSConfig.h` and type

```
$make recompile
```

You might also want to add more sources to `$(LIBOBJ)`.

3 Execution and debugging

3.1 TSIM simulator and GRMON debug monitor

LEON applications can be debugged on either the TSIM simulator or real target hardware through the use of the GRMON debug monitor. Both TSIM and GRMON can be connected to the GNU debugger (sparc-elf-gdb) to perform source-level symbolic debugging.

3.1.1 Running on the TSIM simulator

To execute an application in the TSIM LEON simulator, use the load command to load the binary, and the go command to execute the application:

```
$ tsim-leon3

    TSIM LEON SPARC simulator, version 2.0.3 (professional version)

Copyright (C) 2001, Gaisler Research - all rights reserved.
using 64-bit time
serial port A on stdin/stdout
allocated 4096 K RAM memory, in 1 bank(s)
allocated 2048 K ROM memory
icache: 1 * 4 kbytes, 16 bytes/line (4 kbytes total)
dcache: 1 * 4 kbytes, 16 bytes/line (4 kbytes total)

tsim> load hello.exe

section: .text at 0x40000000, size 35120 bytes
section: .data at 0x40008930, size 2080 bytes
section: .jcr at 0x400091b4, size 4 bytes

tsim> go

resuming at 0x40000000
Hello world!

Program exited normally.
grmon[sim]>
```

3.2 Debugging with GDB

To debug an application with gdb, start grmon with the -gdb option (or issue the gdb command inside grmon). Note that GRMON listens on port 2222 for a gdb connection. This can be changed to any port using the grmon -port switch at start-up.

```
$ tsim-leon3 -gdb

    TSIM LEON SPARC simulator, version 2.0.3 (professional version)

Copyright (C) 2001, Gaisler Research - all rights reserved.
using 64-bit time
serial port A on stdin/stdout
allocated 4096 K RAM memory, in 1 bank(s)
allocated 2048 K ROM memory
icache: 1 * 4 kbytes, 16 bytes/line (4 kbytes total)
dcache: 1 * 4 kbytes, 16 bytes/line (4 kbytes total)
gdb interface: using port 1234
```

Then, start gdb in a separate shell, load the application to the target, add optional breakpoints, and finally execute the application using the gdb run command:

```
$ sparc-elf-gdb hello.exe
GNU gdb 5.3
Copyright 2002 Free Software Foundation, Inc.
```

```
GDB is free software, covered by the GNU General Public License, and you are
welcome to change it and/or distribute copies of it under certain conditions.
Type "show copying" to see the conditions.
There is absolutely no warranty for GDB.  Type "show warranty" for details.
This GDB was configured as "--host=i686-pc-linux-gnu --target=sparc-tsim-elf"...
(gdb) tar extended-remote localhost:1234
Remote debugging using localhost:1234
0x00000000 in ?? ()
(gdb) load
Loading section .text, size 0x8930 lma 0x40000000
Loading section .data, size 0x820 lma 0x40008930
Loading section .jcr, size 0x4 lma 0x400091b4
Start address 0x40000000, load size 37204
Transfer rate: 297632 bits in <1 sec, 275 bytes/write.
(gdb) break main
Breakpoint 1 at 0x40001384: file hello.c, line 4.
(gdb) run
The program being debugged has been started already.
Start it from the beginning? (y or n) y
Starting program: /home/jiri/samples/hello.exe

Breakpoint 1, main () at hello.c:4
4          printf("Hello world!\n");
(gdb)
```

To re-execute the application, first re-load it to the target using the **gdb load** command and the issue **run** again.

3.3 Debugging on target hardware

To connect GRMON to a LEON system, start GRMON on the command line in a shell window. By default, GRMON will connect to the processor debug support unit (DSU) using a serial port of the host (ttyS0 or com1). See the GRMON manual for how to connect via JTAG, PCI, ethernet or Spacewire. Once connected, the application can be downloaded and executed using the same procedure as when the simulator is used:

```
$ grmon -u

GRMON - The LEON multi purpose monitor v1.0.7

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For latest updates, go to http://www.gaisler.com/
Comments or bug-reports to grmon@gaisler.com

using port /dev/ttyS0 @ 115200 baud

initialising .....

Component                               Vendor
Leon3 SPARC V8 Processor                 Gaisler Research
AHB Debug UART                           Gaisler Research
Ethernet DSU interface                   Gaisler Research
LEON2 Memory Controller                  European Space Agency
AHB/APB Bridge                           Gaisler Research
Leon3 Debug Support Unit                 Gaisler Research
Generic APB UART                         Gaisler Research
Multi-processor Interrupt Ctrl           Gaisler Research
Modular Timer Unit                       Gaisler Research

Use command 'info sys' to print a detailed report of attached cores

grmon[grib]> load hello.exe
section: .text at 0x40000000, size 35120 bytes
section: .data at 0x40008930, size 2080 bytes
section: .jcr at 0x400091b4, size 4 bytes
total size: 37204 bytes (99.4 kbit/s)
read 110 symbols
```

entry point: 0x40000000

```
grmon[grlib]> run
Hello world!
```

```
Program exited normally.
grmon[grlib]>
```

Connecting GDB to GRMON when attached to a real LEON target is done in the same way as when using the simulator. Note that GRMON uses port 2222 to communicate with gdb, while TSIM uses port 1234.

3.4 Using the DDD graphical front-end to GDB

DDD is a graphical front-end to gdb, and can be used regardless of target. DDD must be started with the --debugger switch to select the sparc debugger, rather than the native gdb:

```
ddd --debugger sparc-elf-gdb --attach-window
```

For further details on DDD operation, see the DDD home page:

<http://www.gnu.org/software/ddd/>

DDD has also a built-in manual under the HELP menu in the main window.

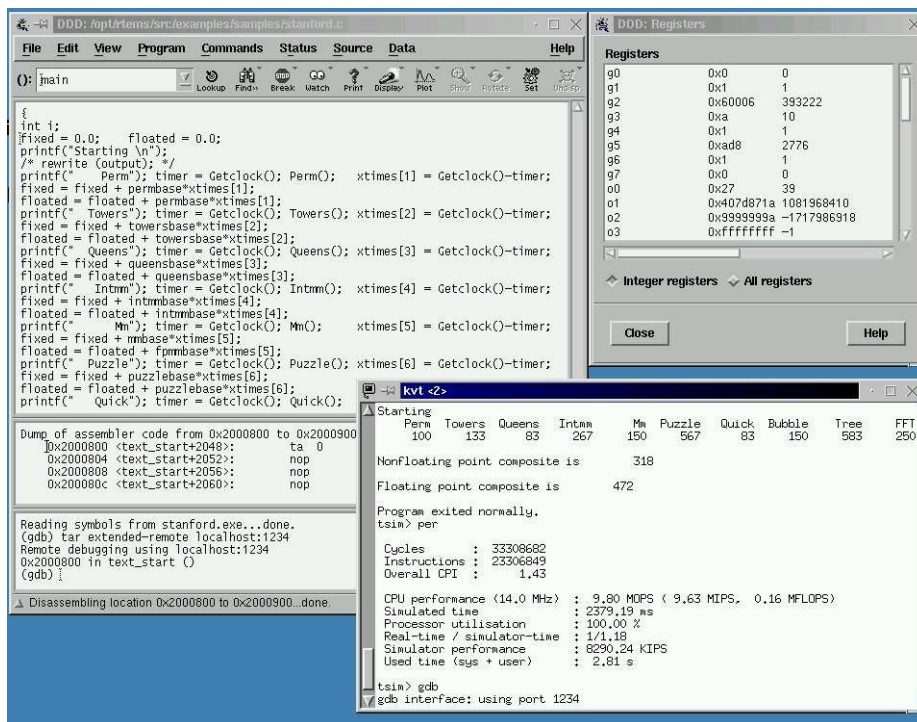


Figure 1. DDD with TSIM

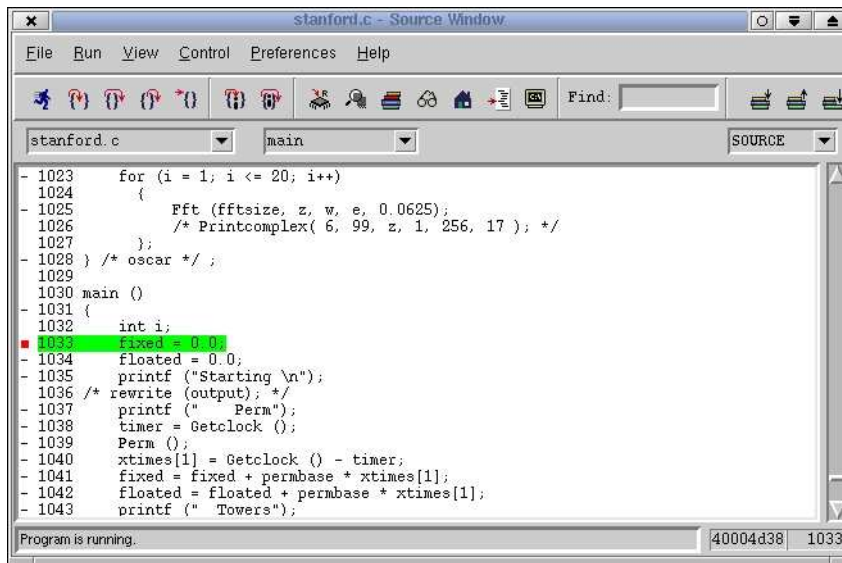
Attaching to TSIM of GRMON is done in the same manner as when using sparc-elf-gdb without DDD. The gdb commands are entered in the bottom command window. Remember to **load** the application first, before issuing a **run** command. On cygwin hosts, the cygwin X-server must first be started by issuing **startx** in a cygwin terminal. This will open an Xterm window, from which DDD should be started with the options mentioned above.

3.5 Using the Insight debugger

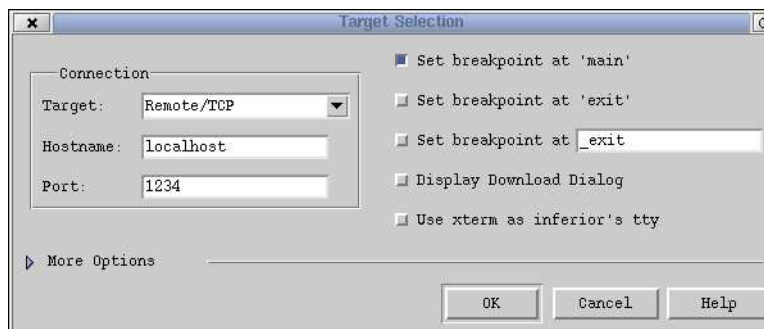
The Insight debugger is based on GDB-6.4 with an TCL/TK based graphical front-end. It can be used on both linux and cygwin hosts. The debugger is started with:

```
sparc-elf-insight app.exe
```

This will create the Insight main window:



Clicking on the RUN button (or selecting Run->Connect) will open the 'Connect to target' menu:



To connect to TSIM, select Remote/TCP and port 1234. To connect to GRMON, select port 2222. Enable the breakpoint on 'main', but disable the breakpoint on 'exit'. Before clicking on OK, make sure that you have started TSIM or GRMON in a separate window, and entered gdb mode.

Insight automatically downloads the application to the target when needed, so the load command does not have to be issued manually. To restart the application, just click on the RUN button again.

NOTE: Insight can only be used with TSIM-2.0.5 and GRMON-1.1.12, or later versions.