Debugging Linux* Systems with GNU* GDB

Agenda

- **Introduction**
- Features
- Debugging on Command Line
- Debugging with Eclipse* IDE
- Documentation
- Summary

Introduction

Why do I need a debug solution?

- Development is a complicated task: You usually apply many **different technologies** throughout a typical developer's day, without always knowing.
- Some **new technologies** (e.g. C++11, vectorization, Intel® Processor Trace, …) might have strange effects. A debugger can help you understand how they work and help validating whether your code's semantic is as expected.
- A debugger helps you to **narrow down problems** caused by deviations from the expected code's behavior.
- It is crucial for a debugger to have **awareness of the underlying processor architecture**. Basic features of the architecture that aid in debugging should also be usable.

A debugger does not only help you finding problems but also shows you how things work!

Introduction

Debug solution from Intel:

- Command line with GNU* GDB
- Eclipse* IDE

How to get it?

- Intel® System Studio:
  https://software.intel.com/en-us/intel-system-studio

For best experience use debug solution from the most recent version!

Introduction

Debug solution from Intel® based on GNU* GDB 7.7:

- Included with Intel® System Studio 2013 and later
- Complements debuggers you might already have

Why to use provided GNU* GDB?

- Capabilities are released back to GNU* community
- Latest GNU* GDB versions in future releases
- Improved C/C++ support thanks to Project Archer and contribution through Intel
- Increased support for Intel® architecture
- Additional debugging capabilities – more later

Introduction

Why different flavors?

- Command line with GNU* GDB:
  - Well known syntax
  - Lightweight: no dependencies
  - Easy setup: no project needs to be created
  - Can be automatized/scripted
- Eclipse* IDE:
  - Comfortable user interface
  - Well known cross-platform IDE
  - Use existing Eclipse* projects
  - Simple integration of the Intel enhanced GNU* GDB
  - Remote System Explorer (RSE) for managing remote systems (targets)

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Features

Overview

Intel's GNU* GDB provides additional extensions that are available on the command line:

- **Data Race Detection (*pdbx*):**
  Detect and locate data races for applications threaded using POSIX* thread (pthread) or OpenMP* models

- **Branch Trace Store (*btrace*):**
  Record branches taken in the execution flow to backtrack easily after events like crashes, signals, exceptions, etc.

- **Pointer Checker:**
  Assist in finding pointer issues if compiled with Intel® C++ Compiler and having Pointer Checker feature enabled

Features

Data Race Detection (PDBX) I

What are data races?

- A data race happens…
  If at least two threads/tasks access the same memory location w/o synchronization and at least one thread/task is writing.

- Example:

```
int a = 1;
int b = 2;
…
int thread1() {
  return a + b;
}
```

```
int thread2() {
  b = 42;
}
```

time

Return value of `thread1()` depends on timing: 3 vs. 43!

Features

Data Race Detection (PDBX) II

What are typical symptoms of data races?

- Data race symptoms:
  - Corrupted results
  - Run-to-run variations
  - Corrupted data ending in a crash
  - Non-deterministic behavior

- Solution is to synchronize concurrent accesses, e.g.:
  - Thread-level ordering (global synchronization)
  - Instruction level ordering/visibility (atomics)
    Note:
    Race free but still not necessarily run-to-run reproducible results!
  - No synchronization: data races might be acceptable

⇨ **GDB data race detection can analyze correctness**

Features

Data Race Detection (PDBX) III

How to detect data races?

- Prepare to detect data races:
  - Only supported with Intel® C++ Compiler:
    Compile with `-debug parallel` (`icc` or `icpc`)
    Only objects compiled with `-debug parallel` are analyzed!
  - Optionally, add debug information via `-g`
- Enable data race detection (PDBX) in debugger:

```
(gdb) pdbx enable
(gdb) c
data race detected
1: write shared, 4 bytes from foo.c:36
3: read shared, 4 bytes from foo.c:40
Breakpoint -11, 0x401515 in L_test_..._21 () at foo.c:36
*var = 42; /* bp.write */
```

Features

Data Race Detection (PDBX) IV

Requires additional library **`libpdbx.so.5`**

- Keeps track of the synchronizations
- Part of Intel® C++ Compiler

Supported parallel programming models:

- OpenMP*
- POSIX* threads

Data race detection can be enabled/disabled at any time

- Only memory access are analyzed within a certain period
- Keeps memory footprint and run-time overhead minimal

There is finer grained control for minimizing overhead and selecting code sections to analyze

⇨ **Filter sets**

Features

Data Race Detection (PDBX) V

More control about what to analyze with filters:

- Add filter to selected filter set

```
(gdb) pdbx filter line foo.c:36
(gdb) pdbx filter code 0x40518..0x40524
(gdb) pdbx filter var shared
(gdb) pdbx filter data 0x60f48..0x60f50
(gdb) pdbx filter reads # read accesses
```

- Ignore events specified by filters (default behavior)

```
(gdb) pdbx fset suppress
```

- Ignore events not specified by filters

```
(gdb) pdbx fset focus
```

exclusive

- Get debug command help

```
(gdb) help pdbx
```

Features

Data Race Detection (PDBX) VI

Use cases for filters:

- Focused debugging, e.g.:
  Debug a single source file and only focus on one specific memory location.

- Limit overhead and control false positives

- Exclude 3rd party code

Features

Data Race Detection (PDBX) VII

Hint:

- Optimized code (symptom):

```
(gdb) run
data race detected
1: write question, 4 bytes from foo.c:36
3: read question, 4 bytes from foo.c:40
Breakpoint -11, 0x401515 in foo () at foo.c:36
 *answer = 42;
(gdb)
```

- Incident has to be analyzed further:
  - Remember: data races are reported on memory objects
  - If symbol name cannot be resolved: only address is printed
- **Recommendation:**
  Unoptimized code (`-O0`) makes it easier to understand
  (due to removed/optimized away temporaries, etc.)

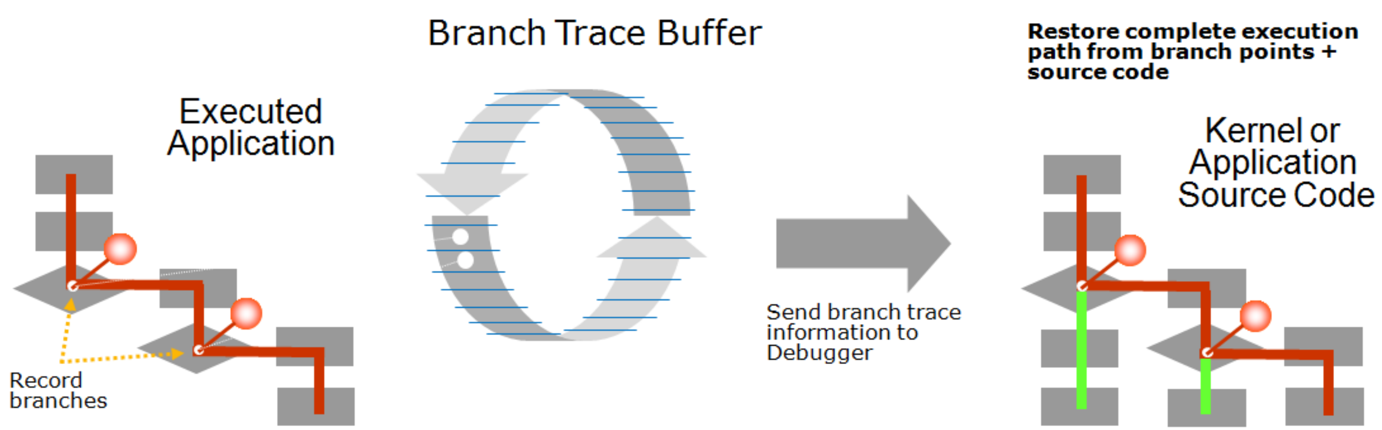
Features

Data Race Detection (PDBX) VIII

One more hint:

- Reported data races appear to be false positives:
  - Not all data races are bad… user intended?
  - OpenMP*: Distinct parallel sections using the same variable (same stack frame) can result in false positives

Features
Branch Trace Store I



- Intel® Atom™ and Intel® Core™ (Haswell and higher) processors supports Branch Trace Store (BTS)
- Allows to unroll execution flow at any point in time

⇨ **Where did things start to go wrong?**

Features

Branch Trace Store II

- Integrated into *process record and replay* subsystem of GNU* GDB 7.6 and later.
- **However:**
  BTS does not allow replaying and reverse execution

- Branch trace per thread (HW & SW)
- Show compact control flow overview
- Show detailed execution trace disassembly (history)

⇨ **Answers: How did I get here?**

Features

Branch Trace Store III

Commands:

- Enable/disable BTS:
  `record btrace/record stop`
  Start/stop recording the branch trace for all threads
- Status of BTS (and *process record and replay* in general):
  `info record`
- Display list of basic blocks:
  `record function-call-history [/l] [/i]`
- Display disassembly of instructions in BTS log:
  `record instruction-history [#-of-instruction]`
- Much more commands; mostly for configuration and displaying!
  See `GDB.pdf` for more information.

Features

Branch Trace Store IV

Useful for:

- Debugging internal state corruption
- Debugging stack corruption (broken backtrace)
- Quick control flow overview

Overhead up to 60x possible!
⇨ Use selective enabling to reduce it

Features

Branch Trace Store – Example I

```
#include <stdio.h>

int *getmem(int i)
{
    // buggy memory pool
    int memory[10];
    return &memory[i];
}

void memzero(int *ptr)
{
    *ptr = 0;
}

void work(int *ptr)
{
    memzero(ptr);
    // do some work here
}
```

```
int main(int argc, char **argv)
{
    int i;
    int *ptr;

    for(i = 0; i < 10; i++) {
        printf("%d\n", i);
        ptr = getmem(i);
        work(ptr);
    }
    return 0;
}
```

Source file: **segv.c**

Features

Branch Trace Store – Example II

Compiling and executing the example:

```
$ icpc segv.c -o segv -g && ./segv
0
1
2
3
4
Segmentation fault (core dumped)
```

Something went wrong here. Let's use the debugger to learn why...

Features

Branch Trace Store – Example III

First run with debugger:

```
$ gdb-ia segv
Reading symbols from segv...done.
(gdb) r
Starting program: segv
0
1
2
3
4

Catchpoint -2 (signal SIGSEGV), work (
    ptr=<error reading variable: Cannot access memory at address
0x7ffeffffff0>)
    at segv.c:18
18 }
...
```

7/16/2014

Features

Branch Trace Store – Example IV

```
...
(gdb) bt
Python Exception <class 'gdb.MemoryError'> Cannot access memory at
address 0x7fff00000008:
#0  work (ptr=<error reading variable: Cannot access memory at
address 0x7ffeffffff0>)
    at segv.c:18
Cannot access memory at address 0x7fff00000008
```

The stack trace cannot be printed. We have no idea what caused the SEGV!

Features

Branch Trace Store – Example V

Second run with BTS:

```
$ gdb-ia segv
Reading symbols from segv...done.
(gdb) b main
Breakpoint 1 at 0x400613: file segv.c, line 25.
(gdb) r
Starting program: segv

Breakpoint 1, main (argc=1, argv=0x7fffffffddf8) at segv.c:25
25      for(i = 0; i < 10; i++) {
(gdb) record btrace
...
```

Features

Branch Trace Store – Example VI

```
...
(gdb) c
Continuing.
0
1
2
3
4

Catchpoint -2 (signal SIGSEGV), work (
    ptr=<error reading variable: Cannot access memory at address
0x7ffeffffff0>)
    at segv.c:18
18 }
(gdb) info record
Active record target: record-btrace
Recorded 1164 instructions in 60 functions for thread 1 (process
13556).
...
```

Features

Branch Trace Store – Example VII

```
...
(gdb) bt
#0  work (ptr=<error reading variable: Cannot access memory at
address 0x7ffeffffff0>)
    at segv.c:18
Cannot access memory at address 0x7fff00000008
(gdb) record function-call-history /l /i
50  1091            free@plt
51  1092-1098           free
52  1099-1124           vfprintf
53  1125-1126           printf
54  1127-1130   segv.c:26-27    main
55  1131-1141   segv.c:4-6  getmem(int)
56  1142-1147   segv.c:27-28    main
57  1148-1154   segv.c:15-16    work(int*)
58  1155-1162   segv.c:10-12    memzero(int*)
59  1163     segv.c:18   work(int*)
```

The last executed function was **`work(…)`**. It's return (line 18) triggered the SEGV!

Features

Pointer Checker

Debugging:

```
int arr[N];
int last(int* arr) {
      return arr[N - 1];
}
void bug() {
      int i = last(arr + 1);
}
```

- Compile application with **-g** & **-check-pointers=[rw|write]**
- It extends pointer with bounds information and checks bounds before each access
- New command: **info sbounds <ptr>**

```
(gdb) c
Continuing.
Upper bound violation.
With bounds {0xec8, 0xeef} accessing at: 0xef0 and size: 4.
Temporary breakpoint -13, 0x40090b in last (arr=0xecc <arr+4>) at
bounds.c:3
4         return arr[N - 1];
(gdb) info sbounds arr
{lbound = 0xec8, ubound = 0xeef}: ptr. value = 0xecc, size = 40
```

Agenda

- Introduction
- Features
- **Debugging on Command Line**
- Debugging with Eclipse* IDE
- Documentation
- Summary

Debugging on Command Line

Remote Debugging I

1. Select **gdbserver** for the target:
   - Linux host:
     `<install-dir>/system_studio_2015.x.y/targets/`
     `<arch>/<target>/bin/gdbserver`
   - Windows host:
     `<install-dir>\System Studio 2015.x.y\targets\`
     `<arch>\<target>\bin\gdbserver`
   - **<arch>** can be: **ia32**, **intel64** or **Quark**
   - **<target>** is one of the supported target systems, e.g.: **Galileo**, **Yocto1.5**, **WindRiverLinux5**, **TizenIVI**, …

2. Copy selected **gdbserver** to the target

Debugging on Command Line

Remote Debugging II

3. Start **`gdbserver`** on the target:
   - Loading application called **`<application>`**:
     ```
     $ gdbserver localhost:2000 <application>
     Process program created; pid = …
     Listening on port 2000
     ```
   - Attach to running application with PID **`<pid>`**:
     ```
     $ gdbserver localhost:2000 --attach <pid>
     Process program created; pid = …
     Listening on port 2000
     ```

   Note:
   Application has to be launched externally before. To avoid runaway, use:
   ```
   …
   volatile int lock_loop = 1;
   while(lock_loop) { lock_loop = 1; } // or: sleep(1)
   …
   ```
   When attached set **`lock_loop`** manually **`0`** to continue.

Debugging on Command Line

Remote Debugging III

4. Start GDB on host:

   - Linux host:

     ```
     $ source <install-dir>/system_studio_2015.x.y/bin/
                    compilervars.[sh|csh] [ia32|ia32_intel64]
     $ gdb-ia <application>
     ```

   - Windows host:

     ```
     $ call <install-dir>\System Studio 2015.x.y\bin\
                    compilervars.bat [ia32|ia32_intel64]
     $ gdb-ia.bat <application>
     ```

5. Connect GDB to **`gdbserver`** on target:

   ```
   (gdb) target remote <target>:2000
   Remote debugging using <target>:2000
   ```

   `<target>` is network name/IP of target system.

Debugging on Command Line

Remote Debugging with Multi-Mode

Alternative usage: Multi-Mode

1. Start **gdbserver** on the target:
   ```
   $ gdbserver --multi localhost:2000
   Listening on port 2000
   ```

2. Start GDB on host:
   ```
   $ gdb-ia[.bat]
   (gdb) target extended-remote <target>:2000
   Remote debugging using <target>:2000
   (gdb) file <application>
   ```

   - Attach:
     ```
     (gdb) attach <pid>
     ```
     <application> is host path, **<pid>** is PID on the target

   - Load & execute:
     ```
     (gdb) set remote exec-file <application_target>
     ```
     <application> is host path, **<application_target>** is target path

Debugging on Command Line

Additional Hints for Remote Debugging

- Sysroot:
  `(gdb) set sysroot <path>`
  Set the path to the system root. `<path>` is the location of system libraries for target on host.

- Search path:
  `(gdb) set solib-search-path <path>`
  `<path>` is path to additional libraries from target to add to the search path on host. Alternatively `$LD_LIBRARY_PATH` can be set on target before launching GDBServer.

- Path substitution:
  `(gdb) set substitute-path <from> <to>`
  Change paths from `<from>` to `<to>`. You can relocate a whole source (sub-)tree with that.

Debugging is no different than known from non-Intel GNU* GDB versions!

See `GDB.pdf` and the Intel® System Studio Product Guide for more information.

Debugging on Command Line

Get Started with PDBX I

- PDBX has some pre-requisites that must be fulfilled for proper operation
- Use **`pdbx check`** command to see whether PDBX is working:

1. First step:
   ```
   (gdb) pdbx check
   checking inferior...failed.
   ```
   Solution:
   Start a remote application (inferior) and hit some breakpoint (e.g. **`b main`** & **`run`**)

2. Second step:
   ```
   (gdb) pdbx check
   checking inferior...passed.
   checking libpdbx...failed.
   ```
   Solution:
   Use **set solib-search-path <lib_paths>** to provide the path of **`libpdbx.so.5`** on the host.

Debugging on Command Line

Get Started with PDBX II

3. Third step:

```
(gdb) pdbx check
checking inferior...passed.
checking libpdbx...passed.
checking environment...failed.
```

Solution:

Set additional environment variables on the target for OpenMP*. Those need to be set with starting GDBServer (similar to setting **$LD_LIBRARY_PATH**).

- **$INTEL_LIBITTNOTIFY32=""**
- **$INTEL_LIBITTNOTIFY64=""**
- **$INTEL_ITTNOTIFY_GROUPS=sync**

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- **Debugging with Eclipse* IDE**
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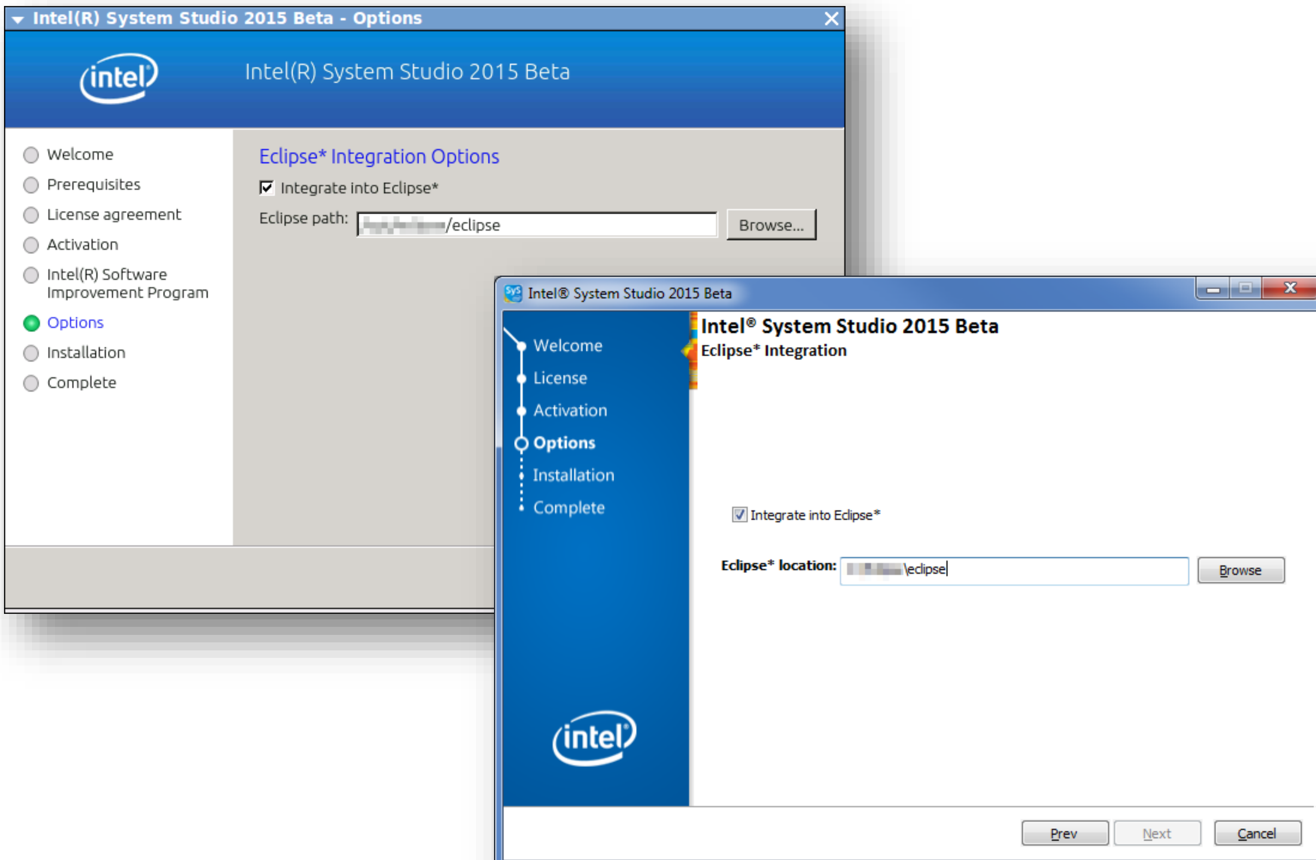
Debugging with Eclipse* IDE
Pre-Requisites I

- Eclipse* IDE:
  - 4.3 with Eclipse C/C++ Development Tools (CDT) 8.1 or later
  - 4.2 with Eclipse C/C++ Development Tools (CDT) 8.1 or later

  We recommend: *Eclipse IDE for C/C++ Developers* (4.3)
- Java* Runtime Environment (JRE) 6.0 or later
- Remote System Explorer (RSE) plugin (optional but recommended)
- Configure RSE to establish connection with the target hardware. Please refer to the RSE documentation for more information: http://www.eclipse.org/tm/tutorial/index.php
- Source/call **`compilervars.[sh|csh|bat]`** before starting Eclipse* IDE (in same environment)

Debugging with Eclipse* IDE
Pre-Requisites II

Integrate into existing Eclipse* IDE during installation:



Debugging with Eclipse* IDE

Remote Debugging I

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     <install-dir>\System Studio 2015.x.y\targets\<arch>\<target>\bin\gdbserver
   - **<arch>** can be: **ia32**, **intel64** or **Quark**
   - **<target>** is one of the supported target systems, e.g.: **Galileo**, **Yocto1.5**, **WindRiverLinux5**, **TizenIVI**, …
2. Copy selected **gdbserver** to the target

Debugging with Eclipse* IDE

Remote Debugging II

3. Start `gdbserver` on the target:

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     ```
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     ```
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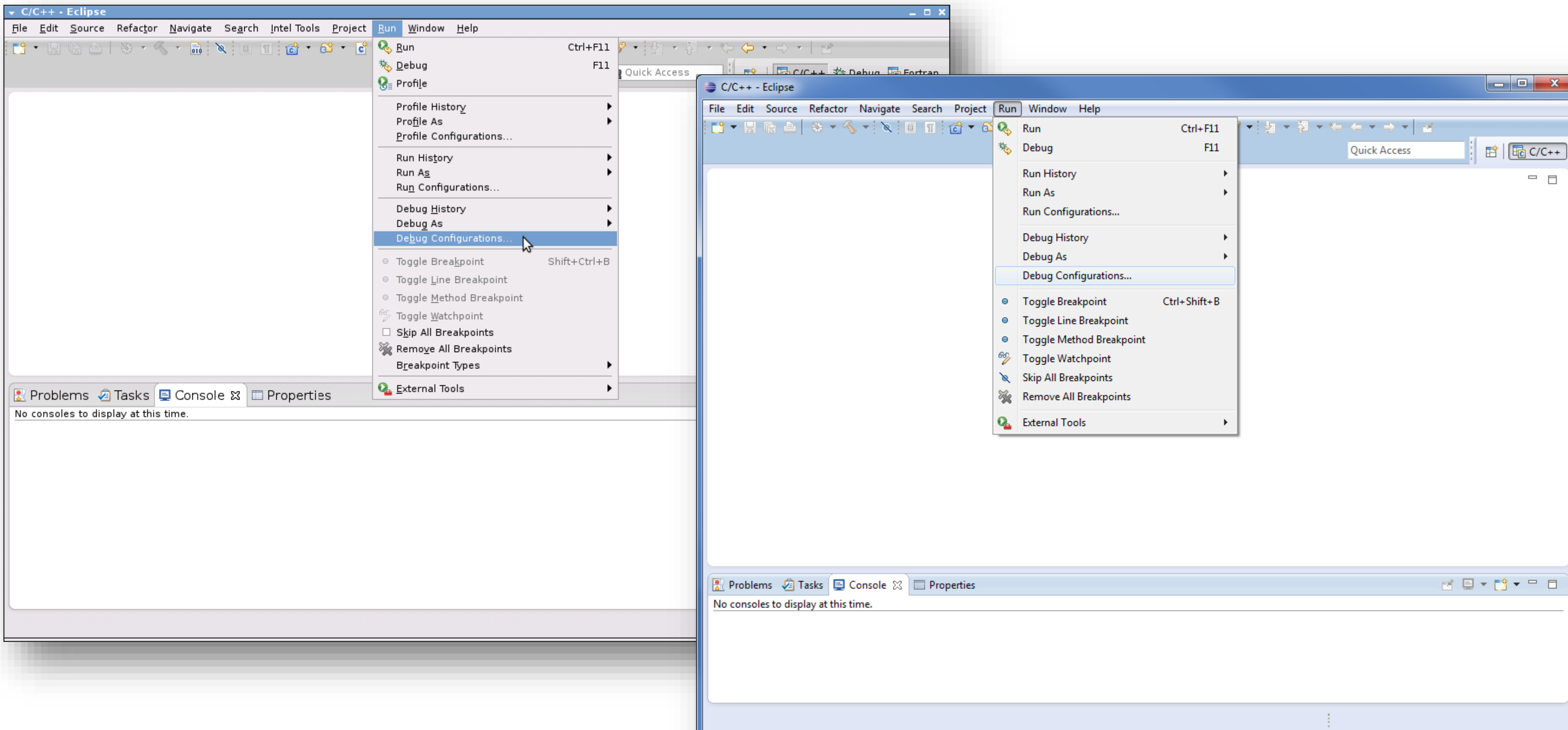
     ```
     $ gdbserver localhost:2000 --attach <pid>
     Process program created; pid = …
     Listening on port 2000
     ```

   Note:
   Application has to be launched externally before. To avoid runaway, use:
   ```
   …
   volatile int lock_loop = 1;
   while(lock_loop) { lock_loop = 1; } // or: sleep(1)
   …
   ```
   When attached set `lock_loop` manually `0` to continue.

Debugging with Eclipse* IDE

Remote Debugging III

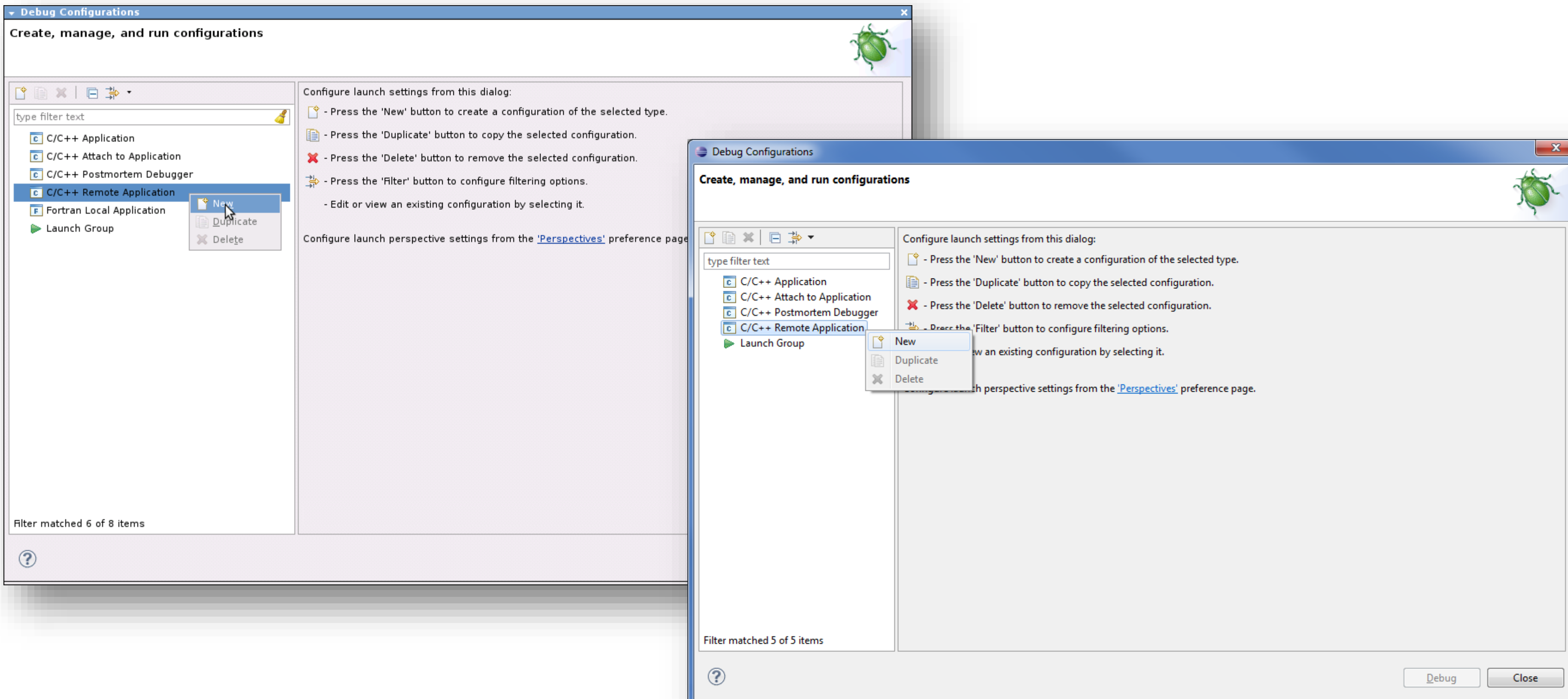
4. Configure Eclipse* IDE to use the provided GDB:
   a. In Eclipse* IDE click on “Run>Debug Configurations…”



Debugging with Eclipse* IDE

Remote Debugging IV

b. Create a new or update an existing “C/C++ Remote Application” or “C/C++ Attach to Application” configuration.



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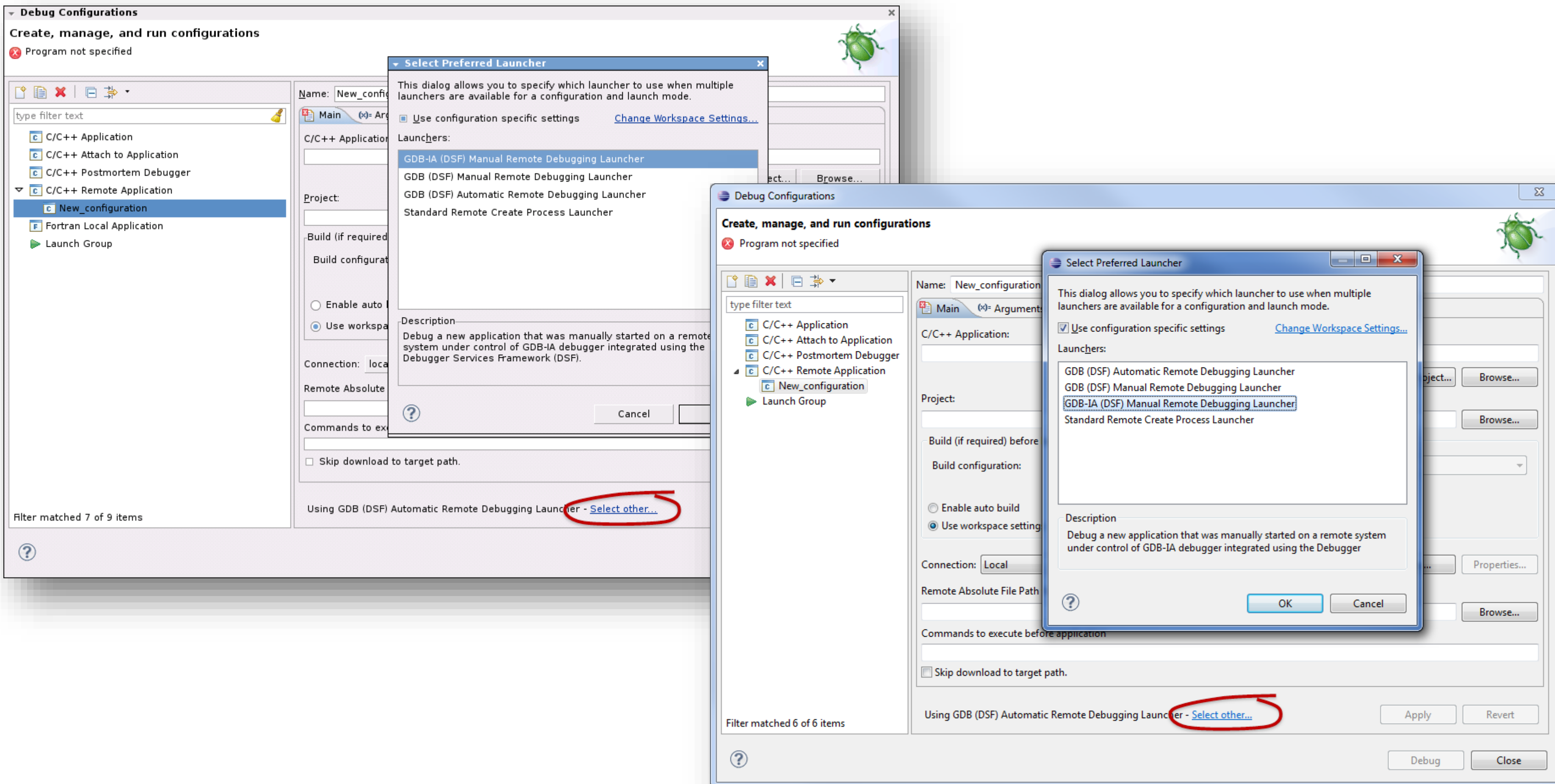
Debugging with Eclipse* IDE

Remote Debugging V

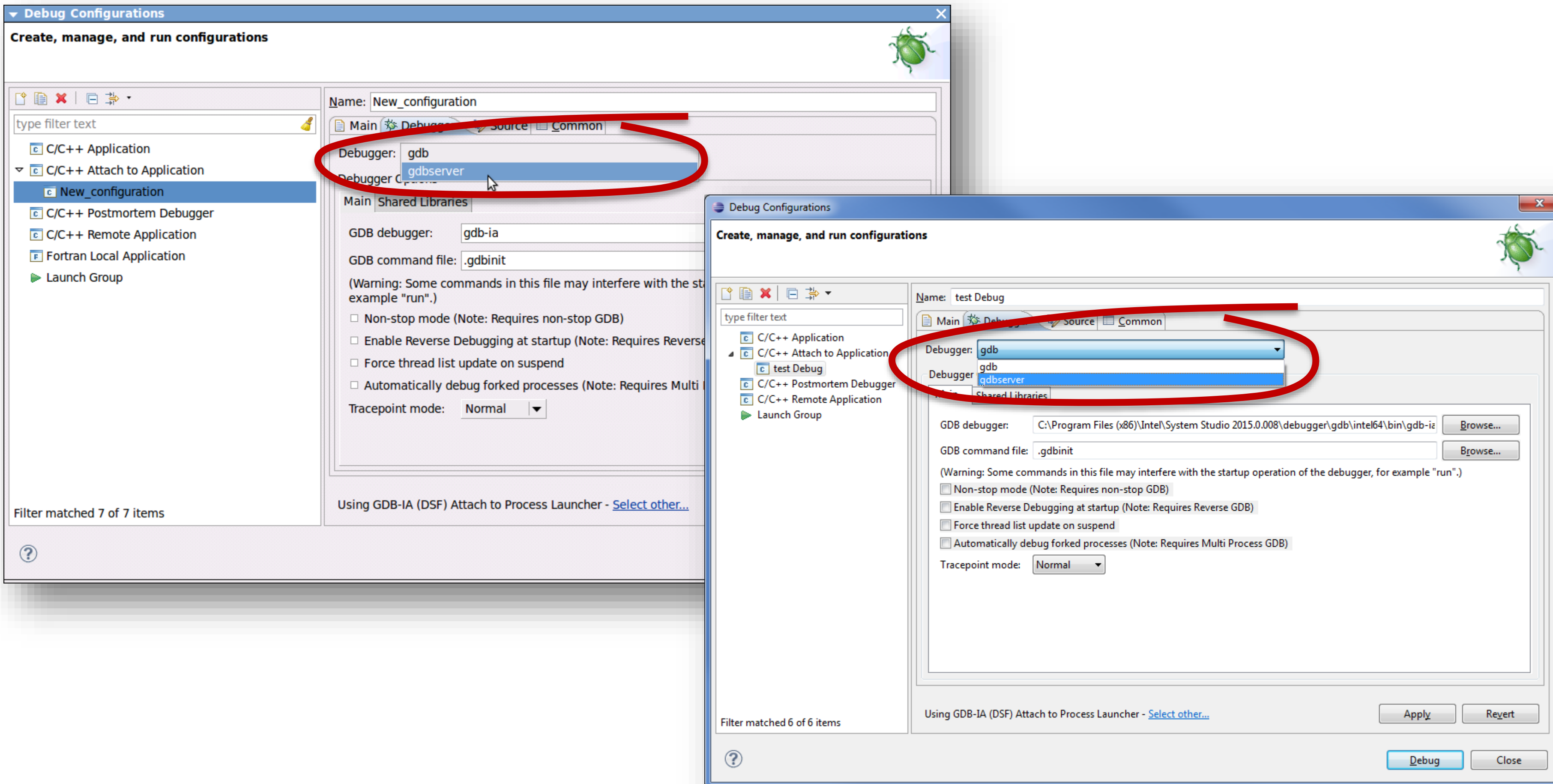
c. Select the launcher: “GDB-IA (DSF)” via link Select other…:



Debugging with Eclipse* IDE

Remote Debugging VI

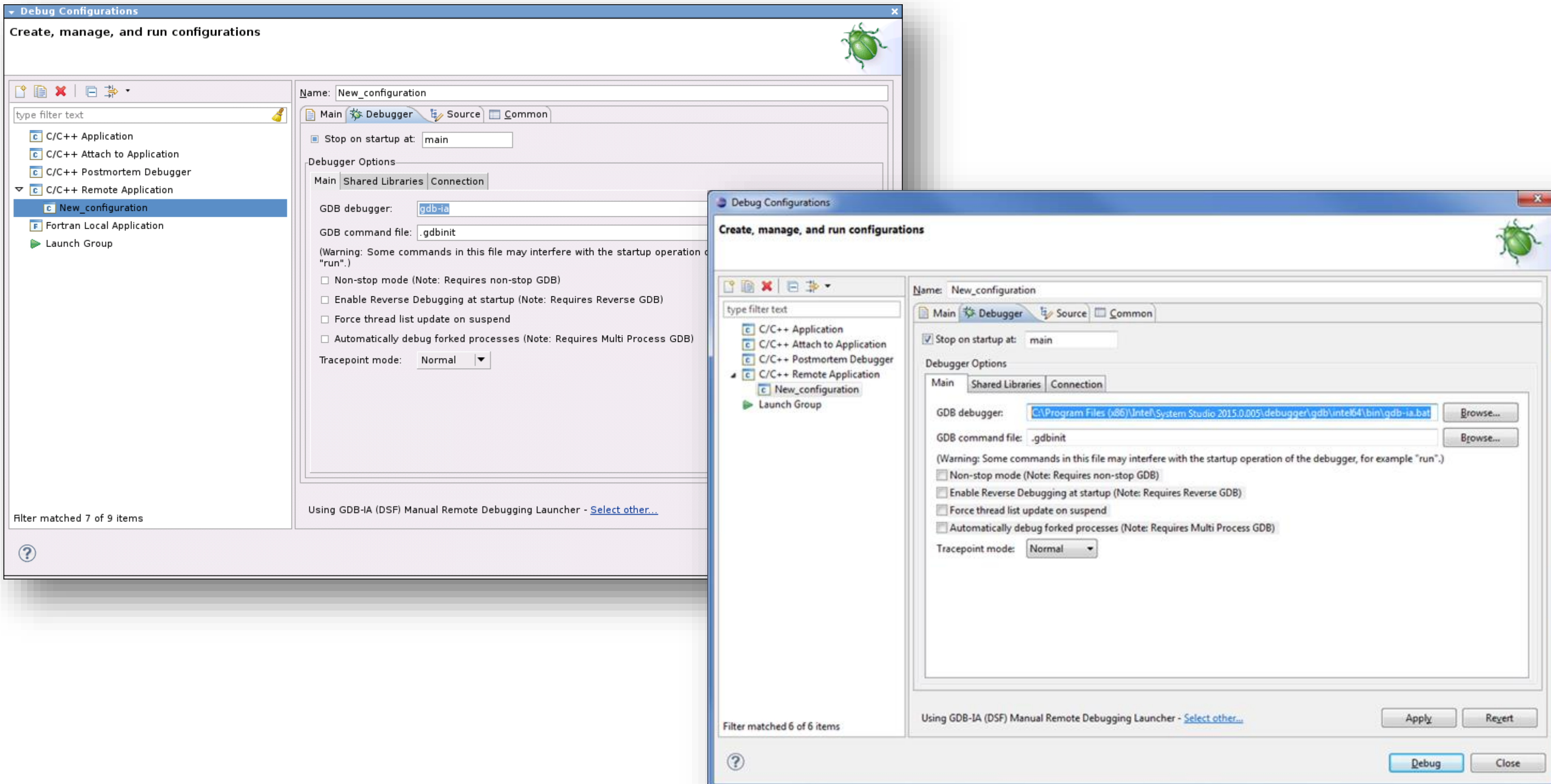
d. In case of attaching, select “gdbserver” as the debugger:



Debugging with Eclipse* IDE

Remote Debugging VII

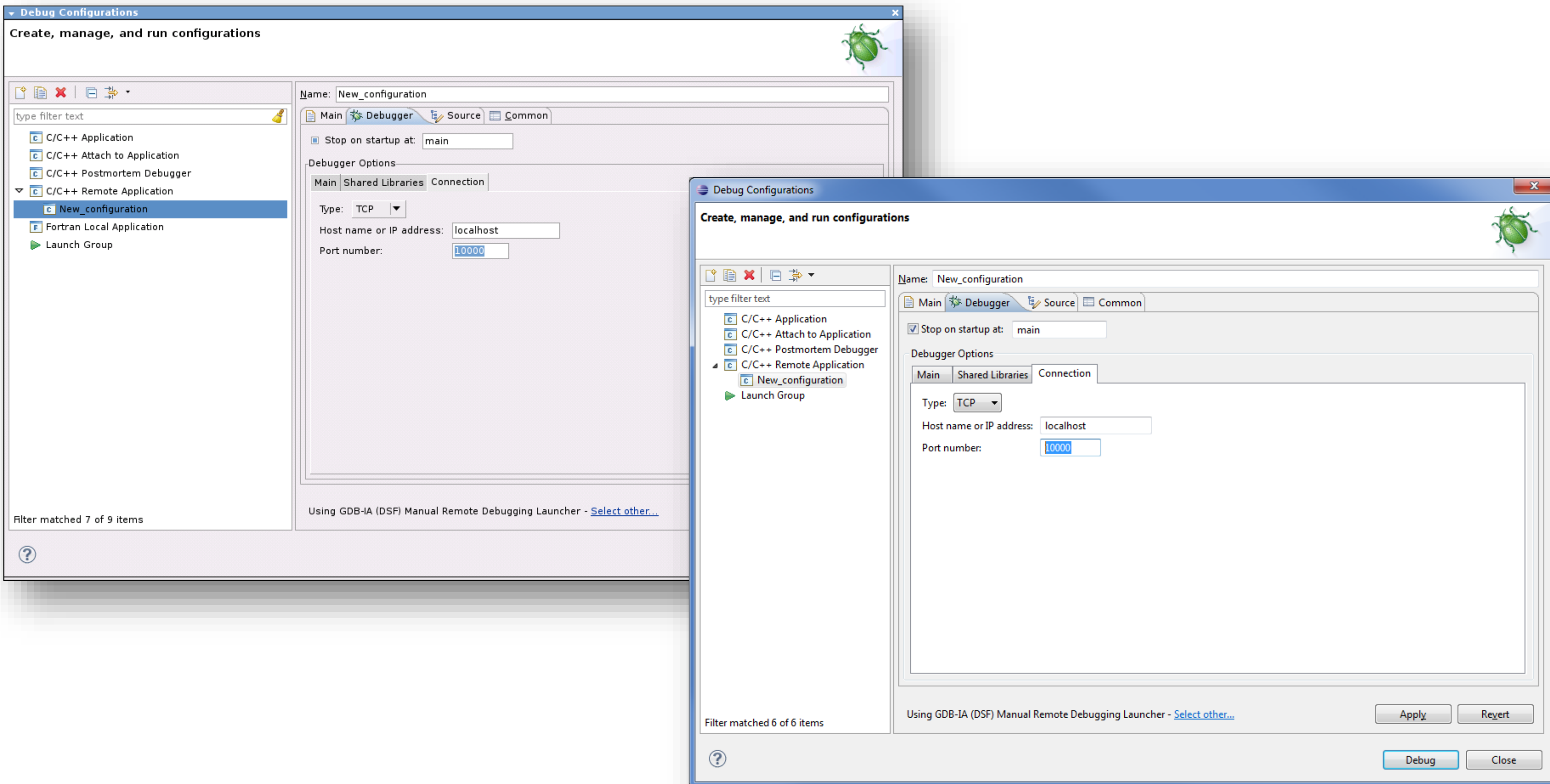
e. The launcher automatically sets the provided GDB:



Debugging with Eclipse* IDE

Remote Debugging VIII

f. Specify the target IP address and port number for **gdbserver**:



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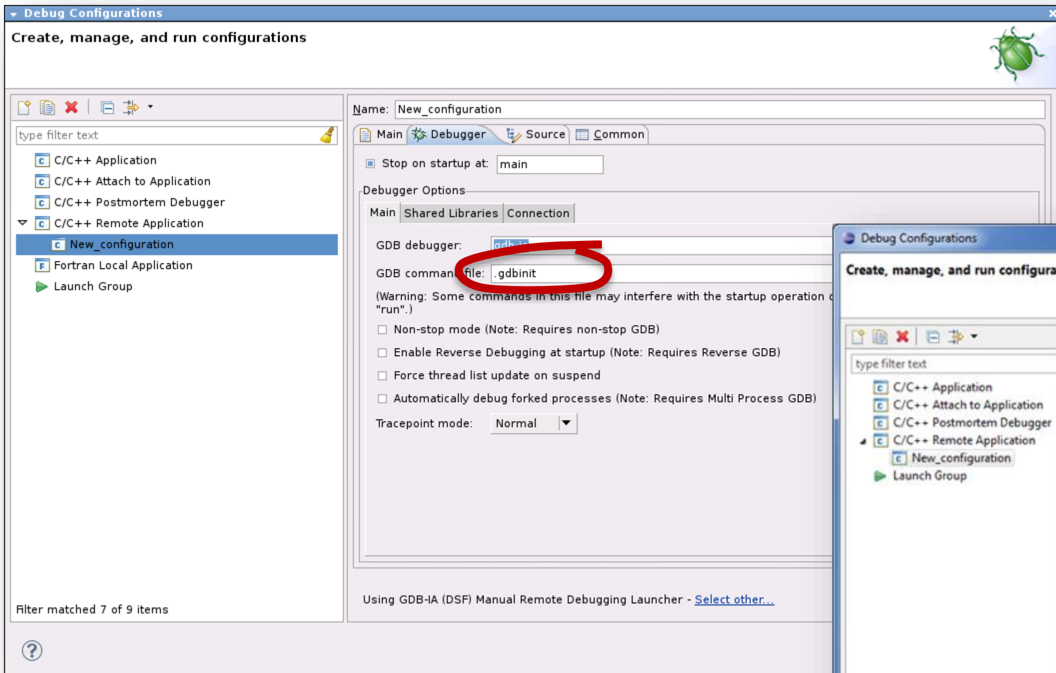
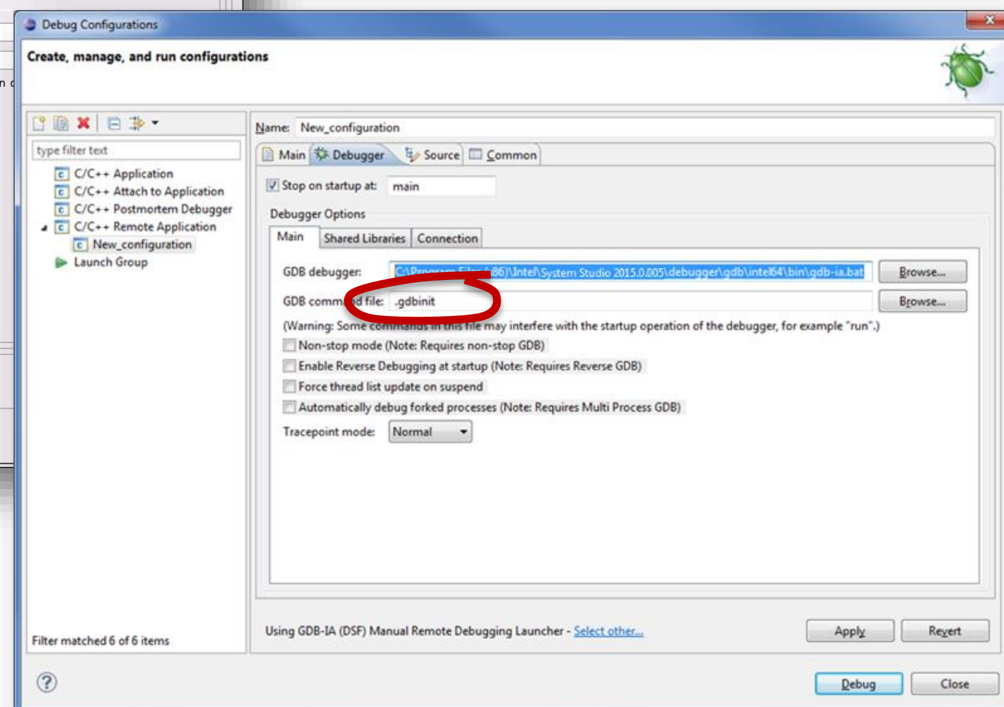
Debugging with Eclipse* IDE
Additional Hints for Remote Debugging I

Create and configure `.gdbinit`:





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Debugging with Eclipse* IDE

Additional Hints for Remote Debugging II

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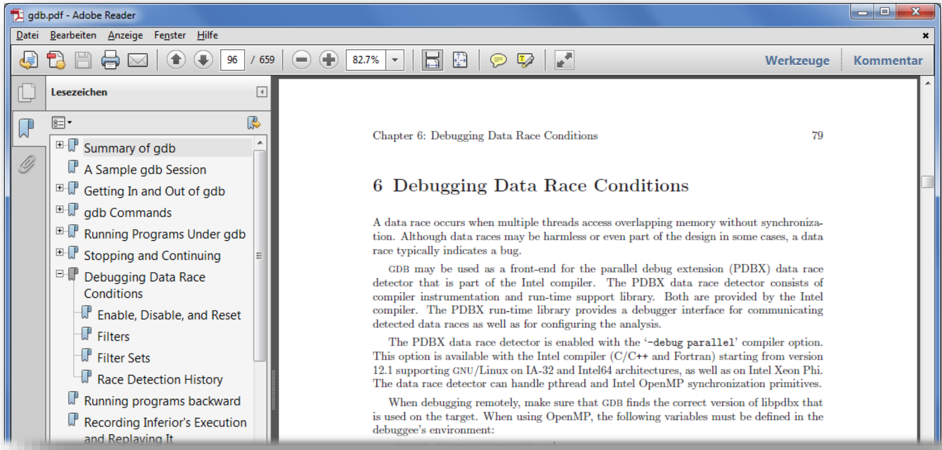
Documentation

Documentation can be found here:

<system_studio_root>/Documentation/en_US/debugger/gdb/GDB.pdf



Release Notes:

https://software.intel.com/en-us/articles/intel-system-studio-release-notes

...or here:

<system_studio_root>/Documentation/en_US/debugger/gdb/GDB_Release_notes.pdf

Agenda

- Introduction
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- **Summary**

Summary

- Intel's GNU* GDB
  - Well known Syntax
  - Seamless integration of Intel extensions
  - Latest Intel® architecture support
  - Contributing to community
  - Lightweight remote debugging of systems

- Eclipse* IDE
  - Can use Intel's GNU* GDB (with some of its features)
  - One of the most famous IDEs on Linux*
  - Support of both C/C++ and Fortran
  - Remote debugging capabilities

Legal Disclaimer & Optimization Notice

Optimization Notice

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Notice revision #20110804