HPC Programming

Debugging, Part I

Peter-Bernd Otte, 15.1.2019

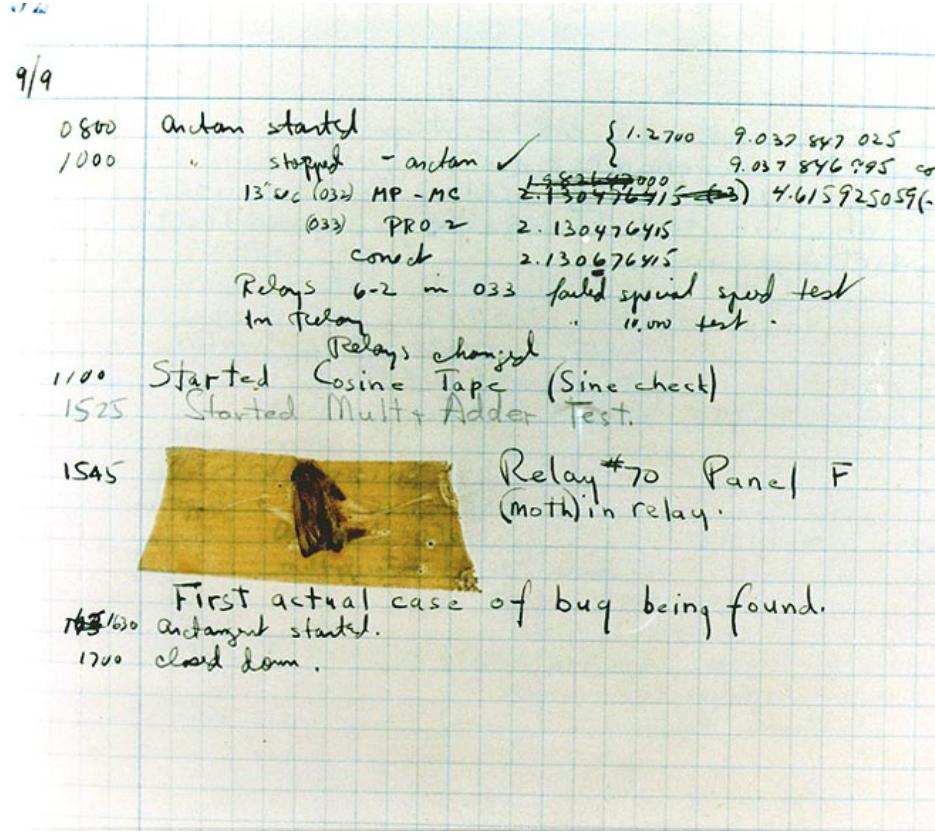
Debugging

1. Introduction / General Debugging
2. Typical bugs
3. Tools Overview
4. Introduction TotalView
5. Debugging with TotalView OpenMP
6. Debugging with TotalView MPI

Definition of a bug

- “bug” := errors or glitches in a program
  → incorrect result.

- most difficult part of debugging: finding the bug.
  Once found, correcting is relatively easy
  - prove: bug bounty programs
  - debuggers: help programmers locate bugs by: executing code line by line, watching variable values
- locating bugs is something of an art:
  - why? a bug in one section of a program cause failures in a completely different section
  - there is no defined right way to debug



1946, moth removed from relay

What's it all about

- humans write high level code, e.g. in C
- hardware understands assembler

```
 1 #include <stdio.h>
 2 #include <time.h>
 3 #include <sys/time.h>
 4 #ifdef _OPENMP
 5 #  include <omp.h>
 6 #endif
 7
 8 #define f(A) (4.0/(1.0+A*A))
 9
10 int n = 100000000;
11
12 int main(int argc, char** argv)
13 {
14   int i;
15   double w,x,sum,pi;
16   clock_t t1,t2;
17   struct timeval tv1,tv2; struct timezo
18 # ifdef _OPENMP
19     double wt1,wt2;
20 # endif
21
22 # ifdef _OPENMP
23     int myrank, num_threads;
```

compiler & linker

```
:::  _start:          xorl     %ebp,%ebp
       0x00400521:
:::    0x00400522:    mov      %rdx,%r9
       0x00400523:
       0x00400524:
:::    0x00400525:    popl     %rsi
:::    0x00400526:    mov      %rsp,%rdx
       0x00400527:
       0x00400528:
:::    0x00400529:    andl     $-16,%rsp
       0x0040052a:
       0x0040052b:
       0x0040052c:
:::    0x0040052d:    pushl    %rax
:::    0x0040052e:    pushl    %rsp
:::    0x0040052f:    movl     $0x400810,%r8
       0x00400530:
       0x00400531:
       0x00400532:
       0x00400533:
       0x00400534:
       0x00400535:
:::    0x00400536:    movl     $0x4007a0,%rcx
```

- error during execution? → today's topic

todays lecture topics

- Today we concentrate on following classes of bugs:
  - Arithmetic
  - Logic
  - resource

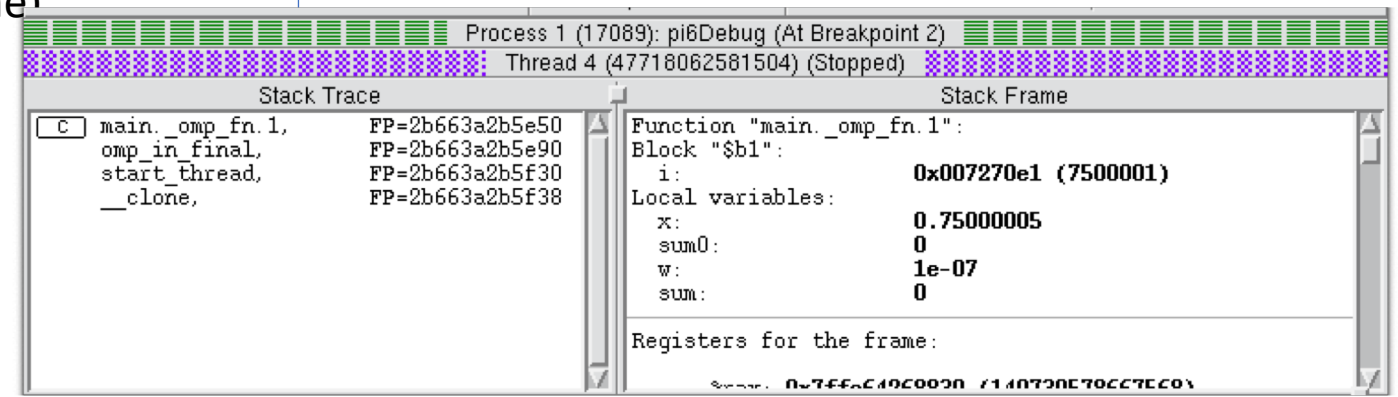
- Next lessons:
  - Multi-threading in OpenMP and multi-processing in MPI
  - Deadlock, Race condition, concurrency errors

- We concentrate on run-time and logical errors,
  no syntax or semantic (→ compiler) nor linker errors.

Call stack

- LIFO (last in, first out)
- Call stack = stack of “stack frames”
- Function call → new stack frame. Removed when call ends
- “stack frame”:
  - Local variables (in example: “c”)
  - Argument parameters (in example: “a, b”)
  - Return address (in example: “1st line in main()”)
  - Saved copies of registers modified by subprograms which might get restored (in example: none)
  - Has Frame Pointer (FP)

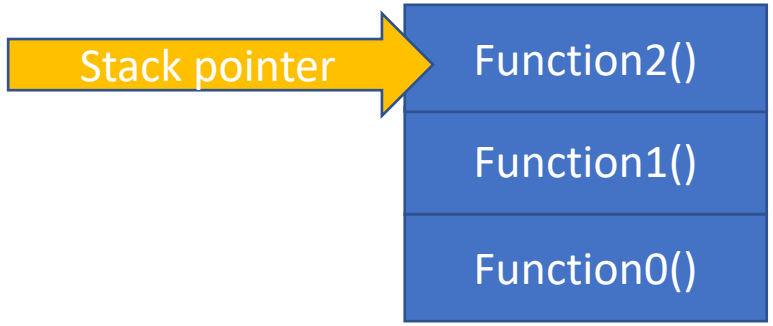
```
int myfunc(int a, int b) {
        int c;
        //do some calculation
        return;
}
int main () {
        myfunc(a,b);
}
```



Program counter and Stack pointer

- Program Counter (PC):
  - Hardware register in processor, indicating the actual point in program sequence.
  - Stack Frame includes a return address
    → PC can be reset at end of called subfunction

- Stack pointer:
  - Address register, that points to the top of the call stack



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let’s focus on the problems…

Common bugs in C

- Arithmetic
  - div 0, over- or underflow, loss of precision
- Logic
  - infinite loops, infinite recursion, off-by-one error
- Resource
  - null pointer dereference, uninitialized variable, wrong data type, access violations and use-after-free error, resource leaks, buffer overflow

- Few examples to warm up…

uninitialized memory

```
double d;
switch (i) {
        case 0: d = 1; break;
        case 1: d = 2; break;
}
printf(“value of d: %f”, d);
```

- value of d is for most cases arbitrary and depends on what is stored in memory before program launched.
- “safety initialisation” recommended.

value outside the domain

```
int x, y, z;
//some calculation
if ( (x+y) < z )
        return 1;
else
        return 0;
```

- what is the result for x=y=z=2E9?
- (x+y) outside of int range → overflow → gets negative.

buffer overflow


```
main () {
        char comment[100];
        int *myPhDResult;
        char sqlCommand[200] = “SELECT comments FROM users”;
        gets(comment);
        //SQLExeceute(sqlCommand);
        printf(“My PhD Result: %i“, myPhDResult);
}
```

- Any code which puts data in some buffer without checks → possible buffer overflow
- when size(entered value) > size(comment)+1 → adjacent memory gets overwritten
- No reliable error message during compilation or runtime! → debugger with memory checks helps

Arithmetic exceptions

- divide by zero (misnormer: “floating point exceptions” do cover int arithmetic errors too)
- off by one: starting a loop at 1 instead of 0, writing <= instead of <, etc…

Syntactically correct “errors”

single statement not in loop:

```
for (int i=0; i<10; i++); x++;
```

Using a single equal sign to check equality:

```
char x=‘y’;
while (x=‘y’) { //Assigns ‘y’ to x, tests if x is zero
        printf(“continue? ”); gets(y);
}
```

- syntactically correct, but most likely different programmer intention
- stick to code formatting rules

Memory leaks I

- frequent in C, no automatic garbage collection (check new techniques like smart pointer in C++11)
- more memory gets allocated during runtime (and halts when all eaten up)

```
for (;;) {
        char *out = (char*) malloc (size);
        /*do some stuff
        and forget to free out*/
}
```

Memory leaks II

- Overstepping array boundaries


```
int array[10];
int myPhDResult;
for (int i=1; i<=10; i++)
        printf("%d ", array[i]);
```

- No hint or halt during runtime
- Only a memory checker finds this error.

return temporary value

```
char *myfunc() {
        char ch;
        //so some stuff
        return (&ch);
}
```

- local variable address from stack is returned
- solution: declare the variable as public before calling myfunc()

free the already freed resource

```
int myfunc(int global) {
        char *str = (char*) malloc(42);
        if (global ==0) free(str);
        //Some more statements, including some malloc like
        char *str2 = (char*) malloc(20);
        free(str);
}
```

- free the already freed resource, but str still points to the old address
- affects by chance the newly allocated variable

NULL dereferencing

```
char *c; //might be NULL
if (x>0) c='h';
printf("The character c is: %c", *c);
```

- if c is NULL → dereferencing fails
- when dereferencing an object, makes sure it initialised in any path.

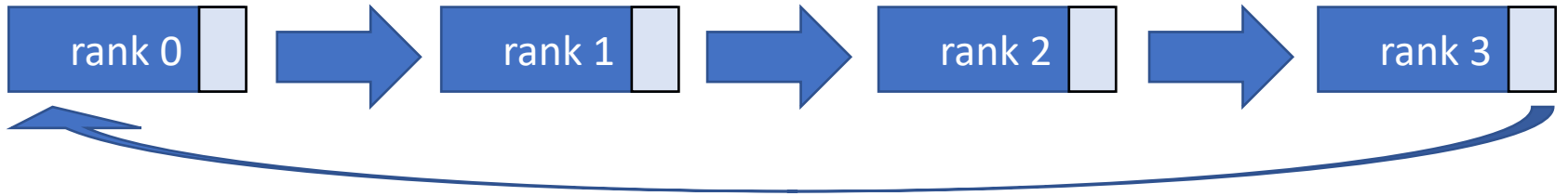
Aliasing

```
char str[42] = “Test Str”;
char *str2 = &str;
strcat(str, str2);
```

- we may get an runtime error
- (strcat is no safe function, buffer overflow when 2nd argument > 1st)
- Aliasing creates problems when different addresses are expected. → try to avoid
- functions which expect parameters to be in certain format → be cautious!

Deadlocks, Race condition

- see lectures from OpenMP and MPI
- Deadlock: cyclic list, all threads proceed when receive OK from predecessor



- Race Condition: multiple threads, shared resources, result depends on scheduler

- Debugging OpenMP and MPI → next lecture.

How to avoid bugs

- Switch on compiler warnings! … and pay attention to them
- Use of simpler methods
  - Split larger methods into small, cohesive ones!
  - Intuitive idea of what's being done
  - few parameters only
- Mixing up various operations in a single expression → confusion
  - Split complicated expressions!
  - Make it easy for the debugger

```
if ( (42.*b/c++) > (43.+(10.*e/f)) ) {
        /*do some operation A*/
} else {
        /*do some operation B*/
}
```

```
double a = 42. * b / c++;
double d = 43. + ( 10. * e / f);
if (a > d) {
        /*do some operation A*/
} else {
        /*do some operation B*/
}
```

Hints

- Problem?
  1. remove all object, intermediate or temporary files
  2. Rebuild with debugging info on (-g) and optimisation off (-O0)
  3. Still problematic? --> debugger!

- Debug first a serial version of your program
- Some errors only occur
  - With optimized code (possible reasons: initialized variables? Wrong pointers? Buffer overflow?)
  - Outside of debug session (possible reason: different timing?)
  - With many processes

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Debuggers in general

- test and debug a target program

- Common features:
  - flow control (run, step, into)
  - actions points
  - view registers values
  - view call stack
  - inspect and edit program memory

Debug Tools Overview

- **GDB** (OpenSource):
  - **Minus**: not optimal for beginners, multi-thread and multi-process possible
- **Valgrind** (OpenSource):
  - Plus: detect memory leaks or cache misses, works also for threads
  - **Minus**: does not run programs in parallel, threads are serialised. Only minimal MPI support
  - Modules on Himster2: debugger/Valgrind/<version>-<toolchain>
- **Intel's Vtune**
  - Profiler for serial and parallel code, OpenMP and MPI
- **RogueWave's TotalView** (Closed Source)
  - More in this lecture
  - **Plus: User friendly; serial, threaded and multi-process programs**
  - **Minus**: Costs you "an arm and a leg"
  - Modules on Himster2: debugger/TotalView/2018.0.5_linux_x86-64

- Which to chose? Availability on your platform and fits your needs.

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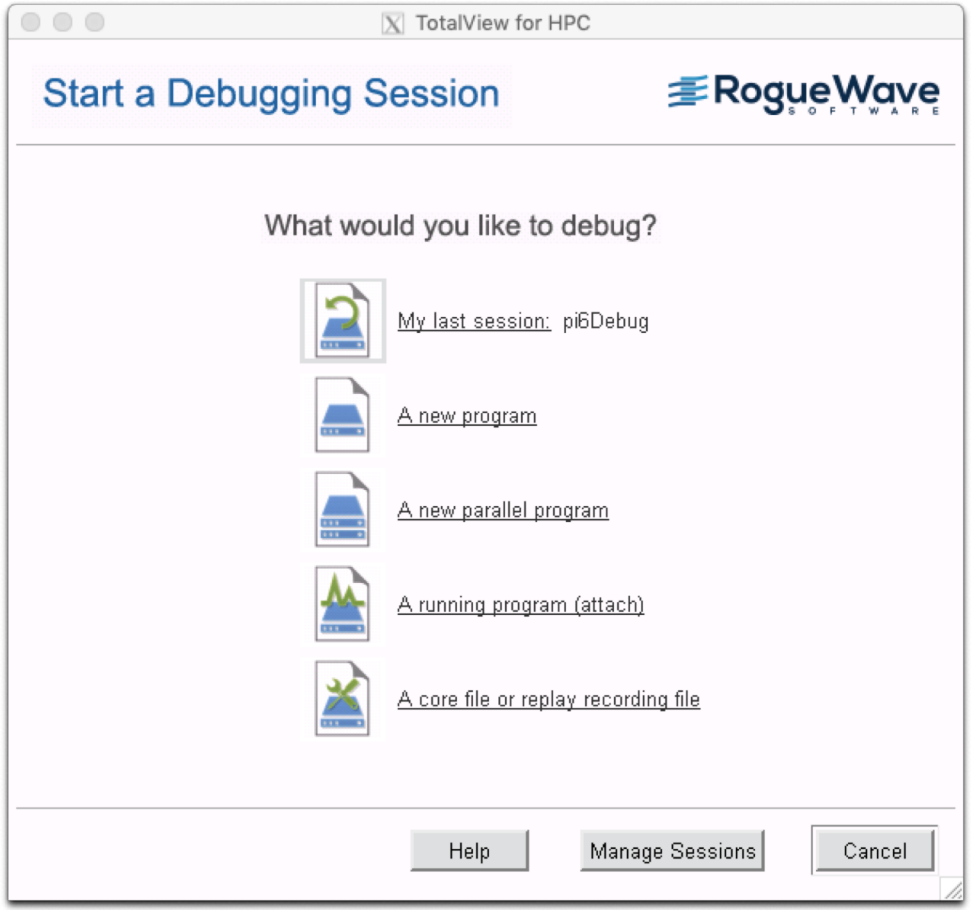
How to use totalview

- via command line, on Himster head node:
  $ module load debugger/TotalView/2018.0.5_linux_x86-64
- interactively:
  $ totalview &
- Normal:
  $ totalview [totalviewArgs] executable [-a executable_args]
- Attach to running program:
  $ totalview [totalviewArgs] executable -pid [PID#] [-a executable_args]
  find out PID# with
  $ps ax
- Attach to a core file:
  $ totalview [totalviewArgs] executable coreFileName [-a executable_args]

Totalview and Preparations

- Main features:
  - Interactive debugging
  - Attaching to a process
  - Analyse core-dumps
  - reverse debugging
    (reverse anytime during debug)

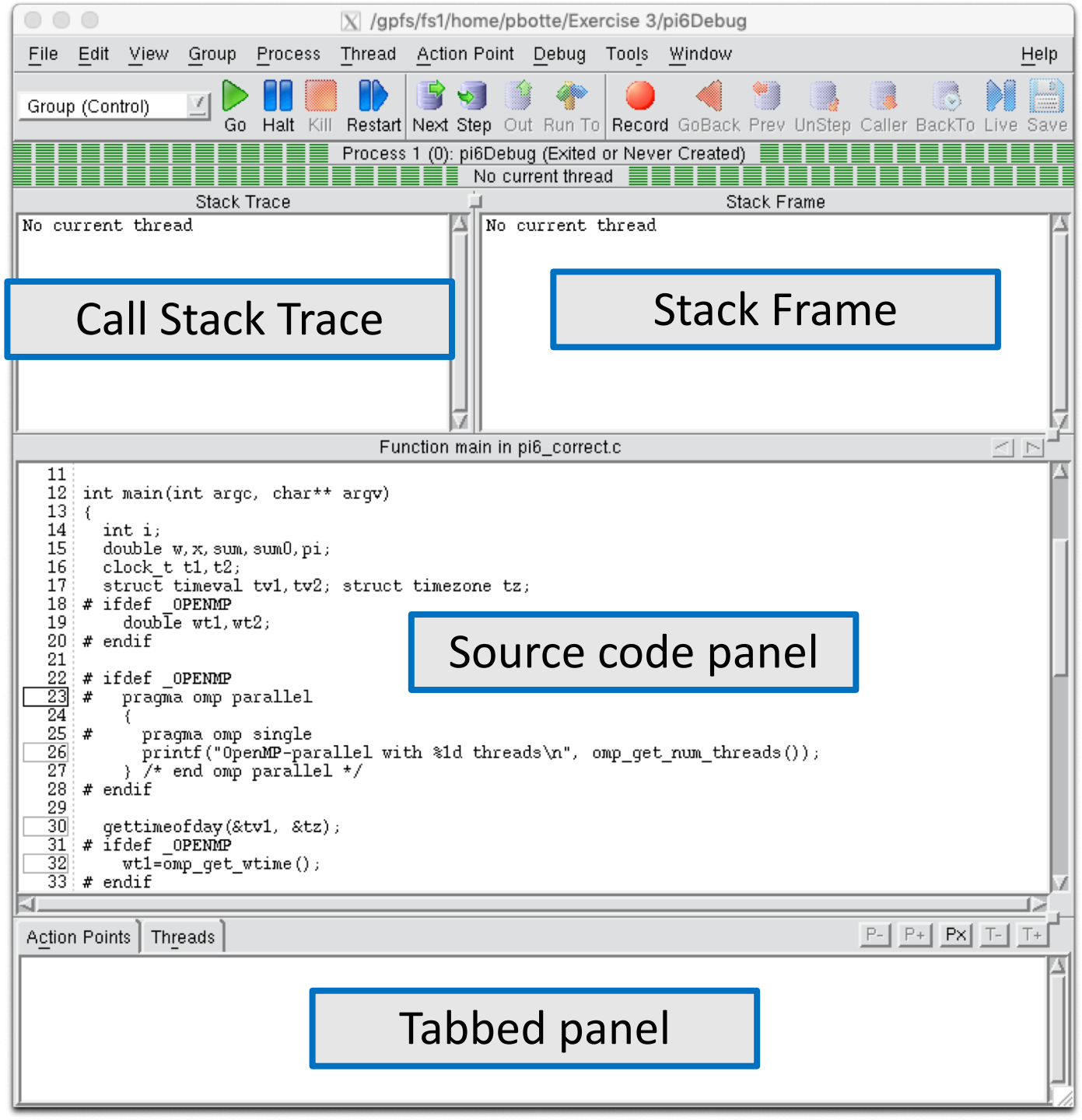
- To enable debugging
  - debug enabled compilation: -g
    - creates pointers to your source code lines
    - source code still needs to be available at the path during compilation
  - 1st step: no optimisations: -O0
    - later use -O3
    - may change the behaviour of your program with different errors



TotalView

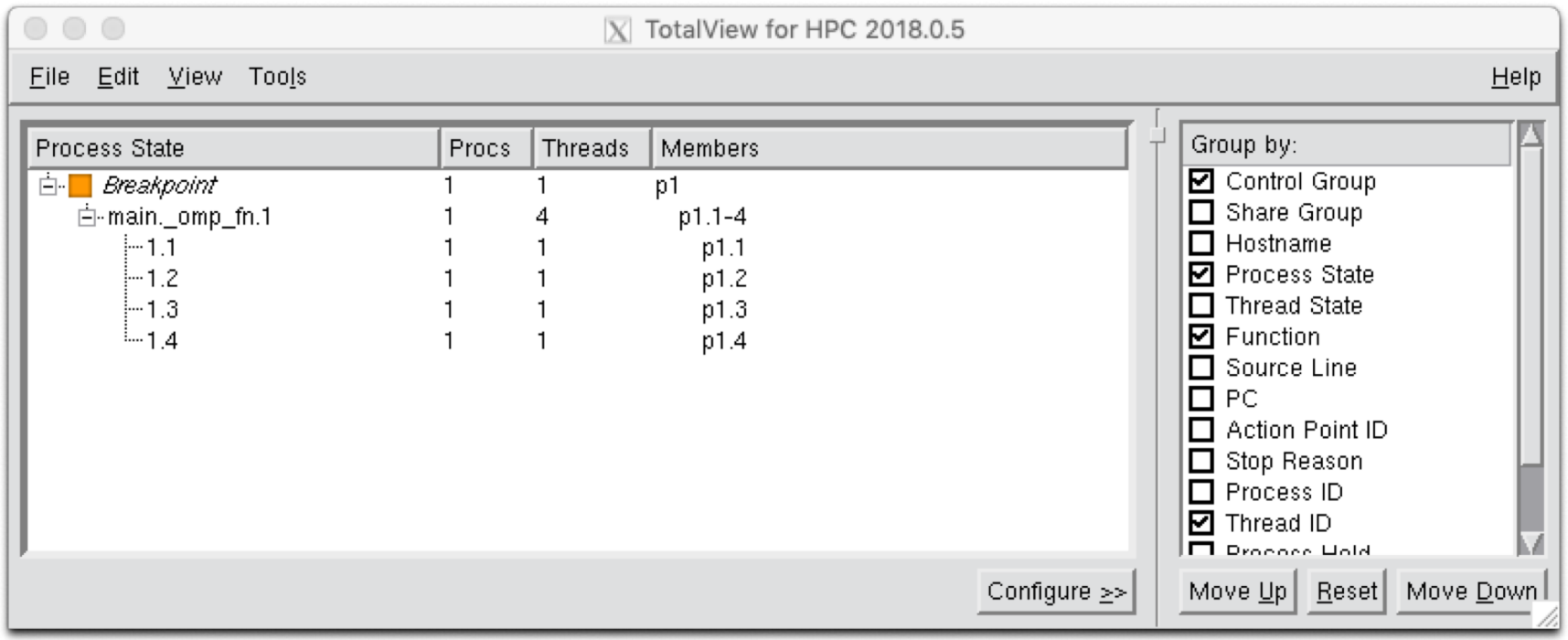
- “Standard tool” for parallel debugging (OpenMP, MPI, CUDA)
- Wide compiler (Python, C, Fortran) and platform support (Linux, Unix, MacOS, no Windows)

- Process window:
  - State of one process / thread



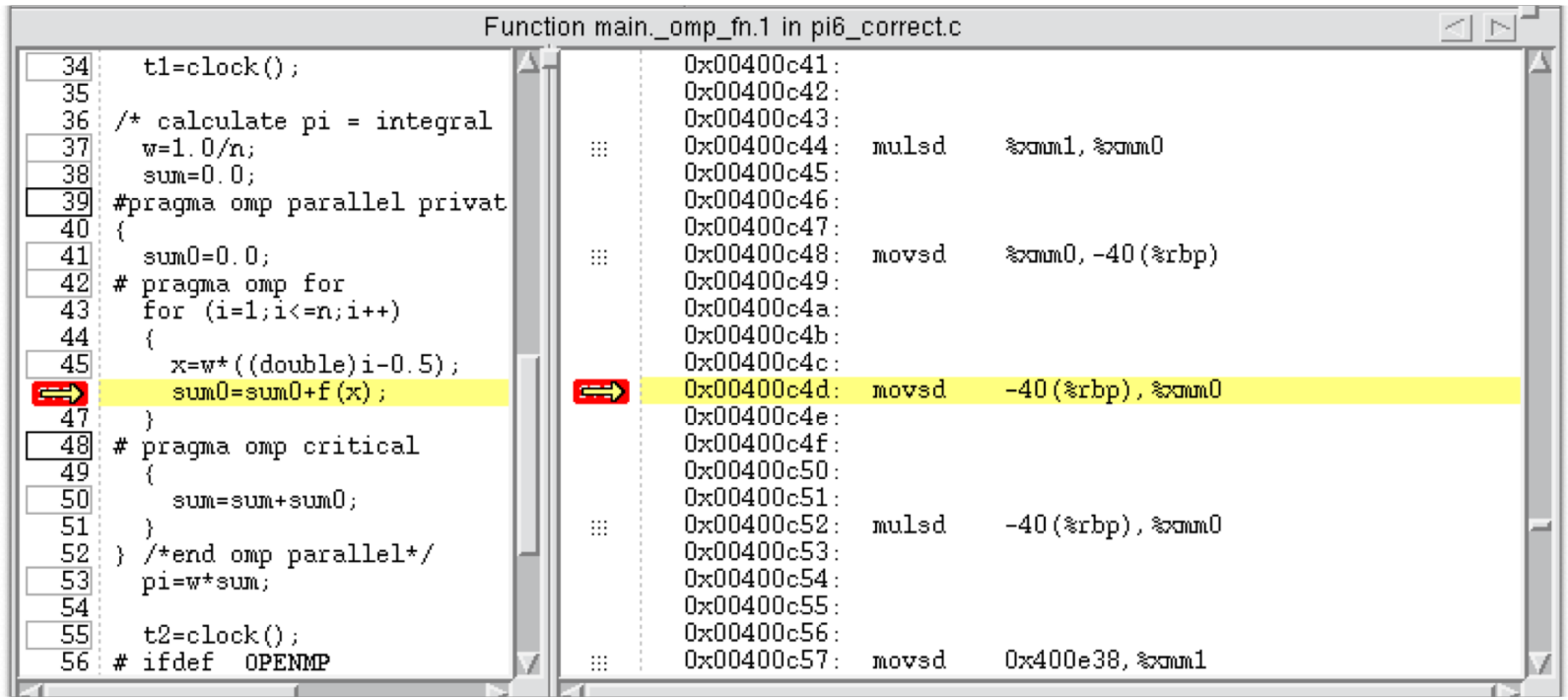
TotalView Root Window

- provides details of state of all processes and threads → important for next lecture



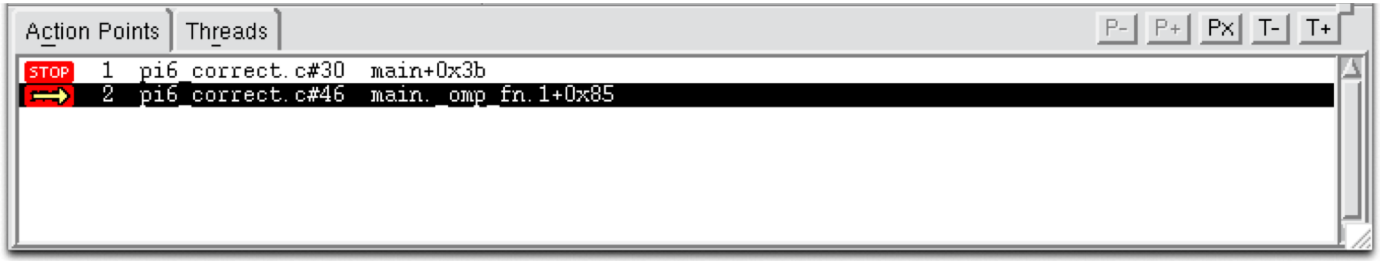
TotalView Source Code Panel

- Toggle Source: Code and/or Assembler (View > Source) (make sure to use “-g”)

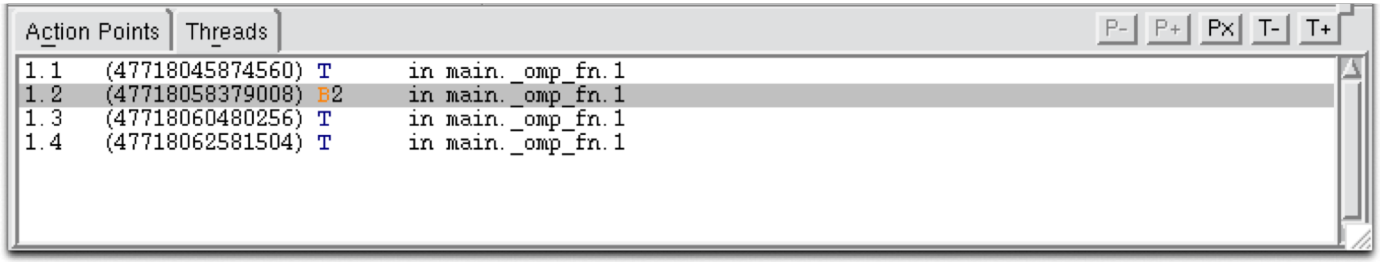


TotalView Tabbed Panel

- Action Points (Right click: Dive, Delete, Disable, Modify)
  - Add: Click on line number in source panel (only code after optimisation possible to add)

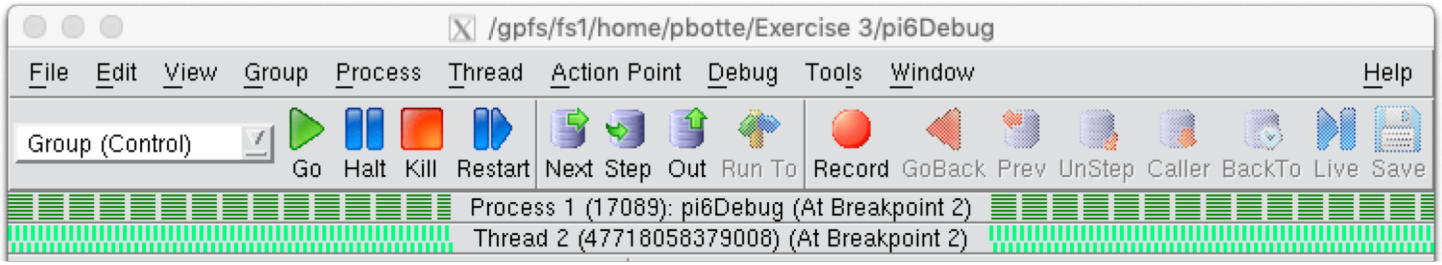


- Threads and Processes with their status



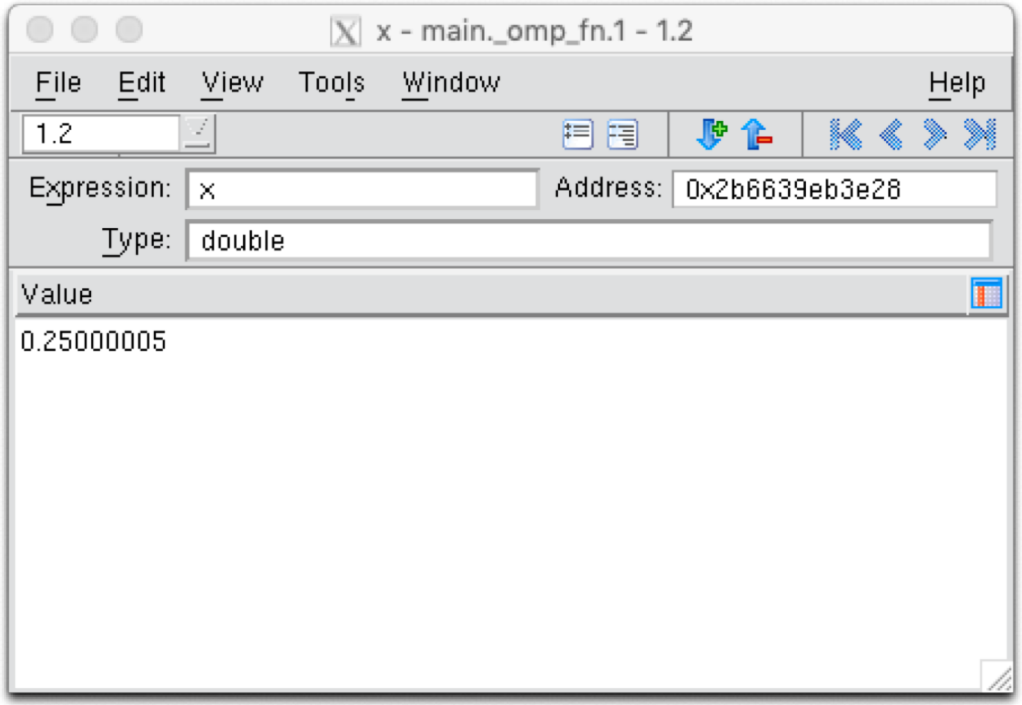
TotalView Stepping Commands

- Select how to proceed from actual PC location
  - next: Next line in same function
  - step: go into sub function
  - return to: go into end of sub function
  - out: leave current function
- Select group of threads / processes affected



TotalView Diving

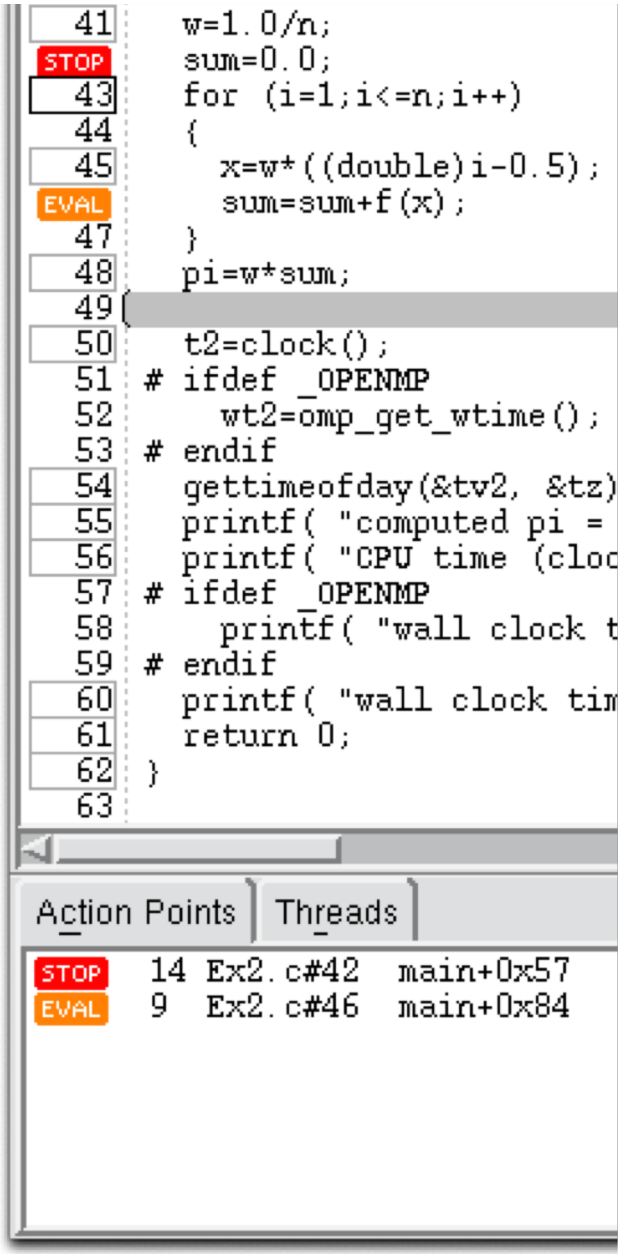
- Double click on variable: “Dive” to get more information



- Right click on value and change it. → live update!

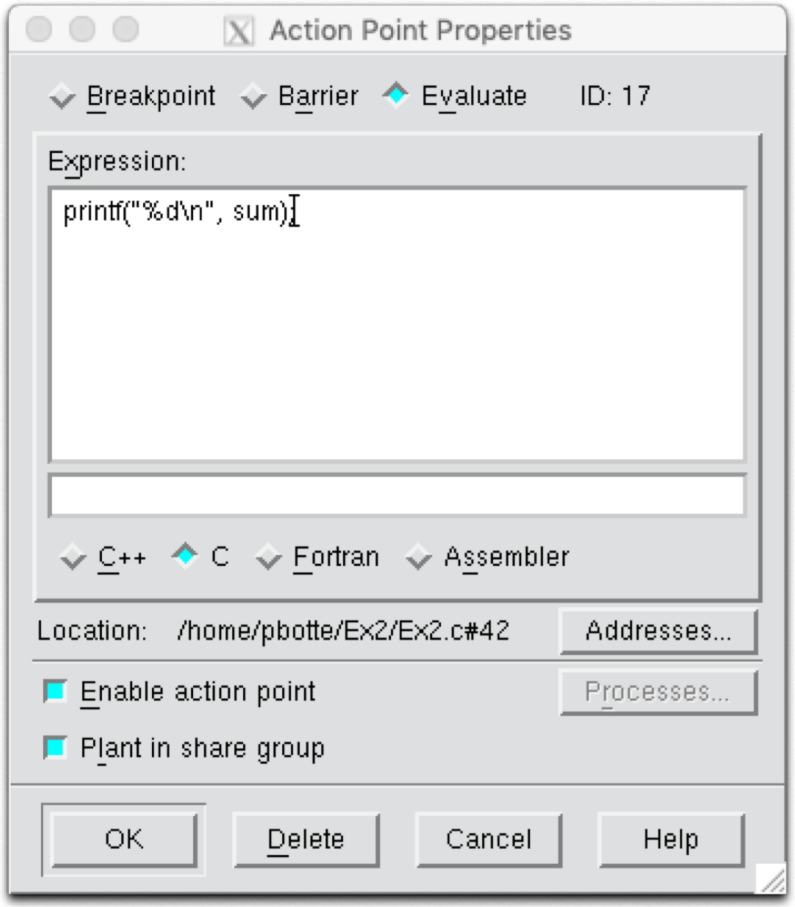
TotalView action points

- click on the source code line surrounded by a small grey box
  - make sure you complied with the correct parameters (-g -O0)
- Execution will stop once this line is reached. To proceed, press Go or other stepping controls.



TotalView Evaluation

- Create a Action Point and change its properties to transform it into a Evaluation point.
- The Expression is executed, once the point is reached.
  - You can write full programs: change variables, conditions, etc.
  - Do a full test drive without recompiling.

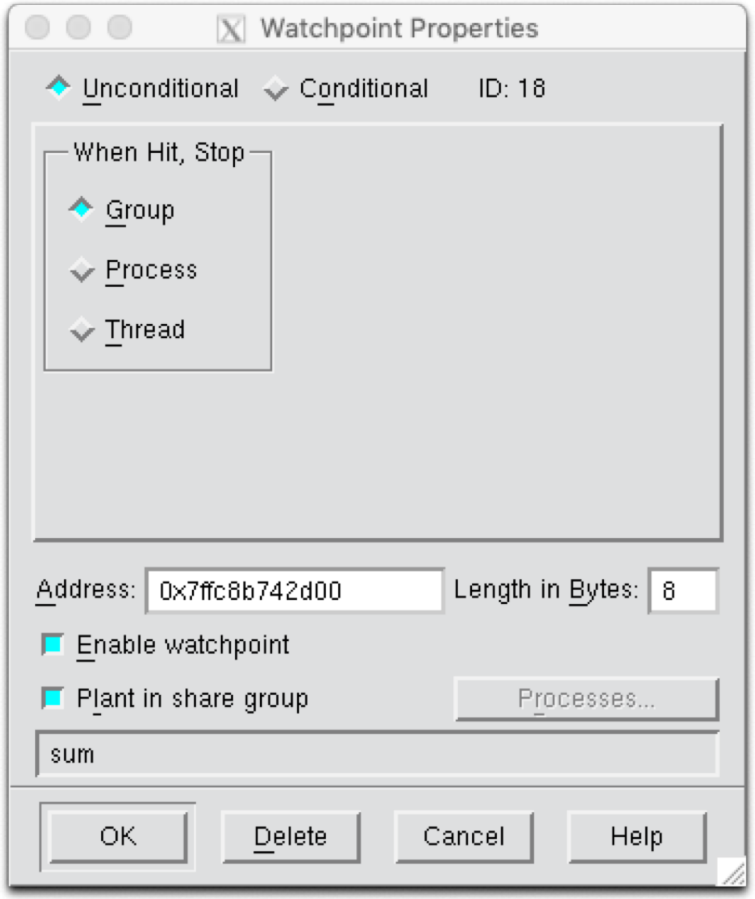


TotalView Watchpoint

- Break point, when a register (variable value) changes

1. Run your program from inside TotalView, halt it.
2. From the menu select: “Action Point > Create Watchpoint” and enter your variable name.

- You can add conditional statement in the properties of the Action Point.
- These Watch Points can also be saved (see Menu Action Point), but by default they get deleted after execution.



Post-Mortem Analysis

Process does segmentation fault etc.

1. In bash: “ulimit -c unlimited” (check with ulimit –a and look for “core file size”)
2. Build your app with -O0 and –g and run
3. Test: ”kill -s SEGV <PID>”
4. Core file will be generated in same directory
5. Analyse with
   “totalview executable coreFileName”
   (or “gdb executable coreFileName”)

- Currently not allowed on Himster2, only backtrace (this will change)
- Hint: With “gcore <pid> -o <filename>“ a core dump is being generated and program remains running.

Live Demo I

1. Login into Himster 2 Headnode
2. Load module debugger/TotalView/2018.0.5_linux_x86-64
3. Run interactively totalview &
4. Provide Application Name and arguments
5. (Post-Mortem Debugging: Provide core file)
6. Setting Breakpoints
   - click in source pane
   - conditional breakpoints possible

Live Demo II

1. Start with “Live Demo I”
2. Inspecting an variable: expression <variablename>, type: <type>
3. Inspecting an array: expression: *<arrayname>, slice: [:], type: <type>[dims]
   - Hint: Drawing possible
4. Inspecting an array: expression: *<arrayname>, slice: [:], type: <type>[dims]
5. Right click and say “Create Watchpoint”
   - Will interrupt as soon as the selected array item changes

Set up your workbench

- Connect two times via SSH to Mogon2 / HIMster2 and work on the head node

    1. Use the first SSH connection for editing (gedit, vi, vim, nano, geany) and compiling
       $ compiling: gcc -g -O0 -o ExecutableName SourceFileName.c

    2. Use the second connection for the interactive usage of TotalView:
       $ module load debugger/TotalView/2018.0.5_linux_x86-64
       $ totalview &

Exercise 1:

Learning objectives:

- Familiarise with TotalView
- Add temporal test code to your program

Steps:

1. Download the skeleton from OpenMP exercise 2 from lecture webpage:
   - wget https://www.hi-mainz.de/fileadmin/user_upload/IT/lectures/WiSe2018/HPC/files/02.zip && unzip 02.zip
2. Compile WITHOUT -fopenmp and open these programs in totalview. With and without:
   1. Debug flag: -g
   2. Optimisation: -O0 and -O3
      Check for source code panel and possible lines to set a break point.
3. get familiar with TotalView: Set a breakpoint, dive into variables, add variables to your expression list, step through your program
4. Change the number of iterations n after you launched your program to n=10. Why does it not work?
5. Compile your program again with a variable n. Change its value to 10 after your program has been launched.
6. Add an Action Point which evaluates the following:
   print out the value of sum.
   hint: add printf("%d\n", sum);
   → Congratulations! You changed your program, did a test drive, without recompiling it!
7. Add an Watchpoint to be notified when the pi is changed.