Manipulating time with GDB

How to use GDB to perform time travel debugging

By Guinevere Larsen

Help us improve

time manipulation with GDB

~~How to use GDB to perform time travel debugging~~

How you can help making GDB better at manipulating time

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Summary

- Introduction
- How does it work
- Where the bugs come from
- A plea to help us fix them!

What are you talking about?

```
(gdb) reverse-continue
Continuing.

No more reverse-execution history.
0x000000000040112a in main ()
```

Who are you, lady?

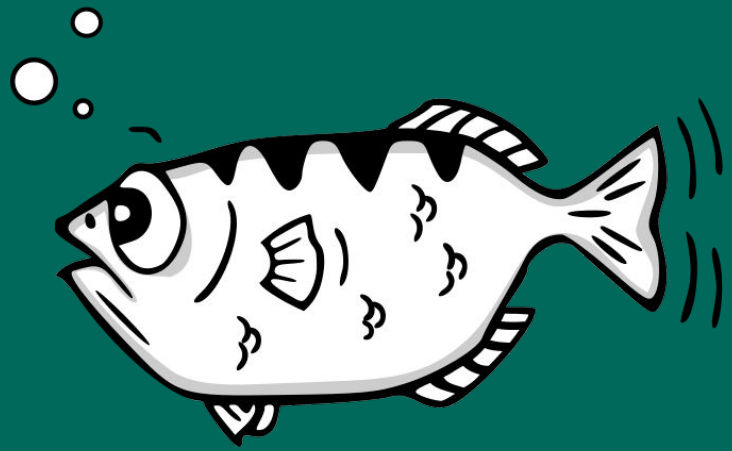
Nice to meet you, I'm Guinevere!

I am hired to work on GDB, and have been doing this for close to 3 years

I am the a maintainer of (one of) the relevant area of GDB

I also like helping new contributors out, and time travel debugging is full of easy bugs to start

And what is this GDB business?



A time wizard's best friend!

The GNU Debugger allows you to stop time for the inferior[1], or slowly execute it, and see how it ticks

Useful for C, C++, Ada, Fortran, and much more!

1. Inferior: GDB lingo for "program being debugged"

Time travel debugging

Also called reverse debugging but that's boring

Lets instructions be undone, meaning you can see where things went wrong

The talk related to rr explains the idea and why it is great

> If you didn't manage to catch it, just use what I teach today to see it later

How is that possible?

```
(gdb) help record
record, rec
Start recording.

List of record subcommands:

record btrace, record b -- Start branch trace recording.
record full -- Start full execution recording.
```

Example:

```
addl $0x1, -0x8(%rbp)
```

Address:
-0x8 (%rbp)
Value:
00 00 00 00
Length:
4 bytes

Register:
%eflags
Values:
[CF AF SF IF]

Register:
%rip
Values:
0x4011ef

GDB Recording

Pro:

- Comes in a single tool
- Fully reconstructs the state

Con:

- Slow
- Harder to support

GDB disassembles one instruction

Store all the information that is overwritten in a linked list

Tells the inferior to execute the instruction

Repeat or stop the execution

GDB recording Simple issues

Spaghetti code:
The main disassembly function is 3 thousand lines strong and almost unreadable

Auxiliary functions and structs could also be better documented.

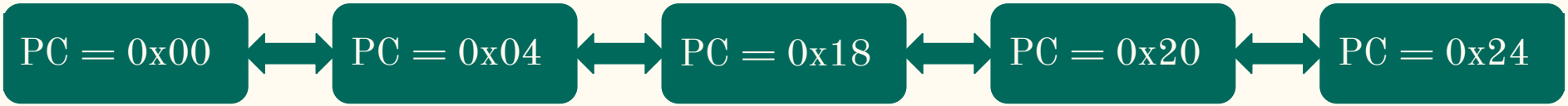
Record Details

Disassembly:

We need to teach GDB about every instruction it needs to support

Instructions reported missing

Longer Example



PC	PC	PC	PC	PC
0x400400	0x400404	0x400418	0x400420	0x400424
Size	Size	Size	Size	Size
4	8	8	4	4
Type	Type	Type	Type	Type
Arithmetic	Control Flow	Control Flow	Arithmetic	Arithmetic

GDB btrace

Pro:

- Comes in a single tool
- Fast

Con:

- Only restores the PC
- Only on some hardware

GDB tells the inferior to run

The CPU stores trace data in a specific region of memory[1]

Once the inferior stops, GDB queries the kernel for that area of memory

It then stores the PC, size and type of instruction for all recorded ones

1. The region is called the Branch Trace Store (BTS) area

GDB btrace issues

Easy access to bugzilla search

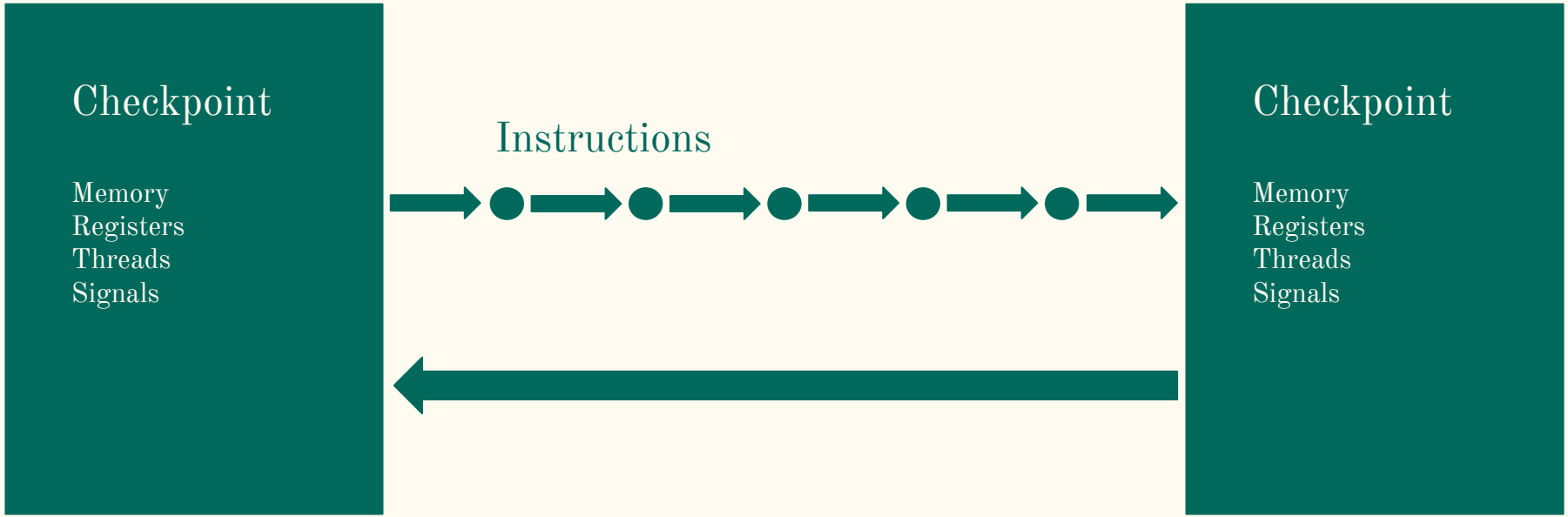
Record Details

Testsuite regressions

Assertion errors

Usability issues

Different long Example



RR

RR can record the execution of a program outside of a debugger

It then saves the execution log to your disk

Finally it starts a gdbserver[1] that is able to use this log to move back and forth

1. Gdbserver is a back-end of GDB, handling the inferior and the OS, but not user commands.

Record Details

udb

Proprietary tool that seems to work similarly.

Disclaimer: These are what I understood based on colleagues explanations, no first hand checking of code was done on either.

How do we use that?

```
(gdb) complete reverse-
reverse-continue
reverse-finish
reverse-next
reverse-nexti
reverse-search
reverse-step
reverse-stepi
```

GDB's front end

2 options:

1. Explicitly using a reverse command

```
reverse-next
```

2. Changing the execution direction:

```
set execution-direction reverse
next
```

GDB's command handling

- If the command started with reverse-, set the execution to reverse

- GDB attempts to reuse as much code as possible for similarly named commands
- Whenever we know something works differently, we explicitly handle it with an if statement.
  - If the command started with reverse-, set the execution back to forward

RR

Uses a smart approach:
Offload as much as possible to GDB

RR, in replay mode, is a gdbserver with a reverse executing target

Meaning GDB handles the logic of understanding commands, reading debug information, etc

All RR has to do is “just” make the hardware behave correctly backwards

Gdbserver is a back-end of GDB, handling the inferior and the OS, but not user commands.

What could possibly go wrong?

```
(gdb) reverse-until
Undefined command: "reverse-until".  Try "help".
(gdb) frame
#0  main () at t.c:24
24          setup (n);
(gdb) set exec-direction reverse
(gdb) step
main () at t.c:23
23          int p = 0;
```

Hide Search Description

Product: gdb **Component:** record **Status:** UNCONFIRMED, NEW, ASSIGNED, SUSPENDED, WAITING, REOPENED

30 bugs found.

ID ▼	Product	Comp ▲	Assignee	Status	Resolution	Summary	Changed
30455	gdb	record	unassigned@sourceware.org	NEW	---	Debuggee with sanitizer causes: Assertion `regnum < gdbarch_num_regs (arch ())' failed.	2023-05-18
30246	gdb	record	unassigned@sourceware.org	UNCO	---	gdb record full, br ... and rc. Sometime variable operate wrong. but rr works, based on ryzen 4800h cpu(zen architecture)	2023-07-30
30073	gdb	record	unassigned@sourceware.org	NEW	---	[intel Efficient-core] FAIL: gdb.btrace/exception.exp: flat (pattern 1)	2023-02-16
30025	gdb	record	unassigned@sourceware.org	NEW	---	Adding an inferior when already recording makes GDB not handle SIGTRAP correctly	2023-01-25

- So, so many things go wrong
- User experience improvements

Issues

Quick access to the bugzilla search

Commands

- Until
  - Works (badly) if setting direction manually
  - No reverse- version

Bug reporting it

Issues

- Record instruction-history
- Record function-call-history
  - only available for btrace

Stackoverflow question

UX

```
(gdb) reverse-next
24        setup (n);
(gdb) reverse-step

No more reverse-execution history.
main () at t.c:23
23        int p = 0;

(gdb)continue
Continuing.

No more reverse-execution history.
main () at t.c:25
25         p++;
```

This is a real debug session

That is not what I would expect the “step” command to do

And if we decide to continue forward, the warning makes it sound like we can’t go forward anymore

Harder issues

In case you want a big challenge

Record full needs a lot of help

- Multiple inferiors
  - The history is saved as a global variable.
  - There is no way to know to whom the history belongs
- Multithreading
  - Similarly, there is no way to know which thread owns a recorded instruction
- Unusably slow
  - Needs profiling, then improving on the hotspots

Where do I come in?

Approved-By: Guinevere Larsen <blarsen@redhat.com> (record-full)

I want to help out!

Things I like:

- Reverse debugging
- Getting people into open source
- Talking about stuff I like

Reach out if you anything piqued your interest!

More questions?

Thank you!

E-mail: blarsen@redhat.com
IRC: guinevere in libera-chat, #gdb
Linkedin: Guinevere Larsen