SuperComputing Applications and Innovation

Debugging

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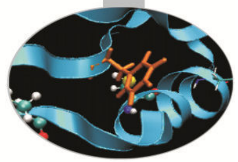
SCAI, Cineca

Contents

Introduction



- One of the most widely used methods to find out the reason of a strange behaviour in a program is the insertion of “printf” or “write” statements in the supposed critical area.
- However this kind of approach has a lot of limits and requires frequent code recompiling and becomes hard to implement for complex programs, above all if parallel. Moreover sometimes the error may not be obvious or hidden.
- Debuggers are very powerful tools able to provide, in a targeted manner, a high number of information facilitating the work of the programmer in research and in the solution of instability in the application.
- For example, with simple debugging commands you can have your program run to a certain line and then pause. You can then see what value any variable has at that point in the code.

Debugging process

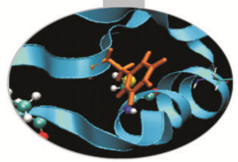
The debugging process can be divided into four main steps:

1. Start your program.
2. Make your program stop on specified conditions.
3. Examine what has happened, when your program has stopped.
4. Change things in your program, or its compilation, so you can experiment with correcting the effects of one bug and go on to learn about another.

Before starting the debugger

- Before starting the debugger, check your compiler documentation to see what compile or run-time checks are available.
- Some compiler options to try
  - switch down the optimisation level (e.g. from –O3). High or "aggressive" optimisations can cause code changes and introduce bugs.
  - turn on compiler options such as –C or –check-bounds to look for incorrect array indices.
  - for xlf try options such as –qflttrap=enable:zerodivide
  - use options for uninitialised variable detection, etc.
- For performance reasons many run-time checks are switched off by default. Remember to switch them off again when debugging is complete.
- If possible also worth using a different compiler to see if the problem persists, or more useful error or warning messages are obtained.

Debugging on the IBM BG/Q



- Because of its particular architecture (cannot login directly on the compute nodes) debugging is more complex on BG/Q.
- IBM provides a number of utilities which can be used without invoking a debugger.
- For further information check out the Cineca HPC user guide:

`http://www.hpc.cineca.it/sites/default/files/Debug%20guide_0.pdf`

IBM BG/Q

- Sometimes it may happen that an unsuccessful job generates a segmentation fault message where the chain of stack frames is reported.
- addr2line is an utility that allows to get information from this file about where the job crashed, using the syntax:
- *addr2line -e ./myexe 0x400ab9*

```
[[P90:05046] *** Process received signal ***
[P90:05046] Signal: Segmentation fault (11)
[P90:05046] Signal code: Address not mapped (1)
[P90:05046] Failing at address: 0x7fff54fd8000
[P90:05046] [ 0] /lib/x86_64-linux-gnu/libpthread.so.0(+0x10060) [0x7f8474777060]
[P90:05046] [ 1] /lib/x86_64-linux-gnu/libc.so.6(+0x131b99) [0x7f84744f7b99]
[P90:05046] [ 2] /usr/lib/libmpi.so.0(ompi_convertor_pack+0x14d) [0x7f84749c75dd]
[P90:05046] [ 3] /usr/lib/openmpi/lib/openmpi/mca_btl_sm.so(+0x1de8) [0x7f846fe14de8]
[P90:05046] [ 4] /usr/lib/openmpi/lib/openmpi/mca_pml_ob1.so(+0xd97e) [0x7f8470c6c97e]
[P90:05046] [ 5] /usr/lib/openmpi/lib/openmpi/mca_pml_ob1.so(+0x8900) [0x7f8470c67900]
[P90:05046] [ 6] /usr/lib/openmpi/lib/openmpi/mca_btl_sm.so(+0x4188) [0x7f846fe17188]
[P90:05046] [ 7] /usr/lib/libopen-pal.so.0(opal_progress+0x5b) [0x7f8473f330db]
[P90:05046] [ 8] /usr/lib/openmpi/lib/openmpi/mca_pml_ob1.so(+0x6fd5) [0x7f8470c65fd5]
[P90:05046] [ 9] /usr/lib/libmpi.so.0(PMPI_Send+0x195) [0x7f84749e1805]
[P90:05046] [10] nr2(main+0xe1) [0x400c55]
[P90:05046] [11] /lib/x86_64-linux-gnu/libc.so.6(__libc_start_main+0xed) [0x7f84743e730d]
[P90:05046] [12] nr2() [0x400ab9]
[P90:05046] *** End of error message ***
```

IBM BG/Q – core files

- By default Fermi IBM BG/Q produces text core files but not necessarily very readable

```
+++PARALLEL TOOLS CONSORTIUM LIGHTWEIGHT COREFILE FORMAT version 1.0
+++LCB 1.0
Program    : deadlock.exe
Job ID     : 96550
Personality:
   ABCDET coordinates : 0,0,0,0,0,3
   Rank               : 3
   Ranks per node     : 4
   DDR Size (MB)      : 16384
+++ID Rank: 3, TGID: 337, Core: 12, HWTID:0 TID: 337 State: RUN
***FAULT Encountered unhandled signal 0x00000009 (9) (???)
While executing instruction at..........0x00000000011f009c
Dereferencing memory at.................0x0000000000000000
Tools attached (list of tool ids).......None
Currently running on hardware thread....Y
General Purpose Registers:
  r00=00000000010dbef8 r01=0000001fffff9860 r02=00000000015b2cc0 r03=0000000000000000 r04=0000000000000001 r05=0000001fffff98d0
r06=0000000000000000 r07=0000001fffff95a0
  r08=0000000001649160 r09=0000000300900020 r10=0000000000000000 r11=0000001f00a00020 r12=0000000024000222 r13=0000001f00707700
r14=0000000000000000 r15=0000000000000000
  r16=0000000000000000 r17=0000000000000000 r18=0000000000000000 r19=0000000000000000 r20=0000000000000001 r21=0000000000000000
r22=0000001f00728848 r23=0000000000000001
  r24=0004000000000000 r25=0000000000000000 r26=00000000015f8ff8 r27=0000000000000001 r28=0000000000000000 r29=0000000000000000
r30=0000000000000000 r31=0000001f007326e0
Special Purpose Registers:
  lr=00000000011f0130 cr=0000000044004222 xer=0000000000000000 ctr=000000000102a7a4
  msr=000000008002f000 dear=0000000000000000 esr=0000000000000000 fpscr=0000000000004000
  sprg0=0000000000000000 sprg1=0000000000000000 sprg2=0000000000000000 sprg3=0000000000000000 sprg4=0000000000000000
  sprg5=0000000000000000 sprg6=000000000056e200 sprg7=0000000000000000 sprg8=0000000000000000
  srr0=00000000011f009c srr1=000000008002f000 csrr0=0000000000000000 csrr1=0000000000000000  mcsrr0=0000000000000000 mcsrr1=0000000000000000
  dbcr0=0000000000000000 dbcr1=0000000000000000 dbcr2=0000000000000000 dbcr3=0000000000000000 dbsr=0000000000000000
Floating Point Registers:
  f00=5500002000000000 1000008800200019  0000000000000000 0000000000000000  f01=0000000000000000 0000000000000000  0000000000000000 0000000000000000
  f02=[illegible]40000 0000000000000000  0000000000000000 [illegible]  [illegible]  0000000000000000 0000000100000000
```

IBM BG/Q core files

- Blue Gene core files are lightweight text files.
- Hexadecimal addresses in section STACK describe function call chain until program exception.
- It's the section delimited by tags: +++STACK / —STACK, in particular the "Saved Link Reg" column.
- These should be passed to the addr2line command or..

```
+++STACK
Frame Address     Saved Link Reg
0000001fffff5ac0  000000000000001c
0000001fffff5bc0  00000000018b2678
0000001fffff5c60  00000000015046d0
0000001fffff5d00  00000000015738a8
0000001fffff5e00  00000000015734ec
0000001fffff5f00  000000000151a4d4
0000001fffff6000  00000000015001c8
---STACK
```

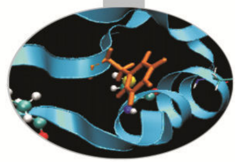
IBM BG/Q core files

- .. use some handy scripts.

```
module load superc
a2l-translate  corefile
addr2line -e <exe> <  core.t0
```

```
+++STACK
Frame Address    Saved Link Reg
0000001ffff5ac0   000000000000001c
0000001ffff5bc0   00000000018b2678
0000001ffff5c60   00000000015046d0
0000001ffff5d00   00000000015738a8
0000001ffff5e00   00000000015734ec
0000001ffff5f00   000000000151a4d4
0000001ffff6000   00000000015001c8
---STACK
```

Most popular debuggers



- Some debuggers are distributed with the compiler suite:
  - Commercial
    - Portland pgdbg
    - Intel idb
  - Free
    - Gnu gdb
- There are also some powerful, commercial debuggers from independent vendors:
  - DDT (Allinea)
  - Totalview (Rogue Wave Software)
  - Valgrind (particularly for Memory problems)

Debugger capabilities

- The purpose of a debugger is to allow you to see what is going on “inside” another program while it executes or what another program was doing at the moment it crashed.
- Using specific commands, debuggers allow real-time visualization of variable values, static and dynamic memory state (stack, heap) and registers state.
- Common errors include:
  - pointer errors
  - array indexing
  - memory allocation
  - argument and parameter mismatches
  - communication deadlocks in parallel programming
  - I/O
- ...

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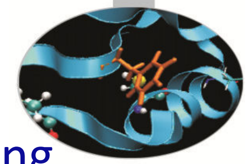
Compiling rules for debugging



- In order to debug a program effectively, the debugger needs debugging information which is produced compiling the program with the "-g" flag.
- This debugging information is stored in the object files fused in the executable; it describes the data type of each variable or function and the correspondence between source line numbers and addresses in the executable code.
- Opimization should be at –O0, -O1 or –O2 level.

- GNU compiler:
  - gcc/g++/gfortran –g [other flags] source –o executable
- INTEL compiler:
  - icc/icpc/ifort –g [other flags] source –o executable
- BGQ - IBM compiler
  - bgxlc/bgxlc++/bgxlf90 –g –qfullpath qkeepparm source –o executable

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Execution

- The standard way to run the debugger is:
  - **debugger executable name or**
  - **debugger exe corefile**
- Otherwise it's possible to first run the debugger and then point to the executable to debug:

  GNU gdb:

```
gdb
> file executable
```

- It's also possible to debug an already-runnnig program started outside the debugger attaching to the process id of the program.
- Syntax:
- GNU gdb:

```
gdb
   > attach process_id
  gdb attach process_id
```

GDB command list

run: start debugged program

list: list specified function or line. Two arguments with comma between specify starting and ending lines to list.

```
list begin,end
```

break <line> <function> : set breakpoint at specified line or function, useful to stop execution before a critical point.

```
break filename:line
break filename:function
```

It's possible to insert a boolean expression with the sintax:

```
break <line> <function> condition
```

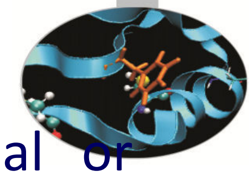
With no **<line> <function>,** uses current execution address of selected stack frame. This is useful for breaking on return to a stack frame.

GDB command list /2

- **clear <line> <func>** : Clear breakpoint at specified line or function.
- **delete breakpoints [num]** : delete breakpoint number “num”. With no argument delete all breakpoints.
- **If** : Set a breakpoint with condition; evaluate the condition each time the breakpoint is reached, and stop only if the value is nonzero. Allowed logical operators: > , < , >= , <= , ==
- Example :

```
break 31 if i >= 12
```

- **condition <num> < expression>** : As the “if” command associates a logical condition at breakpoint number “num”.
- **next <count>:** continue to the next source line in the current (innermost) stack frame, or `count` lines.



GDB command list/3

continue: continue program being debugged, after signal or breakpoint

where : print backtrace of all stack frames, or innermost "count" frames.

step : Step program until it reaches a different source line. If used before a function call, allow to step into the function. The debugger stops at the first executable statement of that function

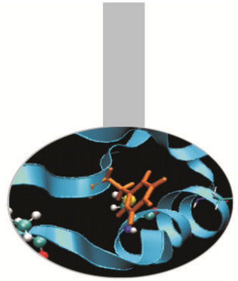
step count : executes **count** lines of code as the `next` command

finish : execute until selected stack frame or function returns and stops at the first statement after the function call. Upon return, the value returned is printed and put in the value history.

set args : set argument list to give program being debugged when it is started. Follow this command with any number of args, to be passed to the program.

set var variable = <EXPR>: evaluate expression `EXPR` and assign result to variable **variable**, using assignment syntax appropriate for the current language

GDB Command list/4



search <expr>: search for an expression from last line listed

reverse-search <expr> : search backward for an expression from last line listed

display <exp>: Print value of expression exp each time the program stops.

print <exp>: Print value of expression exp

This command can be used to display arrays:

print array[num_el] displays element num_el

print *array@len displays the whole array

watch <exp>: Set a watchpoint for an expression. A watchpoint stops execution of your program whenever the value of an expression changes.

info locals: print variable declarations of current stack frame.

show values <number> : shows number elements of value history around item number or last ten.

GDB command list/5

- **backtrace** `<number,full>` **:** *shows one line per frame, for many frames, starting with the currently executing frame (frame zero), followed by its caller (frame one), and on up the stack. With the* `number` *parameter print only the innermost* `number` *frames. With the* `full` *parameter print the values of the local variables also.*
  - `#0  squareArray (nelem_in_array=12, array=0x601010) at variable_print.c:67`
  - `#1  0x00000000004005f5 in main () at variable_print.c:34`
- **frame** `<number>` **:** *select and print a stack frame.*
- **up** `<number>` **:** *allow to go up* `number` *stack frames*
- **down** `<number>` **:** *allow to go up* `number` *stack frames*
- **info** `frame` **:** *gives all informations about current stack frame*
- **detach:** *detach a process or file previously attached.*
- **quit:** *quit the debugger*

Using Core dumps for Postmortem Analysis

- In computing, a core dump, memory dump, or storage dump consists of the recorded state of the working memory of a computer program at a specific time, generally when the program has terminated abnormally.
- Core dumps are often used to assist in diagnosing and debugging errors in computer programs.
- In most Linux Distributions core file creation is disabled by default for a normal user but it can be enabled using the following command :
  - `ulimit -c unlimited`

- Once "ulimit –c" is set to "unlimited" run the program and the core file will be created

- The core file can be analyzed with gdb using the following syntax:
  - `gdb -c core executable`

Debugging a serial program – case study

Example program that:

1. constructs an array of 10 integers in the variable **`array1`**
2. gives the array to a function **`squareArray`** that executes the square of each element of the array and stores the result in a second array named **`array2`**
3. After the function call, it's computed the difference between **`array2`** and **`array1`** and stored in **`array del`**. The array del is then written on standard output
4. Code execution ends without error messages but the elements of array del printed on standard output are all zeros.

Debugging a serial program

```
#include <stdio.h>
#include <stdlib.h>
int indx;
void initArray(int nelem_in_array, int *array);
void printArray(int nelem_in_array, int *array);
int squareArray(int nelem_in_array, int *array);
int main(void) {
   const int nelem = 12;
   int *array1, *array2, *del;
   array1 = (int *)malloc(nelem*sizeof(int));
   array2 = (int *)malloc(nelem*sizeof(int));
   del = (int *)malloc(nelem*sizeof(int));
   initArray(nelem, array1);
   printf("array1 = "); printArray(nelem, array1);
   array2 = array1;
   squareArray(nelem, array2);
```

Debugging a serial program/2

```
for (indx = 0; indx < nelem; indx++)
  {
    del[indx] = array2[indx] - array1[indx];
  }
  printf("La difference fra array2 e array1 e':  ");
  printArray(nelem, del);
  free(array1);
  free(array2);
  free(del);
  return 0;}
void initArray(const int nelem_in_array, int *array)
{
  for (indx = 0; indx < nelem_in_array; indx++)
  {
    array[indx] = indx + 2;}
}
```

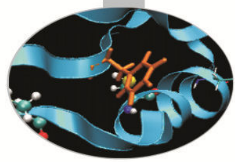
Debugging a serial program/3

```
int squareArray(const int nelem_in_array, int *array)
{
  int indx;
  for (indx = 0; indx < nelem_in_array; indx++)
  {
    array[indx] *= array[indx];}
  return *array;
}
void printArray(const int nelem_in_array, int *array)
{
  printf("[  ");
  for (indx = 0; indx < nelem_in_array; indx++)
  {
    printf("%d  ", array[indx]); }
  printf("]\n\n");
}
```

Debugging a serial program/4

- Compiling: `gcc -g -o ar_diff ar_diff.c`
- Execution: `./arr_diff`
- Expected result:
  - `del = [ 2 6 12 20 30 42 56 72 90 110 132 156 ]`
- Real result
  - `del = [ 0 0 0 0 0 0 0 0 0 0 0 0 ]`

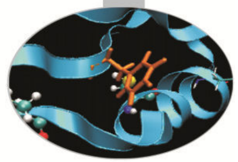
Debugging a serial program/5



- Run the debugger gdb -> gdb ar_diff

- Step1: possible coding error in function squareArray()
- Procedure:
  – list the code with the list command and insert a breakpoint at line 35 “break 35” where there is the call to `squareArray()`. Let’s start the code using the command run. Execution stops at line 35.
  – Let’s check the correctness of the function `squareArray()` displaying the elements of the array array2 using the command `disp`, For example (`disp array2[1] = 9`) produces the expected value

Debugging a serial program



- **Step2**: check of the difference between the element values in the two arrays
  - For loop analysis:

```
 #35: for (indx = 0; indx < nelem; indx++)
(gdb) next
37          del[indx] = array2[indx] - array1[indx];
(gdb) next
35        for (indx = 0; indx < nelem; indx++)
```

  - Visualize array after two steps in the for loop:

```
(gdb) disp array2[1]
array2[1]=9
(gdb) disp array1[1]
array1[1]=9
```

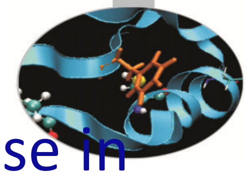
Debugging a serial program

- As highlighted in the previous slide the values of the elements of array1 and array2 are the same. But this is not correct because array, array1, was never passed to the function squareArray(). Only array2 was passed in line 38 of our code. If we think about it a bit, this sounds very much like a “pointer error”.

- To confirm our suspicion, we compare the memory address of both arrays:
  - `(gdb) disp array1`
  - `1: array1 = (int *)` **`0x607460`**
  - `(gdb) disp array2`
  - `2: array2 = (int *)` **`0x607460`**

- We find that the two addresses are identical.

Debugging a serial program



The error occurs in the statement: array2 = array1 because in this way the first element in array2 points to the address of the first element in array1.

Solution:

To solve the problem we just have to change the statement

```
array2 = array1;
```

in

```
for (indx = 0; index < nelem; indx++)
{
  array2[ k ]  =  array1[ k ]
}
```

Parallel debugging

- Parallel debugging is more complex than serial because multiple processes need to be debugged simultaneously.
- Normally debuggers can be applied to multi-threaded parallel codes, containing OpenMP or MPI directives, or even OpenMP and MPI hybrid solutions.
- For OpenMP, the threads of a single program are akin to multiple processes except that they share one address space (that is, they can all examine and modify the same variables). On the other hand, each thread has its own registers and execution stack, and perhaps private memory.
- GDB provides some facilities for debugging OpenMP and MPI programs but usually a dedicated debugger such as Totalview is employed.

Debugging OpenMP Applications

GDB facilities for debugging multi-threaded programs :

- automatic notification of new threads
- **thread <thread_number>** command to switch among threads
- **info threads** command to inquire about existing threads

```
(gdb) info threads
* 2 Thread 0x40200940 (LWP 5454)  MAIN__.omp_fn.0 (.omp_data_i=0x7fffffffd280)
    at serial_order_bug.f90:27
  1 Thread 0x2aaaaaf7d8b0 (LWP 1553) MAIN__.omp_fn.0
    (.omp_data_i=0x7fffffffd280) at serial_order_bug.f90:27
thread apply <thread_number> <all> args allow to apply a command to apply a
    command to a list of threads.
```

- When any thread in your program stops, for example, at a breakpoint, all other threads in the program are also stopped by GDB.
- GDB cannot single-step all threads in lockstep. Since thread scheduling is up to your debugging target's operating system (not controlled by GDB), other threads may execute more than one statement while the current thread completes a single step unless you use the command :set scheduler-locking on.
- GDB is not able to show the values of private and shared variables in OpenMP parallel regions.

Debugging OpenMP Applications

- In the following OpenMP code, using the SECTIONS directive, two threads initialize threir own array and than sum it to the other

```
PROGRAM lock
      INTEGER*8 LOCKA, LOCKB
      INTEGER NTHREADS, TID, I,OMP_GET_NUM_THREADS, OMP_GET_THREAD_NUM
      PARAMETER (N=1000000)
      REAL A(N), B(N), PI, DELTA
      PARAMETER (PI=3.1415926535)
      PARAMETER (DELTA=.01415926535)

      CALL OMP_INIT_LOCK(LOCKA)
      CALL OMP_INIT_LOCK(LOCKB)

!$OMP PARALLEL SHARED(A, B, NTHREADS, LOCKA, LOCKB) PRIVATE(TID)

      TID = OMP_GET_THREAD_NUM()
!$OMP MASTER
      NTHREADS = OMP_GET_NUM_THREADS()
      PRINT *, 'Number of threads = ', NTHREADS
!$OMP END MASTER
      PRINT *, 'Thread', TID, 'starting...'
!$OMP BARRIER
```

Debug openMP applications

```
!$OMP SECTIONS
!$OMP SECTION
PRINT *, 'Thread',TID,' initializing A()'
CALL OMP_SET_LOCK(LOCKA)
DO I = 1, N
A(I) = I * DELTA
ENDDO
CALL OMP_SET_LOCK(LOCKB)
PRINT *, 'Thread',TID,' adding A() to B()'
DO I = 1, N
B(I) = B(I) + A(I)
ENDDO
CALL OMP_UNSET_LOCK(LOCKB)
CALL OMP_UNSET_LOCK(LOCKA)
```

```
!$OMP SECTION

   PRINT *, 'Thread',TID,' initializing B()'
   CALL OMP_SET_LOCK(LOCKB)
      DO I = 1, N
         B(I) = I * PI
      ENDDO
   CALL OMP_SET_LOCK(LOCKA)
   PRINT *, 'Thread',TID,' adding B() toA()'
      DO I = 1, N
         A(I) = A(I) + B(I)
      ENDDO
   CALL OMP_UNSET_LOCK(LOCKA)
   CALL OMP_UNSET_LOCK(LOCKB)

!$OMP END SECTIONS NOWAIT

      PRINT *, 'Thread',TID,' done.'

!$OMP END PARALLEL

      END
```

Debugging OpenMP Applications

- Compiling:

```
gfortran -fopenmp -g -o omp_debug omp_debug.f90
```

- Execution:
  - `export OMP_NUM_THREADS=2`
  - `./omp_debug`
  - The program produces the following output before hanging:

```
Number of threads =           2
Thread           0 starting...
Thread           1 starting...
Thread           0  initializing A()
Thread           1  initializing B()
```

Debugging OpenMP Applications

- In the debugger:
  - List the source code from line 10 to 50:
  - Insert breakpoint at beginning of parallel region and run:

```
list 10,50
b 20
run
```

```
2 Thread 0x40200940 (LWP 8533)  MAIN__.omp_fn.0
  (.omp_data_i=0x7fffffffd2b0) at
  openmp_bug2_nofix.f90:20
 1 Thread 0x2aaaaaf7d8b0 (LWP 8530)  MAIN__.omp_fn.0
  (.omp_data_i=0x7fffffffd2b0) at
  openmp_bug2_nofix.f90:20
```

- The print statements aren’t executed so insert breakpoints in the two sections:

```
thread apply 2 b 35
thread apply 1 b 49
```

Debugging OpenMP Applications

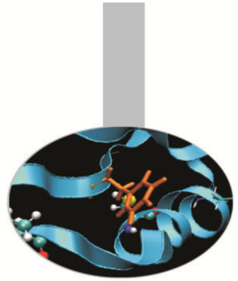
- Restart execution:

```
thread apply all cont
```

- Execution hangs so ctrl-c and check where threads are:

```
thread apply all where
Thread 2 (Thread 0x40200940 (LWP 8533)):
  0x00000000004010b5 in MAIN__.omp_fn.0
   (.omp_data_i=0x7fffffffd2b0) at
   openmp_bug2_nofix.f90:29

Thread 1 (Thread 0x2aaaaaf7d8b0 (LWP 8530)):
  0x000000000400e6d in MAIN__.omp_fn.0
   (.omp_data_i=0x7fffffffd2b0) at
   openmp_bug2_nofix.f90:43
```

Debugging OpenMP Applications



- Thread number 2 is stopped at line 29 on the statement:

```
CALL OMP_SET_LOCK(LOCKB)
```

- Thread number 1 is stopped at line 43 on the statement :

```
CALL OMP_SET_LOCK(LOCKA)
```

- So it's clear that the bug is in the calls to routines `OMP_SET_LOCK` that cause execution stopping
- Looking at the order of the routine calls to `OMP_SET_LOCK` and `OMP_UNSET_LOCK` it is clear there is an error.
- The correct order provides that the call `to OMP_SET_LOCK` must be followed by the corresponding `OMP_UNSET_LOCK`
- Arranging the order the code finishes successfully

Debugging MPI applications

- Even more difficult than OpenMP since in principle could involve many thousands of tasks.
- Many MPI errors are possible including: invalid arguments, type matching, race conditions, deadlocks etc.
- Debugging communications is not easy. Some communication-related bugs may be hidden by MPI buffering such that they occur only for certain numbers of tasks or program inputs.
- Generally best to use the minimum no. of tasks necessary to reproduce the unexpected behaviour.

Debugging MPI Applications

- There are two common ways to use serial debuggers such GDB to debug MPI applications

1. Attach to individual MPI processes after they are running using the "attach" method available for serial codes launching instances of the debugger to attach to the different MPI processes.

2. Open a debugging session for each MPI process through the command "mpirun".

Debugging MPI Applications

Attach method

– Run the application in the usual way.

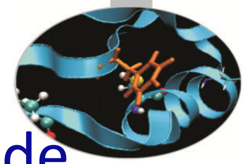
`mpirun -np 4 executable`

– From another shell, use the top command to find the MPI processes which bind to the executable:

```
top - 15:06:40 up 91 days,  4:00,  1 user,  load average: 5.31, 3.34, 2.66
Tasks: 198 total,   9 running, 188 sleeping,   0 stopped,   1 zombie
Cpu(s): 97.4%us,  2.3%sy,  0.0%ni,  0.2%id,  0.0%wa,  0.0%hi,  0.1%si,  0.0%st
Mem:  16438664k total,  3375504k used, 13063160k free,    72232k buffers
Swap: 16779884k total,    48328k used, 16731556k free,  1488208k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
12515 dagna     25   0  208m  10m 4320 R 99.8  0.1   0:10.23 Isola_MPI_2_inp
12516 dagna     25   0  208m  10m 4312 R 99.8  0.1   0:10.23 Isola_MPI_2_inp
12514 dagna     25   0  208m  10m 4320 R 99.5  0.1   0:10.15 Isola_MPI_2_inp
12513 dagna     25   0  235m  18m 4656 R 97.5  0.1   0:09.97 Isola_MPI_2_inp
 6244 dagna     15   0 82108 2660 1904 S  0.0  0.0   0:00.08 bash
 6428 dagna     15   0  101m 2472 1296 S  0.0  0.0   0:00.06 sshd
 6429 dagna     15   0 82108 2668 1908 S  0.0  0.0   0:00.08 bash
12512 dagna     15   0 74500 3396 2420 S  0.0  0.0   0:00.03 mpirun
12549 dagna     15   0 28792 2184 1492 R  0.0  0.0   0:00.01 top
```

PID executable MPI processes

Debugging MPI Applications



- Run up to “n” instances of the debugger in “attach” mode, where n is the number of the MPI processes of the application. Using this method you should have to open up to n shells.

- Referring to the previous slide we have to run four instances of GDB:

```
gdb attach 12513 (shell 1)
gdb attach 12514 (shell 2)
gdb attach 12515 (shell 3)
gdb attach 12516 (shell 4)
```

- Use debugger commands for each shell as in the serial case

Debugging MPI Applications

- mpirun method
  - This technique launches a separate window for each MPI process in MPI_COMM_WORLD, each one running a serial instance of GDB that will launch and run your MPI application.

```
mpirun -np 2 xterm -e gdb nome_eseguibile
```

```
[corso@corsi110 Isola]$ mpirun -np 2 xterm -e gdb ./Isola_MPI_2_input_gdb
```

Debugging MPI – case study

```
#include <stdio.h>
#include <stdlib.h>
#include <mpi.h>
void main(int argc, char *argv[]){
   int nvals, *array, myid, i;
   MPI_Status status;
   MPI_Init(&argc, &argv);
   MPI_Comm_rank(MPI_COMM_WORLD, &myid);
   nvals = atoi(argv[1]);
   array = (int *) malloc(nvals*sizeof(int));
   for(i=0; i<nvals/2; i++);
      array[i] = myid;
   if(myid==0){
     MPI_Send(array,nvals/2,MPI_INT,1,1,MPI_COMM_WORLD);

   MPI_Recv(array+nvals/2,nvals/2,MPI_INT,1,1,MPI_COMM_WORLD,&status);
   }
   else
{
   MPI_Send(array,nvals/2,MPI_INT,0,1,MPI_COMM_WORLD);
   MPI_Recv(array+nvals/2,nvals/2,MPI_INT,0,1,MPI_COMM_WORLD,&status);
   }
printf("myid=%d:array[nvals-1]=%dn",myid,array[nvals-1]);
MPI_Finalize();
```

Debugging MPI Applications – case study

- Compile: `mpicc -g -o hung_comm hung.c`
- Run:
  - Array dimension: 100
    - `mpirun -np 2 ./hung_comm 100`
    - `myid = 0: array[nvals-1] = 1`
    - `myid = 1: array[nvals-1] = 0`
  - Array dimension: 1000
    - `mpirun -np 2 ./hung_comm 100`
    - `myid = 0: array[nvals-1] = 1`
    - `myid = 1: array[nvals-1] = 0`
  - Array dimension 1000
    - `mpirun -np 2 ./hung_comm 10000`

With array dimension equal to 10000 the program hangs!
Why ?

Debugging MPI Applications – case study

- Debugging hints:
  - use gdb and two processes
  - insert breakpoint at first MPI_SEND
  - set program arguments with `set args 1000000`
  - when program hangs, CTRL-C and `where`

MPI Run-time diagnostics

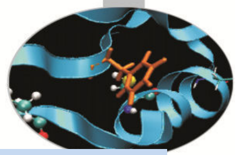
- Somtimes useful to know how the MPI tasks were created and on which physical nodes they were created (*binding*).

```
#!/bin/bash
#PBS -l walltime=30
#PBS -l select=2:ncpus=4:mpiprocs=4
#PBS -A cin_staff
#PBS -o out
#PBS -e err

cd $PBS_O_WORKDIR
module load autoload openmpi
mpirun --display-allocation --display-map exe
```

```
======================   ALLOCATED NODES
===============

 Data for node: Name: node102   Num slots: 4    Max slots: 0
 Data for node: Name: node103ib0       Num slots: 4    Max slots:
0

=====================================================
 ========================   JOB MAP
=====================
 Data for node: Name: node102   Num procs: 4
        Process OMPI jobid: [38452,1] Process rank: 0
        Process OMPI jobid: [38452,1] Process rank: 1
        Process OMPI jobid: [38452,1] Process rank: 2
        Process OMPI jobid: [38452,1] Process rank: 3

 Data for node: Name: node103ib0       Num procs: 4
        Process OMPI jobid: [38452,1] Process rank: 4
        Process OMPI jobid: [38452,1] Process rank: 5
        Process OMPI jobid: [38452,1] Process rank: 6
        Process OMPI jobid: [38452,1] Process rank: 7
```

openmpi

MPI Run-time diagnostics

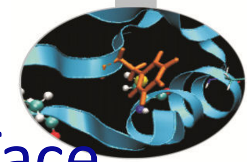


```
#!/bin/bash
#PBS -l walltime=30
#PBS -l select=2:ncpus=4:mpiprocs=4
#PBS -A cin_staff
#PBS -o out
#PBS -e err

cd $PBS_O_WORKDIR
module load autoload intelmpi

export I_MPI_DEBUG=5
mpirun ./spawnexample
```

```
[0] MPI startup(): Rank   Pid     Node name  Pin cpu
[0] MPI startup(): 0      18836   node102    {0,1,2}
[0] MPI startup(): 1      18837   node102    {3,4,5}
[0] MPI startup(): 2      18838   node102    {6,7,8}
[0] MPI startup(): 3      18839   node102    {9,10,11}
[0] MPI startup(): 4      32649   node103    {0,1,2}
[0] MPI startup(): 5      32650   node103    {3,4,5}
[0] MPI startup(): 6      32651   node103    {6,7,8}
[0] MPI startup(): 7      32652   node103    {9,10,11}
```

Intel mpi

Also possible via the **`MPI_Get_processor_name`** function call



Debugging MPI with PMPI

- MPI implementations also provide a profiling interface called PMPI.
- In PMPI each standard MPI function (MPI_) has an equivalent function with prefix PMPI_ (e.g. PMPI_Send, PMI_RECV, etc).
- With PMPI it is possible to customize normal MPI commands to provide extra information useful for profiling or debugging.
- Not necessary to modify source code since the customized MPI commands can be linked as a separate library during debugging. For production the extra library is not linked and the standard MPI behaviour is used.

PMPI Examples

Profiling

```
// profiling example
static int send_count=0;
int MPI_Send(void*start,int count, MPI_Datatype datatype, int dest,
   int tag, MPI_Comm comm)
{
send_count++;
return PMPI_Send(start, count, datatype, dest, tag, comm);
}
```

Debugging

```
! Unsafe uses of MPI_Send
! MPI_Send can be implemented as MPI_Ssend (synchronous send)
subroutine MPI_Send( start, count, datatype, dest,
 tag, comm, ierr )
 integer start(*), count, datatype, dest, tag, comm
 call PMPI_Ssend( start, count, datatype,
 dest, tag, comm, ierr )
end
```

Debugging MPI with totalview and RCM

- Totalview is a powerful, sophisticated, programmable tool for debugging serial or parallel programs.
- Being a graphical tool, for best results recommended to use a remote visualization tool such as RCM (Remote Connection Manager), rather than just an X-display (slow).
- It is also a commercial product, so licenses are limited!

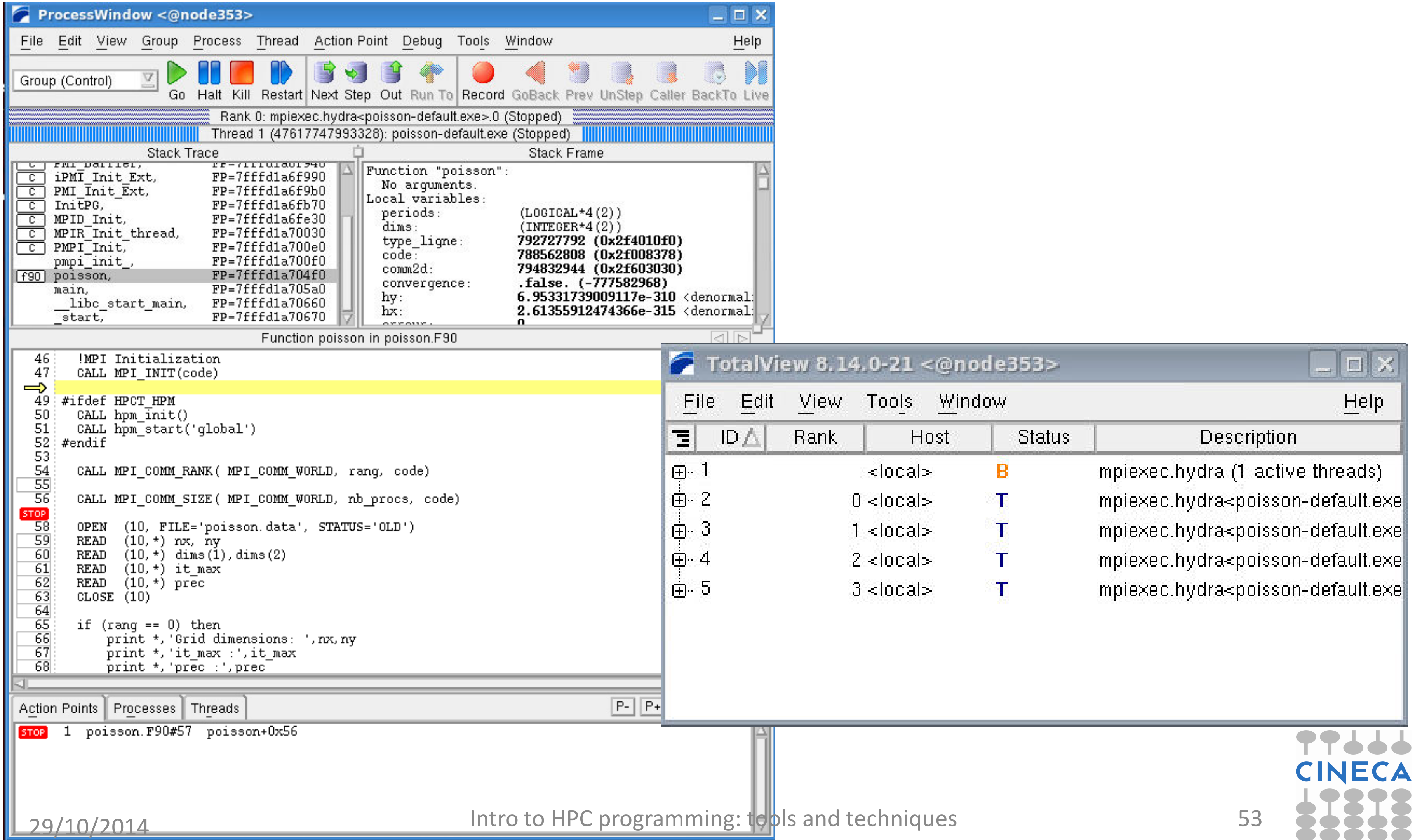
Debugging MPI with Totalview and RCM

1. Download and install RCM on workstation: http://www.hpc.cineca.it/content/remote-visualization-rcm
2. Launch RCM and log on to PLX/Fermi. You will be given a Linux-style desktop.
3. Open a terminal and prepare a PBS/Loadleveler job script. Insert the DISPLAY number in the job script. Or open an interactive PBS session (not BG/Q).

Debugging MPI with totalview and RCM

```
#!/bin/bash

#PBS -l walltime=00:30:00
#PBS -l select=1:ncpus=4:mpiprocs=4:mem=15gb
#PBS -N totalview
#PBS -o job.out
#PBS -e job.err
#PBS -q debug
####     account number (type saldo -b)
#PBS -A your_account_here

module load profile/advanced
module load autoload openmpi/1.6.3--gnu--4.7.2
module load totalview/8.12.0-1
export DISPLAY=node097:1

cd $PBS_O_WORKDIR
mpirun -tv -n 4 poisson.exe
```

Debugging MPI with totalview and RCM



Summary

- All programs have bugs.
- Parallel programs are particularly difficult because of the need to debug multiple processes and possibly, complex communication patterns.
- A debugging strategy should include:
  - compiler options to lower side-effects of optimisation and increase the level of compile-time and run-time checking.
  - post-mortem analysis of stack traces and core files
  - run-time diagnostic options
  - the use of debuggers such as gdb or Totalview
  - in tandem with profilers or similar tools to understand better what the program is doing