Karlsruhe Institute of Technology

SCC
Steinbuch Centre for Computing

Introduction to Debugging on HPC

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Debugging

Debugging ...

- Software contains errors and bugs!
- Debugging: Process of finding and fixing these bugs
- Debugging steps
  - Recognize that a bug exists
  - Determine the origin of the bug
  - Find a fix
  - Apply and test the fix
- Complex task ⇒ Tools can assist with this
- Special attention should be paid to avoiding bugs (e.g. unit tests, documentation, ...)
- See: WikiBook: Computer Programming Principles

Debugging ...

Additional challenges when debugging HPC codes

- Concurrency
- Multiple levels of parallelism (MPI, OpenMP, SIMD, ...)
- Heterogenes execution platform (CPU, Accelerator)
- Code runtime
- Size of datasets
- Remote code execution on compute resources
- Asynchronous, non-interactive code execution on compute resources

Debugging, Common Bugs

- Use of uninitialized values

```
double x, y;
x = y + 1.;
```

- Use after free

```
auto charArray = new char[10];
delete[] charArray;
std::cout << charArray[0] << std::endl;
```

- Out of bound access

```
auto charArray = new char[10];
charArray[10] = 10;
```

Debugging, Common Bugs ...

- Numerical problems

```
double x = 1, y = 0;
std::cout << x / y << std::endl;
```

- Datatype underflow / overflow

```
int i = INT_MAX;
i++;
```

- Deadlocks

```
MPI_Ssend(&send_data, 1, MPI_INT, right_neighbour, 0, MPI_COMM_WORLD);
MPI_Recv(&recv_data, 1, MPI_INT, left_neighbour, 0, MPI_COMM_WORLD, &status);
```

GNU Compiler Collection: Static Analyzer

- Static-analysis of source code during compile time
  ⇒ A kind of extended warnings
  ⇒ No need to run the binary
- Potentially false negatives
- Problems that can be detected
  - double memory free
  - double file close
  - use of memory after free
  - use of uninitialized values
  - ...
- GCC Static Analyzer Options
- Basic usage

```
gcc -fanalyzer ${SOURCE}
```

Example

- Use after free
- Uninitialized values

GNU Compiler Collection: Sanitizer

- Compiler adds run-time instrumentation
- Analysis during runtime
- Problems that can be detected
  - out of bounds memory access
  - use of uninitialized values
  - undefined behaviour
  - use of memory after free
  - thread data race conditions
  - ...
- GCC Program Instrumentation Options
- Basic usage

```
gcc -fsanitize=${SANITIZER_TYPE} ${SOURCE}
```

Example

- Use after free
- Division by zero
- Datatype Overflow
- Data race

Strace

- Linux syscall tracer
  ⇒ Monitor interactions between processes and the Linux kernel
- Dynamic-analysis during runtime
- Potentially large overhead
- strace.io
- Man page strace
- Basic usage

```
module add devel/strace
strace    ${BINARY}  # trace binary
strace -p ${PID}     # trace already running process
```

Example

- Basic usage
- MPI usage scenarios

Ltrace

- Intercepts and records dynamic library calls
- Dynamic-analysis during runtime
- Potentially large overhead
- ltrace.org
- Man page ltrace
- Basic usage

```
ltrace    ${BINARY}  # trace binary
ltrace -p ${PID}     # trace already running process
```

Example

- Basic usage
- MPI usage scenarios

Valgrind

- Tool to detect
  - memory management bugs
  - threading bugs
  - profile your programs
- Prepare unoptimized binary with debug symbols during compile time
- Dynamic-analysis during runtime
- Binary is executed in virtual machine with JIT
  $\Rightarrow$ Massive increase in runtime and memory consumption
- Problems that can be detected by *memcheck*
  - use of memory after free
  - out of bounds memory access
  - use of uninitialized values
  - memory leaks
- Potentially many false positives $\Rightarrow$ suppress mechanisms

Valgrind ...

- valgrind.org
- Valgrind User Manual
- Basic usage

```
module add \
    compiler/gnu \
    devel/valgrind
gcc -O1 -g ${SRC} -o ${BINARY}
valgrind ${BINARY}
```

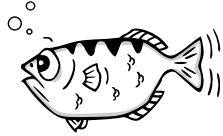
Example

- Use after free
- Out of bound access
- MPI usage scenarios

GDB (The GNU Project Debugger)

- Inspect a program during execution
- Pause the program (at breakpoints or on conditions)
- Read values from memory or stack
- Change values in memory or stack
- GDB: The GNU Project Debugger
- GDB User Manual, Man page GDB
- Basic usage

```
module add compiler/gnu
gcc -O1 -ggdb ${SRC} -o ${BINARY}
gdb ${BINARY}
```



GDB (The GNU Project Debugger) ...

Most frequently used GDB commands

`break <func>`	Set a breakpoint at `<func>`
`run`	Run program
`bt`	Backtrace (show call stack)
`next`	Execute next program line. Do not step into function calls
`step`	Execute next program line. Step into function calls
`c`	Continue running program (until next break point)
`print <expr>`	Print value of `<expr>`

Example

- Division by zero
- Remote debugging

Visual Studio Code

- Visual Studio Code
- Open source
- Platforms: Linux, macOS and Windows
- Feature rich integrated development environment
  - Syntax highlighting, bracket-matching, auto-indentation, ...
  - Intelligent code completion
  - Refactoring
  - Many programming languages
- Tools integrated for
  - Version control (GIT)
  - Build (code configuration, compile, linting, static checks)
  - Debug (GDB, LLDB)
- Extensions (add languages, debuggers, and tools)

Visual Studio Code - Debugging

- Extensions for debugging support:
  - C/C++: C/C++ for Visual Studio Code
  - Fortran: Modern Fortran
- Documentation
  - Visual Studio Code - Debugging
  - Debug C++ in Visual Studio Code
- Features
  - (Un)conditional breaking / logging points
  - Expression evaluation
  - Multithreaded debugging (OpenMP)
  - Call stack
  - Stepping
  - Watch window

Visual Studio Code - Debugging ...

- Debug modes:
  - Config: `.vscode/launch.json`
  - Attach to running application
  - Launch application
  - Connect to running debug server (gdb Machine Interface)
- Debug actions

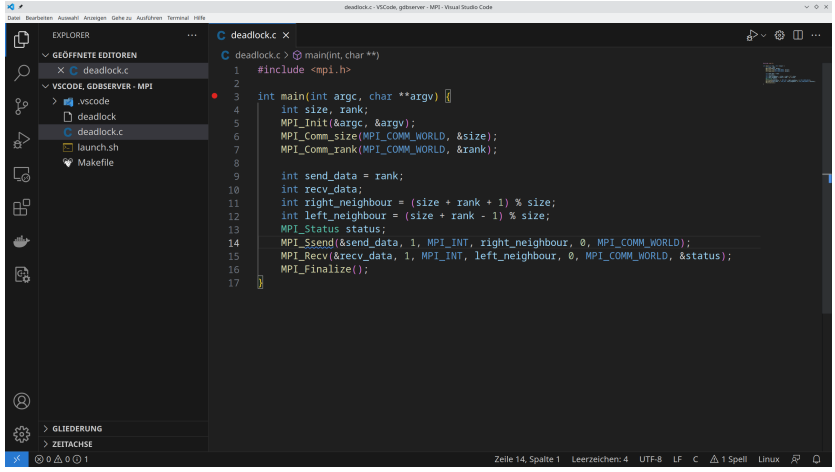
`F5`	Continue / Pause
`F10`	Step Over
`F11`	Step Into
`Shift + F11`	Step Out
`Shift + F5`	Stop

Visual Studio Code - Debugging ...

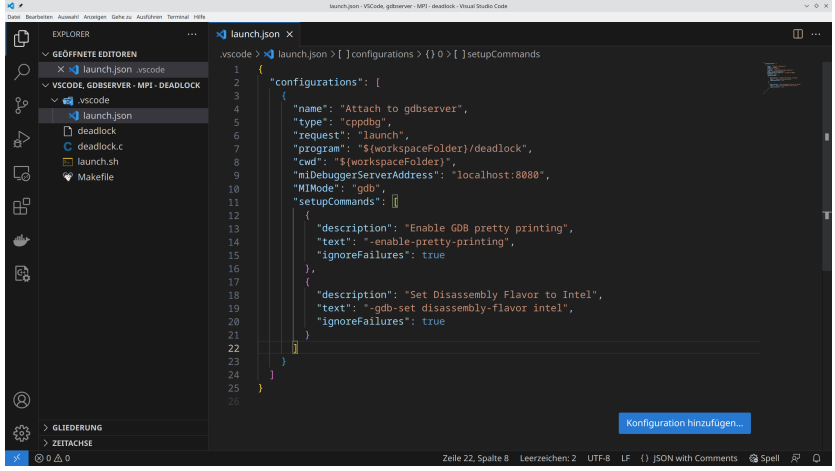
Example config `.vscode/launch.json` (get config options: `Ctrl + Space`):

```
{
  "configurations": [
    {
      "name": "Attach to gdbserver",
      "type": "cppdbg",
      "request": "launch",
      "program": "${workspaceFolder}/division_by_zero",
      "cwd": "${workspaceFolder}",
      "miDebuggerServerAddress": "localhost:8080",
      "MIMode": "gdb",
      "setupCommands": [ { ... } ]
    }
  ]
}
```

Visual Studio Code ...



Visual Studio Code ...



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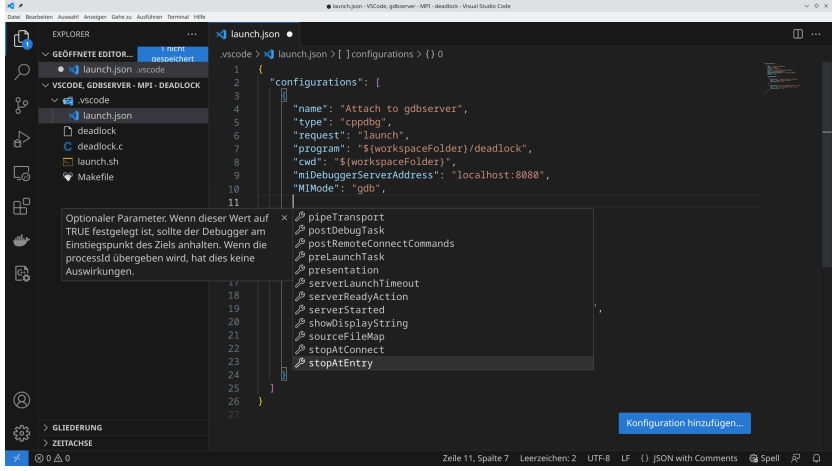

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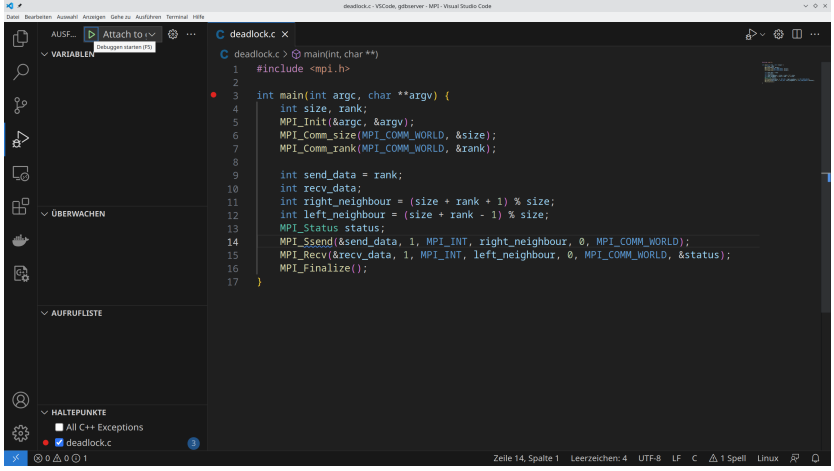
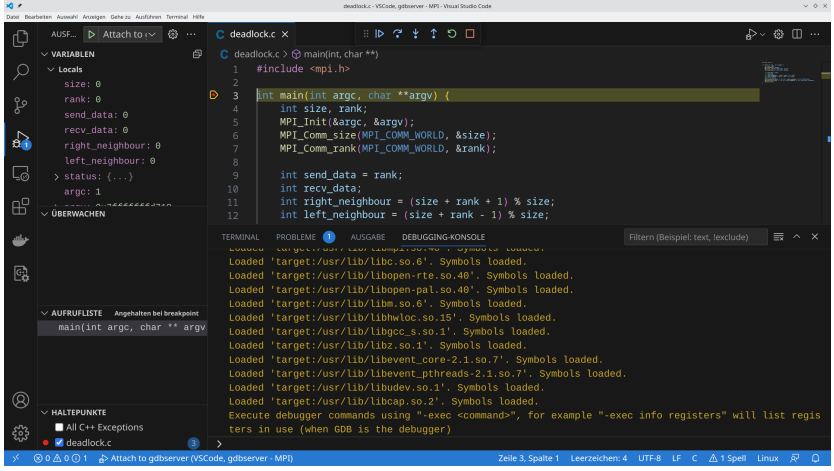


Visual Studio Code ...



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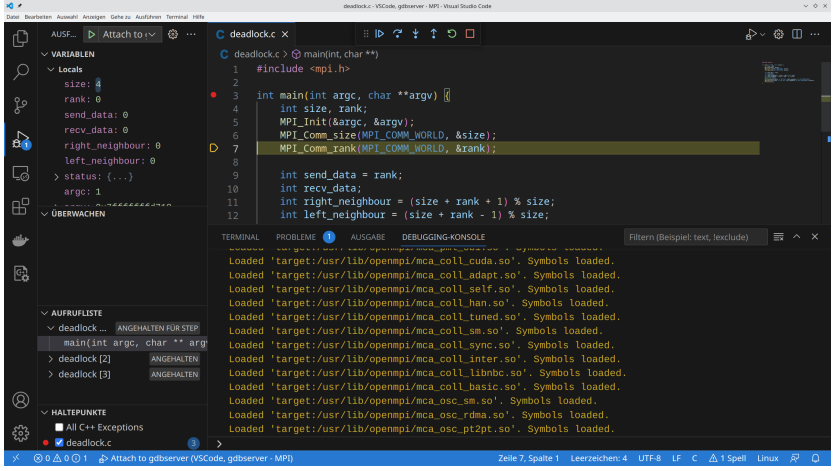

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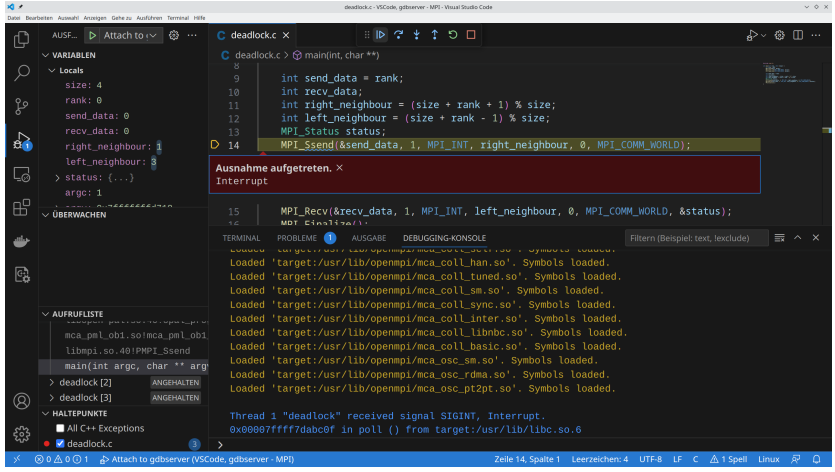
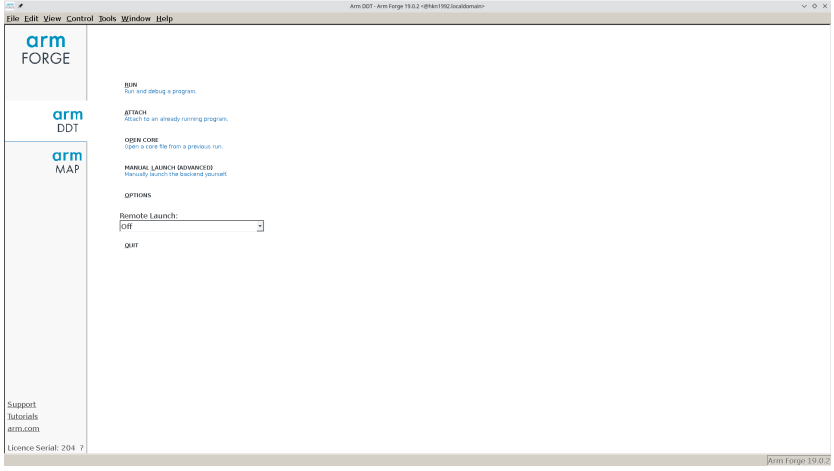


ARM Forge DDT (Distributed Debugging Tool)

- Graphical debugger
- Supports OpenMP, MPI and GPUs
- Commercial license available on HoreKa
- Arm DDT
- Get started, User Guide, Tutorials
- Basic usage

```
module add devel/ddt/
ddt
```

ARM Forge DDT (Distributed Debugging Tool) ...



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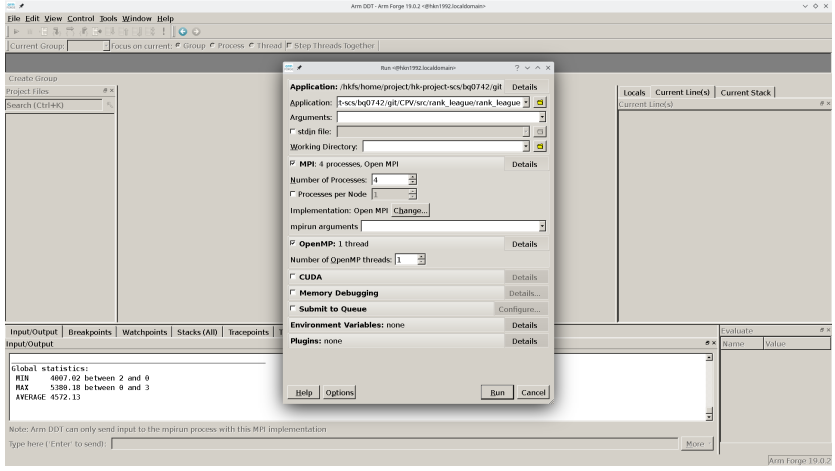

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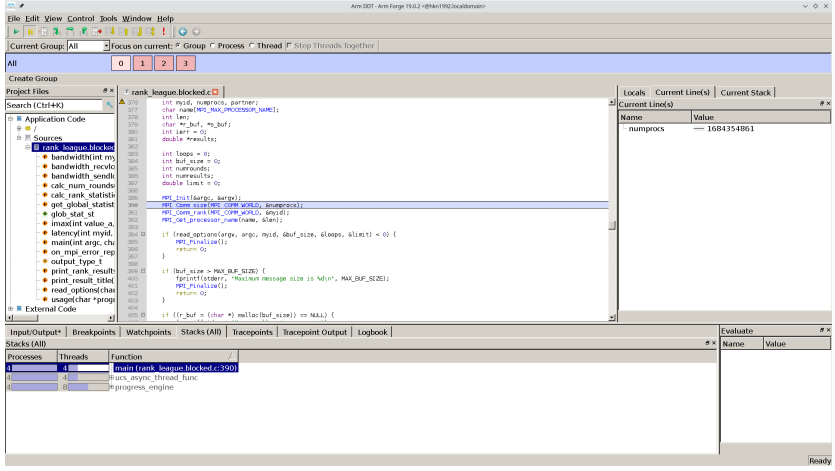

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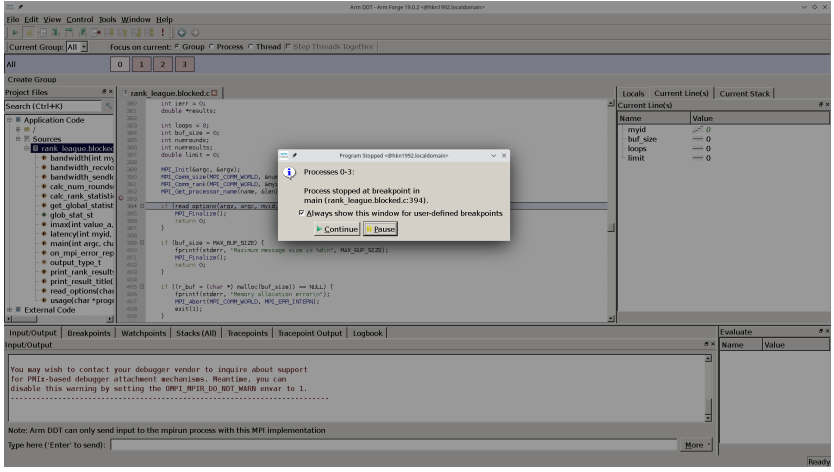

ARM Forge DDT (Distributed Debugging Tool) ...