Understanding, Scripting and Extending GDB

Kevin Pouget
Jean-François Méhaut, Fabrice Rastello

Université Grenoble Alpes / LIG, INRIA, CEA

11^{iemes} Journées Compilations, Aussois, France
9 septembre 2016

What is a debugger?

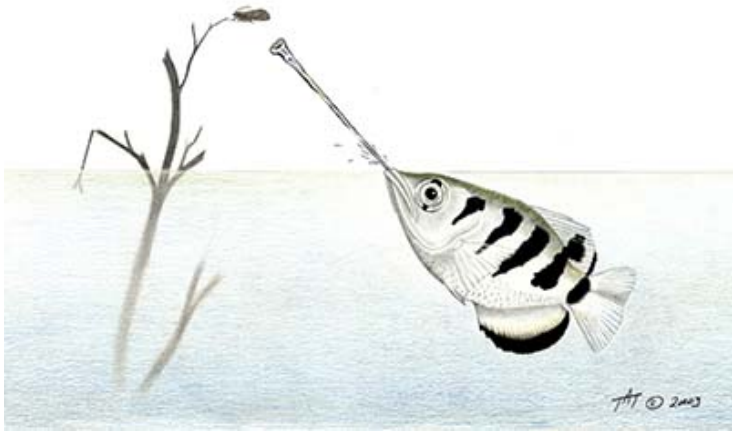
Introduction

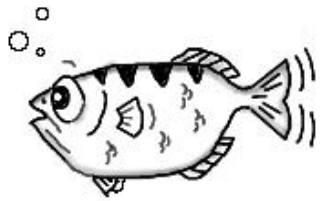
Compiler Optimization and Runtime SystEms

What is a debugger?

It's *not* a tool to *remove* bugs!

(not even to shoot them like the Archerfish of GDB's logo ;)





What is a debugger?

It's *not* a tool to *remove* bugs!

?

Tools like GDB have the ability to ...

- access the program state
  - read and write memory cells and CPU registers ...
  - in the language's type system
- control the execution execution
  - execute internal code on specific events
  - execute code in the process' address-space

What is a debugger?

It's *not* a tool to *remove* bugs!

?

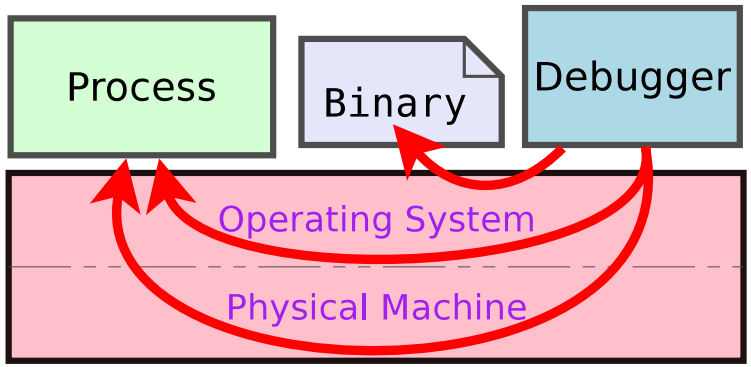
Tools like GDB have the ability to ...

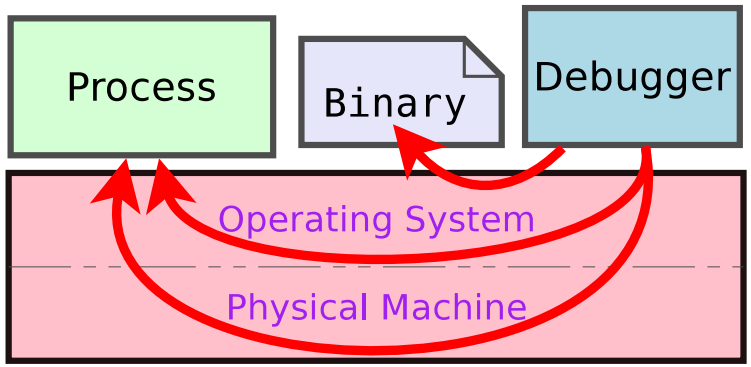
- access the program state
- control the execution execution

But ...

- the execution is 100% native
- everything done through collaboration between ...
  - the OS, the compiler, the CPU ... and old hackers' tricks!

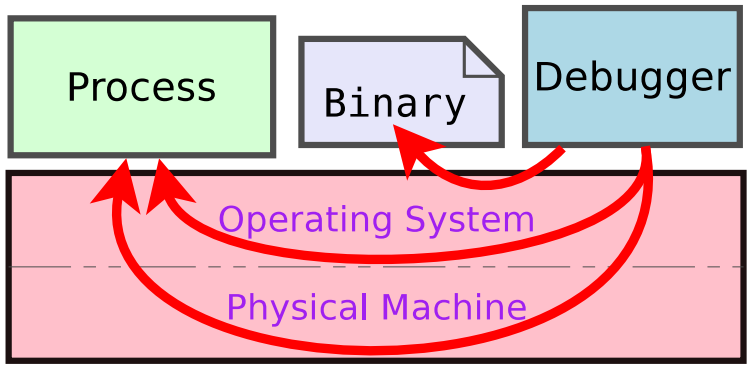

Introduction
Compiler Optimization and Runtime SystEms


Process
Binary
Debugger
Operating System
Physical Machine



Help from the compiler

- DWARF: type system and calling conventions

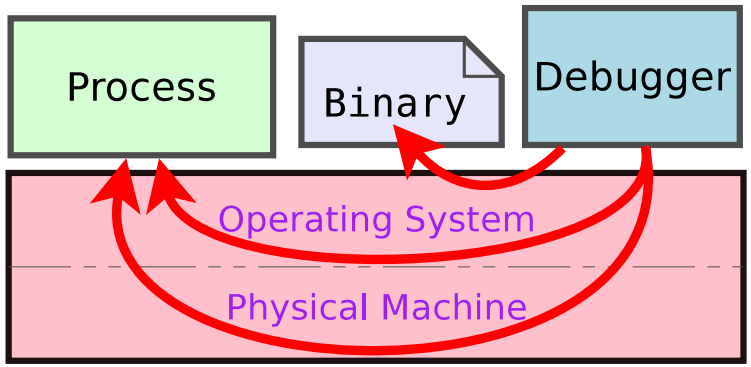


Help from the compiler

- DWARF: type system and calling conventions

Help from the CPU

- not much (mainly watchpoint and instruction-level step-by-step)



Help from the compiler

- DWARF: type system and calling conventions

Help from the CPU

- not much (mainly watchpoint and instruction-level step-by-step)

Help from the OS

- ... the rest (access to the memory/registers + scheduler)

Introduction: Definitions

Compiler Optimization and Runtime SystEms

- Stopping the execution ...

  breakpoint on an address *execution*

  watchpoint on an address *access* (read or write)

  catchpoints on particular *events* (signals, syscalls, fork/exec, ...)

Introduction: Definitions

Compiler Optimization and Runtime SystEms

- Stopping the execution ...

breakpoint	on an address *execution*
watchpoint	on an address *access* (read or write)
catchpoints	on particular *events* (signals, syscalls, fork/exec, ...)

- Controlling the execution:

next/i	go to next line/instruction
step/i	step into the current's line *function call* (if any)
finish	continue until the end of the current function
return	abort the current function call

Agenda

Compiler Optimization and Runtime SystEms

1. GDB Under the Hood
2. Programming GDB in Python
3. Your Turn

Agenda

Compiler Optimization and Runtime SystEms

1. GDB Under the Hood
   - Help from the Compiler
   - Help from the OS
   - Help from the CPU
   - Internal algorithms
2. Programming GDB in Python
   - Python Interface
   - Short Examples & CLI Reminder
3. Your Turn
   - Section breakpoint
   - Return `true` breakpoint
   - Register watchpoint
   - Step into next call
   - Faking function execution

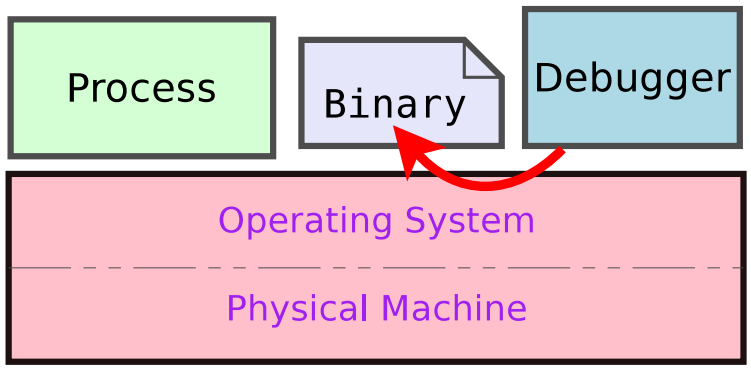
1 GDB Under the Hood
- Help from the Compiler
- Help from the OS
- Help from the CPU
- Internal algorithms

2 Programming GDB in Python
- Python Interface
- Short Examples & CLI Reminder

3 Your Turn
- Section breakpoint
- Return `true` breakpoint
- Register watchpoint
- Step into next call
- Faking function execution

Everything GDB knows about the language (Dwarf)

- the type system
- the calling conventions and local variables
- the address-to-line mapping




```
docker@[host]/dwarf $ dwarfdump prodconsum
```

Everything GDB knows about the language (Dwarf)

- the type system
- the calling conventions and local variables
- the address-to-line mapping

```
struct Context {
        pthread_cond_t *cond;
        ...
};

void *consumer(void *_context){
       struct Context *context = ...;
       ...
}
```

Everything GDB knows about the language (Dwarf)

- the type system
- the calling conventions and local variables
- the address-to-line mapping

```
DW_TAG_subprogram
    DW_AT_name          consumer
    DW_AT_decl_file     prodconsum.c
    DW_AT_type          <0x00000094> # void *
    DW_AT_low_pc        0x00400d47
    DW_AT_high_pc       <offset-from-lowpc>237
    DW_AT_frame_base    len 0x0001: 9c: DW_OP_call_frame_cfa
    ...
```

Everything GDB knows about the language (Dwarf)

- the type system
- the calling conventions and local variables
- the address-to-line mapping

```
DW_TAG_subprogram
    DW_AT_name              consumer
    ...
    DW_TAG_formal_parameter
        DW_AT_name                  _context
        DW_AT_decl_file             0x00000001 prodconsum.c
        DW_AT_decl_line             0x0000007b   # 123
        DW_AT_type                  <0x00000094> # void *
        DW_AT_location              len 0x0002: 9158: DW_OP_fbreg -40
        ...
```

Everything GDB knows about the language (Dwarf)

- the type system
- the calling conventions and local variables
- the address-to-line mapping

```
DW_TAG_subprogram
    DW_AT_name              consumer
    ...
    DW_TAG_variable
        DW_AT_name              context
        DW_AT_decl_file         0x00000001 prodconsum.c
        DW_AT_decl_line         0x0000007d   # 125
        DW_AT_type              <0x00000596> # struct Context *
        DW_AT_location          len 0x0002: 9168: DW_OP_fbreg -24
        ...
```

Everything GDB knows about the language (Dwarf)

- the type system
- the calling conventions and local variables
- the address-to-line mapping

```
DW_TAG_pointer_type              # <0x00000596> struct Context*
   DW_AT_byte_size               0x00000008
   DW_AT_type                    <0x0000050a>
DW_TAG_structure_type            # <0x0000050a> struct Context
   DW_AT_name                    Context
   DW_AT_byte_size               0x00000018
   DW_TAG_member
      DW_AT_name                    cond
      DW_AT_type                    <0x0000054c> # pthr_cond_t *
      DW_AT_data_member_location 0
```

Under the Hood: Help from the Compiler

Compiler Optimization and Runtime SystEms

Everything GDB knows about the language (Dwarf)

- the type system
- the calling conventions and local variables
- the address-to-line mapping

```
DW_TAG_pointer_type                 # 0x00000094 void *
  DW_AT_byte_size                   0x00000008


DW_TAG_base_type                    # 0x0000003f int
  DW_AT_name                        int
  DW_AT_byte_size                   0x00000004
  DW_AT_encoding                    DW_ATE_signed
```

Everything GDB knows about the language (Dwarf)

- the type system
- the calling conventions and local variables
- the address-to-line mapping

```
<pc>        [lno,col] NS BB ET PE EB IS= DI= uri: "filepath"
0x00400aa6  [  44, 0] NS uri: "prodconsum.c"
0x00400aae  [  46, 0] NS
0x00400abc  [  47, 0] NS
0x00400aca  [  48, 0] NS
0x00400ad1  [  50, 0] NS
0x00400ae2  [  51, 0] NS
0x00400af3  [  56, 0] NS
0x00400afd  [  57, 0] NS
...
```

1 GDB Under the Hood
- Help from the Compiler
- Help from the OS
- Help from the CPU
- Internal algorithms

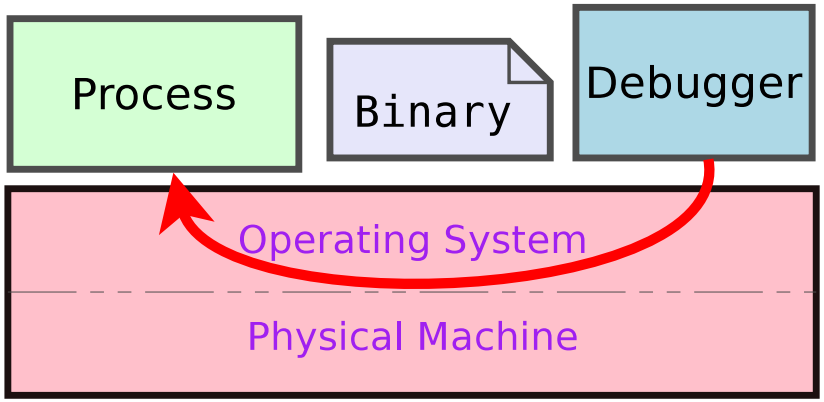
2 Programming GDB in Python
- Python Interface
- Short Examples & CLI Reminder

3 Your Turn
- Section breakpoint
- Return `true` breakpoint
- Register watchpoint
- Step into next call
- Faking function execution

Under the Hood: Help from the OS

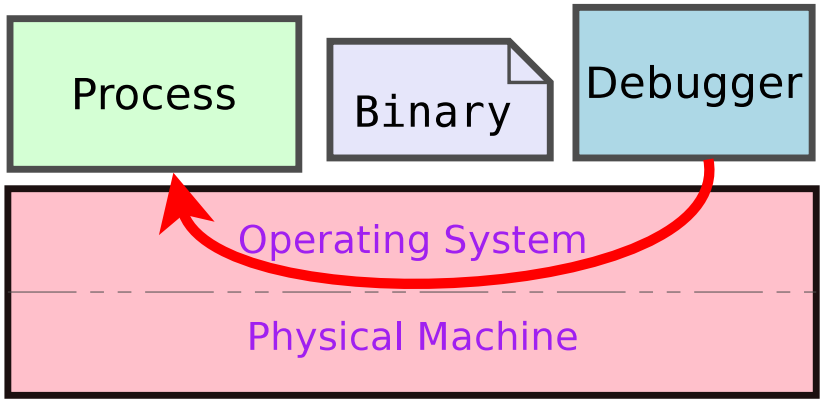
Compiler Optimization and Runtime SystEms

Everything GDB knows about the execution



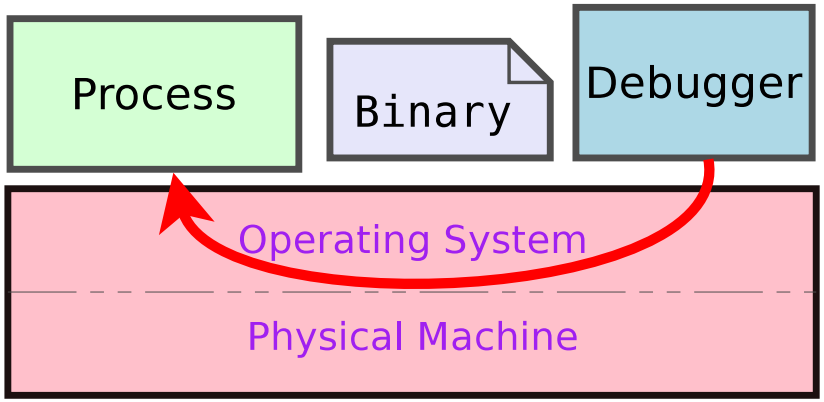
In Linux: the `ptrace` API
(link: kernel/ptrace.c)

Everything GDB knows about the execution



- read/write access to memory addresses
  - `PTRACE_PEEKTEXT, PTRACE_PEEKUSER, PTRACE_POKE...`
  - `copy_to_user()`, `copy_from_user()`

Everything GDB knows about the execution

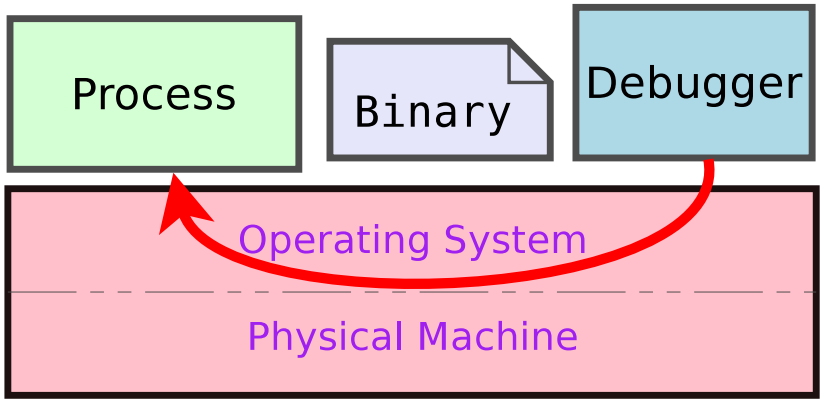


- read/write access to memory addresses
  - `PTRACE_PEEKTEXT, PTRACE_PEEKUSER, PTRACE_POKE...`
  - `copy_to_user()`, `copy_from_user()`
- read/write access to CPU registers
  - registers are saved in the scheduler's `struct task_struct`
  - `copy_regset_to`, `copy_regset_from_user`

Under the Hood: Help from the OS

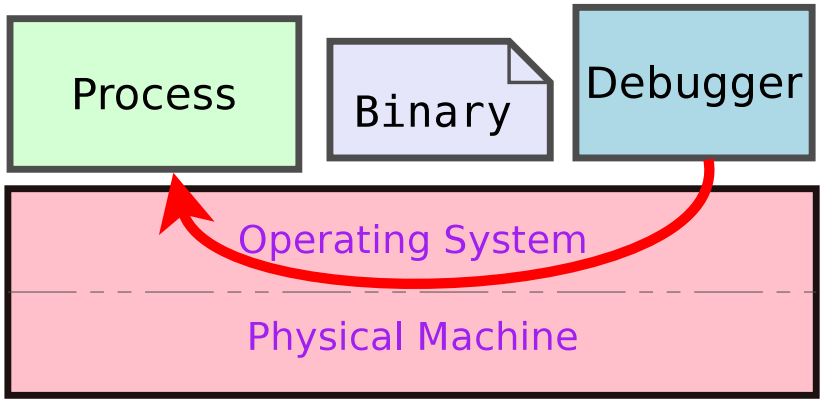
Compiler Optimization and Runtime SystEms

Everything GDB knows about the execution



- read/write access to memory addresses
- read/write access to CPU registers
- (re)start and stop the process
  - basic scheduler operations
  - ie: put it on the run-queue, send a signal-like interruption request, ...

Everything GDB knows about the execution



- read/write access to memory addresses
- read/write access to CPU registers
- (re)start and stop the process
- a few more notifications...
  - catching syscalls
  - handling signals
  - ...

Agenda

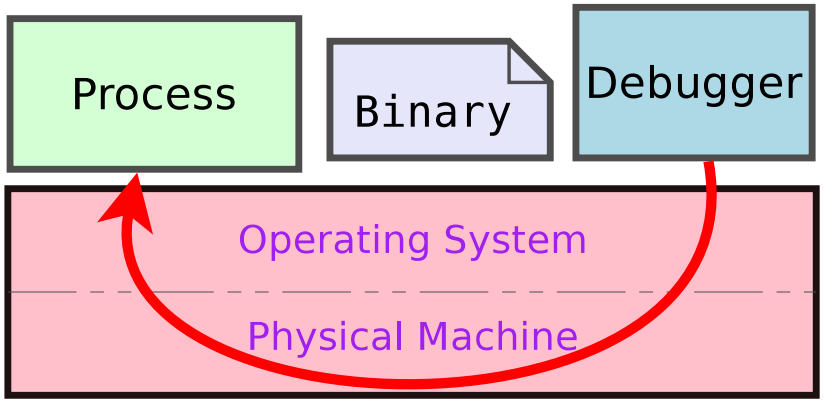
Compiler Optimization and Runtime SystEms

1. GDB Under the Hood
   - Help from the Compiler
   - Help from the OS
   - Help from the CPU
   - Internal algorithms
2. Programming GDB in Python
   - Python Interface
   - Short Examples & CLI Reminder
3. Your Turn
   - Section breakpoint
   - Return `true` breakpoint
   - Register watchpoint
   - Step into next call
   - Faking function execution

GDB Under the Hood: Help from the CPU

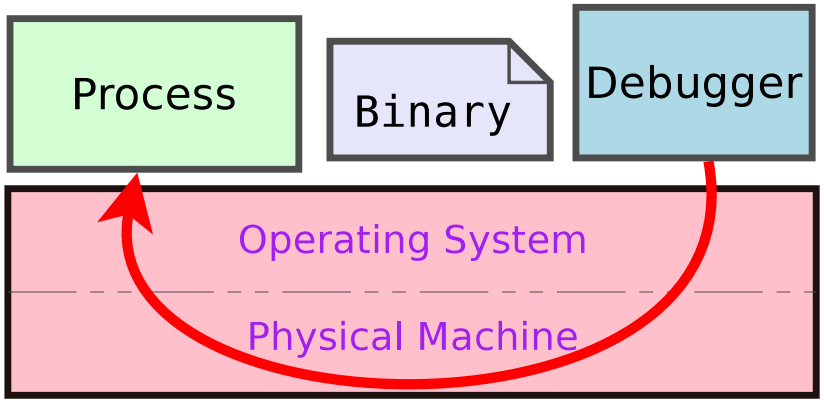
Compiler Optimization and Runtime SystEms

~~Everything GDB ...~~ Single-stepping and Watchpoints



Single-stepping execute one CPU instruction

~~Everything GDB ...~~ Single-stepping and Watchpoints



Single-stepping execute one CPU instruction

Watchpoint stop on memory-address read and write

- it's inefficient to implement in software
- most CPUs only have 4 WP registers

Agenda

Compiler Optimization and Runtime SystEms

1. GDB Under the Hood
   - Help from the Compiler
   - Help from the OS
   - Help from the CPU
   - Internal algorithms
2. Programming GDB in Python
   - Python Interface
   - Short Examples & CLI Reminder
3. Your Turn
   - Section breakpoint
   - Return `true` breakpoint
   - Register watchpoint
   - Step into next call
   - Faking function execution

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Callstack

Finish

Step

Next

Breakpoint

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Callstack

- newest frame based on CPU registers (IP, FP, BP)
- older frames based on calling conventions
  (=where registers are stored)

Finish

Step

Next

Breakpoint

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Callstack

- newest frame based on CPU registers (IP, FP, BP)
- older frames based on calling conventions
  (=where registers are stored)

Finish

- set temporary breakpoint on the upper-frame PC
  (+ exception handlers / setjumps)

Step

Next

Breakpoint

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Callstack

- newest frame based on CPU registers (IP, FP, BP)
- older frames based on calling conventions
  (=where registers are stored)

Finish

- set temporary breakpoint on the upper-frame PC
  (+ exception handlers / setjumps)

Step

- get current line lower-bound address in DWARF info
- single-step until out / in a new frame

Next

Breakpoint

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Callstack

- newest frame based on CPU registers (IP, FP, BP)
- older frames based on calling conventions
  (=where registers are stored)

Finish

- set temporary breakpoint on the upper-frame PC
  (+ exception handlers / setjumps)

Step

- get current line lower-bound address in DWARF info
- single-step until out / in a new frame

Next

- same as above, but `finish` in new frames

Breakpoint

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Callstack
- newest frame based on CPU registers (IP, FP, BP)
- older frames based on calling conventions (=where registers are stored)

Finish
- set temporary breakpoint on the upper-frame PC (+ exception handlers / setjumps)

Step
- get current line lower-bound address in DWARF info
- single-step until out / in a new frame

Next
- same as above, but `finish` in new frames

Breakpoint
- it's a bit more complicated ...

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Breakpoint

- original_insn = *&to_breakpoint
- *&to_breakpoint = <special instruction>
- continue && wait(signal)
  - SIGTRAP if ISA has a breakpoint insn (0xcc in x86)
  - SIGILL if illegal instruction

- if PC $\notin$ set(bpts): deliver(signal); done;
- otherwise: # breakpoint hit
  - cancel(signal)
  - **stop** if not(bpt.cond or bpt.py) ||
    bpt.cond() || bpt.py.stop()
  - *&to_breakpoint = original_insn
  - cpu(single_step)
  - *&to_breakpoint = <special instruction>
  - continue && wait(...)

Breakpoint

- `original_insn = *&to_breakpoint`
- `*&to_breakpoint = <special instruction>`
- `continue && wait(signal)`
  - `SIGTRAP` if ISA has a breakpoint insn (`0xcc` in x86)
  - `SIGILL` if illegal instruction
- `if PC ∉ set(bpts): deliver(signal); done;`
- `otherwise: # breakpoint hit`
  - `cancel(signal)`
  - **stop** `if not(bpt.cond or bpt.py) || bpt.cond() || bpt.py.stop()`
  - `*&to_breakpoint = original_insn`
  - `cpu(single_step)`
  - `*&to_breakpoint = <special instruction>`
  - `continue && wait(...)`

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Breakpoint

- `original_insn = *&to_breakpoint`
- `*&to_breakpoint = <special instruction>`
- `continue && wait(signal)`
  - `SIGTRAP` if ISA has a breakpoint insn (`0xcc` in x86)
  - `SIGILL` if illegal instruction

- `if PC ∉ set(bpts): deliver(signal); done;`
- `otherwise: # breakpoint hit`
  - `cancel(signal)`
  - **stop** `if not(bpt.cond or bpt.py) || bpt.cond() || bpt.py.stop()`
  - `*&to_breakpoint = original_insn`
  - `cpu(single_step)`
  - `*&to_breakpoint = <special instruction>`
  - `continue && wait(...)`

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Breakpoint

- `original_insn = *&to_breakpoint`
- `*&to_breakpoint = <special instruction>`
- `continue && wait(signal)`
  - `SIGTRAP` if ISA has a breakpoint insn (`0xcc` in x86)
  - `SIGILL` if illegal instruction
- `if PC ∉ set(bpts): deliver(signal); done;`
- `otherwise: # breakpoint hit`
  - `cancel(signal)`
  - **stop** `if not(bpt.cond or bpt.py) || bpt.cond() || bpt.py.stop()`
  - `*&to_breakpoint = original_insn`
  - `cpu(single_step)`
  - `*&to_breakpoint = <special instruction>`
  - `continue && wait(...)`

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Breakpoint

- `original_insn = *&to_breakpoint`
- `*&to_breakpoint = <special instruction>`
- `continue && wait(signal)`
  - `SIGTRAP` if ISA has a breakpoint insn (`0xcc` in x86)
  - `SIGILL` if illegal instruction
- `if PC ∉ set(bpts): deliver(signal); done;`
- `otherwise: # breakpoint hit`
  - `cancel(signal)`
  - **stop** `if not(bpt.cond or bpt.py) || bpt.cond() || bpt.py.stop()`
  - `*&to_breakpoint = original_insn`
  - `cpu(single_step)`
  - `*&to_breakpoint = <special instruction>`
  - `continue && wait(...)`

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Breakpoint

- `original_insn = *&to_breakpoint`
- `*&to_breakpoint = <special instruction>`
- `continue && wait(signal)`
  - `SIGTRAP` if ISA has a breakpoint insn (`0xcc` in x86)
  - `SIGILL` if illegal instruction
- `if PC ∉ set(bpts): deliver(signal); done;`
- `otherwise: # breakpoint hit`
  - `cancel(signal)`
  - **stop** `if not(bpt.cond or bpt.py) || bpt.cond() || bpt.py.stop()`
  - `*&to_breakpoint = original_insn`
  - `cpu(single_step)`
  - `*&to_breakpoint = <special instruction>`
  - `continue && wait(...)`

GDB Under the Hood: Internal algorithms

Compiler Optimization and Runtime SystEms

Breakpoint

- `original_insn = *&to_breakpoint`
- `*&to_breakpoint = <special instruction>`
- `continue && wait(signal)`
  - `SIGTRAP` if ISA has a breakpoint insn (`0xcc` in x86)
  - `SIGILL` if illegal instruction
- `if PC ∉ set(bpts): deliver(signal); done;`
- `otherwise: # breakpoint hit`
  - `cancel(signal)`
  - **stop** `if not(bpt.cond or bpt.py) || bpt.cond() || bpt.py.stop()`
  - `*&to_breakpoint = original_insn`
  - `cpu(single_step)`
  - `*&to_breakpoint = <special instruction>`
  - `continue && wait(...)`

Agenda

Compiler Optimization and Runtime SystEms

1. GDB Under the Hood
   - Help from the Compiler
   - Help from the OS
   - Help from the CPU
   - Internal algorithms
2. Programming GDB in Python
   - Python Interface
   - Short Examples & CLI Reminder
3. Your Turn
   - Section breakpoint
   - Return `true` breakpoint
   - Register watchpoint
   - Step into next call
   - Faking function execution

Scripting

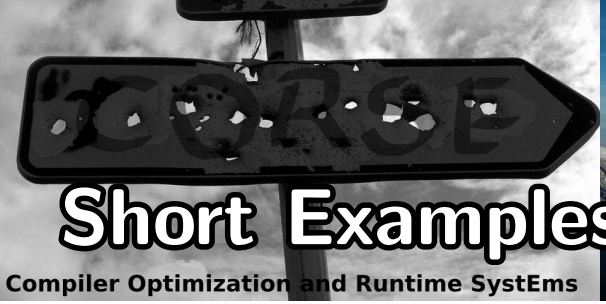
- action on breakpoints
- new commands
- value and type manipulation
- access the callstack and local variables/registers/...
- action on events (exec. stop/cont/exit, library loading, ...)
- ...
- for the rest: `gdb.execute("command", to_string=True)`

Extending

Scripting

Extending

- pretty-printers — improve variable printing based on its type
- frame decorators — custom display of the callstack
- frame unwinders — tell GDB how non-standard callstacks are structured
- more to come (eventually):
  - process abstractions
    - access to embedded systems, virtual machines, core files ...
  - thread management



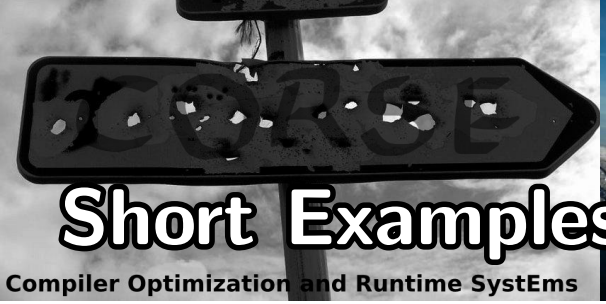
Short Examples & CLI Reminder

To program GDB, you must know its capabilities!

- print a variable

`print i`

```
(gdb) p context
$1 = {
  cond = 0x400e40 <__libc_csu_init>,
  mutex = 0x4009b0 <_start>,
  holder = -128,
  error = 32767
}
```



Short Examples & CLI Reminder

To program GDB, you must know its capabilities!

- print a variable — `print i`
- print its type — `ptype i`

```
(gdb) ptype context
type = volatile struct Context {
    pthread_cond_t *cond;
    thread_mutex_t *mutex;
    char holder;
    int error;
}
```

Short Examples & CLI Reminder

To program GDB, you must know its capabilities!

- print a variable — `print i`
- print its type — `ptype i`
- print it as another type — `print (unsigned int) i`

```
(gdb) print (unsigned int) context.holder
$3 = 4294967168
```

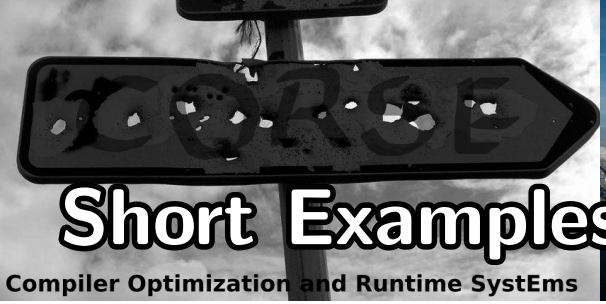
Short Examples & CLI Reminder

To program GDB, you must know its capabilities!

- print a variable — `print i`
- print its type — `ptype i`
- print it as another type — `print (unsigned int) i`
- print its address / target — `print &i; print *i`

```
(gdb) p &context.mutex
$5 = (pthread_mutex_t **) 0x7fffffffe588

(gdb) p *context.mutex
$6 = {
  __data = {
    __lock = -1991643855,
   ...
```

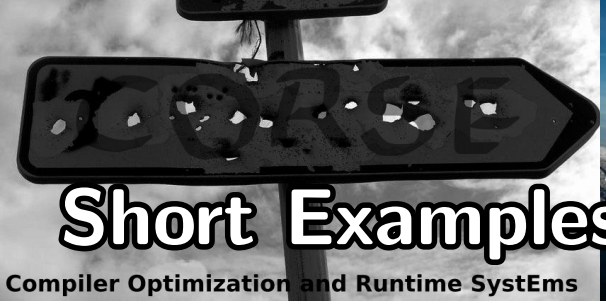


Short Examples & CLI Reminder

To program GDB, you must know its capabilities!

- print a variable — `print i`
- print its type — `ptype i`
- print it as another type — `print (unsigned int) i`
- print its address / target — `print &i; print *i`

Command interpreter for C!



Short Examples & CLI Reminder

To program GDB, you must know its capabilities!

- print a variable — `print i`
- print its type — `ptype i`
- print it as another type — `print (unsigned int) i`
- print its address / target — `print &i; print *i`

- evaluate C expression — `i + 1; i & 0x4`

Short Examples & CLI Reminder

To program GDB, you must know its capabilities!

- print a variable — `print i`
- print its type — `ptype i`
- print it as another type — `print (unsigned int) i`
- print its address / target — `print &i; print *i`

- evaluate C expression — `i + 1; i & 0x4`
- evaluate functions — `f(i)`

```
(gdb) p puts("creating first thread") # print or call
creating first thread
$10 = 23
```

Short Examples & CLI Reminder

To program GDB, you must know its capabilities!

```
# access to variables
<gdb.Value(int)>  i = gdb.parse_and_eval("i")
<gdb.Type(int)>   i.type
<gdb.Type(uint)>  uint = gdb.lookup_type("unsigned int")
<gdb.Value(uint)> i.cast(uint)

# frame access
gdb.newest_frame().read_var("i")
gdb.newest_frame().older().read_reg("pc")

# function call
<gdb.Value()> ret = gdb.parse_and_eval("puts")("text")
text
```

Short Examples & CLI Reminder

- disassemble a specified section of memory `disassemble main`

Short Examples & CLI Reminder

- disassemble a specified section of memory `disassemble main`

```
(gdb) disassemble main
Dump of assembler code for function main:
   0x00000400aa6 <+0>:     push   %rbp
   0x00000400aa7 <+1>:     mov    %rsp,%rbp
   0x00000400aaa <+4>:     sub    $0x30,%rsp
=> 0x00000400aae <+8>:     mov    $0x30,%edi
   0x00000400ab3 <+13>:    callq  0x400950 <malloc>
```

Short Examples & CLI Reminder

- disassemble a specified section of memory `disassemble main`

```
(gdb) disassemble main
Dump of assembler code for function main:
   0x00000400aa6 <+0>:     push   %rbp
   0x00000400aa7 <+1>:     mov    %rsp,%rbp
   0x00000400aaa <+4>:     sub    $0x30,%rsp
=> 0x00000400aae <+8>:     mov    $0x30,%edi
   0x00000400ab3 <+13>:    callq  0x400950 <malloc>
```

- in Python: `gdb.execute("disa fct", to_string=True)` or

```
frame = gdb.selected_frame()
frame.architecture().disassemble(frame.read_register("pc"))
# end_pc=..., count=...
[{'addr': 4595344, 'asm': 'sub    $0x28,%rsp', 'length': 4}]
```

Short Examples & CLI Reminder

- disassemble a specified section of memory `disassemble main`

Short Examples & CLI Reminder

- disassemble a specified section of memory `disassemble main`

- test condition on breakpoint `break <LOC> if f(i) == &j`

Short Examples & CLI Reminder

- disassemble a specified section of memory `disassemble main`

- test condition on breakpoint `break <LOC> if f(i) == &j`
  - internally, the breakpoint is hit all the time
  - but GDB only notifies the user if the condition is met

Short Examples & CLI Reminder

- disassemble a specified section of memory `disassemble main`

- test condition on breakpoint `break <LOC> if f(i) == &j`
  - internally, the breakpoint is hit all the time
  - but GDB only notifies the user if the condition is met

```
class MyBreakpoint(gdb.Breakpoint):
  def __init__(self): ...
  def stop(self): return do_I_want_to_stop()
```

Short Examples & CLI Reminder

Compiler Optimization and Runtime SystEms

Create a new breakpoint

CLI

```
break fct
command
  silent
  print i
  cont
end
```

Python

```
class MyBreakpoint(gdb.Breakpoint):
  def __init__(self):
    gdb.Breakpoint(self, "fct", internal=True)
    self.silent = True

  def stop(self):
    print(gdb.parse_and_eval("i"))
    return True or False
```

Short Examples & CLI Reminder

Executing code on function before / after a function call

```
import my_gdb
class my_gdb.FunctionBreakpoint(...):
  def __init__(self, fname): ...

  def prepare_before(self):
        return (stop here?,
                stop after?,
                data for after)

  # breakpoint on newest_frame.older().read_reg(pc)
  def prepare_after(self, data):
        return True or False
```

Short Examples & CLI Reminder

Create a new command

CLI

```
define cmd
  ...
  ...
end
```

Python

```
class MyCommand(gdb.Command):
  def __init__(self):
    gdb.Command(self, "cmd", gdb.COMMAND_NONE)

  def invoke (self, args, from_tty):
    ...
```

Short Examples & CLI Reminder

Executing code on events (not used today)

```
def say_hello(evt): print("hello")
gdb.events.stop.connect(say_hello) # then disconnect
gdb.events.cont.connect(say_hello)

gdb.events.exited
gdb.events.new_objfile # shared library loads, mainly
gdb.events.clear_objfiles

gdb.events.inferior_call_pre/post
gdb.events.memory_changed
gdb.events.register_changed

gdb.events.breakpoint_created/modified/deleted
```

Agenda

Compiler Optimization and Runtime SystEms

1. GDB Under the Hood
   - Help from the Compiler
   - Help from the OS
   - Help from the CPU
   - Internal algorithms
2. Programming GDB in Python
   - Python Interface
   - Short Examples & CLI Reminder
3. Your Turn
   - Section breakpoint
   - Return `true` breakpoint
   - Register watchpoint
   - Step into next call
   - Faking function execution

Your turn!

1. Section breakpoint
2. Break when returned `true`
3. Register watchpoint
4. Step-to-next-call
5. Faking function execution

`https://sourceware.org/gdb/current/onlinedocs/gdb/Python-API.html`

Your turn!

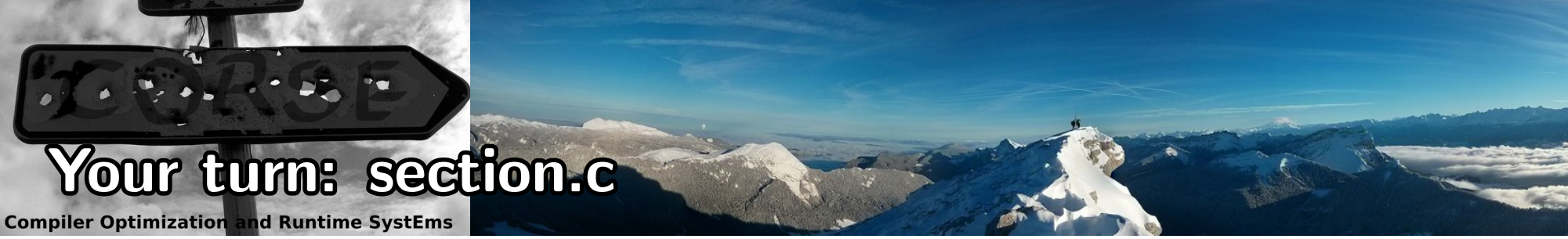
- `docker run -it`
  - `-v $HOME/jdd_debug:/home/jdd/host`
  - `-e GROUPID=$(id -g) -e USERID=$(id -u)`
  - `--cap-add sys_ptrace # or --priviledged`
  - `pouget/gdb-tuto`

- edit in `host@$HOME/jdd_debug` or `docker@/home/jdd/host`

- consider adding in your `$HOME/.gdbinit`
  - `source $HOME/jdd_debug/gdbinit`

Your turn!

- `docker run -it`
  - `-v $HOME/jdd_debug:/home/jdd/host`
  - `-e GROUPID=$(id -g) -e USERID=$(id -u)`
  - `--cap-add sys_ptrace # or --priviledged`
  - `pouget/gdb-tuto`
- `make all; make help`
- `make run_{section|return|watch|step|fake} DEMO={y|n}`
  - `DEMO=y` to run my code, `DEMO=n` for yours (default)



Your turn: section.c

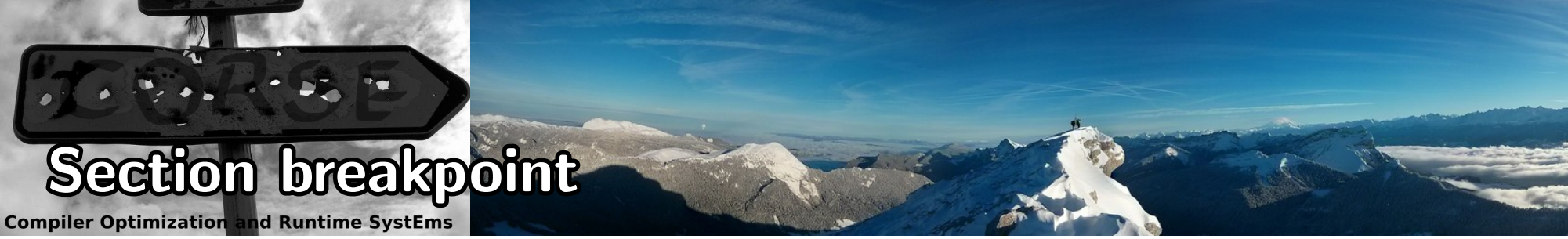
Compiler Optimization and Runtime SystEms

Your turn!

```
int main() {
  int i;

  srand(time(NULL));
  int bad = rand() % NB_ITER;

  for(i = 0; i < NB_ITER; i++) {
    if (i != bad) start_profiling();
    run(i); # calls bugs(i) if not profiling
    if (i != bad) stop_profiling();
  }
}
```



Section breakpoint

Compiler Optimization and Runtime SystEms

Context

- We want to profile the function `run()`.
  - profiling starts with function `start_profiling()`
  - and stops with function `stop_profiling()`.

Problem

- `run()` is sometimes called outside of the profiling region.

$\Rightarrow$ we want to stop the debugger there.

```
(gdb) break_section start_profiling stop_profiling run
Section bpt set on start_profiling/run/stop_profiling
(gdb) run
Section breakpoint hit outside of section
15          if (!is_profiling) bug(i);
```

Section breakpoint

Compiler Optimization and Runtime SystEms

Idea:

- breakpoint on `start_profiling()` that sets a flag,
- breakpoint on `stop_profiling()` that unsets a flag,
- breakpoint on `run()` that checks the flag

Better:

- `start()` / `stop()` breakpoints enable/disable the bpt on `run()`

Return `true` breakpoint

Compiler Optimization and Runtime SystEms

Context

- I want to stop the execution whenever function `run()` has returned `true`.

Problem (kind of :)

- Function `run()` has many return statements
- I don't want to breakpoint all of them.

```
(gdb) break_return run 1
(gdb) run
Stopped after finding 'run' return value = 1 in $rax.
#0  0x00000000004006f7 in main () at section.c:36
```

Return true breakpoint

Compiler Optimization and Runtime SystEms

```
(gdb) break_return <fct> <expected value>
```

Idea:

- `BreakReturn_cmd.invoke`
  - parse and cast the expected value:
    `gdb.parse_and_eval(<expected value>)`
  - Function breakpoint on target function:
    `FunctionReturnBreakpoint(<fct>, <expected value>)`
- `FunctionReturnBreakpoint.prepare_before()`
  - before the function call: nothing to do
- `FunctionReturnBreakpoint.prepare_after()`
  - after the call: read register `eax`
    `my_gdb.my_archi.return_value(<expected value>.type)`

Register watchpoint

Compiler Optimization and Runtime SystEms

Context

- Inside a function, we want to see all the accesses to a register.

Problem

- GDB only supports *memory* watchpoints

```
(gdb) reg_watch eax main void *
20 watchpoints added in function main
(gdb) cont
before: (void *) 0xfffffffffffffd256
   0x0000000004006a4 <+18>:        mov    %eax,%edi
after:  <unchanged>
(gdb) cont
before: (void *) 0xfffffffffffffd256
   0x0000000004006be <+44>:        mov    %ecx,%eax
```

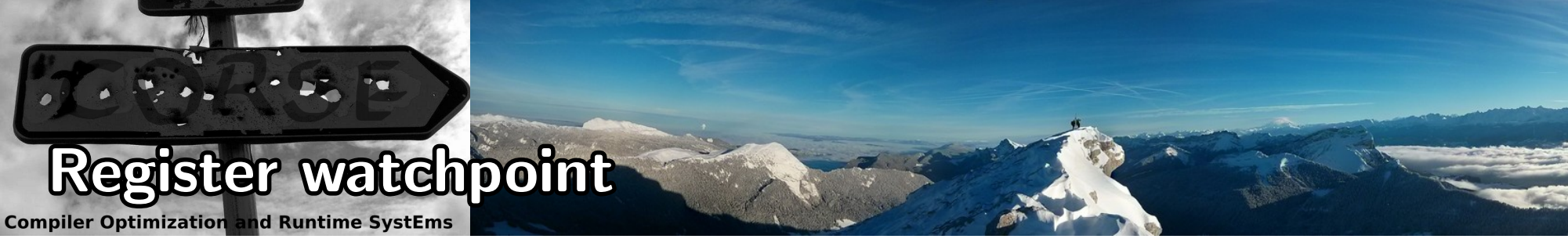
Register watchpoint

Compiler Optimization and Runtime SystEms

```
(gdb) reg_watch <reg name> <fct> [<fmt>]
```

Idea:

- ensure that target function exists
  `if not gdb.lookup_symbol(fct)[0]:...`
  - may through a `gdb.error` if there is no frame selected
- examine the function binary instructions
  - `gdb.execute("disassemble {fct}", to_string=True)`
- for all of them,
  - check if `<reg name>` appears
  - if yes, breakpoint it's address (`*addr`)
- ...



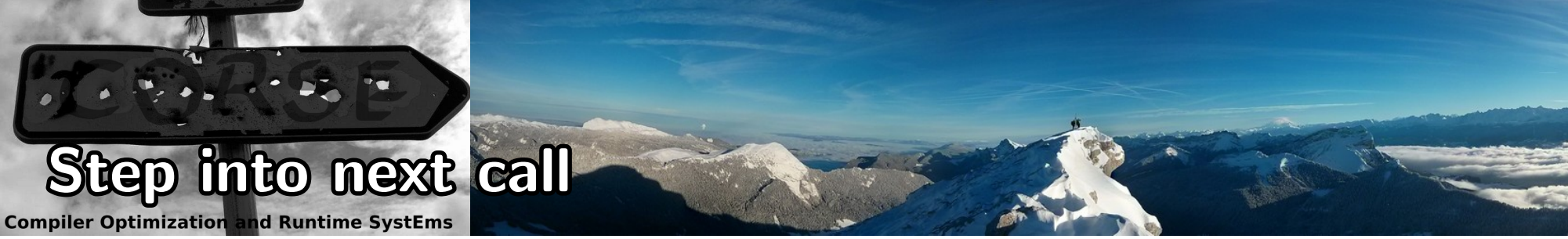
Register watchpoint

Compiler Optimization and Runtime SystEms

```
(gdb) reg_watch <reg name> <fct> [<fmt>]
```

Idea:

- on breakpoint hit:
  - read and print the current value of the register
    `gdb.parse_and_eval("({fmt}) ${regname}")`
  - print the line to be executed (from disassembly)
  - in `my_gdb.before_prompt`:
    - ★ execute instruction (`nexti`)
    - ★ re-read the register value
    - ★ print it if different
  - mandatory stop here
    (GDB cannot `nexti` from a `Breakpoint.stop` callback)



Context

- I want to step into the next function call, even if far away.
  - stop right before — `step-before-next-call`
  - stop right after — `step-into-next-call`

```
(gdb) step-before-next-call
step-before-next-call: next instruction is a call.
0x4006ed: callq  0x40062f <start_profiling>
(gdb) step-into-next-call
Stepped into function start_profiling
#0  start_profiling () at section.c:21
21          assert(!is_profiling);
#1  0x00000000004006f2 in main () at section.c:37
37            if (i != bad) start_profiling();
```

Step into next call

Compiler Optimization and Runtime SystEms

Idea:

- `step-before-next-call`:
  - run instruction by instruction
    `gdb.execute("stepi")`
  - until the current instruction contains a call
    `gdb.selected_frame().read_register("pc")`
    `arch = gdb.selected_frame().architecture()`
    `"call" in arch.disassemble(current_pc)[0]["asm"]`
- `step-into-next-call`:
  - run step by step: `gdb.execute("stepi")`
  - stop when the stack depth increases

```
def callstack_depth():
  depth = 1; frame = gdb.newest_frame()
  while frame: frame = frame.older(); depth += 1
  return depth
```

Faking function execution

Compiler Optimization and Runtime SystEms

Context

- I don't want function `run()` code to execute,
- Instead I want to control its side effects from the debugger.

```
(gdb) run
BUG BUG BUG (i=<random>)

(gdb) skip_function run; run
[nothing]

(gdb) fake_run_function # calls bug(i) if not i % 10
BUG BUG BUG (i=0)
BUG BUG BUG (i=10)
BUG BUG BUG (i=20)...
```

Faking function execution

Compiler Optimization and Runtime SystEms

Idea:

- `skip_function <fct>`:
  - Breakpoint on `<fct>`, then call `return`:

```
gdb.execute("return")
```

- `fake_run_function`:
  - as above, but run code before return:

```
i = int(gdb.newest_frame().read_var("i"))
```

```
if not i % 10:  gdb.execute("call bug({})".format(i))
```

Understanding, Scripting and Extending GDB

Kevin Pouget
Jean-François Méhaut, Fabrice Rastello

Université Grenoble Alpes / LIG, INRIA, CEA

11^{iemes} Journées Compilations, Aussois, France
9 septembre 2016