Tutorial on Parallel Debugging

Victor Eijkhout

TACC HPC Training 2021

Defensive programming

- Better than finding errors is peventing 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, Xcode, ...

- 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 unitialized 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:3
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
(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):

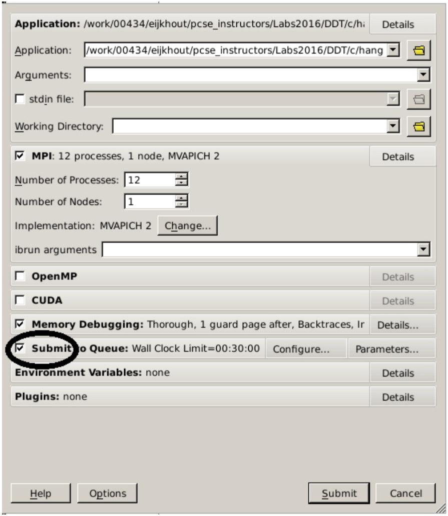
  ```
  # submit DCV job:
  sbatch /share/doc/slurm/job.dcv
  # when the job is running:
  cat dcvserver.out
  ```

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

DDT modes

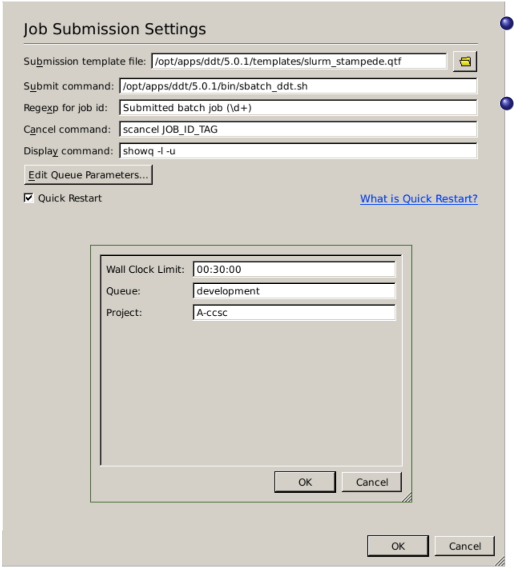
- Start on login node, let DDT submit to queue
  you may need to wait a little while
- Start on compute node, DDT runs directly, not through queue
- Also ‘reverse connect’ and batch mode, see
  `https://portal.tacc.utexas.edu/tutorials/ddt`

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.

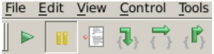
Submission setup



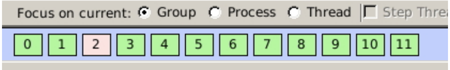
- Project: your own, or one for this class
- Queue: development often quickest

```c
int main(int argc,char **argv) {
  MPI_Comm comm;

  MPI_Init(&argc,&argv);
  comm = MPI_COMM_WORLD;

  loop_for_awhile(comm);

  MPI_Finalize();
  return 0;
}
```

- Program starts at `MPI_Init`
- Use run controls



Hanging processes

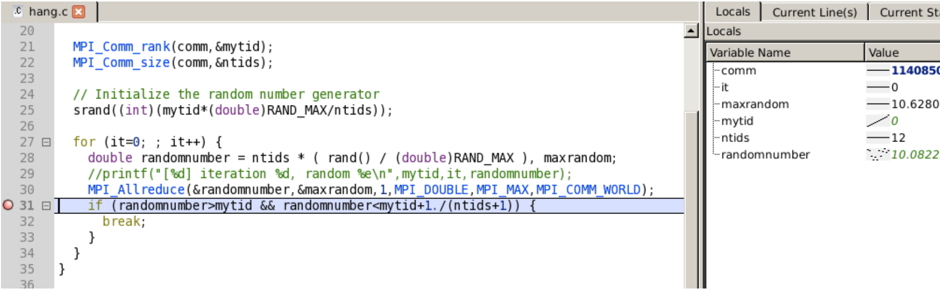


- Red: stopped at an interrupt or breakpoint
- Green: still running.
  All green but ‘nothing happening’: probably hanging program.
- Combination: some processes are not getting to the breakpoint: probably deadlocked.

Call stacks

- 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



- 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.

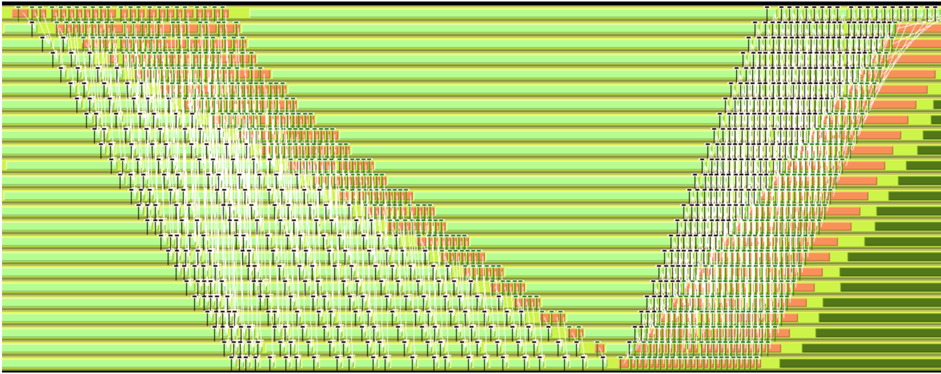
Replace `MPI_Send` with `MPI_Ssend` which enforces blocking behavior. Now what happens?

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 `isendrev.c`.
Is this optimal?