



TEXAS ADVANCED COMPUTING CENTER

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# Tutorial on Parallel Debugging

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# Defensive programming

- Better than finding errors is preventing them:  
defensive programming.
- One possibility: Use ‘assertions’ about things that have to be true.

```
#include <assert.h>
// for C++: #include <cassert>
assert( x>= 0 );
y = sqrt(x)
```

- Program will terminate if the assertion fails.
- Disable assertions in production by defining `NDEBUG`

# Compiling for debug

Enable debug mode with `-g` option:

```
mpicc -g -O2 yourprogram
```

Debug option can be used with any optimization level, but sometimes good to start at `-O0`:

```
mpicc -g -O0 yourprogram
```

Compiler optimizations may confuse you otherwise.

# Important! Note! About! Exercises!

- ① You should have a directory `exercises_ddt_c` (or maybe `f`). Go there.
- ② Start an interactive session: `idev`
- ③ Exercise slides will have a program name at the top: `[roots]`.  
This means you compile with `make roots`
- ④ Run your program with `./roots` if sequential  
or `ibrun roots` for parallel.

# **Traditional sequential debugging**

# Debugging approaches

- Print statements:
  - can be effective, but they often perturb the behaviour:  
crashing code mysteriously works with print statements.
  - Also: the error is often not where you think it is.
  - Lots of recompilation.
- Interactive debuggers, different approaches:
  - 1 Start program in debugger
  - 2 Attach debugger to running program
  - 3 Do ‘post mortem’ analysis on ‘core dump’.

# Interactive debuggers

- Commandline based tools:

`gdb` comes free with Gnu compilers; other debuggers are very similar  
(Apple has switched to `lldb`, which has different commands)

- Graphic frontends: Visual Studio, CLion, Eclipse, ...

- Catch interrupts and inspect state of the program

- Interrupt a run yourself to inspect variables (breakpoints)

- Step through a program.

# Example

- Compile `roots.c`: `make roots`
- Run the program, first on the commandline. Output?
- Execute this sequence of commands:
  - `gdb root`
  - `run`, observe the output
  - `quit`

# Diagnosing the problem

- Floating point errors do not stop your program!
- In the debugger type:
  - `break roots.c:32` or whatever the first line of the `root` function is
  - `run` and note that it stops at the break point.
  - `where` displays the 'stack frames'; frame 3 to go there
  - `list` shows you the sources around the breakpoint
  - `print n` to show your the current value
  - `cont` to continue execution.
- Better: `break roots.c:32 if (n<0)`

## More gdb

command	meaning
run / cont	start / continue
break file.c:123	breakpoint at line
break <location> if <condition>	conditional stop
delete 1 / enable 2 / disable 3	break point manipulation
where	show call stack
frame 2	specific frame

For more commands see the cheat sheet in the course package.

## Exercise 1 (roots)

You can force your execution to stop at floating point errors:

```
feenableexcept
```

Uncomment that line in the source, compile and run program, both commandline and debugger.

In the debugger, inspect the offending line in all frames.

# Everyone's favourite error: memory problems

- Write outside the bounds of an array  
(runtime checks are too expensive)
- Write to unallocated memory
- Read from uninitialized memory.

First two can usually be caught with a debugger;  
third one: use a memory tool like valgrind

```
module load valgrind
```

```
valgrind myprogram # sequential  
ibrun valgrind myprogram # parallel
```

## Exercise 2 (array1)

Compile and run array1.c.

(Look in the source to see the problem.)

If the program does not crash, recompile:

```
make clean array1 EXTRA_OPTIONS=5000
```

or even more.

# Memory tools: valgrind

- At TACCP module load valgrind
- run with valgrind array1
- Look at the diagnostics. Do you understand them?

# Same program in the debugger

```
Program received signal SIGSEGV, Segmentation fault.  
0x0000000000400b31 in main (argc=1, argv=0x7fffffff95a8) at array1.c:  
33         squares[i] = 1./(i*i);  
Missing separate debuginfos, use: debuginfo-install glibc-2.17-260.el7  
(gdb) where  
#0  0x0000000000400b31 in main (argc=1, argv=0x7fffffff95a8) at array1.c:33  
(gdb) print i  
$1 = 5784  
(gdb) print squares  
$2 = (float *) 0x7fffffff95a0
```

After a while you ‘get a feel’ for what is a legitimate address and what is not. This is not.

## Exercise 3 (array2)

Access out of bounds. Can you find the problem with the debugger or with valgrind?

Bonus exercise: what does valgrind say if you remove the initialization of sum?

# Parallel debugging

# Your minimal parallel debugger

```
mpirun -np 4 xterm -e gdb yourprogram
```

Pops up 4 xterms.

Great for debugging on your laptop.

Not great at scale.

# The DDT debugger

Originally by Allinea, now bought by ARM.

- Graphical front-end to gdb-like and valgrind-like capabilities
- Some specifically parallel features
- Commercial, and with very few open source alternatives  
(Eclipse with PTP)
- An absolute life-saver!

# Using the DDT debugger

Load the module:

```
module load ddt
```

Call the debugger:

```
ddt yourprogram
```

# Graphics on a TACC cluster

- Through an X forwarding connection:

```
ssh -X you@stampede.tacc.utexas.edu
```

- use VNC.

- use DCV (<https://portal.tacc.utexas.edu/tutorials/remote-desktop-access>):

```
//portal.tacc.utexas.edu/tutorials/remote-desktop-access):
```

```
# submit DCV job:
```

```
sbatch /share/doc/slurm/job.dcv
```

```
# when the job is running:
```

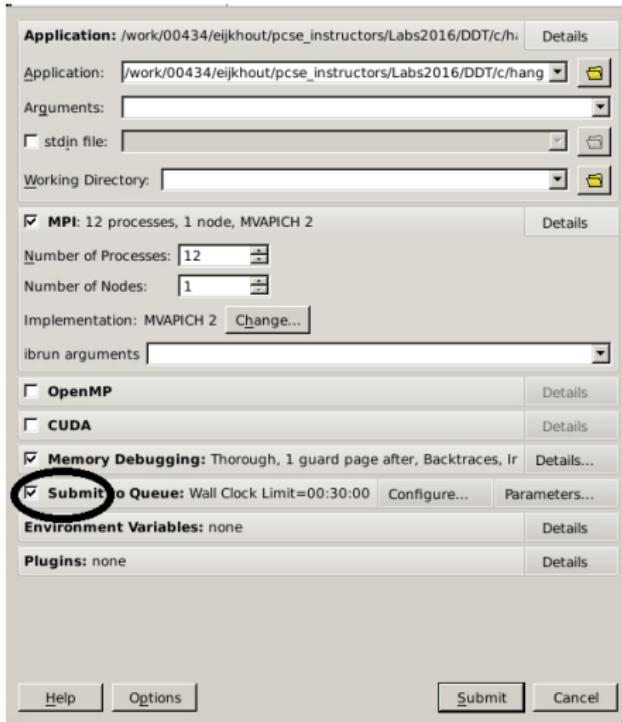
```
cat dcvserver.out
```

The `dcvserver.out` file contains a URL: this gives a graphical terminal session in your browser.

# DDT modes

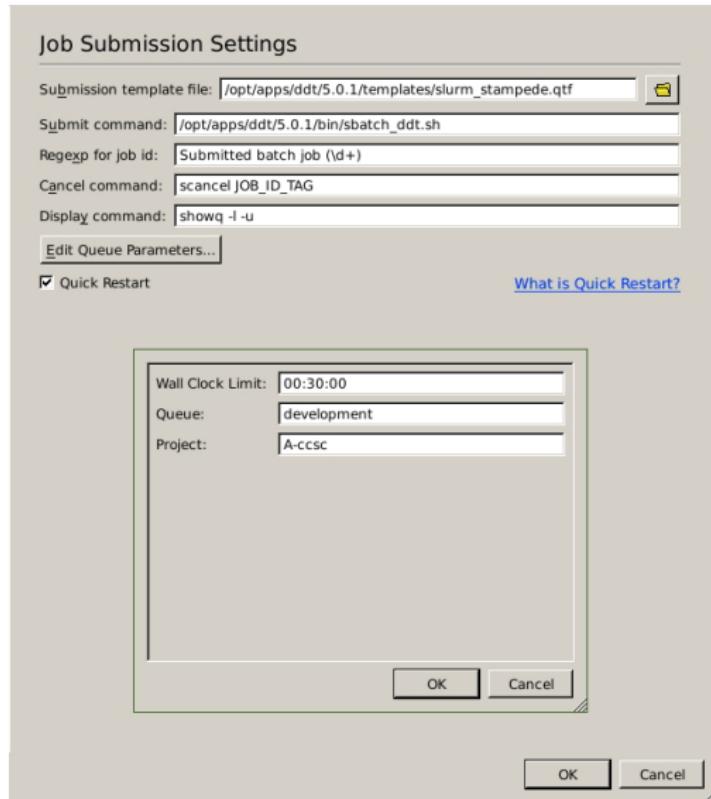
- Start on login node, let DDT submit to queue  
you may need to wait a little while
- Start on compute node, DDT runs directly, not through queue
- Also 'reverse connect' and batch mode, see  
<https://portal.tacc.utexas.edu/tutorials/ddt>

# Run parameters



- MPI or OpenMP? Processes, nodes, threads.
- Memory debugging
- Commandline arguments
- Check 'submit' when running on a login node:  
it submits to the queue for you;  
uncheck if starting from idev session.

# Submission setup



- Project: your own, or one for this class
- Queue: development often quickest

```
37 int main(int argc,char **argv) {  
38     MPI_Comm comm;  
39  
40     MPI_Init(&argc,&argv);  
41     comm = MPI_COMM_WORLD;  
42  
43     loop_for_awhile(comm);  
44  
45     MPI_Finalize();  
46     return 0;  
47 }  
48 }
```

- Program starts at MPI\_Init
- Use run controls



# Hanging processes



- Red: stopped at an interrupt or breakpoint
- Green: still running.  
All green but ‘nothing happening’: probably hanging program.
- Combination: some processes are not getting to the breakpoint: probably deadlocked.

# Call stacks

Input/Output		Breakpoints		Watchpoints		Stacks	Traces
Processes		Function					
12		main (hang.c:43)					
11		loop_for_awhile (hang.c:30)					
1		loop_for_awhile (hang.c:35)					

- Hit the pause button, go to ‘stacks’ panel.
- Not every process is in the same source line.
- Click on process number to see what it’s doing.

# Breakpoints

```
.c hang.c x | Locals | Current Line(s) | Current St  
20  
21     MPI_Comm_rank(comm,&mytid);  
22     MPI_Comm_size(comm,&ntids);  
23  
24 // Initialize the random number generator  
25 srand((int)(mytid*(double)RAND_MAX/ntids));  
26  
27 #include <mpi.h>  
28  
29 for (it=0; ; it++) {  
30     double randomnumber = ntids * ( rand() / (double)RAND_MAX ), maxrandom;  
31     //printf("[%d] iteration %d, random %e\n",mytid,it,randomnumber);  
32     MPI_Allreduce(&randomnumber,&maxrandom,1,MPI_DOUBLE,MPI_MAX,MPI_COMM_WORLD);  
33     if (randomnumber>mytid && randomnumber<mytid+1./ (ntids+1)) {  
34         break;  
35     }  
36 }
```

Variable Name	Value
comm	1140856
it	0
maxrandom	10.6280
mytid	0
ntids	12
randomnumber	10.0822

- Set breakpoint by clicking left of the line
- when you run, it will stop at the breakpoint.
- Values display: everyone the same `it`
- value of `mytid` linearly increasing
- value of `randomnumber` all over the place.

## Exercise 4 (finalize)

Compile and run `finalize.c`.

Every process completes the run, yet the program is incorrect.

- Uncomment the barrier command and rerun. What do you observe?
- Set a breakpoint inside the conditional. Do all processes reach it?

## Exercise 5 (bcast)

Compile and run bcast.c.

The program finishes, yet it is not correct. (Why?)

Recompile:

```
make clean
```

```
make bcast EXTRA_OPTIONS=-DN=100000
```

Does the program still complete?

## Exercise 6 (sendrecv1)

Another program that is incorrect, but that finishes because small messages slip through the network.

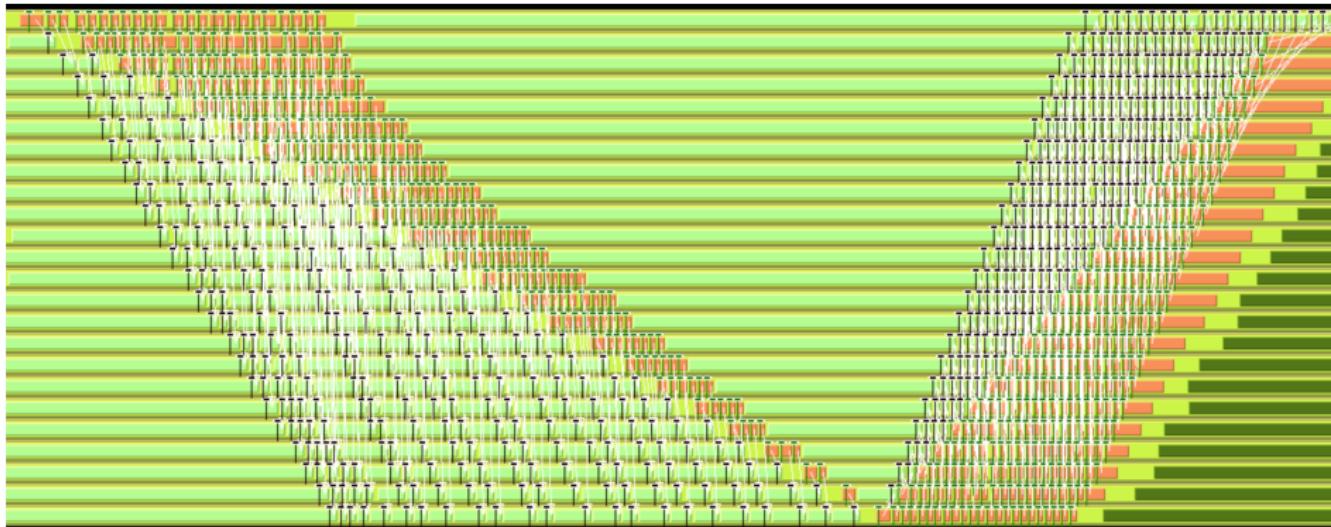
Replace MPI\_Send with MPI\_Ssend which enforces blocking behavior.  
Now what happens?

## Exercise 7 (sendrecv2)

This code fixes the problem with sendrecv1.  
But is this sensible?

- module load tau
- **Compile with TAU:**  
`make clean; make sendrecv2`
- **Run and generate trace files:**  
`make taurun PROGRAM=sendrecv2`
- **Postprocess:**  
`make tau PROGRAM=sendrecv2`
- **Somewhere with X windows:**  
`jumpshot tautrace_sendrecv2.slog2`

# TAU visualization



## Exercise 8 (`isendrecv`)

The proper solution is of course the use of `MPI_Irecv`.

Make a TAU visualization of a run of `isendrecv.c`.

Is this optimal?