ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

CSCS
Swiss National Supercomputing Centre

Debugging Tools

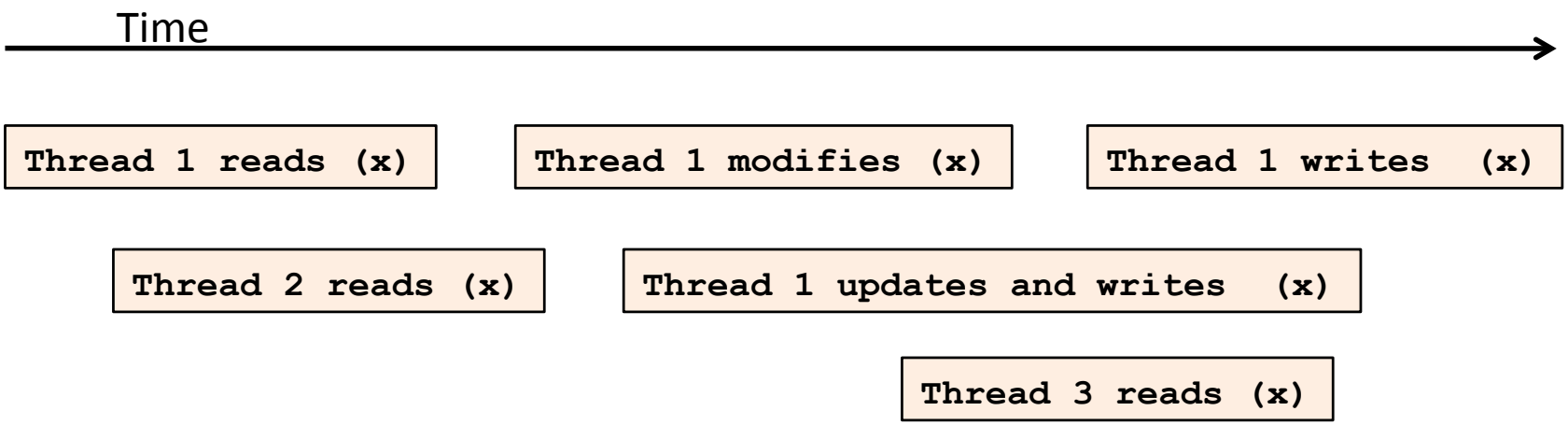
Multi-threaded Programming, Tuning and Optimization on Multi-core MPP Platforms

February 15-17, 2011

CSCS Manno

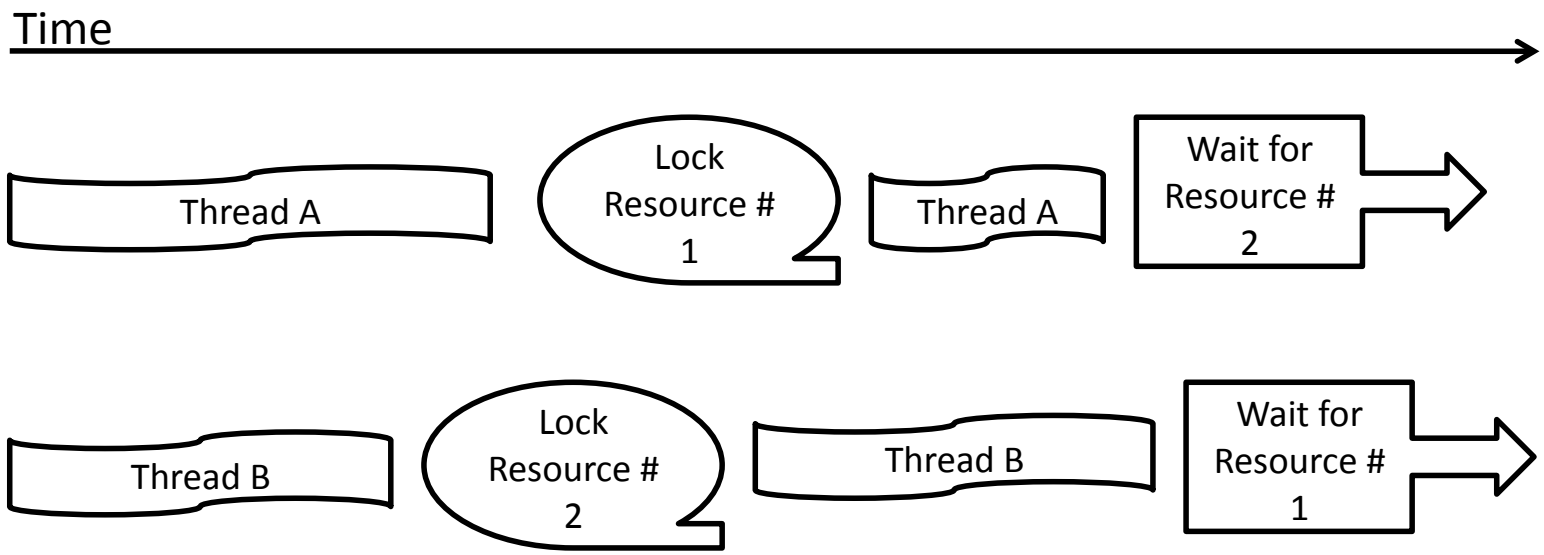
Potential Errors in Multithreaded Codes (1)

- Data Race Condition
  - Two or more threads accessing and updating same memory location
  - Unintended and unsynchronized access to shared variable resulting in unexpected behavior



Potential Errors in Multithreaded Codes (2)

- Deadlocks
  - Threads waiting on a resource that never becomes available



Deadlock Examples

```
!$OMP PARALLEL DEFAULT(SHARED)

!$OMP CRITICAL
      DO I = 1, 10
        X= X + 1
!$OMP   BARRIER
        Y= Y + I*I
      END DO
!$OMP END CRITICAL

!$OMP END PARALLEL
```

```
#pragma omp parallel
   myid = omp_get_thread_num();
   if (myid %2) {
      // do some odd work
      #pragma omp barrier
      // do more work
   }
   else {
      // do some even work
      #pragma omp barrier
      // do more work
   }
}
```

How To Avoid Deadlocks

- Using Barrier in for selected number of threads
- Avoid the lock functions as much as possible
- Avoid nesting of locks

Potential Errors in Multithreaded Codes (3)

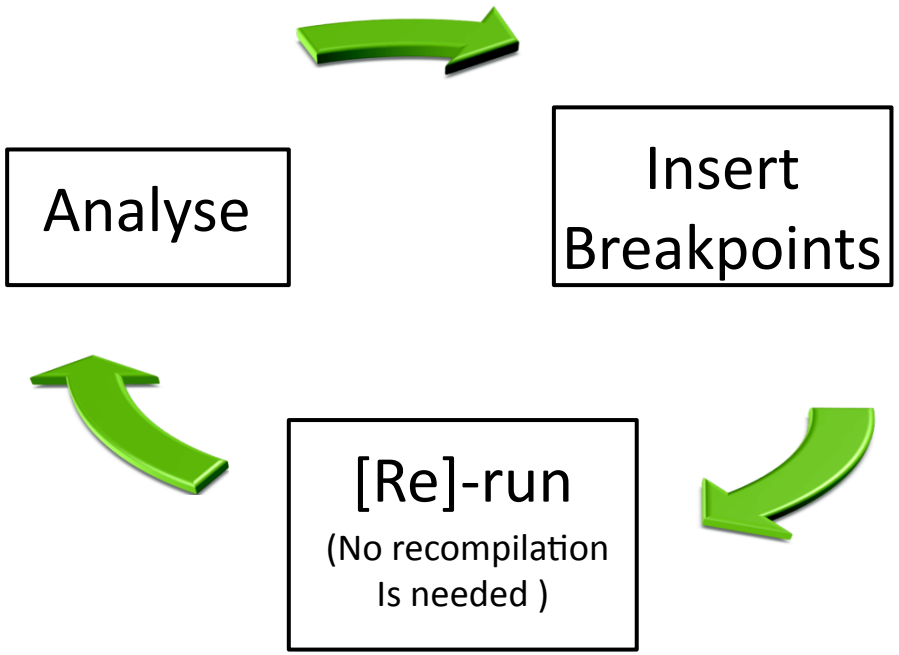
- Livelock
  - Infinite loop conditions for certain loops (traditional loop errors)
- Memory issues
  - Stack overflows due to replication of private data items
  - Memory leaks

Debugging

What is going on inside your application ?

A debugger will follow the program through execution so you can watch your program execute step by step and view the contents of memory :

* Let you examine the program execution step by step
* Make the program stops on specified places or on specified conditions
* Give information about current variables' values, the memory and stack



Important Debugging Concepts

- Stopping and watching a program execution at a certain point
  - Breakpoints
  - Watchpoints
- Stepping and continuing to control program execution
  - Single step lines of code
  - Single step assembler instructions
  - Resume program execution
- Examining the stack
  - Backtracing

Debugging Considerations Unique to OpenMP

- Challenges
  - Nondeterministic failures
  - Reproducibility and predictability of bugs
  - Compiler transformation manifests complex bugs
  - Memory analysis for data scoping constructs

- Use multi-threading feature of a debugger to:
  - Identify exactly when the failure occur (thread level)
  - Review program execution and memory contents
  - Inspect core files after a crash

Debugging Tools Available on CSCS Platforms

- Two tools available at the moment
  - Totalview (for hybrid MPI+OpenMP applications)
    - module avail xt-totalview
  - gdb
    - module avail gdb
- Must compile with the -g compiler flag
- For failures or crashes that occur after long execution times
  - Cray Fast Track Debugging (compile with -gFast)—only available for Cray compilers
  - For further info: http://docs.cray.com/books/S-9401-0909//S-9401-0909.pdf

Other Tools to Aid Multi-threaded Programming

- Debugging tools
  - Allinea DDT (MPI + OpenMP)
  - Debugger from different compiler vendors
  - …
- Correctness tools
  - Intel Inspector
  - Rogue Wave ThreadSpotter
  - …

Further Info

- Debugging and Performance Analysis Tools available at CSCS http://www.cscs.ch/145.0.html
- Craydocs http://docs.cray.com/
- Totalview tools (deubugger, memory scape and replay engine) http://www.totalviewtech.com/home/
- Allinea DDT http://www.allinea.com/products/ddt/
- Acumem ThreadSpotter and SlowSpotter http://www.acumem.com
- Eclipse Parallel Tools Platform http://www.eclipse.org/ptp/
- Intel Parallel Inspector http://software.intel.com/en-us/articles/intel-parallel-inspector/

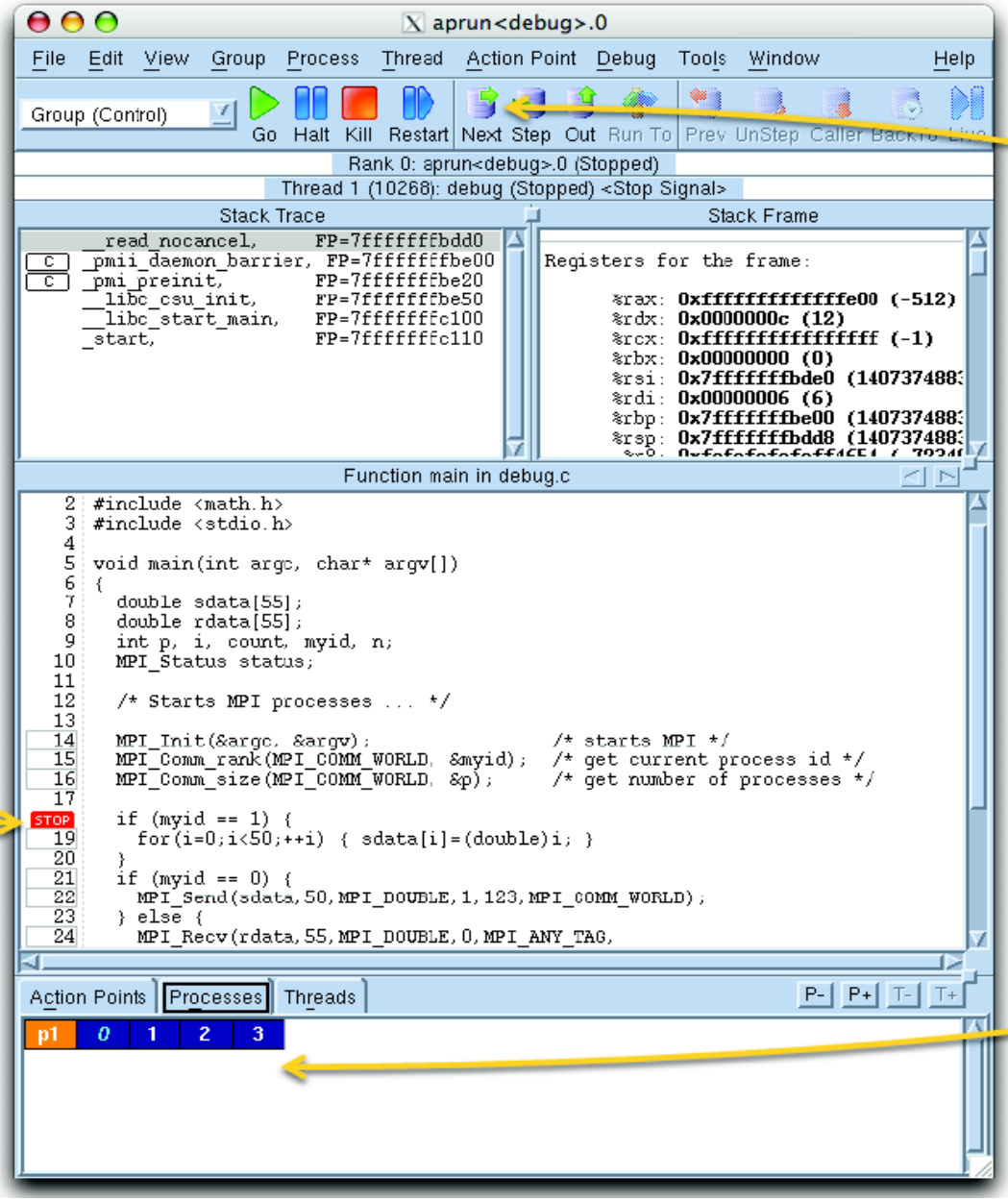
Totalview

- TotalView is a debugger with support for Fortran, C, C++, MPI, OpenMP and threads.
- TotalView is an interactive tool that lets you debug serial, multiprocessor and multithreaded programs. It can be executed either as a graphical user interface (by using the totalview executable) or from a command-line interface (by using the totalviewcli executable). Totalview provides source-level debugging of Fortran and Fortran 90, C, and C++ codes. It can be used to debug parallel programs based on MPI. It also has facilities for multi-process thread-based parallel programs such as OpenMP.

```
 palu1: module load PrgEnv-gnu
 palu1: module list
Currently Loaded Modulefiles:
  1) modules/3.2.6.6
  2) nodestat/2.2-1.0301.24557.5.3.gem
  3) sdb/1.0-1.0301.24568.5.18.gem
  4) MySQL/5.0.64-1.0301.2899.20.1.gem
  5) lustre-cray_gem_s/1.8.2_2.6.27.48_0.12.1_1.0301.
  6) udreg/2.1-1.0301.2797.5.2.gem
  7) ugni/2.1-1.0301.2798.5.2.gem
  8) gni-headers/2.1-1.0301.2792.5.1.gem
  9) dmapp/2.2-1.0301.2791.5.1.gem
 10) xpmem/0.1-2.0301.24575.5.2.gem
 11) slurm
 12) Base-opts/1.0.2-1.0301.24518.5.1.gem
 13) xtpe-network-gemini
 14) gcc/4.5.1
 15) totalview-support/1.1.1
 16) xt-totalview/8.8.0a
 17) xt-libsci/10.4.9
 18) xt-mpt/5.1.2
 19) pmi/1.0-1.0000.8160.39.2.gem
 20) /opt/cray/xt-asyncpe/4.5/modulefiles/xtpe-mc12
 21) xt-asyncpe/4.5
 22) PrgEnv-gnu/3.1.49A
 palu1:
```

TOTALVIEW TECHNOLOGIES

Breakpoints

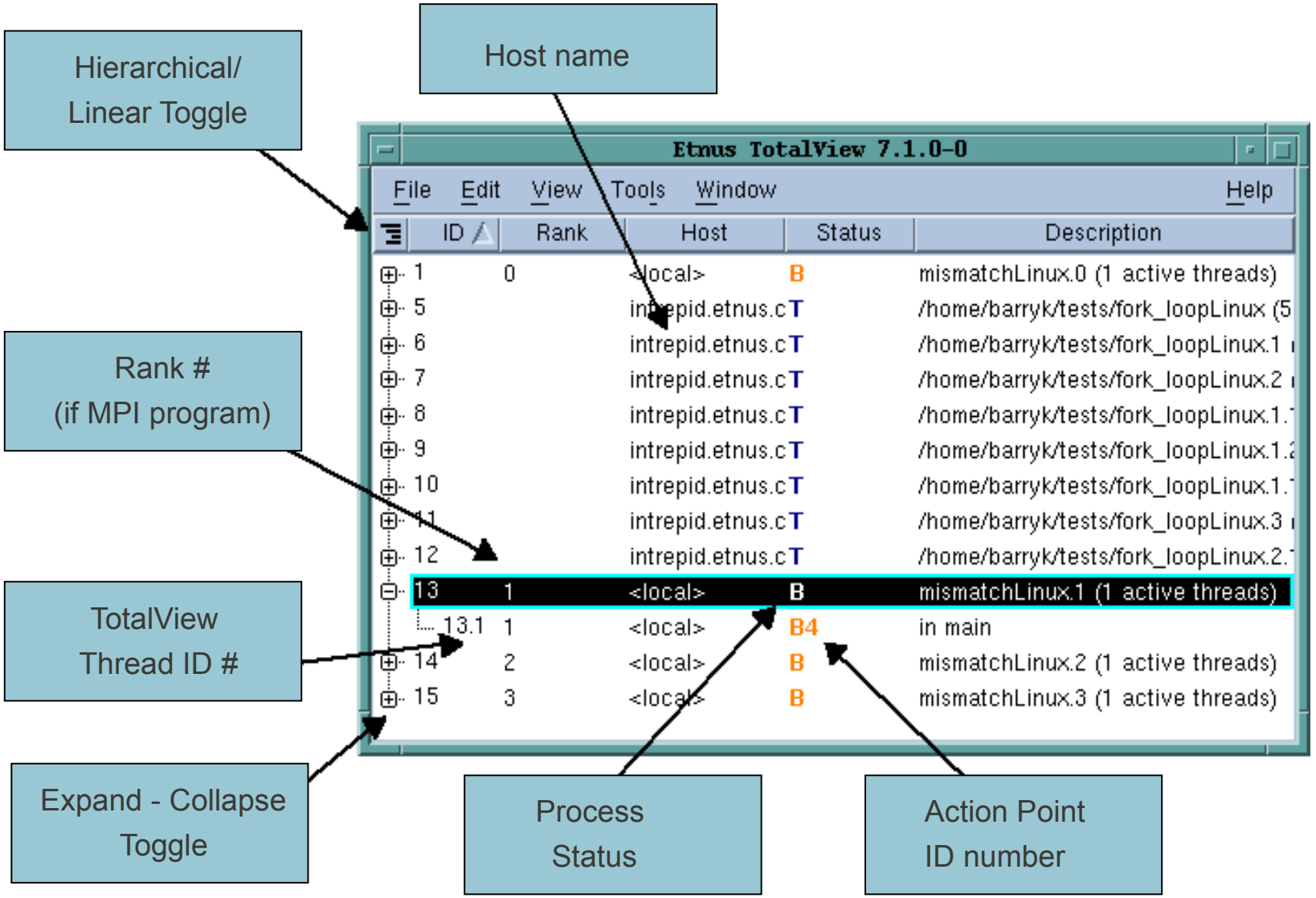


Execution Toolbars

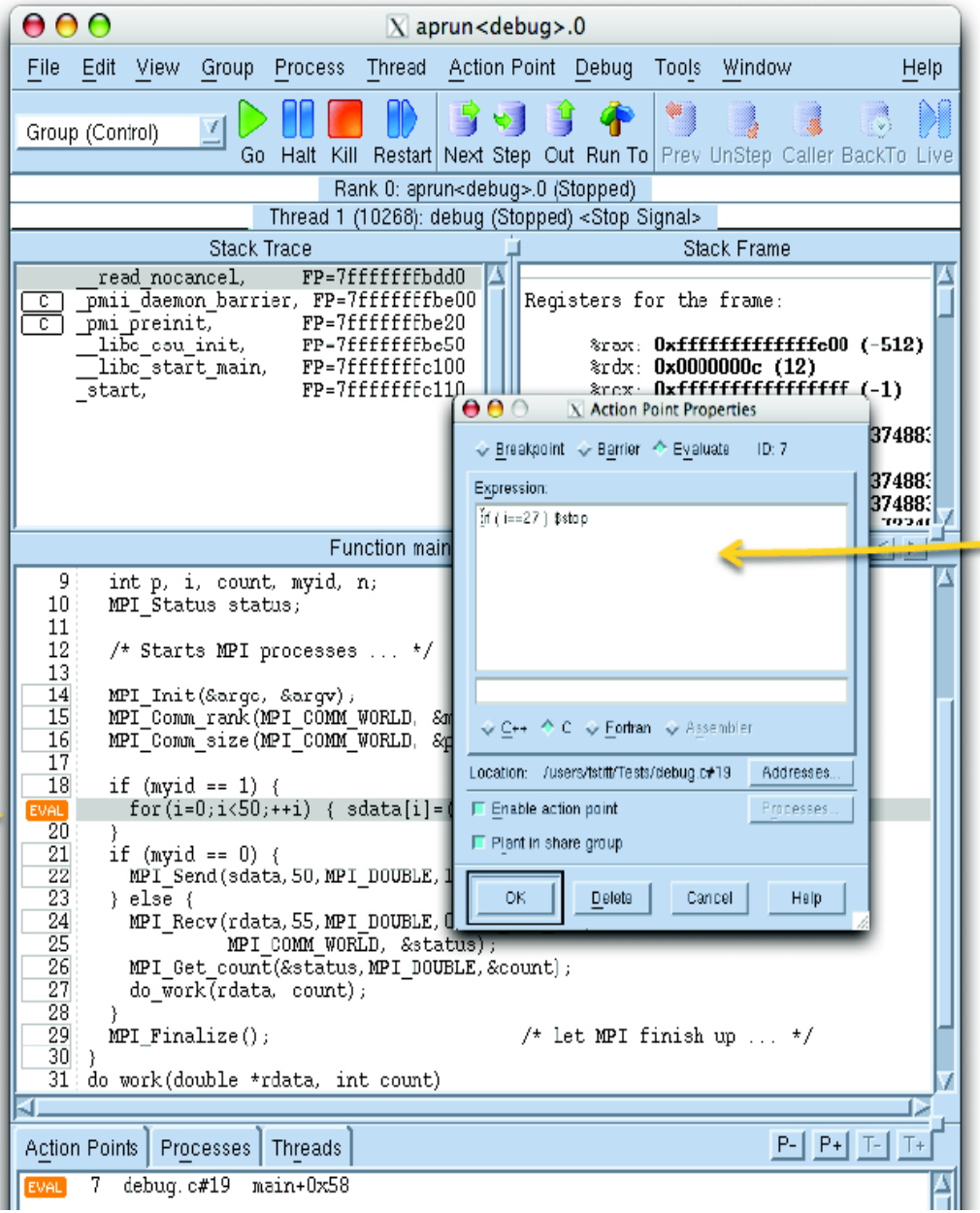
Set Breakpoint

Co-operating Processes

Root window


Hierarchical/
Linear Toggle
Host name
Rank #
(if MPI program)
TotalView
Thread ID #
Expand - Collapse
Toggle
Process
Status
Action Point
ID number
Etnus TotalView 7.1.0-0
File Edit View Tools Window Help
ID Rank Host Status Description
1 0 <local> B mismatchLinux.0 (1 active threads)
5 intrepid.etnus.cT /home/barryk/tests/fork_loopLinux (5
6 intrepid.etnus.cT /home/barryk/tests/fork_loopLinux.1
7 intrepid.etnus.cT /home/barryk/tests/fork_loopLinux.2
8 intrepid.etnus.cT
9 intrepid.etnus.cT
10 intrepid.etnus.cT
11 intrepid.etnus.cT /home/barryk/tests/fork_loopLinux.3
12 intrepid.etnus.cT
13 1 <local> B mismatchLinux.1 (1 active threads)
13.1 1 <local> B4 in main
14 2 <local> B mismatchLinux.2 (1 active threads)
15 3 <local> B mismatchLinux.3 (1 active threads)

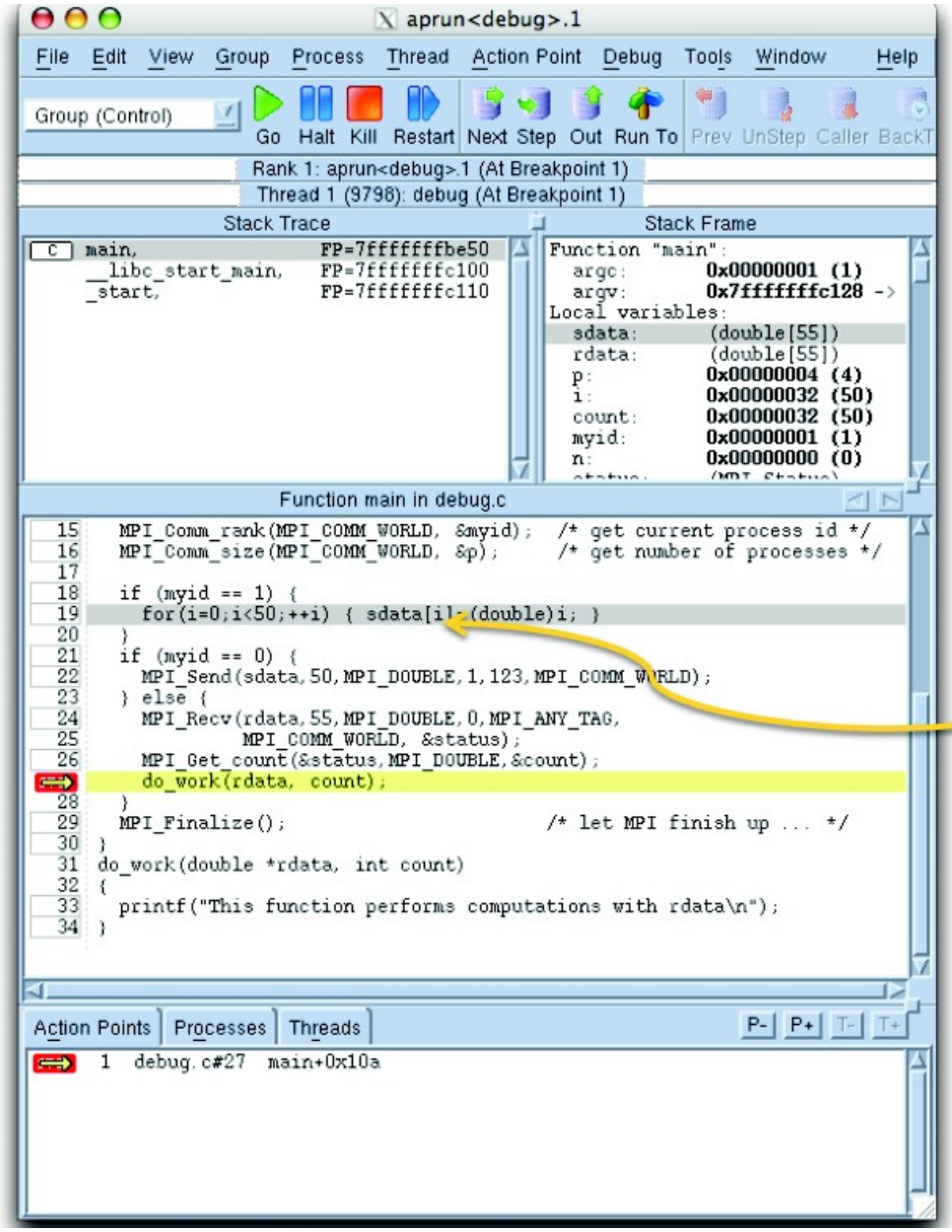
Action points



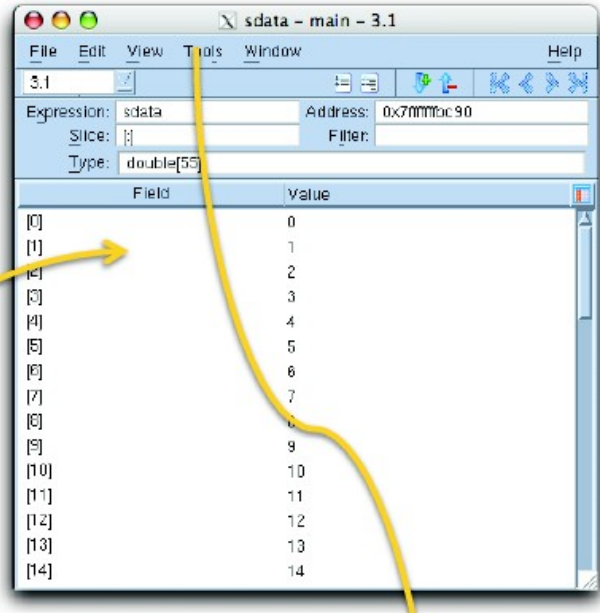
Set Evaluation Point

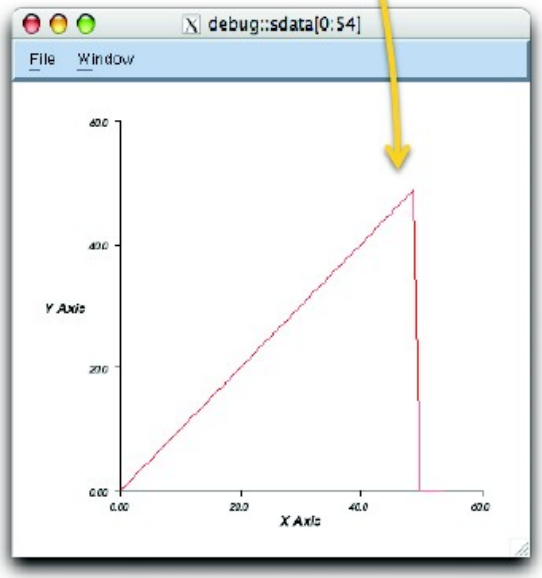
Enter Stopping Condition

Examining data

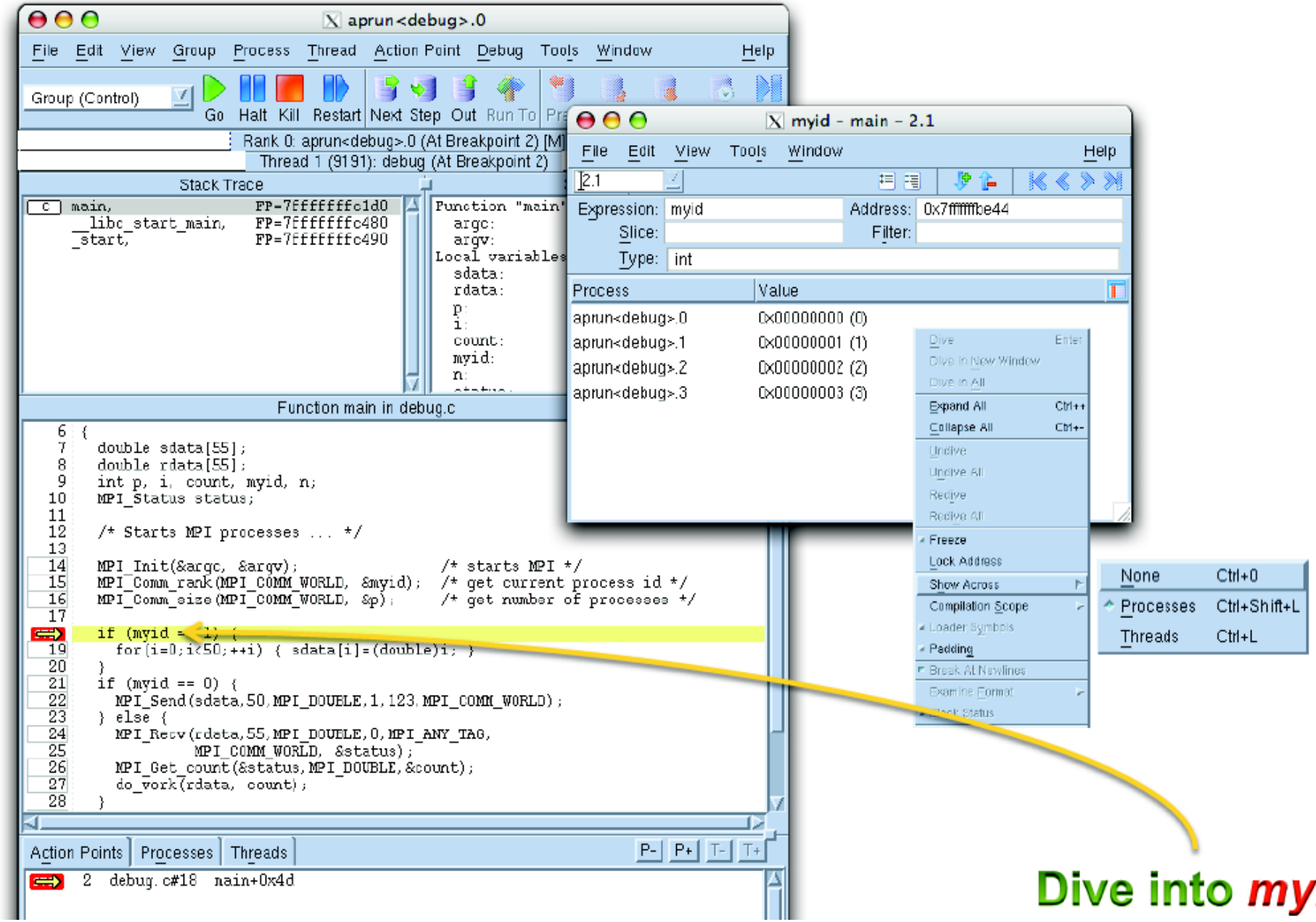


Dive in And Visualize

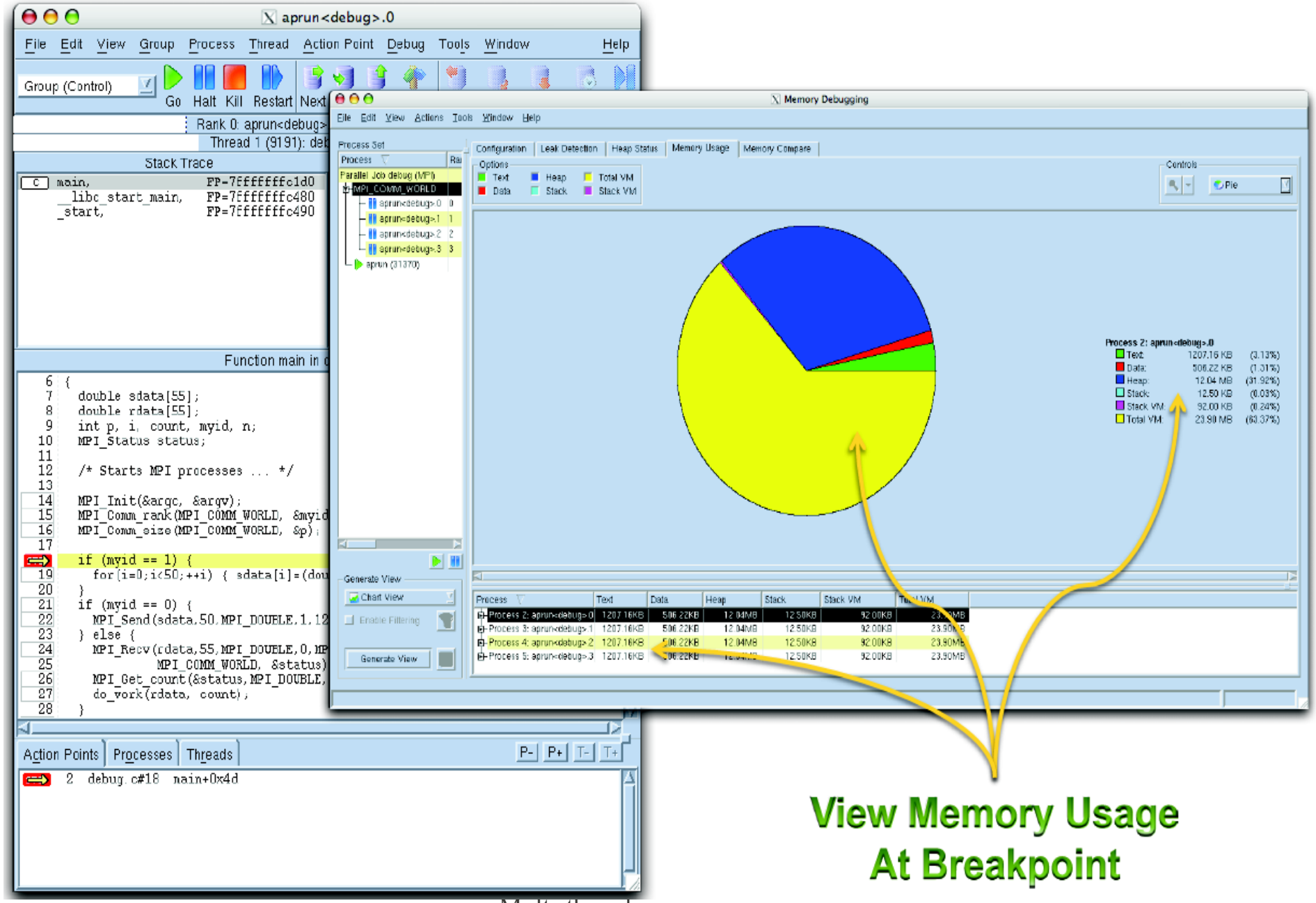




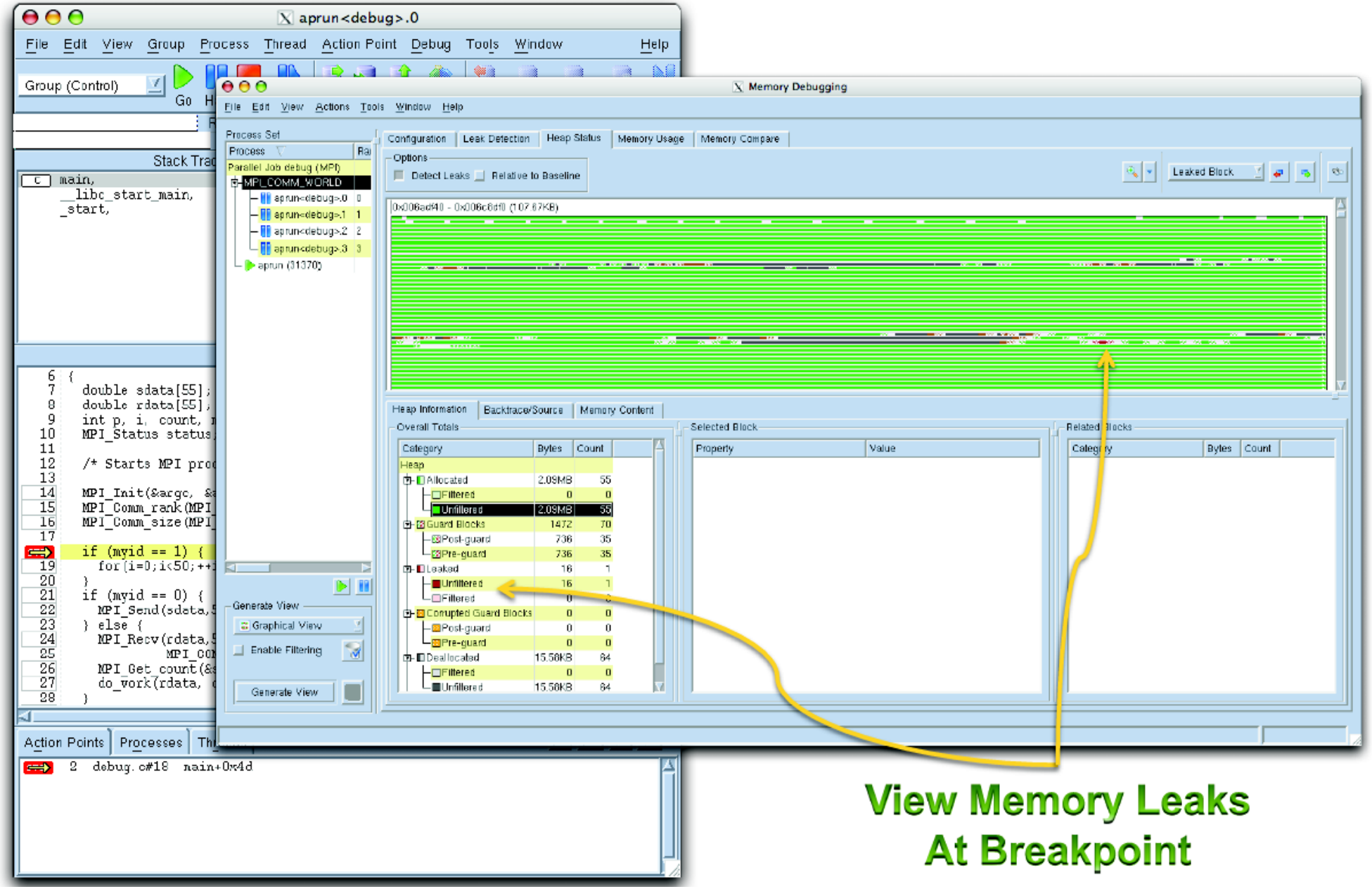
Viewing data across processes



Memory usage



Memory leaks



Demo : Totalview

Getting started (1)

/bin/bash 60x38

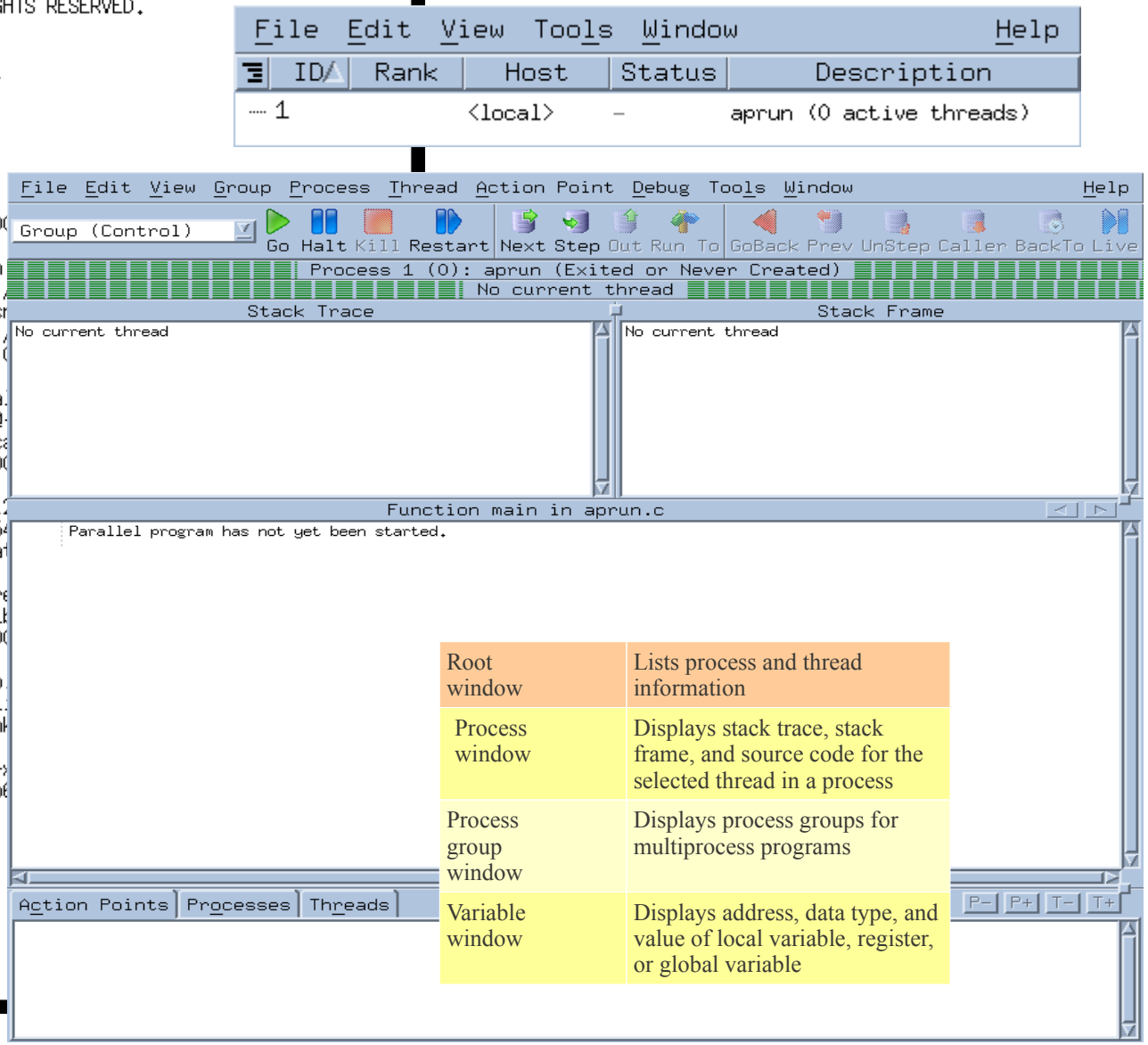
```
 1       program affinity
 2 !$      use omp_lib
 3
 4 #ifdef _MPI
 5       use mpi
 6 #endif
 7       IMPLICIT NONE
 8
 9       integer, external :: running_on
10       character(len=8) :: nid
11       integer :: coreid
12       integer :: rc=0, rank=0, numtask=0, corespercn=24
13       integer:: threadid=0, nthreads=0
14
15 #ifdef _MPI
16       call MPI_INIT ( rc )
17       call MPI_COMM_RANK ( MPI_COMM_WORLD, rank, rc )
18       call MPI_COMM_SIZE ( MPI_COMM_WORLD, numtask, rc )
19 #endif
20
21 !$omp parallel private(threadid,coreid,nid)
22 !$      threadid = omp_get_thread_num()
23 !$      nthreads = omp_get_num_threads()
24
25       call print_nodeaffinity(nid)
26       coreid = running_on()
27       print *, &
28         "rank=",rank,"/",numtask,            &
29         " cnid=",trim(nid(1:8)),             &
30         " threadid=",threadid ,"/",nthreads, &
31         " core=", coreid
32 !$omp end parallel
33 #ifdef _MPI
34       call MPI_FINALIZE ( rc )
35 #endif
36
37       end program affinity
"aff3.F90" 37 lines --2%--                1,1           All
```

Getting started (2)

```
 palu1: ls
aff2.F90  Makefile  runningon.c
 palu1: make  FFLAGS="-g -fopenmp -D_MPI"
cc -g -fopenmp -D_MPI -c runningon.c
ftn -g -fopenmp -D_MPI -c aff2.F90
ftn -g -fopenmp -D_MPI -o exe runningon.o aff2.o
/usr/lib/../lib64/libpthread.a(sem_open.o): In function `sem_open':
/usr/src/packages/BUILD/glibc-2.9/nptl/sem_open.c:330: warning: the use of `mktemp' is dangerous, better use `mkstemp'
 palu1:
 palu1:
 palu1: salloc -N2
salloc: Granted job allocation 2959
 palu1: squeue -u $USER
JOBID  USER     ACCOUNT           NAME PARTITION ST EXEC_HOST REASON          START_TIME     TIME  TIME_LEFT NODES PRIORITY
2959   piccinal csstaff          bash       day  R     palu1 None       2011-02-09T09:58     0:08      59:52     2        2
 palu1:
 palu1: export OMP_NUM_THREADS=2 ; aprun -n2 -N1 -d24 exe
 rank=           0 /           2  cnid=nid00003 threadid=           1 /           2  core=           1
 rank=           0 /           2  cnid=nid00003 threadid=           0 /           2  core=           0
 rank=           1 /           2  cnid=nid00004 threadid=           0 /           2  core=           0
 rank=           1 /           2  cnid=nid00004 threadid=           1 /           2  core=           1
 done
 done
Application 108245 resources: utime ~0s, stime ~0s
 palu1: exit
exit
salloc: Relinquishing job allocation 2959
salloc: Job allocation 2959 has been revoked.
 palu1:
```

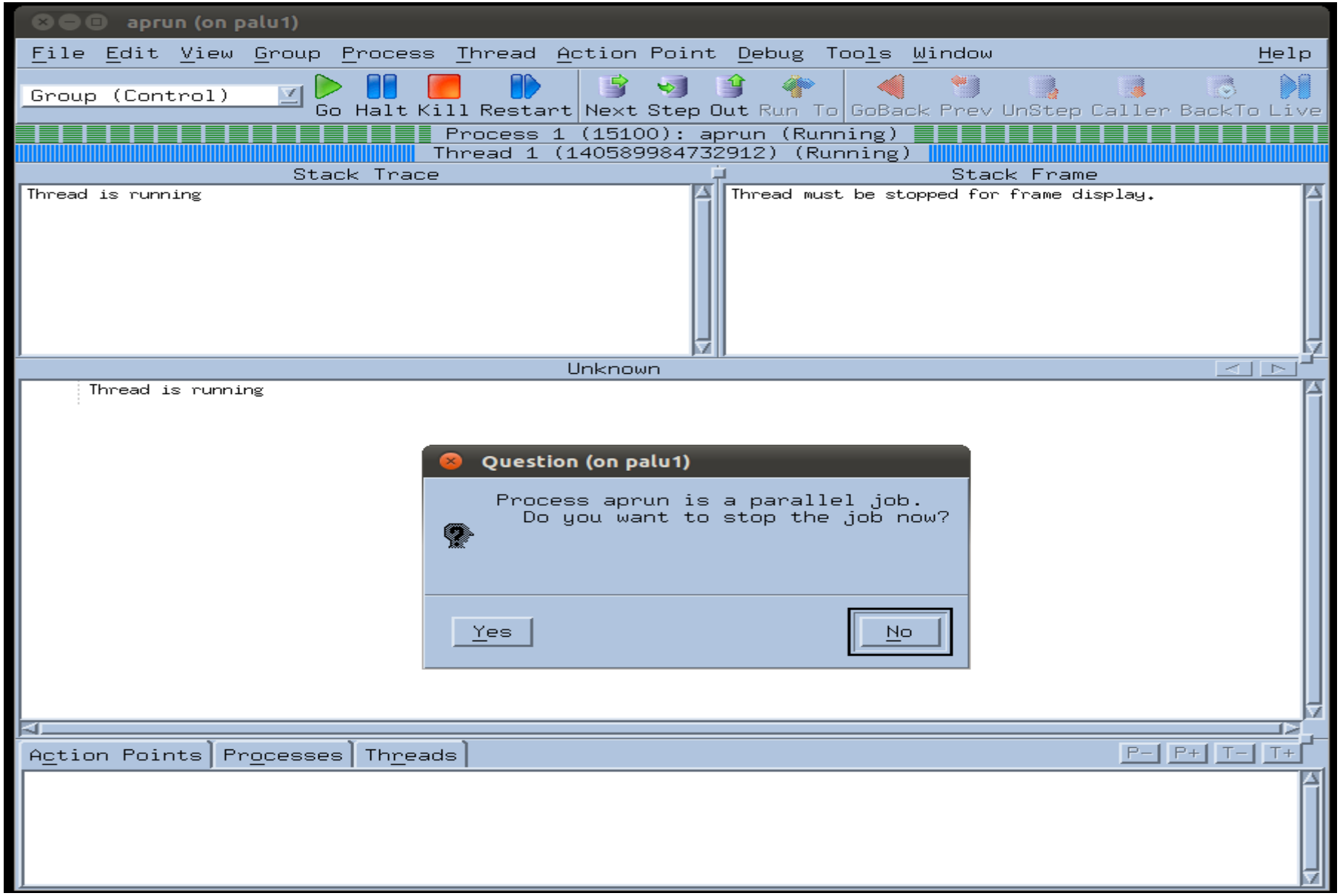
Launching Totalview (1)

```
 palu1: salloc -N2
salloc: Granted job allocation 2960
 palu1: export OMP_NUM_THREADS=2 ; totalview aprun -a -n2 -N1 -d24 exe
Linux x86_64 TotalView 8.8.0-1
Copyright 2007-2010 by TotalView Technologies, LLC. ALL RIGHTS RESERVED.
Copyright 1999-2007 by Etnus, LLC.
Copyright 1999 by Etnus, Inc.
Copyright 1996-1998 by Dolphin Interconnect Solutions, Inc.
Copyright 1989-1996 by BBN Inc.
TotalView Technologies ReplayEngine
Copyright 2010 TotalView Technologies
ReplayEngine uses the UndoDB Reverse Execution Engine
Copyright 2005-2010 Undo Limited
Reading symbols for process 1, executing "aprun"
Library /usr/bin/aprun, with 2 asects, was linked at 0x0040(
t 0xff00000090000000
Mapping 25131 bytes of ELF string data from '/usr/bin/aprun
Indexing 26800 bytes of DWARF '.debug_frame' symbols from '/
Indexing 28044 bytes of DWARF '.eh_frame' symbols from '/usr
Skimming 181212 bytes of DWARF '.debug_info' symbols from '/
Library @syscall_library@-64, with 1 asects, was linked at (
ially loaded at 0xff0000009009d800
INFO: Using previously cached local copy of library "@sysca.
Mapping 82 bytes of ELF string data from '@syscall_library@-
Indexing 192 bytes of DWARF '.eh_frame' symbols from '@sysca
Library /lib64/libdl.so.2, with 2 asects, was linked at 0x0(
d at 0xff0000009009e100
Mapping 459 bytes of ELF string data from '/lib64/libdl.so.2
Indexing 620 bytes of DWARF '.eh_frame' symbols from '/lib64
Library /lib64/libpthread.so.0, with 2 asects, was linked at
loaded at 0xff000000900a0500
Mapping 14508 bytes of ELF string data from '/lib64/libpthre
Indexing 12804 bytes of DWARF '.eh_frame' symbols from '/lib
Library /lib64/libc.so.6, with 2 asects, was linked at 0x00(
 at 0xff000000900baa00
Mapping 21676 bytes of ELF string data from '/lib64/libc.so.
Indexing 126700 bytes of DWARF '.eh_frame' symbols from '/li
Library /lib64/ld-linux-x86-64.so.2, with 2 asects, was link
ally loaded at 0xff0000009007ee00
Mapping 380 bytes of ELF string data from '/lib64/ld-linux-x
Indexing 6072 bytes of DWARF '.eh_frame' symbols from '/lib6
one
```

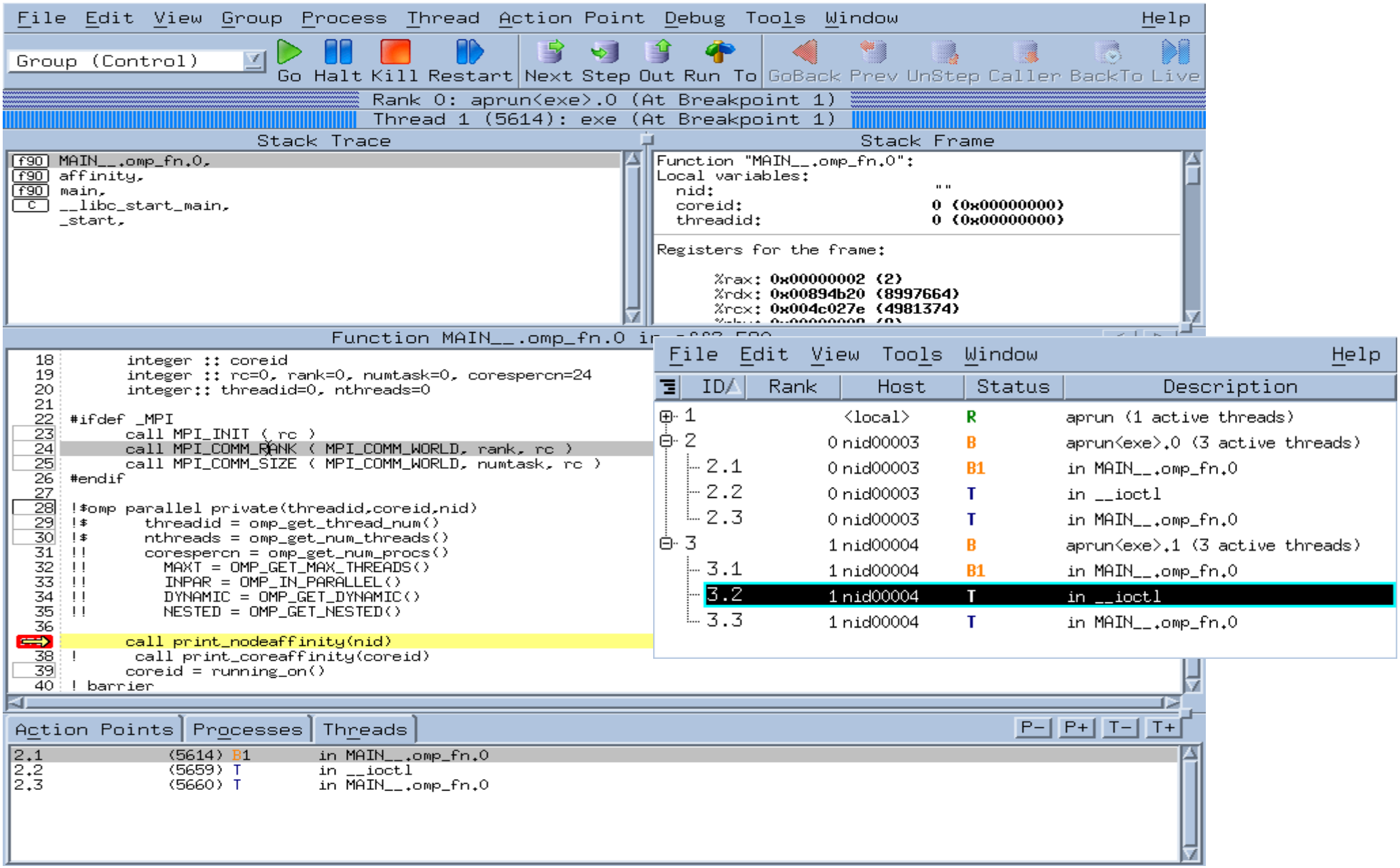


Root window	Lists process and thread information
Process window	Displays stack trace, stack frame, and source code for the selected thread in a process
Process group window	Displays process groups for multiprocess programs
Variable window	Displays address, data type, and value of local variable, register, or global variable

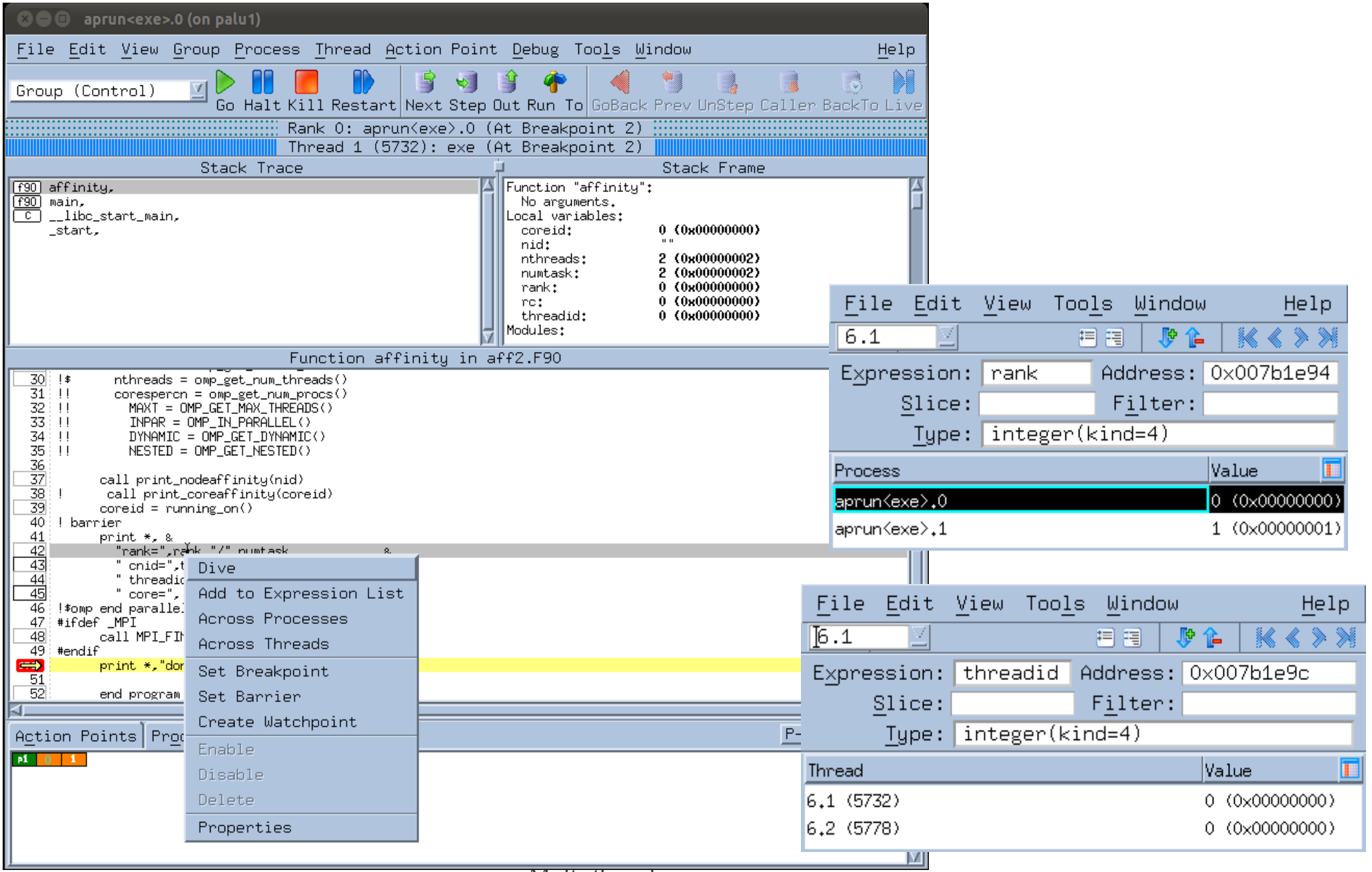
Launching Totalview (2)



Inserting Breakpoints



Viewing data across processes and threads



Restarting and exiting Totalview

```
Application 108251 resources: utime ~0s, stime ~0s
The TotalView Debugger Server has died
 palu1: export OMP_NUM_THREADS=2 ; totalview aprun -a -n2 -N1 -d24 exe
Linux x86_64 TotalView 8.8.0-1
Copyright 2007-2010 by TotalView Technologies, LLC. ALL RIGHTS RESERVED.
Copyright 1999-2007 by Etnus, LLC.
Copyright 1999 by Etnus, Inc.
Copyright 1996-1998 by Dolphin Interconnect Solutions, Inc.
Copyright 1989-1996 by BBN Inc.
TotalView Technologies ReplayEngine
Copyright 2010 TotalView Technologies
ReplayEngine uses the UndoDB Reverse Execution Engine
Copyright 2005-2010 Undo Limited
Reading symbols for process 1, executing "aprun"
Library /usr/bin/aprun, with 2 asects, was linked at 0x00400000, and initially loaded at 0xff000000900000
Mapping 25131 bytes of ELF string data from '/usr/bin/aprun'...done
Indexing 26800 bytes of DWARF '.debug_frame' symbols from '/usr/bin/aprun'...done
Indexing 28044 bytes of DWARF '.eh_frame' symbols from '/usr/bin/aprun'...done
Skimming 181212 bytes of DWARF '.debug_info' symbols from '/usr/bin/aprun'...done
Library @syscall_library@-64, with 1 asects, was linked at 0xfffffffff700000, and initially loaded at 0x
INFO: Using previously cached local copy of library "@syscall_library@-64"
Mapping 82 bytes of ELF string data from '@syscall_library@-64'...done
Indexing 192 bytes of DWARF '.eh_frame' symbols from '@syscall_library@-64'...done
Library /lib64/libdl.so.2, with 2 asects, was linked at 0x00000000, and initially loaded at 0xff000000900
Mapping 459 bytes of ELF string data from '/lib64/libdl.so.2'...done
Indexing 620 bytes of DWARF '.eh_frame' symbols from '/lib64/libdl.so.2'...done
Library /lib64/libpthread.so.0, with 2 asects, was linked at 0x00000000, and initially loaded at 0xff0000
Mapping 14508 bytes of ELF string data from '/lib64/libpthread.so.0'...done
Indexing 12804 bytes of DWARF '.eh_frame' symbols from '/lib64/libpthread.so.0'...done
Library /lib64/libc.so.6, with 2 asects, was linked at 0x00000000, and initially loaded at 0xff000000900b
Mapping 21676 bytes of ELF string data from '/lib64/libc.so.6'...done
Indexing 126700 bytes of DWARF '.eh_frame' symbols from '/lib64/libc.so.6'...done
Library /lib64/ld-linux-x86-64.so.2, with 2 asects, was linked at 0x00000000, and initially loaded at 0xf
Mapping 380 bytes of ELF string data from '/lib64/ld-linux-x86-64.so.2'...done
Indexing 6072 bytes of DWARF '.eh_frame' symbols from '/lib64/ld-linux-x86-64.so.2'...done
Library /lib64/libnss_files.so.2, with 2 asects, was linked at 0x00000000, and initially loaded at 0xff00
Mapping 2007 bytes of ELF string data from '/lib64/libnss_files.so.2'...done
Indexing 3260 bytes of DWARF '.eh_frame' symbols from '/lib64/libnss_files.so.2'...done
Launching TotalView Debugger Servers with command:
svrlaunch  /opt/toolworks/totalview.8.8.0a/linux-x86-64/bin/tvdsvrmain  '-verbosity info '  172.26.0.31
INFO: Using previously cached local copy of library "/dsl/var/spool/alps/108253/exe"
Library /dsl/var/spool/alps/108253/exe, with 2 asects, was linked at 0x00400000, and initially loaded at
Mapping 132443 bytes of ELF string data from '/dsl/var/spool/alps/108253/exe'...done
Indexing 79272 bytes of DWARF '.debug_frame' symbols from '/dsl/var/spool/alps/108253/exe'...done
Indexing 115132 bytes of DWARF '.eh_frame' symbols from '/dsl/var/spool/alps/108253/exe'...done
Skimming 1646889 bytes of DWARF '.debug_info' symbols from '/dsl/var/spool/alps/108253/exe'...done
Reading symbols for process 2, executing "./exe"
Reading symbols for process 3, executing "./exe"
 rank=          0 /          2  cnid=nid00003 threadid=          0 /          2  core=          0
 rank=          0 /          2  cnid=nid00003 threadid=          1 /          2  core=          1
 rank=          1 /          2  cnid=nid00004 threadid=          0 /          2  core=          0
 rank=          1 /          2  cnid=nid00004 threadid=          1 /          2  core=          1
 done
 done
Application 108253 resources: utime ~0s, stime ~0s
 palu1: exit
exit
salloc: Relinquishing job allocation 2960
salloc: Job allocation 2960 has been revoked.
 palu1:
```

Frequently used GDB commands

General Commands

- help [name] : Show information about GDB command
- run [<args>] : runs selected program with arguments <args>
- attach <pid> : attach gdb to a running process
- Kill : kills the process being debugged
- Quit : quits the gdb program

Stepping and Continuing

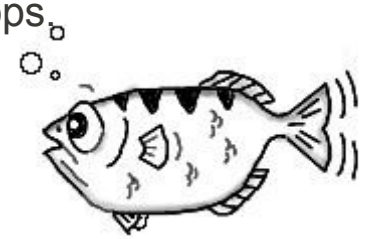
- c[ontinue] : continue execution (after a stop)
- s[tep] : step one line, entering called functions
- n[ext] : step one line, without entering functions

Breakpoint commands

- b[reak] [<where>] : sets breakpoints. <where> can be a function name, a line number or a hex address
- [r]watch <expr> : sets a watchpoint, which will break
- when <expr> is written to [or read]
- info break[points] : prints out a listing of all breakpoints
- d[elete] [<nums>] : deletes breakpoints

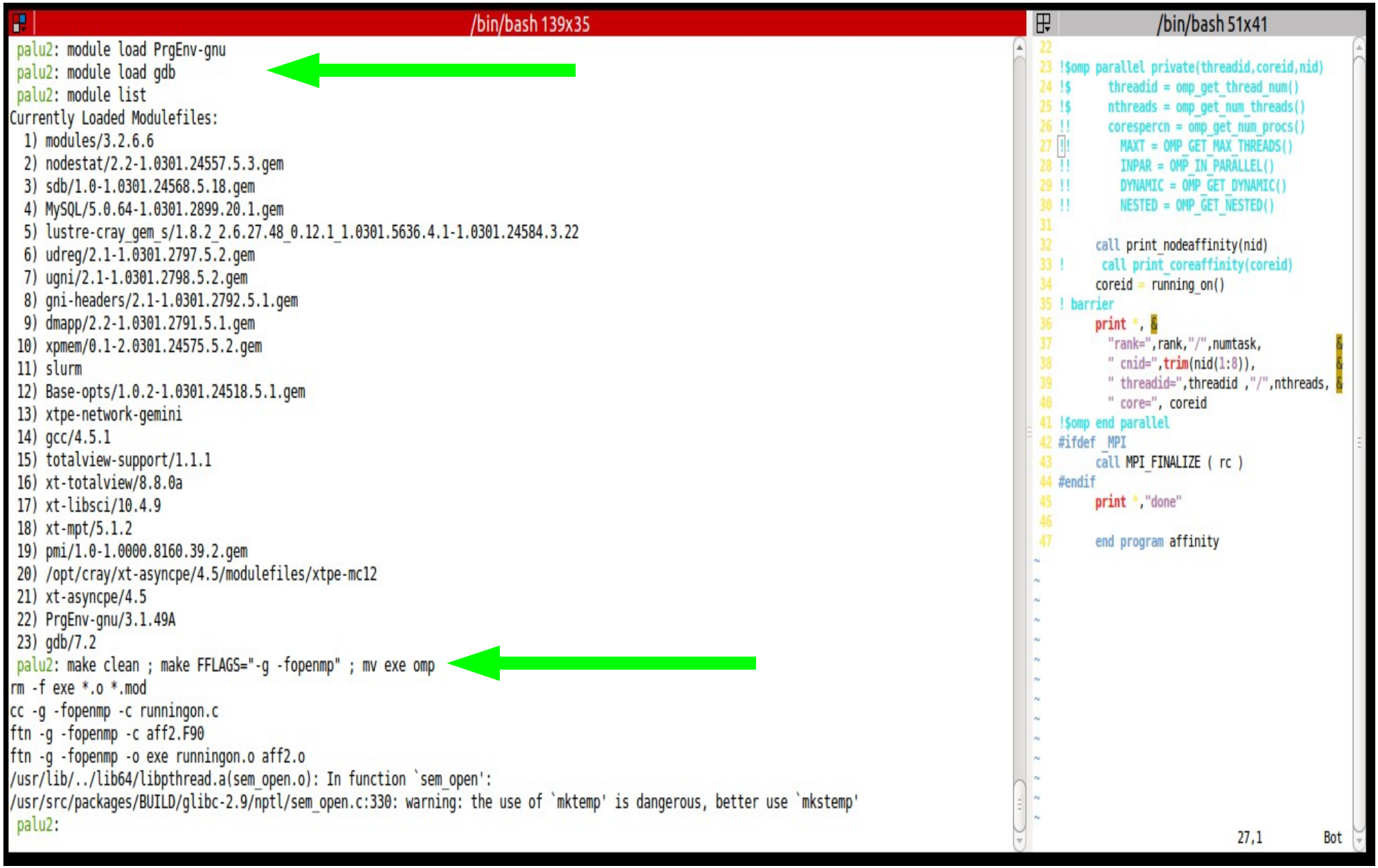
Commands for looking around

- list [<where>] : prints out source code at <where>
- backtrace [<n>] : prints a backtrace <n> levels deep
- info [<what>] : prints out info on <what>
- p[rint] [<expr>] : prints out <expr>
- d[isplay] : prints value of expression each time the program stops

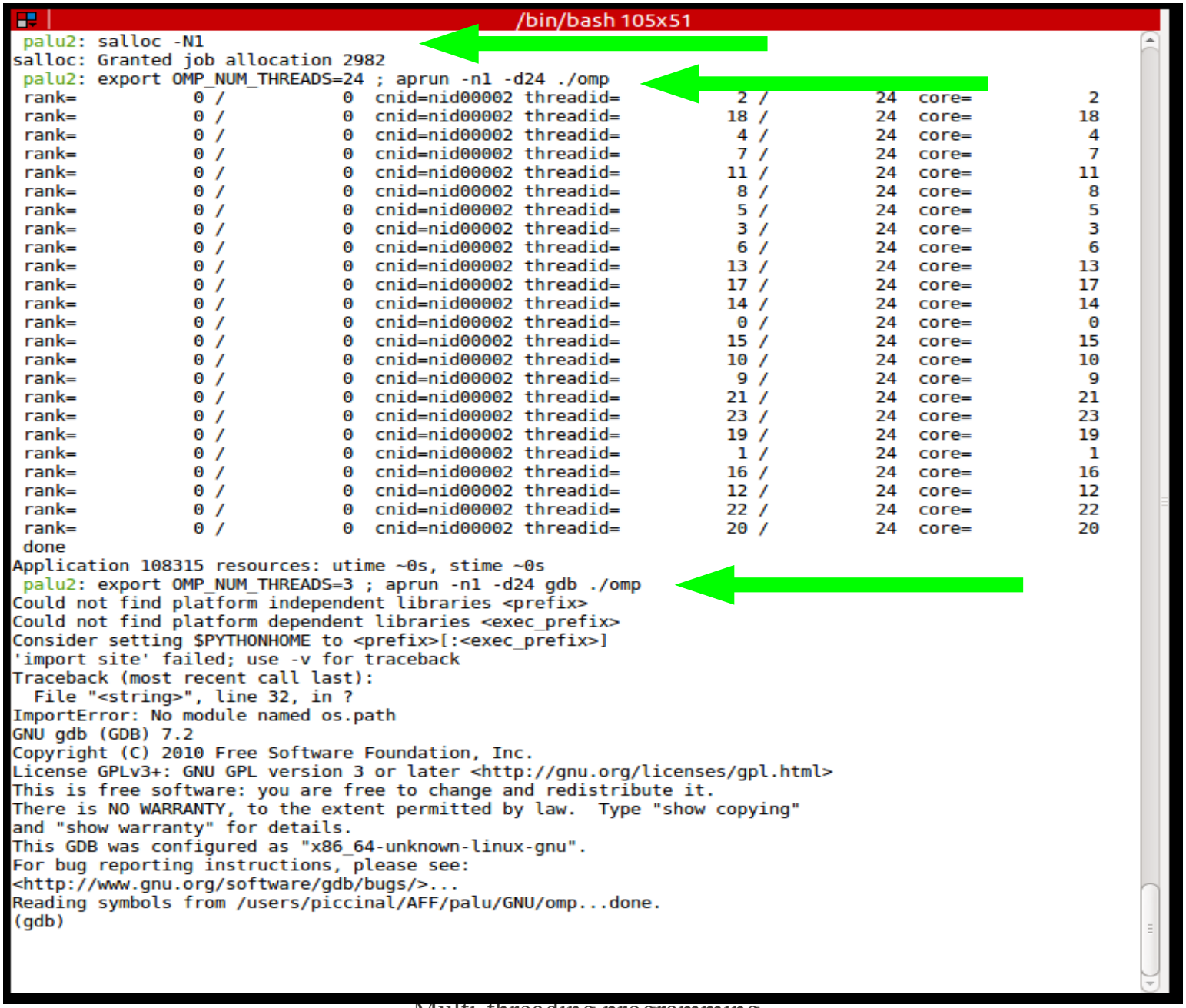


Demo : GDB

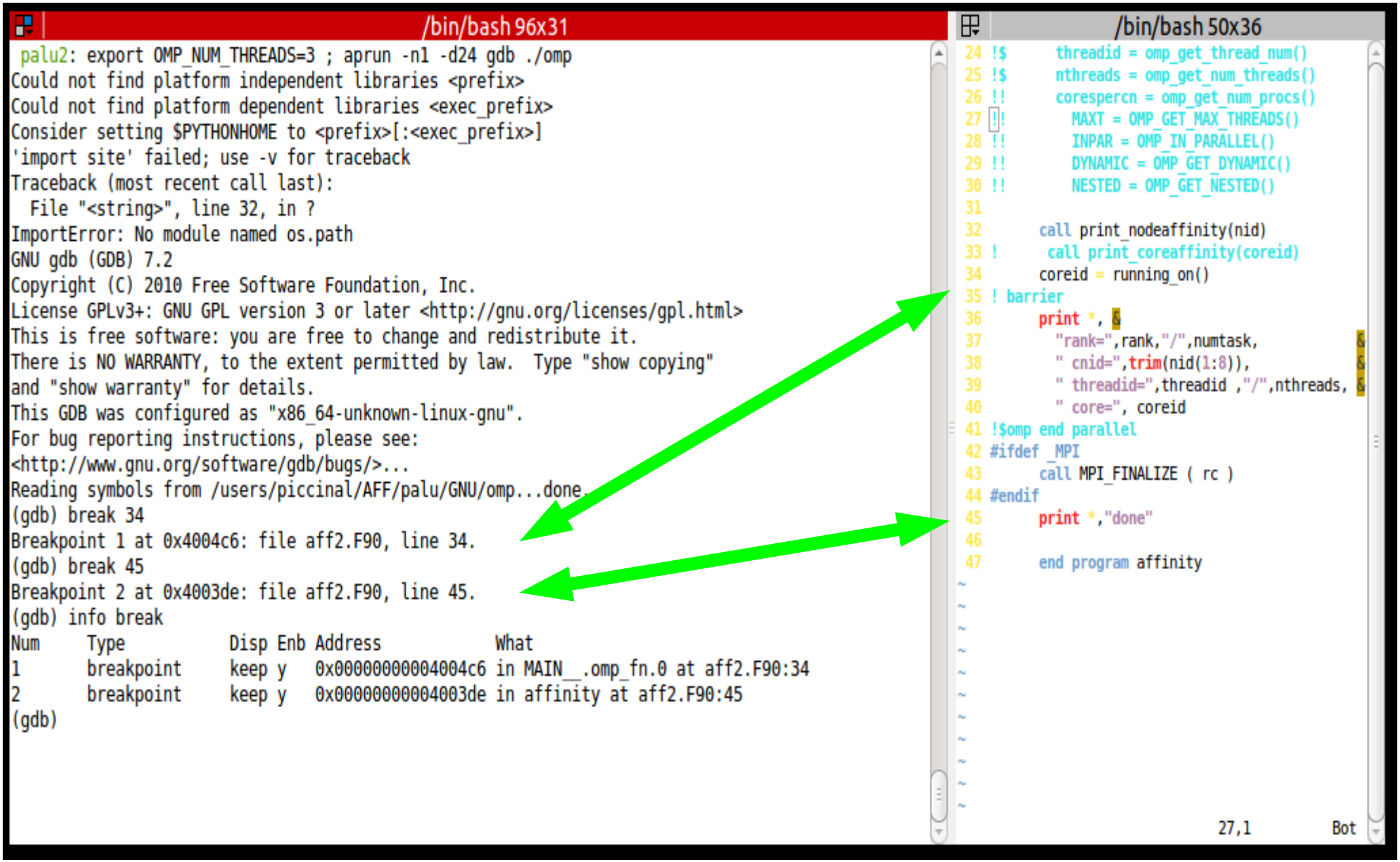
Getting started



Launching GDB



Inserting Breakpoints



Viewing data across threads (1)

/bin/bash 96x31

```
(gdb) help run
Start debugged program.  You may specify arguments to give it.
Args may include "*", or "[...]"; they are expanded using "sh".
Input and output redirection with ">", "<", or ">>" are also allowed.

With no arguments, uses arguments last specified (with "run" or "set args").
To cancel previous arguments and run with no arguments,
use "set args" without arguments.
(gdb) run
Starting program: /users/piccinal/AFF/palu/GNU/omp
[Thread debugging using libthread_db enabled]
[New Thread 0x2aaaaacac950 (LWP 13736)]
[New Thread 0x2aaaaaead950 (LWP 13737)]

Breakpoint 1, MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
34              coreid = running_on()
(gdb) info thread
  3 Thread 0x2aaaaaead950 (LWP 13737)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
  2 Thread 0x2aaaaacac950 (LWP 13736)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
* 1 Thread 0x6d38c0 (LWP 13733)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
(gdb) print threadid
$1 = 0
(gdb) list
34              coreid = running_on()
35      ! barrier
36              print *, &
37                "rank=",rank,"/",numtask,          &
38                " cnid=",trim(nid(1:8)),           &
39                " threadid=",threadid ,"/",nthreads, &
40                " core=", coreid
41      !$omp end parallel
```

/bin/bash 50x36

```
24 !$      threadid = omp_get_thread_num()
25 !$      nthreads = omp_get_num_threads()
26 !!      corespercn = omp_get_num_procs()
27 !!        MAXT = OMP_GET_MAX_THREADS()
28 !!        INPAR = OMP_IN_PARALLEL()
29 !!        DYNAMIC = OMP_GET_DYNAMIC()
30 !!        NESTED = OMP_GET_NESTED()
31
32        call print_nodeaffinity(nid)
33 !       call print_coreaffinity(coreid)
34        coreid = running_on()
35 ! barrier
36        print *, &
37          "rank=",rank,"/",numtask,                 &
38          " cnid=",trim(nid(1:8)),                  &
39          " threadid=",threadid ,"/",nthreads,      &
40          " core=", coreid
41 !$omp end parallel
42 #ifdef _MPI
43        call MPI_FINALIZE ( rc )
44 #endif
45        print *,"done"
46
47        end program affinity
~
~
~
~
~
~
~
~
~
~
~
                                   27,1          Bot
```

Viewing data across threads (2)

/bin/bash 96x31

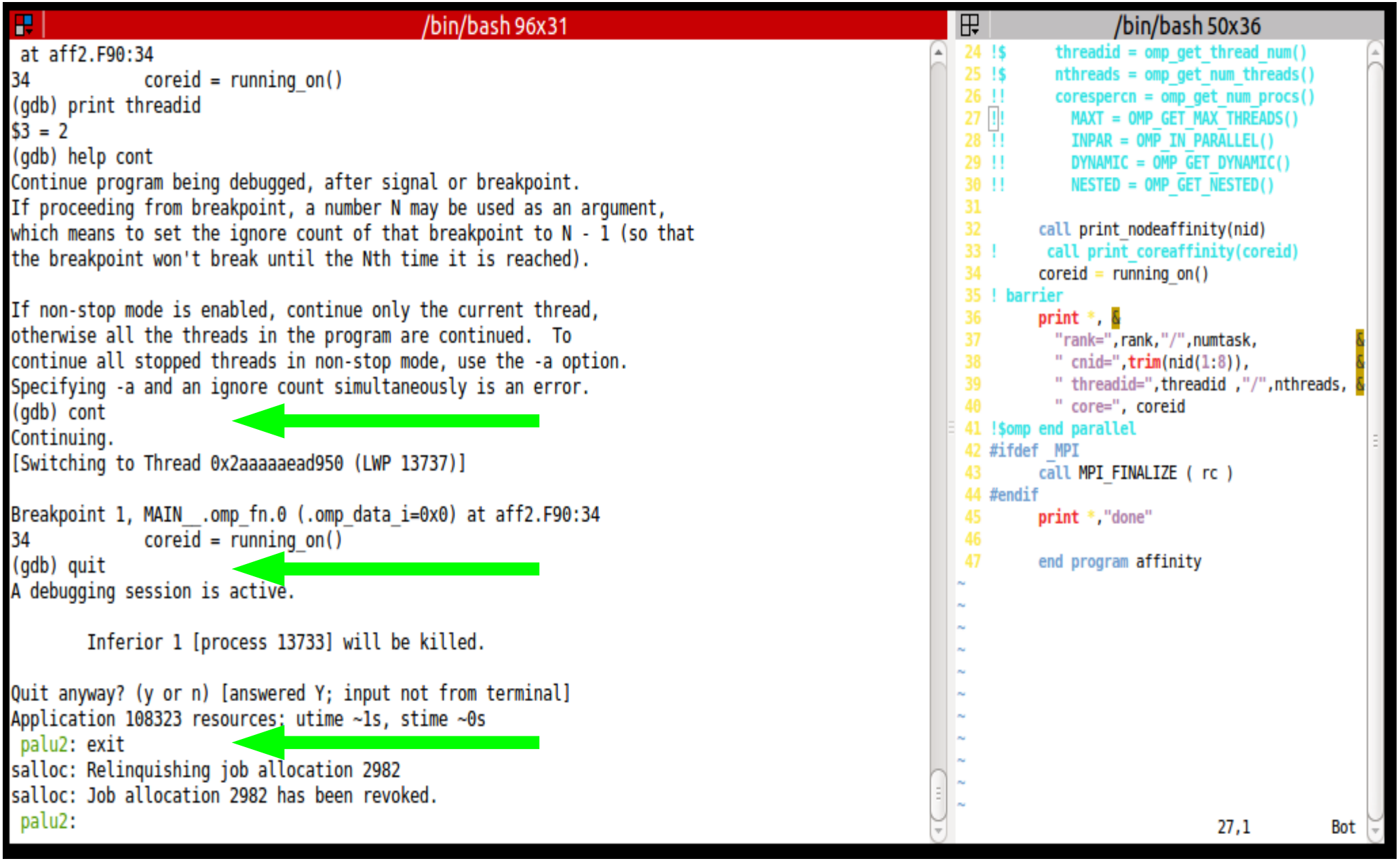
```
(gdb) info thread
  3 Thread 0x2aaaaaead950 (LWP 13737)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
  2 Thread 0x2aaaaacac950 (LWP 13736)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
* 1 Thread 0x6d38c0 (LWP 13733)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
(gdb) thread 2
[Switching to thread 2 (Thread 0x2aaaaacac950 (LWP 13736))]#0  MAIN__.omp_fn.0 (.omp_data_i=0x0)
 at aff2.F90:34
34            coreid = running_on()
(gdb) info thread
  3 Thread 0x2aaaaaead950 (LWP 13737)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
* 2 Thread 0x2aaaaacac950 (LWP 13736)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
  1 Thread 0x6d38c0 (LWP 13733)  MAIN__.omp_fn.0 (.omp_data_i=0x0) at aff2.F90:34
(gdb) print threadid
$2 = 1
(gdb) thread 3
[Switching to thread 3 (Thread 0x2aaaaaead950 (LWP 13737))]#0  MAIN__.omp_fn.0 (.omp_data_i=0x0)
 at aff2.F90:34
34            coreid = running_on()
(gdb) print threadid
$3 = 2
(gdb) help cont
Continue program being debugged, after signal or breakpoint.
If proceeding from breakpoint, a number N may be used as an argument,
which means to set the ignore count of that breakpoint to N - 1 (so that
the breakpoint won't break until the Nth time it is reached).

If non-stop mode is enabled, continue only the current thread,
otherwise all the threads in the program are continued.  To
continue all stopped threads in non-stop mode, use the -a option.
Specifying -a and an ignore count simultaneously is an error.
(gdb)
```

/bin/bash 50x36

```
24 !$      threadid = omp_get_thread_num()
25 !$      nthreads = omp_get_num_threads()
26 !!      corespercn = omp_get_num_procs()
27 !!        MAXT = OMP_GET_MAX_THREADS()
28 !!        INPAR = OMP_IN_PARALLEL()
29 !!        DYNAMIC = OMP_GET_DYNAMIC()
30 !!        NESTED = OMP_GET_NESTED()
31
32        call print_nodeaffinity(nid)
33 !       call print_coreaffinity(coreid)
34        coreid = running_on()
35 ! barrier
36        print *, &
37          "rank=",rank,"/",numtask,                &
38          " cnid=",trim(nid(1:8)),                 &
39          " threadid=",threadid ,"/",nthreads, &
40          " core=", coreid
41 !$omp end parallel
42 #ifdef _MPI
43        call MPI_FINALIZE ( rc )
44 #endif
45        print *,"done"
46
47        end program affinity
~
~
~
~
~
~
~
~
~
~
~
~
                                          27,1          Bot
```

Restarting and exiting GDB



- Questions ?
- Hands-on exercises
- Thank you for your attention

Hands-on exercise1

Data race condition

- A data race occurs under the following conditions:
  - 2 or more threads in a process concurrently access the same memory location,
  - At least one of the threads is accessing the memory location for writing, and
  - The threads are not using any exclusive locks to control their accesses to that memory.
- When these three conditions hold, the order of accesses is non-deterministic. Therefore each run can give different results depending on the order of the accesses. Some data races may be harmless (for example, when the memory access is used for a busy-wait), but many data races are either bugs or caused by bugs in the program.

The object of this exercise is to determine whether it's safe to parallelise every DO loop that you see. Follow these steps :

- copy loopy.f90 to your directory.
- compile the code sequentially (that is with no '-fopenmp' flag) and determine the correct result.
- parallelise every loop and run the program on 2, 6, 12 and 24 threads (you can do this interactively) and compare these results with those from above.
- What's wrong ?
- Rewrite your parallelised code to give the correct results irrespective of the number of threads used.

Hands-on exercise2

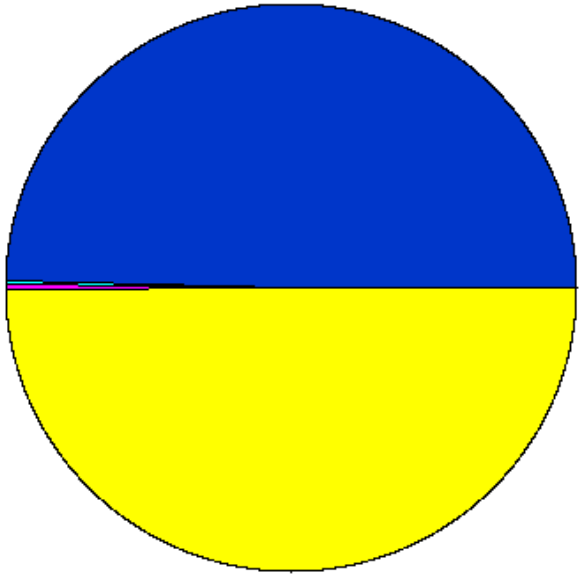
Segmentation faults

- Default thread stack size can be easy to exhaust. OpenMP thread stack size is an implementation dependent resource. In this case, the array is too large to fit into the thread stack space and causes the segmentation fault.
- The OpenMP standard does not specify how much stack space a thread should have. Consequently, implementations will differ in the default thread stack size.
- Default thread stack size can also be non-portable between compilers. Threads that exceed their stack allocation may or may not seg fault. An application may continue to run while data is being corrupted.
- OMP_STACKSIZE (OMP/3.0) : controls the size of the stack for (non-master) threads.
- Set the default thread stack size (in kilobytes by default) or B, K, M or G (bytes, kilobytes, megabytes or gigabytes).

The object of this exercise is to use the debuggers to find the origin of the segmentation fault. Follow these steps :

- copy crash.f to your directory.
- module load PrgEnv-gnu gdb
- compile (with '-g -fopenmp' flag) and run the code with any number of threads.
- What's wrong ?

Hands-on exercise2

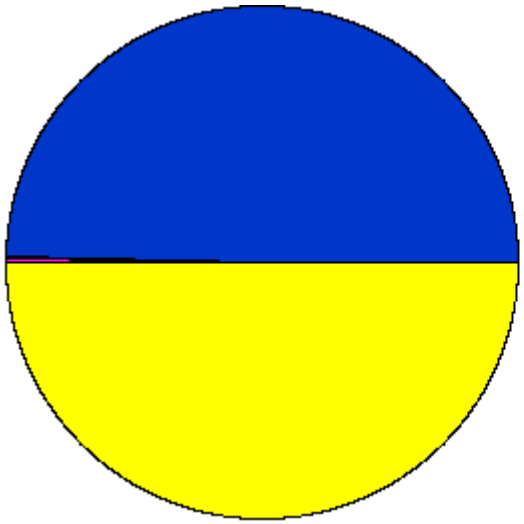


Process 2: aprun<memoryscape>.0

Text:	1881.69 KB	(0.03%)
Data:	145.23 KB	(0.00%)
Heap:	3085.24 MB	(49.53%)
Stack:	16.77 MB	(0.27%)
Stack VM:	16.78 MB	(0.27%)
Total VM:	3108.05 MB	(49.90%)

If OMP_STACKSIZE is not set, the initial value of the stacksize-var internal control variable is set to the default value.

MemoryScape only shows information for the main thread's stack.



Process 2: aprun<memoryscape>.0

Text:	1881.69 KB	(0.03%)
Data:	145.23 KB	(0.00%)
Heap:	3089.10 MB	(49.60%)
Stack:	8.39 MB	(0.13%)
Stack VM:	16.78 MB	(0.27%)
Total VM:	3111.91 MB	(49.97%)

Hands-on exercise3

Deadlock

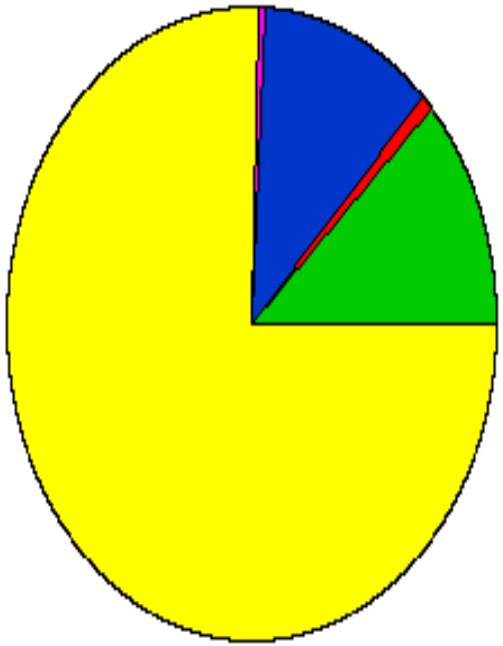
- Deadlock describes a condition where two or more threads are blocked (hang) forever, waiting for each other. Suppose we have a process with two or more threads. A deadlock occurs when the following three conditions hold :
  - Threads already holding locks request new locks,
  - The requests are made concurrently, and
  - Two or more threads form a circular chain where each thread waits for a lock that the next thread in the chain holds.
- Here is an example of a deadlock condition:
  - Thread 1: holds lock A, requests lock B
  - Thread 2: holds lock B, requests lock A
- A deadlock can be of two types: A "potential deadlock" or an "actual deadlock". A potential deadlock is a deadlock that did not occur in a given run, but can occur in different runs of the program depending on the timings of the requests for locks by the threads. An actual deadlock is one that actually occured in a given run of the program. An actual deadlock causes the threads involved to hang, but may or may not cause the whole process to hang.

/bin/bash 36x11

```
1 !$OMP PARALLEL DEFAULT(SHARED)
2 !$OMP CRITICAL
3       DO I = 1, 10
4         X= X + 1
5 !$OMP   BARRIER
6         Y= Y + I*I
7       END DO
8 !$OMP END CRITICAL
9 !$OMP END PARALLEL
~
<9L, 169C written 1,1          All
```

/bin/bash 37x14

```
 1 #pragma omp parallel
 2    myid = omp_get_thread_num();
 3    if (myid %2) {
 4       // do some odd work
 5       #pragma omp barrier
 6       // do more work
 7    }
 8    else {
 9       // do some even work
10       #pragma omp barrier
11       // do more work
12    }
13 }
                    9,7          Top
```



Process 1 (25994): aprun

Text:	2.33 MB	(11.82%)
Data:	167.91 KB	(0.83%)
Heap:	2.25 MB	(11.42%)
Stack:	18.30 KB	(0.09%)
Stack VM:	92.00 KB	(0.46%)
Total VM:	14.87 MB	(75.38%)

KO

Process	Text	Data	Heap	Stack	Stack VM	Total VM
Process 1 (25994): aprur	2.33MB	167.91KB	2.25MB	18.30KB	92.00KB	14.87MB
@syscall_library@-64	1476	264				
aprun	434.52KB	72.15KB				
ld-linux-x86-64.so.2	117.62KB	4.19KB				
libc.so.6	1339.36KB	34.88KB				
libdl.so.2	7.17KB	920				
libgcc_s.so.1	81.51KB	1544				
libnss_files.so.2	40.71KB	1872				
libpthread.so.0	86.49KB	17.88KB				
libtvheap-64.so	277.89KB	34.32KB				