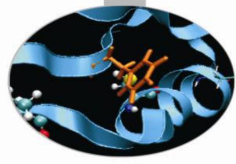

Debugging

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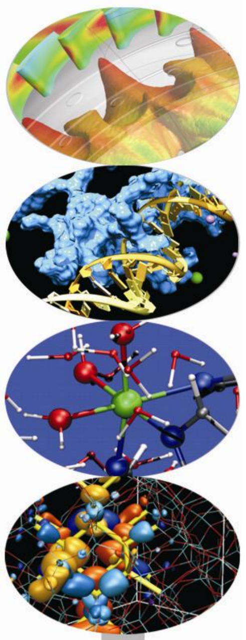
SuperComputing Applications and Innovation Department

18/02/2013



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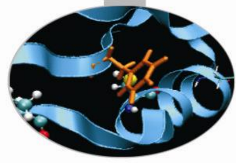
Introduction



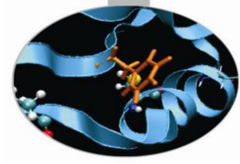
One of the most widely used methods to find out the reason of a strange behavior in a program is the insertion of “printf” or “write” statements in the supposed critical area.

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 errors may not be obvious or hidden when print statements are added and reappear when they’re removed.

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 three 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.

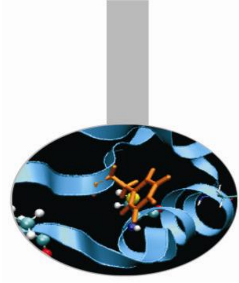
2. Make your program stop on specified conditions.

3. Examine what has happened, when your program has stopped.

4. Change things in your program, so you can experiment with correcting the effects of one bug and go on to learn about another.

Ca. **80%** of software development costs spent on identifying and correcting defects.
It is much more expensive (in terms of time and effort) to detect/locate existing bugs, than prevent them in the first place.

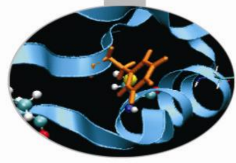
The Fundamental question



How can I prevent Bugs?

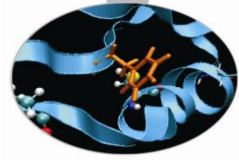
- Design.
- Good writing.
- Self-checking code.
- Test scaffolding.

Preventing bugs via design



Programming is a design activity.
It’s a creative act, not mechanical code generation.

- Good modularization.
- Strong encapsulation/information hiding.
- Operations should be testable.



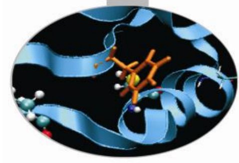
Good writing

- Clarity is more important than efficiency: clarity of writing and style.
    - Use simple expressions, not complex
    - Use meaningful names
    - Clarity of purpose for:
        - Functions.
        - Loops.
        - Nested constructs. Studies have shown that few people can understand nesting of conditional statements to more than 3 levels.
    - Comments,comments,comments.
    - Small size of functions,routines.

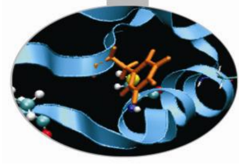
A study at IBM found that the most error-prone routines were those larger than 500 lines of code.

Self-checking code

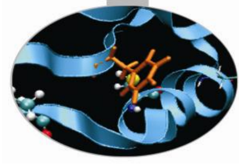
- Check assumptions.
- Use "assert" macro (C / C++).
- Build custom "assert" macros.
- Assertions about intermediate values.
- Pre-conditions, post-conditions.



Test scaffolding



- Test drivers
- Unit testing
- Integration testing
- Test suites
- Expected outputs



Classification of errors

Syntax

- **Definition**: errors in grammar (violations of the "rules" for forming legal language statements).
- **Examples**: undeclared identifiers, mismatched parentheses in an expression, an opening brace without a matching closing brace, etc.
- **Occur**: an error that is caught in the process of **compiling** the program.

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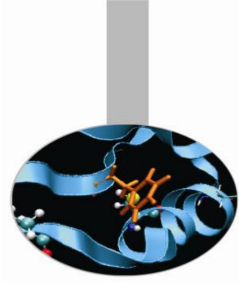


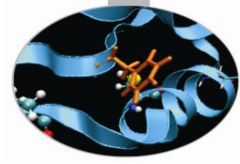
Classification of errors

Runtime

- **Definition**: "Asking the computer to do the impossible!"
- **Examples**: division by zero, taking the square root of a negative number, referring to the 101th on a list of only 100 items, deferencing a null pointer, etc.
- **Occur**: an error that is not detected until the program is executed, and then causes a processing error to occur.

To prevent most of this errors make use of self-checking code

Classification of errors



Logic

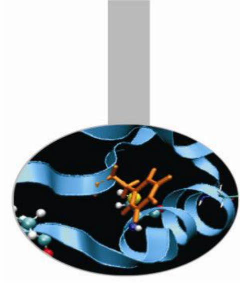
- **Definition**: the program compiles (no syntax errors) and runs to a normal completion (no runtime erros), but the output is wrong. A statement may be syntactically correct, but mean something other than what we intended. Therefore it has a different effect, causing the program output to be wrong.

- **Examples**: improper initialization of variables, performing arithmetic operations in the wrong order, using an incorrect formula to compute a value, etc.

- **Occur**: an error that affect the way the code works.

It is a type of error that only the programmer can recognize. Finding and correcting logic errors in a program is known as debugging.

Common runtime signals



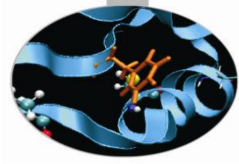
Signal name	OS Signal Name	Description
Floating point exception	SIGFPE	The program attempted an arithmetic operation with values that do not make sense
Segmentation fault	SIGSEGV	The program accessed memory incorrectly
Aborted	SIGABRT	Generated by the runtime library of the program or a library it uses, after having detecting a failure condition.

FPE example

```
main()
{
   int a = 1.;
   int b = 0.;
   int c = a/b;
}
```

```
[pdagna00@node342 ~ ]$ gcc fpe_example.c
```

```
[pdagna00@node342 ~ ]$ ./a.out
Floating point exception
```

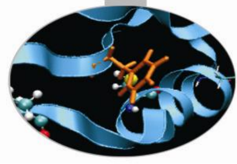


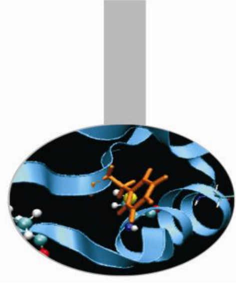
SEGV example

```
main()
{
    int array[5];
    int i;
    for (i = 0; i < 255; i++) array[i] = 10;
    return 0;
}
```

```
[pdagna00@node342 ~ ]$ gcc segv_example.c
```

```
[pdagna00@node342 ~ ]$ ./a.out
Segmentation fault
```





ABORT example

```
# include <assert.h>
main()
{
int i=0;
assert(i != 0);
}
```

```
[pdagna00@node342 ~ ]$ gcc abort_example.c
```

```
[pdagna00@node342 ~ ]$ ./a.out
a.out: assert.c:5: main: Assertion `i != 0' failed.
Aborted
```

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Addr2line command

Sometimes it may happen that an unsuccesful job generates a segmentation fault message where the chain of stack frames is reported.

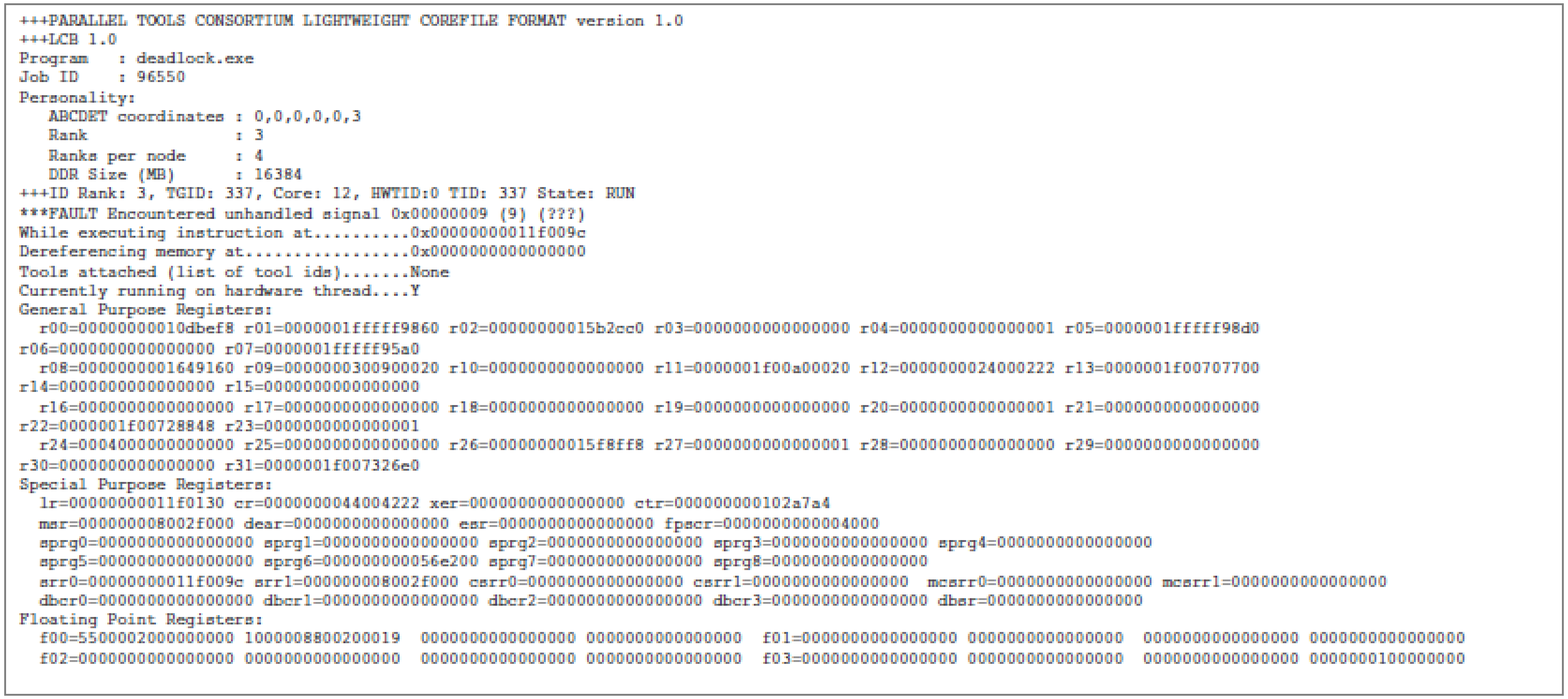
```
[[P90:05046] *** Process received signal ***
[P90:05046] Signal: Segmentation fault (11)
[P90:05046] Signal code: Address not mapped (1)
[P90:05046] Failing at address: 0x7fff54fd8000
[P90:05046] [ 0] /lib/x86_64-linux-gnu/libpthread.so.0(+0x10060) [0x7f8474777060]
[P90:05046] [ 1] /lib/x86_64-linux-gnu/libc.so.6(+0x131b99) [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 ***
```

addr2line is an utility that allows to get information from this file about where the job crashed, using the sintax:

- addr2line –e ./myexe 0x400ab9

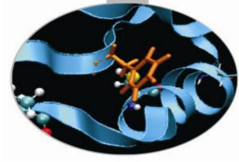
Addr2line command - BGQ

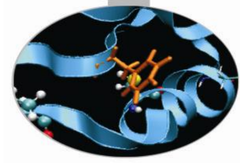
If nothing is specified, an unsuccessful job generates a text core file for the processes that caused the crash.
However, those core files are all but easily readable!



```
+++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=0000000000000000 0000000000000000  0000000000000000 0000000000000000  f03=0000000000000000 0000000000000000  0000000000000000 0000000100000000
```

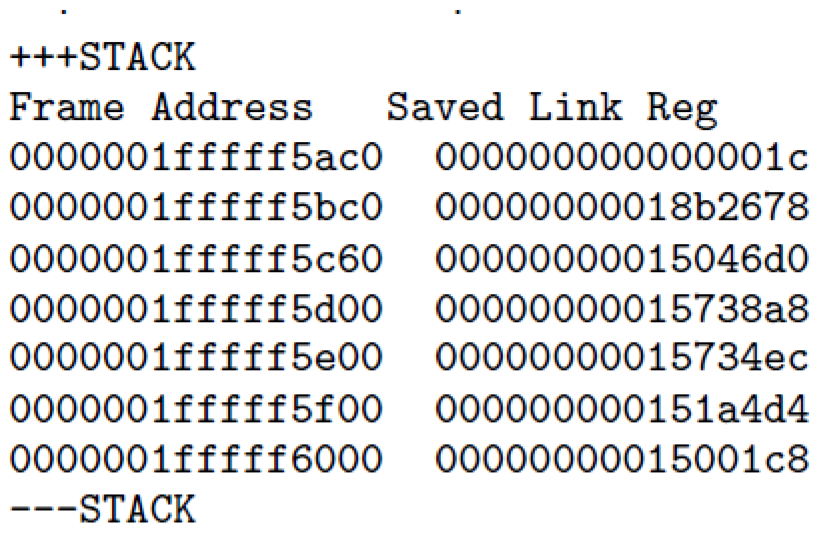
addr2line is an utility that allows to get from this file information about where the job crashed





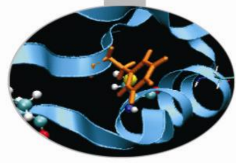
Addr2line command - BGQ

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



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

In particular, **“Saved Link Reg”** column is the one we need!



Addr2line command - BGQ

From the core file output, save only the addresses in the “**Saved Link Reg”** column:

```
000000000000001c
00000000018b2678
00000000015046d0
00000000015738a8
00000000015734ec
000000000151a4d4
00000000015001c8
```

Replace the first eight 0s with 0x:

```
00000000018b2678 => 0x018b2678
```

Lauch addr2line:

- addr2line –e ./myexe 0x018b2678

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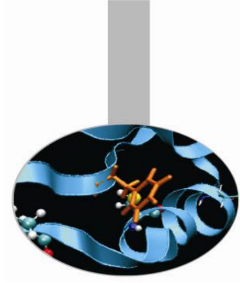
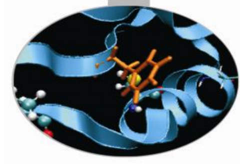
Most poular debuggers



- **Debuggers are generally distributed within the compiler suite**.
  - Commercial:
    - Portland pgdbg
    - Intel idb
  - Free:
    - GNU gdb

- **Moreover there are companies specialized in the production of very powerful debuggers , among them most popular are:**
    - Allinea DDT
    - Totalview



Debugger capabilities

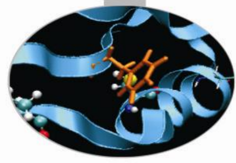
The purpose of a debugger is to allow you to see what is going on “inside” another program while it executes or what another program was doing at the moment it crashed.

Using specifics commands, debuggers allow real-time visualization of variable values, static and dynamic memory state (stack, heap) and registers state.

Most common errors are:

1. pointer errors
2. array indexing errors
3. allocation errors
4. routines dummy and actual arguments mismatch
5. infinite loops
6. I/O errors

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.

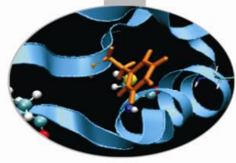
  – **GNU compiler**:
  ```
  - gcc/g++/gfortran -g [other flags] source -o executable
  ```

  – **PGI compiler**:
  ```
  - pgcc/pgCC/pgf90 -g [other flags] source -o executable
  ```

  – **INTEL compiler**:
  ```
  - icc/icpc/ifort -g [other flags] source -o executable
  ```

  – **BGQ - IBM compiler**
  ```
  - bgxlc/bgxlc++/bgxlf90 -g [other flags] source -o executable
  ```

Execution



- The **standard way** to run the debugger is:
  - `debugger_name executable`

Otherwise it's possible to first run the debugger and then point to the executable to debug:

- GNU gdb:
  - `gdb`

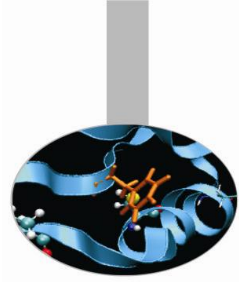
    `> file executable`

- It's also possible to **debug an already-runnig** program started outside the debugger **attaching** to the **process id** of the program.

Syntax:

- GNU gdb:
  - `gdb`

    `> attach process_id`
  - `gdb attach process_id`



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
```

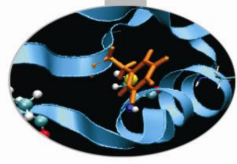
`break <line> <function> :` set breakpoint at specified line or function, useful to stop execution before a critical point.

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

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

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

Command list



- `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.

Command list

`continue`: continue program being debugged, after signal or breakpoint

`where` : print backtrace of all stack frames, or innermost “count” frames.

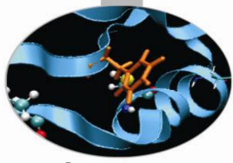
`step :` Step program until it reaches a different source line. If used before a function call, allow to step into the function. The debugger stops at the first executable statement of that function

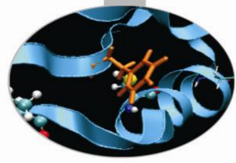
`step count :` executes `count` lines of code as the `next` command

`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.





Command list

`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:

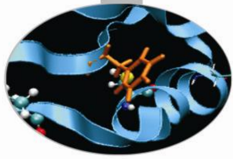
`print array[num_el]` displays element `num_el`

`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.



Command list

- `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

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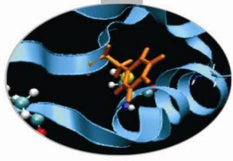
Attach method procedure



If an application crashes after few seconds the attach method could be very difficult to be used.

– An inelegant-but-functional technique commonly used with this method is to insert the following code in the application where you want to attach. This code will then spin on the sleep() function forever waiting for you to attach with a debugger.

C/C++

```
{
  int i = 0;
  printf("PID %d ready for attach\n",
getpid());
  fflush(stdout);
  while (0 == i) sleep(5);
}
```

Fortran

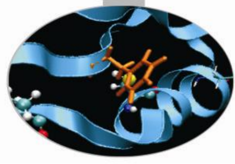
```
integer ::  i = 0
write (*,*) "PID", getpid()," ready  for
attach"
   DO WHILE (i == 0)
    call sleep(5)
   ENDDO
```

– Recompile and re-launch the code attaching with the debugger to the process returned by the function "`getpid()`"

– With the `next` command go to the `while` or `DO` instruction and change "i" with a value ≠ 0 : `set var i = 7`

– Then set a breakpoint after this block of code and continue execution until the breakpoint is hit.

Using Core dumps for Postmortem Analysis

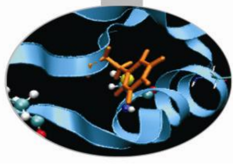


- In computing, a core dump, memory dump, or storage dump consists of the recorded state of the working memory of a computer program at a specific time, generally when the program has terminated abnormally.
- Core dumps are often used to assist in diagnosing and debugging errors in computer programs.
- 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 Serial Program

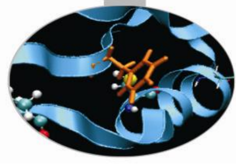


"pointer error" example

Program that:

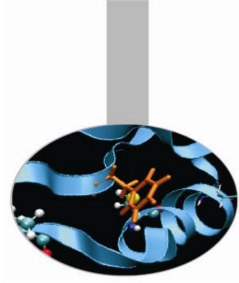
1. constructs an array of 10 integers in the variable `array1`
2. gives the array to a function `squareArray` that executes the square of each element of the array and stores the result in a second array named `array2`
3. After the function call, it's computed the difference between `array2` and `array1` 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 Serial Program

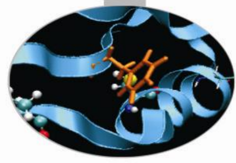


```
#include <stdio.h>
#include <stdlib.h>
int indx;
void initArray(int nelem_in_array, int *array);
void printArray(int nelem_in_array, int *array);
int squareArray(int nelem_in_array, int *array);
int main(void) {
const int nelem = 12;
int *array1, *array2, *del;
array1 = (int *)malloc(nelem*sizeof(int));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



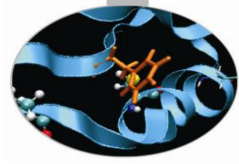
```
for (indx = 0; indx < nelem; indx++)
   {
     del[indx] = array2[indx] - array1[indx];
   }
   printf("La fifferenza fra array2 e array1 e':  ");
   printArray(nelem, del);
   free(array1);
   free(array2);
   free(del);
   return 0;}
void initArray(const int nelem_in_array, int *array)
{
   for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



Debugging Serial Program

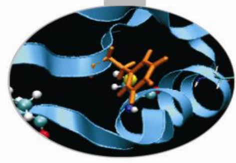
```
int squareArray(const int nelem_in_array, int *array)
{
  int indx;
  for (indx = 0; indx < nelem_in_array; indx++)
  {
    array[indx] *= array[indx];}
  return *array;
}
void printArray(const int nelem_in_array, int *array)
{
  printf("[  ");
  for (indx = 0; indx < nelem_in_array; indx++)
  {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

Debugging Serial Program



- 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 Serial Program



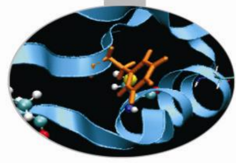
Debugging

- **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 Serial Program



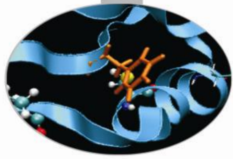
- **Step2**: check of the difference between the element values in the two arrays
  - For loop analysis:

```
 #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 Serial Program



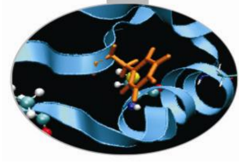
As highlighted in the previous slide the values of the elements of `array1` and `array2` are the same. But this is not correct because array, `array1`, was never passed to the function `squareArray()`. Only array2 was passed in line 38 of our code. If we think about it a bit, this sounds very much like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

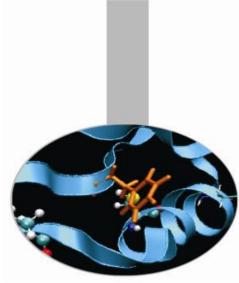
Solution:

To solve the problem we just have to change the statement

```
array2 = array1;
```

in

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



Parallel debugging

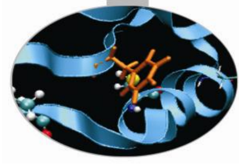
Normally debuggers can be applied to **multi-threaded parallel codes**, containing OpenMP or MPI directives, or even **OpenMP and MPI** hybrid solutions.

In general 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 multi-thread programs.

Although specific commands are not provided, gdb still allows a very powerful approach for codes parallelized using MPI directives. For this reason it's widely used by programmers also for these kind of codes.

Debug OpenMP Applications



GDB facilities for debugging multi-thread 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.

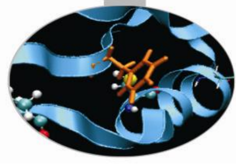
GDB **cannot single-step all threads** in lockstep. Since thread scheduling is up to your debugging target's operating system (not controlled by GDB), **other threads may execute more than one statement while the current thread completes a single step** unless you use the command `:set scheduler-locking on.`

GDB is not able to show the values of private and shared variables in OpenMP parallel regions.

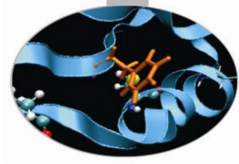
Debug OpenMP Applications

- **Example of “hung process”**
  - 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
```



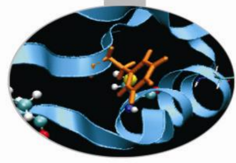
Debug OpenMP Applications



```
!$OMP SECTIONS
!$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
```

Debug OpenMP Applications

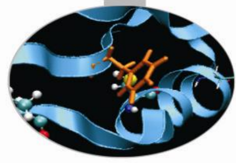


- Compiling:

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

- Esecution:
  - `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()
```



Debug OpenMP Applications

- Debugging
- List the source code from line 10 to 50 using the command: `list 10,50`
- Insert a breakpoint at the beginning of the parallel region `b 20` and run the executable with the command: `run`
- Check the threads are at the breakpoint : `info threads`

```
* 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
```

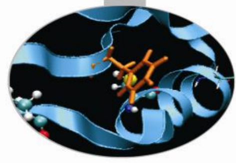
- Looking at the source it’s clear that in the SECTION region the threads don’t execute the statements:

```
PRINT *, 'Thread',TID,' adding A() to B()'
PRINT *, 'Thread',TID,' adding B() to A()`
```

- Insert a breakpoint in the two sections:

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

Debug OpenMP Applications

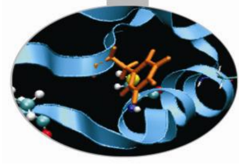


- Restart the execution: `thread apply all cont`

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

- The execution hangs without reaching the breakpoints!
- Stop execution with “`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)):
  0x0000000000400e6d in MAIN__.omp_fn.0 (.omp_data_i=0x7fffffffd2b0)
   at openmp_bug2_nofix.f90:43
```



Debug OpenMP Applications

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

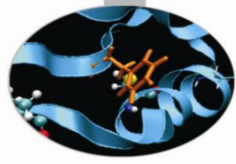
```
CALL OMP_SET_LOCK(LOCKB)
```

- 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 raise up the there is an error.
- The correct order provides that the call to `OMP_SET_LOCK` must be followed by the respective `OMP_UNSET_LOCK`
- Arranging the order the code finishes successfully

Debug MPI Applications

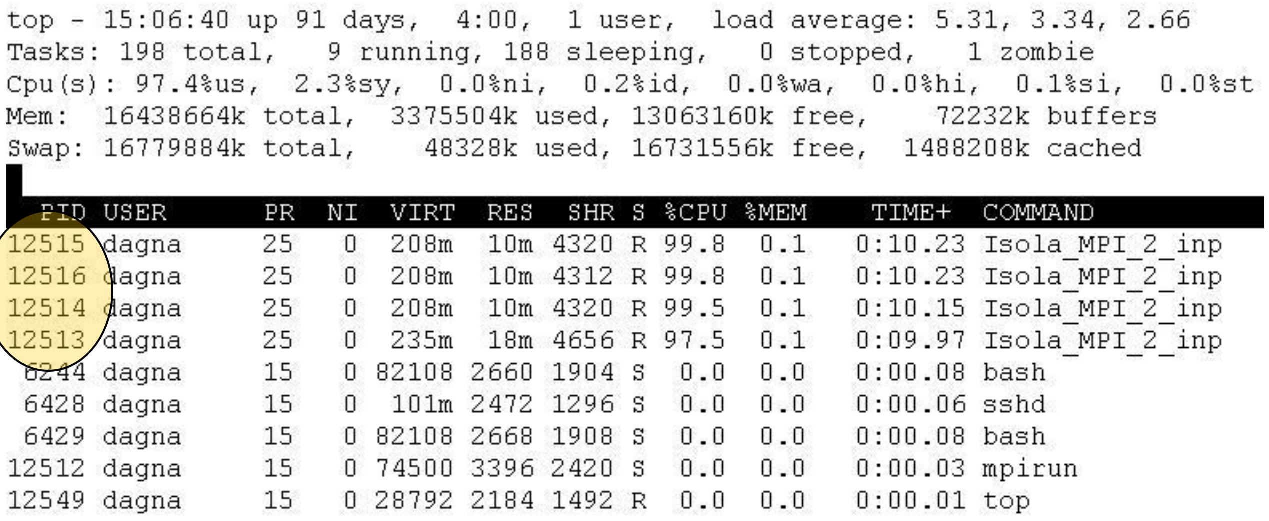


- There are two common ways to use serial debuggers such GDB to debug MPI applications
  - Attach to individual MPI processes after they are running using the "`attach`" method available for serial codes launching some instances of the debugger to attach to the different MPI processes.
  - Open a debugging session for each MPI process trough the command "`mpirun`".

Debug MPI Applications

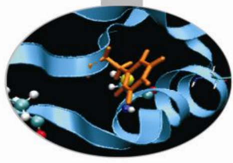
- **Attach method procedure.**
  - Run the MPI application in the standard way
    - `mpirun -np 4 executable`
    - From another shell, using the “`top`” command look at the MPI processes which are bind to the executable.

PID executable MPI processes



```
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
```

Debug MPI Applications

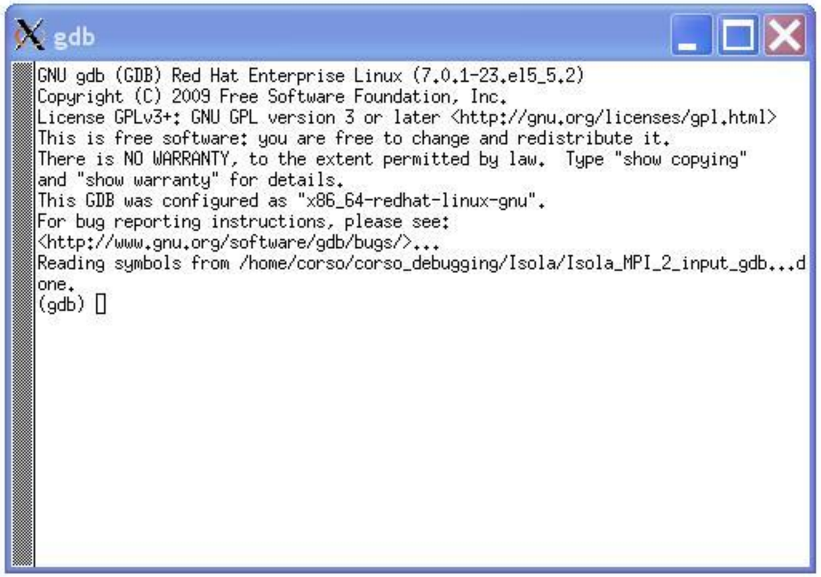


- **Attach method procedure**.
  - Run up to "n" instances of the debugger in "`attach`" mode, where "n" is the number of the MPI processes of the application. Using this method you should have to open up to "n" shells. For this reason, if not necessary, is advisable to use a little number of MPI processes.
  - 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

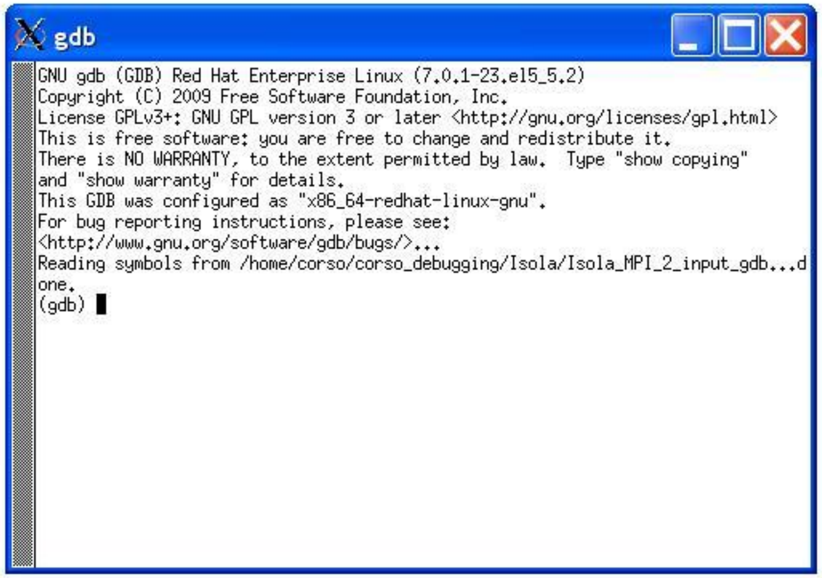
Debug MPI Applications

- **Procedure with the "`mpirun`" command.**
  - 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
```

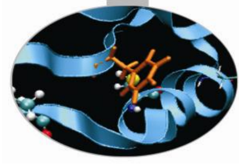


```
GNU gdb (GDB) Red Hat Enterprise Linux (7.0.1-23.el5_5.2)
Copyright (C) 2009 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.  Type "show copying"
and "show warranty" for details.
This GDB was configured as "x86_64-redhat-linux-gnu".
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>...
Reading symbols from /home/corso/corso_debugging/Isola/Isola_MPI_2_input_gdb...d
one.
(gdb)
```



```
GNU gdb (GDB) Red Hat Enterprise Linux (7.0.1-23.el5_5.2)
Copyright (C) 2009 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.  Type "show copying"
and "show warranty" for details.
This GDB was configured as "x86_64-redhat-linux-gnu".
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>...
Reading symbols from /home/corso/corso_debugging/Isola/Isola_MPI_2_input_gdb...d
one.
(gdb)
```

  - Now we can debug our MPI application using for each shell all the functionalities of GDB.

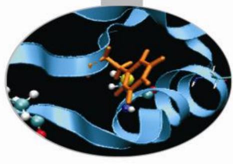


Debug MPI Applications

Debug MPI hung process

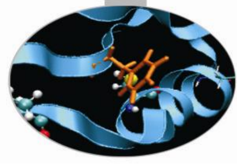
- In parallel codes using message passing, processes are typically performing independent tasks simultaneously. When the time comes to send and receive messages, certain conditions must be met in order to successfully transfer the data. One of these conditions involves blocking vs. *nonblocking* sends and receives.
- In a blocking send, the function or subroutine does not return until the "buffer" (the message being sent) is reusable. This means that the message either has been safely stored in another buffer or has been successfully received by another process.
- There is generally a maximum allowable buffer size. If the message exceeds this size, it must be received by the complimentary call (e.g., MPI_RECV) before the send function returns. This has the potential to cause processes to hang if the message passing is not handled carefully.

Debug MPI Applications



The following code is designed to run on exactly two processors. An array is filled with process numbers. The first half of the array is filled with the local process number, and the second half of the array is filled with the other process number. The second halves of the local arrays are filled by message passing.

```
#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));
```

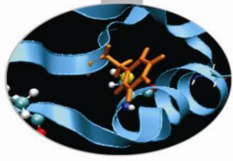


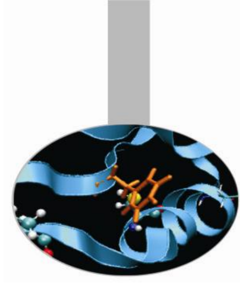
Debug MPI Applications

```
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();
}
```

Debug MPI Applications

- Compile: `mpicc -g -o hung_comm hung_comm.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 1000`
    - myid = 0: array[nvals-1] = 1
    - myid = 1: array[nvals-1] = 0
  - Array dimension: 10000
    - `mpirun -np 2 ./hung_comm 10000`
    - With array dimension equal to 10000 the program hangs!





Debug MPI Applications

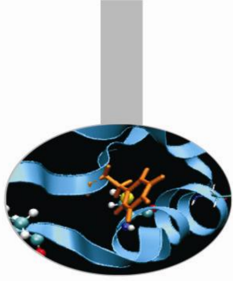
Debugging

- **Run GDB with mpirun:**
  - `mpirun -np 2 xterm -e gdb hung_proc`

- When the two separate windows, containing the “GDB” instances, are ready, visualize the source with `list` and insert a **breakpoint** at line 19 with `break 19` where there is the first MPI_Send call.
- Let’s give the message dimension with `set args 1000000`
- Run the code with the command `run` on the two shells, which continues until line 19 is hit.
- Step line by line on the two shells using `next`

```
(gdb) next
20 MPI_Send(array,nvals/2,MPI_INT,1,1,MPI_COMM_WORLD);
(gdb) next
23 MPI_Send(array,nvals/2,MPI_INT,0,1,MPI_COMM_WORLD);
```

Debug MPI Applications



- The second `next` doesn't produce any output underlying that the execution is halted in the calls to `MPI_Send` waiting for the corresponding `MPI_Recv`.
- Let's type "`Ctrl c`" to exit from hanging. Using `where` we receive some information about where the program stopped. Among them there is the following message that indicates that the process is waiting for the completion of the send:
- `#4  `**`ompi_request_wait_completion`**` (buf=0x2aaab4801010, count=500000, datatype=0xfb8, dst=0, tag=1, sendmode=MCA_PML_BASE_SEND_STANDARD, comm=0x60c180) at ../../../../ompi/request/request.h:375`
- `#7  0x0000000000401fee in main (argc=2, argv=0x7fffffffd2a8) at hung_proc.c:23`
- **Solution**:
  - Reverse the two calls `MPI_Send` and `MPI_Recv` at lines 23 and 24.