Parallel Debugging with DDT

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Outline

- Software Bugs
- What is Debugging?
- Symbolic Debuggers
- What is DDT?
- Setting up DDT on Teach
  - Hello-mpi Hands-on
- Matrix-Matrix Multiply Hands-on Example

Outline

- Other Useful Features of DDT
  - Client-Server Mode
  - Attach Mode
  - Submitting Jobs to a Scheduler
  - Running Core Files

Software Bugs

Software Bugs

- Writing clean, efficient, error-free code is nearly impossible
- At some point you will run into situations such as:
  - Compile time errors
  - Segmentation faults

```
laptop:~$ gcc app.c -o app
laptop:~$ ./app
Segmentation fault
```

  - Your code doesn't do what you expect
  - Incorrect results
- These are all examples of what is known as a *software bug*

Common Symptoms

- Compile time errors
  - Code syntax errors (easy to fix)
  - Linker errors when linking against libraries
  - Cross-compilation, i.e. compiling for a different computing architecture compared to the host
  - Compilation warnings

  Always turn compiler warnings on and fix or understand them before running your code! It will save you future headaches.
- But just because it compiles does not mean it is correct!

Common Symptoms

- Runtime errors
  - Floating point exceptions
  - Segmentation faults
  - Aborted
  - Incorrect output (e.g. NaNs, Inf)

Error Examples

Type	Reason
Arithmetic	Corner cases e.g. `sqrt(-0.0)`, infinities
Memory Access	Index out of range, uninitialised pointers
Logic	Infinite loop, corner cases
Misuse	Wrong input, ignored error, no initialisation
Syntax	Wrong operators/arguments
Resource Starvation	Memory leak, quota exceeded
Parallel	Race conditions, deadlock

What is going on?

- Almost always, a condition you are sure is satisfied, is not
- But your application likely relies on many such assumptions
- First order of business is finding out what is going wrong and what assumption is not warranted
- Follow the *Fundamental Principle of Confirmation*:
  - Process of confirming, one by one, that many things you **believe** to be true about the code are actually true
- Debugger: program to help detect errors in other programs
- **Debugging: Methodical process of finding and fixing flaws in software**
- **You are the real debugger**

How to Avoid Debugging

- Write better code:
  - Simple, clear, straightforward code
  - Modular (no global variables or 10,000 line functions)
  - Avoid "cute" tricks (no obfuscated C code winners)
- Improve your code/algorithm/language/API understanding
- Don't reinvent the wheel, use existing libraries
- Write (simple) tests for each part of your code
- Use version control (GIT) so you can "roll back" your code if a bug is found

Debugging Workflow

- As soon as you are convinced there is a real problem, create the simplest test case that reproduces the bug
- This is science: model, hypothesis, experiment, conclusion
- Try a smaller problem size, turning off physical effects with options, etc. until you have a simple, fast repeatable example of the bug
- Try to narrow it down to a particular module/function/class. For Fortran, switch on bounds checking (`-fbounds-check`)
- Now you're ready to start debugging

Ways to Debug

- Preemptive:
  - Turn on compiler warnings: fix or understand them!

```
laptop:~$ gcc/gfortran -Wall
```

  - Check your assumptions (e.g. use `assert`)
- Inspect the exit code and read the error messages!
- Use a debugger
- Add print statements
  - **No way to debug!**

What's wrong with using print statements?

Strategy

- Constant cycle:
  1. Strategically add print statements
  2. Compile
  3. Run
  4. Analyse output
- Bug not found? Repeat from 1. again
- Have to remove extra code after the bug is fixed
- Rinse and repeat for each bug

Disadvantages

- Time consuming
- Error prone
- Changes memory, timing...

There's a better way!

Symbolic Debuggers

Symbolic Debuggers

Features

1. Crash inspection
2. Function call stack
3. Step through code
4. Automated interruption
5. Variable checking and setting

Use a graphical debugger or not?

- Local work station: graphical is convenient
- Remotely (Niagara): can be slow, but we will look at ways to improve this later

In any case, graphical and text-based debuggers use the same concepts

Preparing Your Code for the Debugger

- Add debugging flags when compiling your code:

```
laptop:~$ gcc/g++/gfortran -g [-gstabs]
laptop:~$ icc/icpc/ifort -g [-debug parallel]
laptop:~$ nvcc -g -G
```

- Optional flag: switch off optimisation `-O0` (sometimes symbol values are hidden to the debugger at higher optimisation levels e.g. `-O2`, `-O3`)

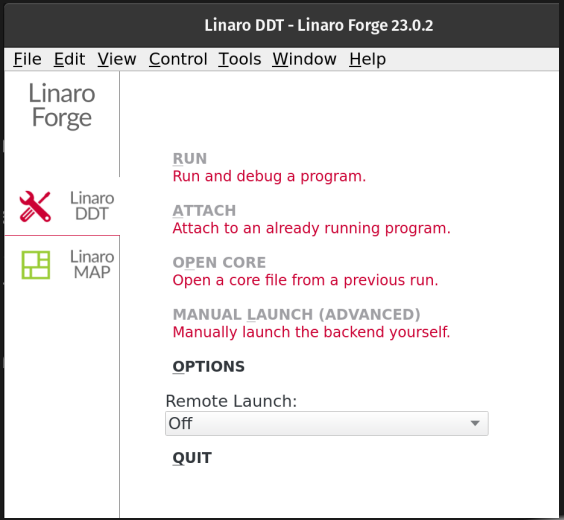
Examples of Symbolic Debuggers

- Command-line based debuggers: GDB, LLDB
- Graphical based debuggers: **DDT**, Visual Studio, Eclipse
  - Nice, more intuitive graphical user interface
  - Front-end to command-line based tools: Same concepts
  - Need graphics support: X11 forwarding (or VNC)
- The rest of the workshop will focus on DDT

What is DDT?

What is DDT?

- **DDT** stands for **Distributed Debugging Tool**
- Powerful GUI-based commercial debugger by *Linaro*
- Developed for debugging parallel, multi-threaded, and distributed applications
- Widely used in high-performance computing environments
- Available on Niagara and other Alliance systems (*Note: license only allows debugging up to 64 processes*)



DDT Features

- **Key Features:**
  - Parallel and distributed debugging capabilities
  - Graphical user interface for intuitive navigation
  - Support for multiple programming languages (e.g. C, C++, Fortran, Python)
  - Supports MPI, OpenMP, threads, CUDA, ROCm and more
  - Integrated performance analysis tools - *MAP*
  - Memory debugging functionalities

Launching DDT on Teach

- Load the latest software stack with a compiler and MPI module:

```
teach-login01:~$ module load TeachEnv/2022a gcc openmpi
```

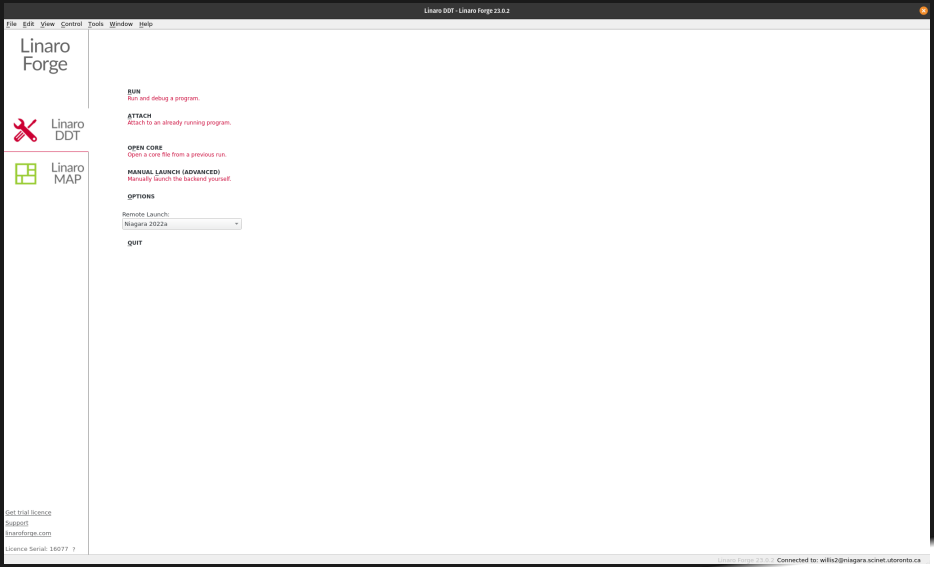
- Load DDT:

```
teach-login01:~$ module load ddt
```

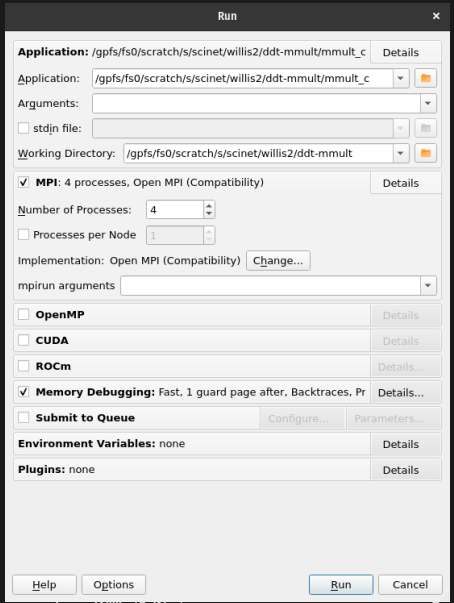
- Start DDT with one of these commands:

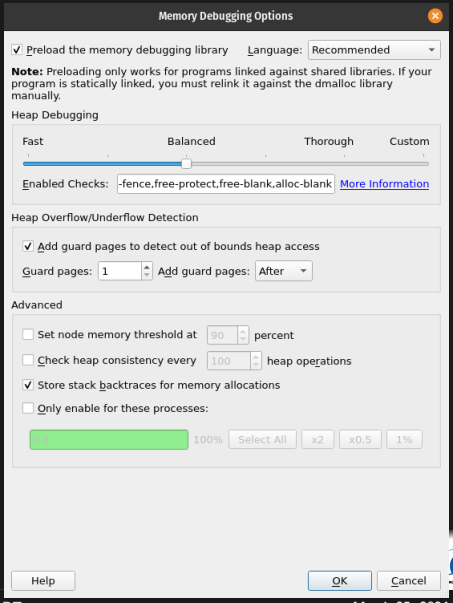
```
teach-login01:~$ ddt
teach-login01:~$ ddt <exe compiled with -g flag>
teach-login01:~$ ddt <exe compiled with -g flag> <arguments>
teach-login01:~$ ddt -n <numprocs> <exe compiled with -g flag> <arguments>
```

Launching DDT on Teach

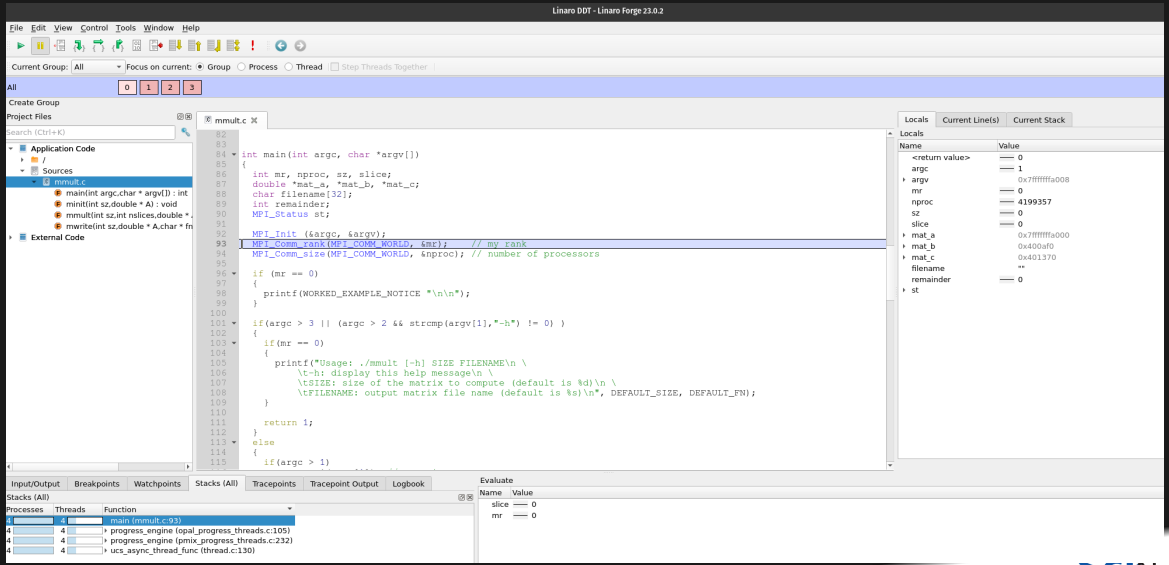


Creating a Debug Session

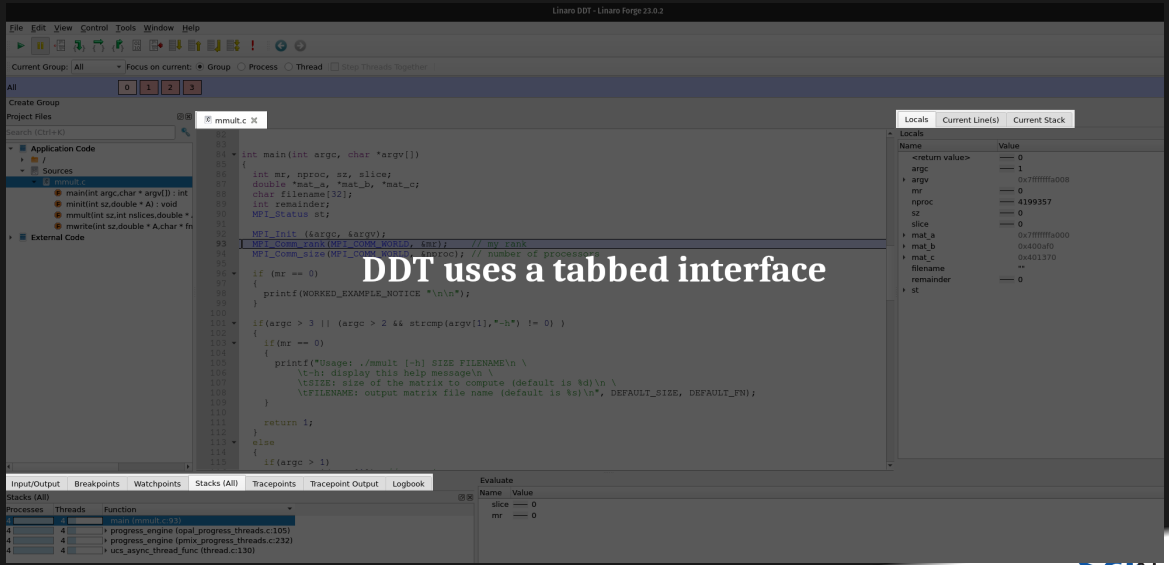




User Interface



User Interface

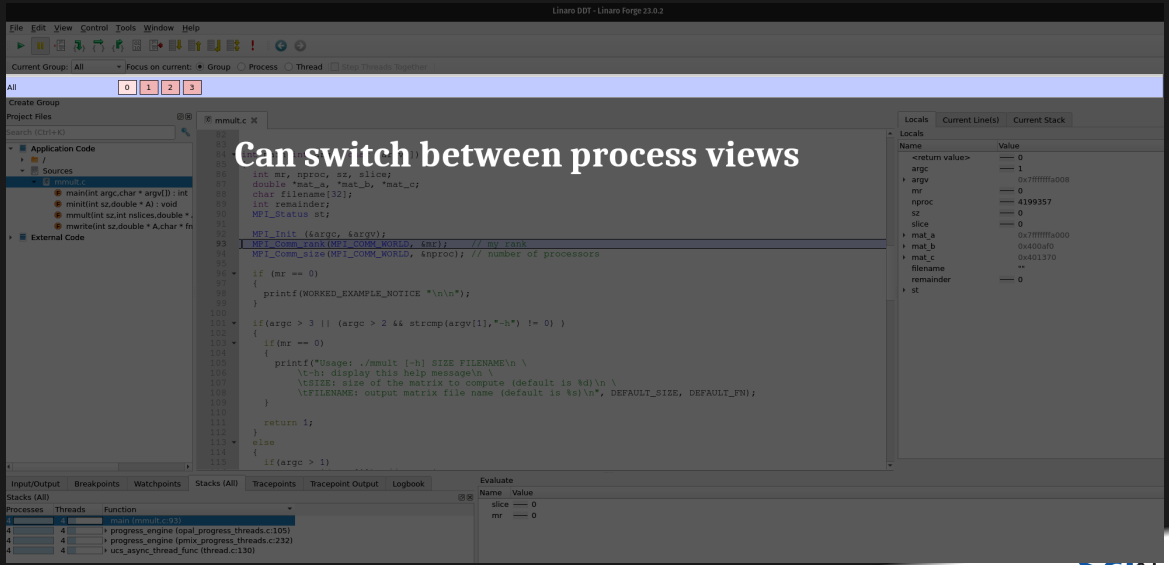


DDT uses a tabbed interface

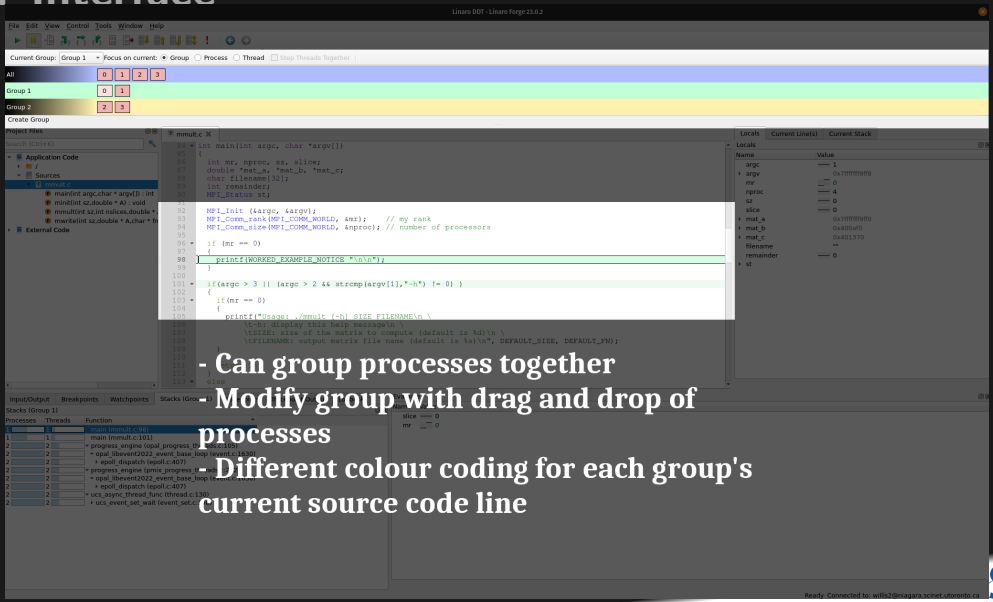
User Interface

DDT automatically finds the source code from the executable

User Interface

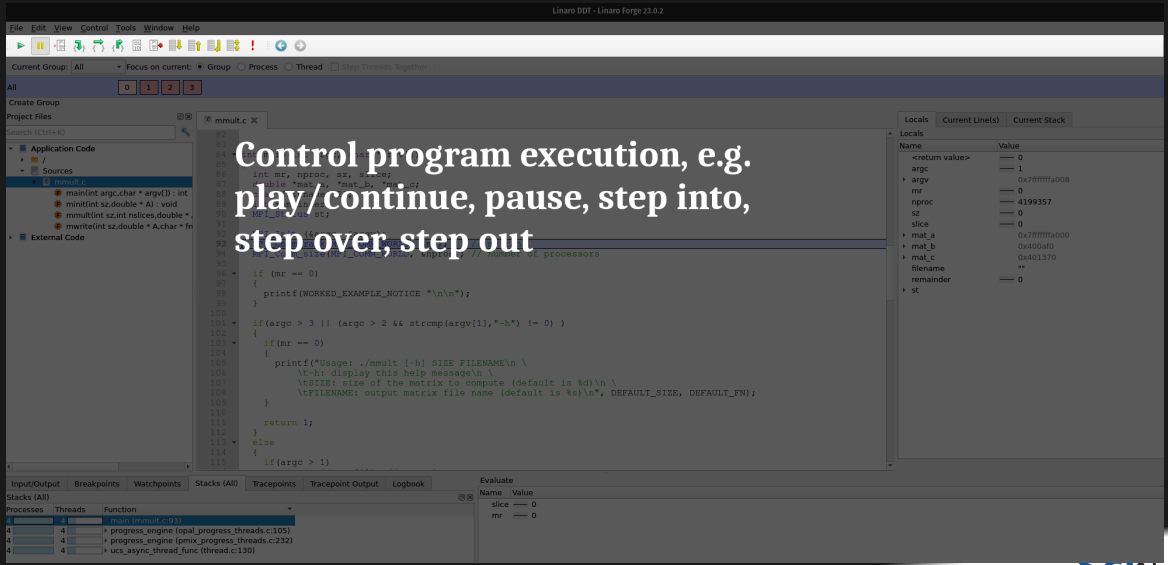


User Interface



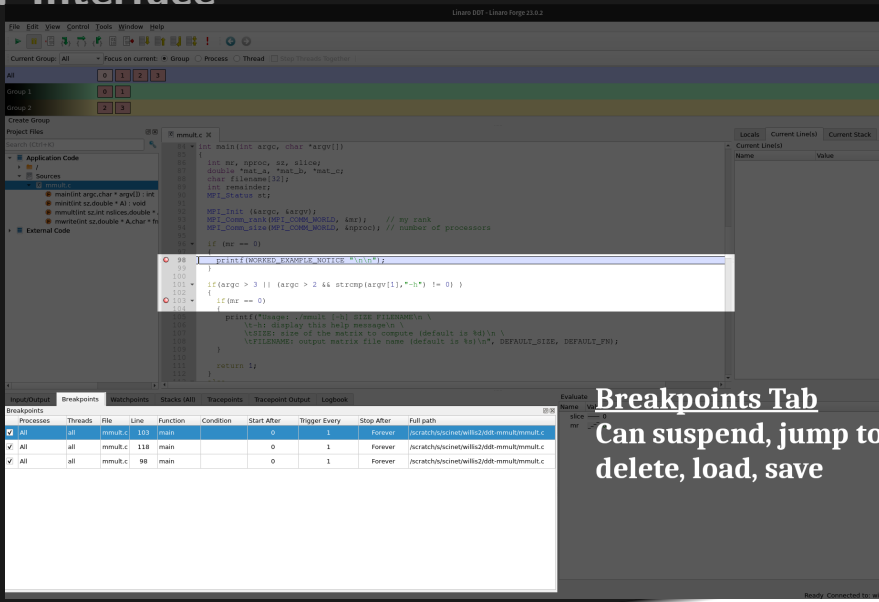
- Can group processes together
- Modify group with drag and drop of processes
- Different colour coding for each group's current source code line

User Interface



Control program execution, e.g. play/continue, pause, step into, step over, step out

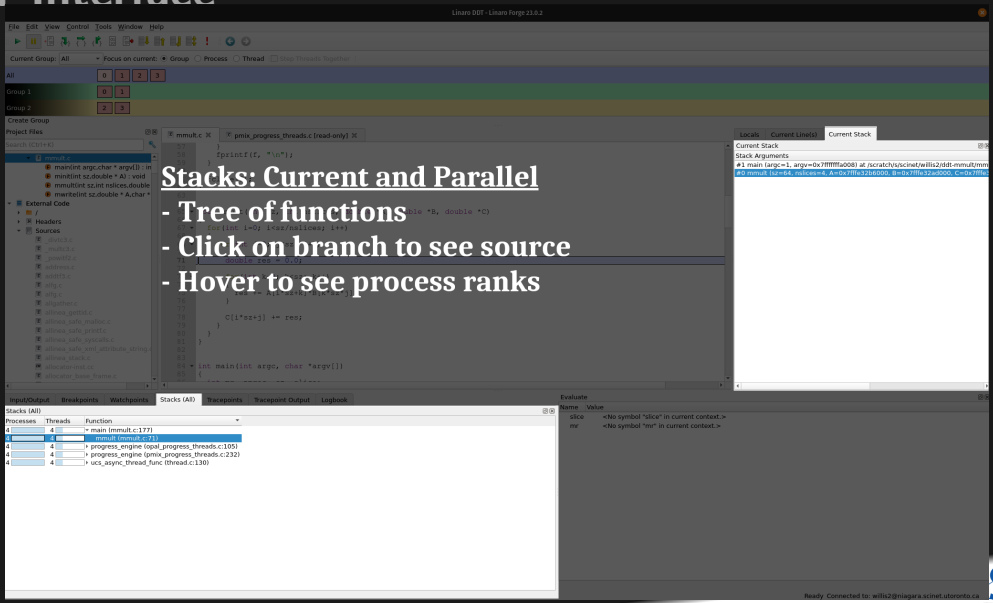
User Interface



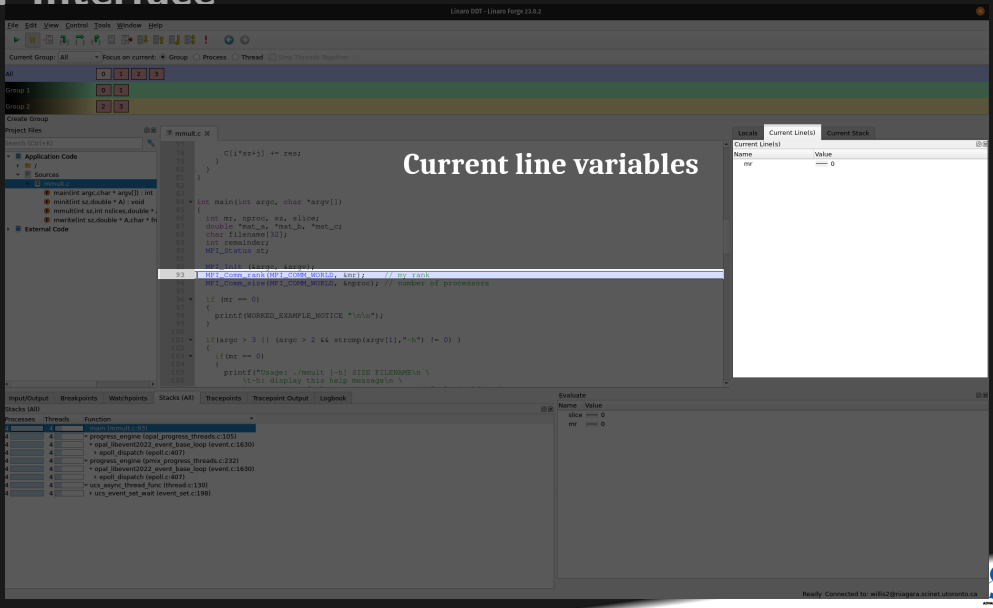
Breakpoints Tab

Can suspend, jump to, delete, load, save

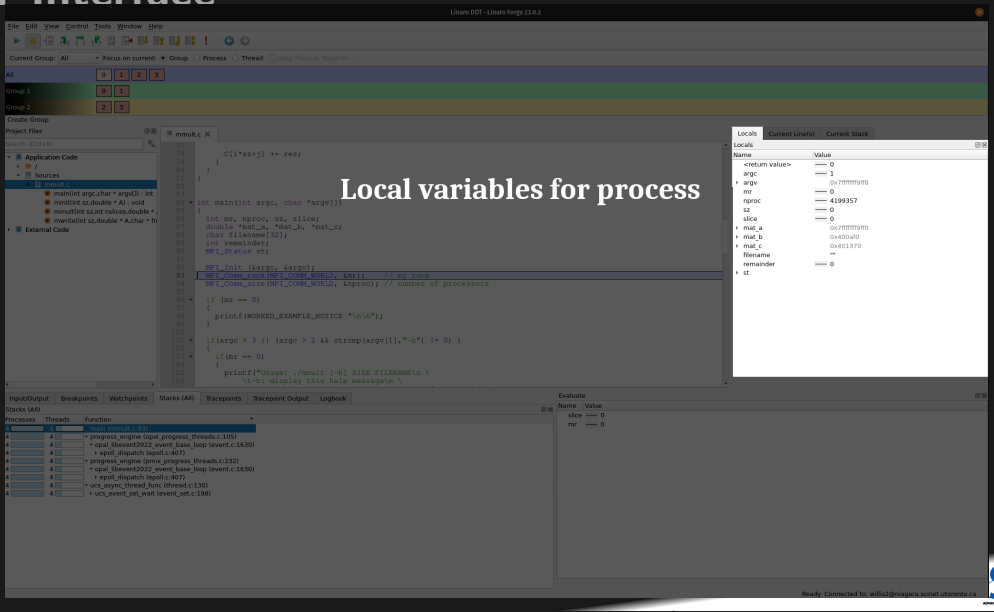
User Interface



User Interface

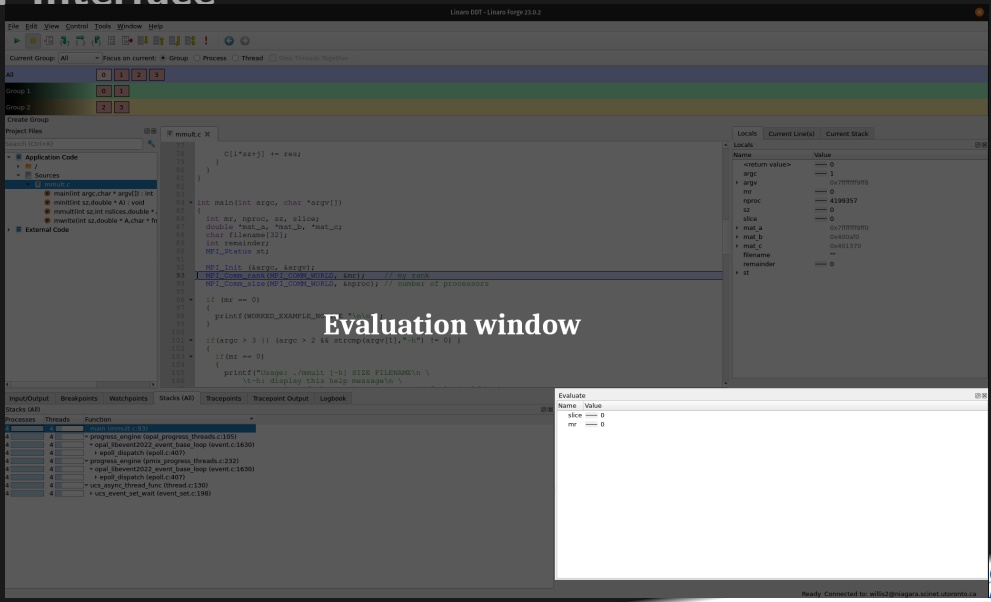


User Interface



Local variables for process

User Interface



Evaluation window

DDT Setup Demonstration

Hands-on `hello-mpi` Example

- Login to Teach

```
laptop:~$ ssh -X USERNAME@teach.scinet.utoronto.ca
```

- Load compilers, MPI library and `ddt`:

```
teach-login01:~$ module load TeachEnv/2022a gcc openmpi ddt
```

- Copy examples from the course directory:

```
teach-login01:~$ cp -r /home/l/lcl_uothpc245/hpc245starter/ddt-examples .
```

- Compile MPI Hello World example, `hello-mpi.c`:

```
teach-login01:~/ddt-examples/ddt-hello-mpi$ mpicc -g hello-mpi.c -o hello-mpi
```

- Run ddt:

```
teach-login01:~/ddt-examples/ddt-hello-mpi$ ddt -n <numprocs> hello-mpi
```

- Experiment with different features of DDT

Memory Debugging in DDT

- Memory debugging can be turned on in the *Run* window
- Causes the code to stop on an error i.e. memory corruption/leak
- Allows you to check the pointer where the memory corruption has occurred
- Can give an overall view of the memory stats/usage
- Lets look at a real example

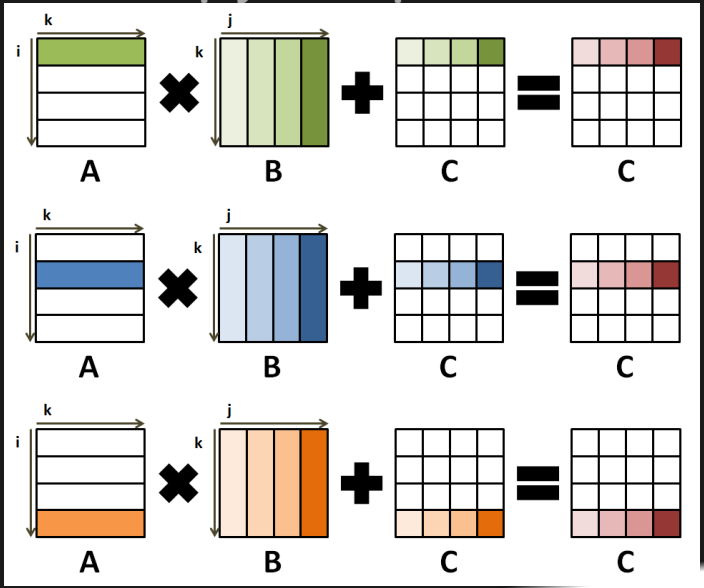
Matrix-Matrix Multiply Example

- Imagine we want to compute the result of this Matrix equation in parallel with MPI:

$$C = A * B + C$$

- The algorithm works as follows:
  1. Rank 0 initialises A, B and C
  2. Rank 0 sends the entire matrix B, with slices of A and C to all other ranks
  3. Each rank performs matrix multiplication on their domain and computes a slice of C
  4. Rank 0 collects the slices of C from each rank and forms the final matrix C
  5. Rank 0 writes C to a file

Matrix-Matrix Multiply Example



Hands-on Matrix-Matrix Multiply

- Change to the `ddt-mmult` directory from the course examples and compile the code:

```
teach-login01:~/ddt-mmult$ make
```

- This will build C and Fortran executables with `-g -O0` named `mmult_c` and `mmult_f`
- The example can then be run with:

```
teach-login01:~/ddt-mmult$ mpirun -np 4 ./mmult_c
```

- For python, load a python module and compile the C and Fortran libraries with:

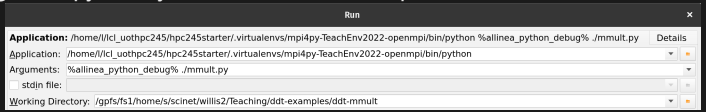
```
teach-login01:~/ddt-mmult$ module load python/3.11.5
teach-login01:~/ddt-mmult$ make -f mmult_py.makefile
```

- You will also need a python virtual environment with the `mpi4py` package. I have created one here: `/home/l/lcl_uothpc245/hpc245starter/.virtualenvs/mpi4py-TeachEnv2022-openmpi`
  - `source` the virtual environment before running the example:

```
source $HOME/../hpc245starter/.virtualenvs/mpi4py-TeachEnv2022-openmpi/bin/activate
mpirun -np 4 python ./mmult.py
```

Hands-on Matrix-Matrix Multiply

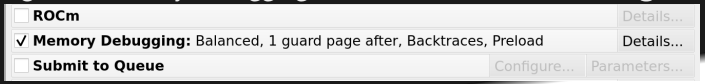
- Try running the code. What output do you get?
- Run the code in DDT to find out what the error is
- Note: if running with python you will need the setup shown below



or from the command line:

```
teach-login01:~/ddt-mmult$ ddt -n 4 python %allinea_python_debug% ./mmult.py
```

- Can you locate the error?
- Can you fix it?
- Hints: Try running with *memory debugging* enabled and make sure **Add guard pages** is enabled



Matrix-Matrix Multiply Demonstration

Other Useful Features of DDT

- Client-Server mode
- Editing and recompiling code from within DDT GUI
- Attaching to a running job
- Submit SLURM jobs with DDT
- Running with core files

Client-server Mode

- This mode can be very beneficial if you have a slow internet connection
- Keeps the bulk of the computation on Teach (*server*)
- Only sends minimal amounts of information (network traffic) to your locally running version of DDT (*client*)
- Results in a much smoother experience, avoids slow/laggy interface

Client-server Mode Setup

Setting up the server side

- Connect to Teach and create a startup script which will be run by the server and load the modules that your code needs:

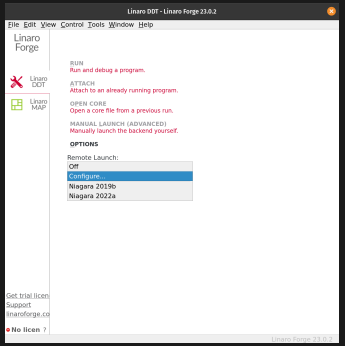
```
#!/bin/bash
module purge
module load TeachEnv/2022a
module load forge/23.0.2
module load gcc openmpi python
export ARM_TOOLS_CONFIG_DIR=${SCRATCH}/.arm
mkdir -p ${ARM_TOOLS_CONFIG_DIR}
```

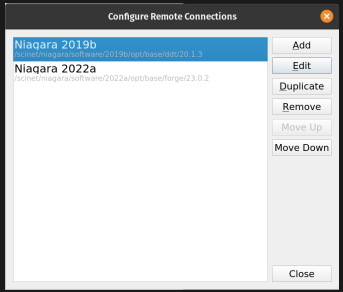
- Name it `ddt_remote_setup.sh` and place it in `$SCRATCH`

Client-server Mode Setup

Setting up the client side

1. Download DDT on your local machine from Linaro and make sure the versions matches the one on Teach (23.0.2): https://www.linaroforge.com/downloadForge/
2. Launch `ddt` and select *Configure* from *Remote Connections*

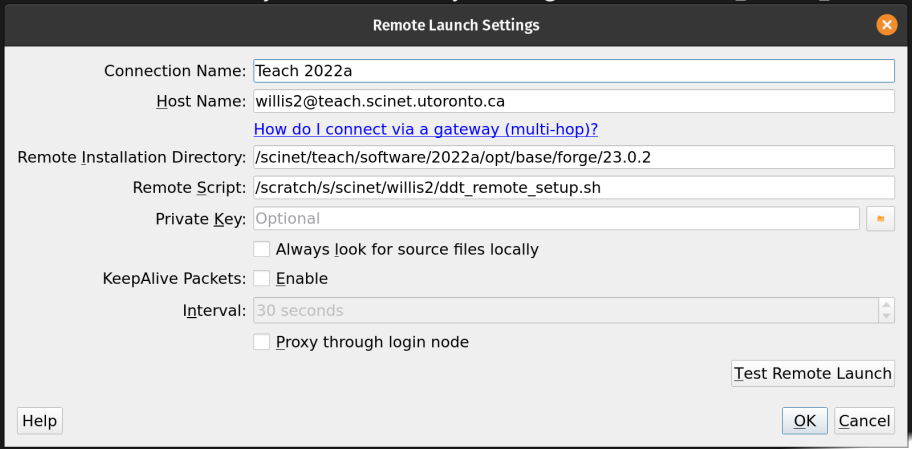




Client-server Mode Setup

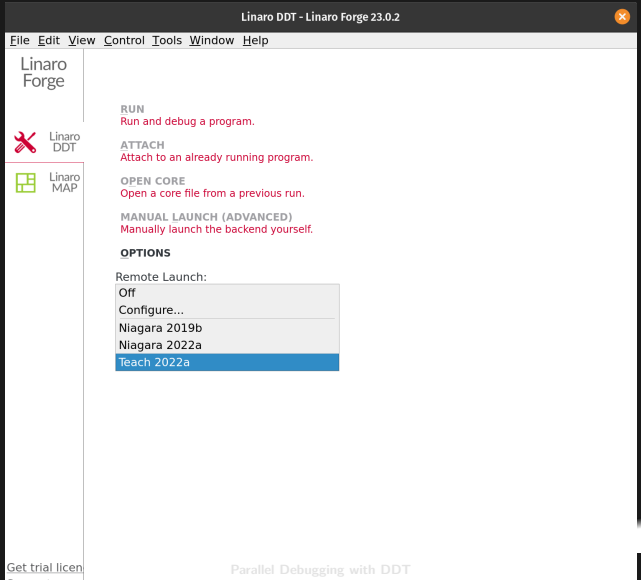
3. Click *Add* and fill out the fields as shown below

Note: *Remote Installation Directory* can be found by running `echo $MODULE_FORGE_PREFIX` on Teach



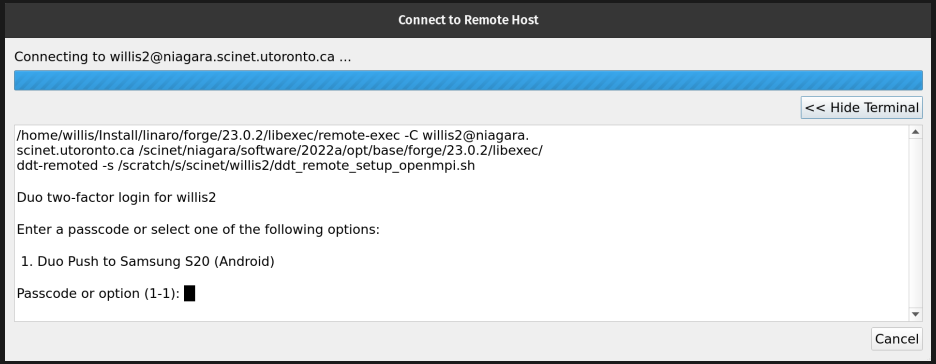
Client-server Mode Setup

4. Click *OK* and now the DDT starting screen should look like this:



Client-server Mode Setup

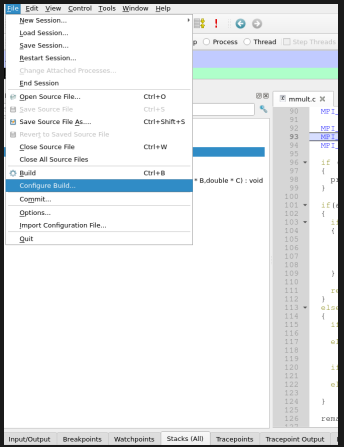
5. If you have MFA enabled follow the instructions outlined in the text box:

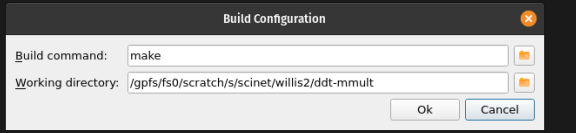


- More detailed instructions can be found here: https://docs.linaroforge.com/23.0.2/html/forge/forge/connecting_to_a_remote_system/connecting_remotely.html

Editing and Compiling

- DDT also has the ability to edit and recompile source code on-the-fly
- Making it much easier to try potential bug fixes

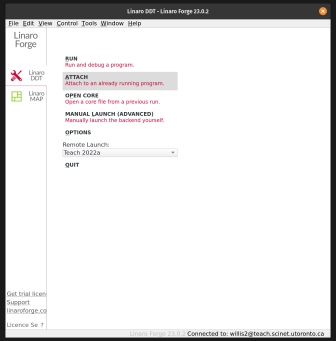


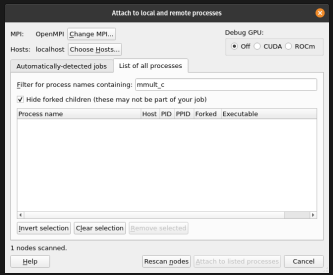


- Build demonstration

Attach to a Running Job

- DDT allows you to attach to an already running job
- For example, say you have submitted a job to the scheduler on Teach and want to monitor it
- You can use the *Attach* button
- More detailed instructions can be found here: https://docs.linaroforge.com/23.0.2/html/forge/ddt/get_started_ddt/attaching_to_running_programs.html#index-9





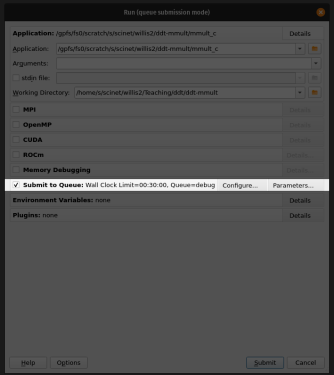
- Attach demonstration

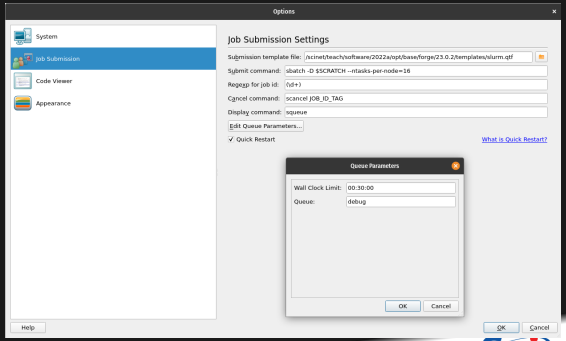
Submit SLURM Jobs

- DDT allows you to submit jobs directly to the SLURM scheduler on Teach
- The job will be monitored in the queue and as soon as it runs DDT will attach to the job

Setup

- Click *Run -> Submit to Queue -> Configure*





Running `.core` Files

- When your code terminates unexpectedly it will generate what is known as a *core dump*
- A core dump is a set of files ending in `.core` per process running
- Each `.core` file contains the process's address space (memory) at the time of the crash
- DDT allows you to run with the core files showing the state of the code at the time of the crash
- Can be useful if your job fails after running for a long time
- If no core dump is generated check that `ulimit -c` is set to `unlimited`, this sets the maximum size a `.core` file can be
- Demonstration

Summary

- DDT is a powerful graphical debugger
- Supports parallel debugging in multiple languages (e.g. C, C++, Fortran, Python)
- Supports MPI, OpenMP, threads, CUDA and more
- DDT documentation: https://docs.linaroforge.com/23.0.2/html/forge/ddt/index.html

Support

Questions? Need help?

Don't be afraid to contact us! We are here to help.

- Email to **support@scinet.utoronto.ca** or to **niagara@computecanada.ca**

References

- Slide 19: Linaro DDT
- Slide 38: Matrix-Matrix Multiply Worked Example
- Slide 44: Client-Server Mode
- Slide 51: Attach Mode
- Slide 52: Submitting to a Queue