Improving Debugging For Optimized Rust Code

Master Thesis

Niklas Lundberg

Department of Computer Science, Electrical and Space Engineering
Luleå University of Technology

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Overview

1. Introduction
2. DWARF
3. Evaluation and Discussion
4. Conclusion

What is debugging

- Debugging is the process of finding an resolving errors, flaws, or faults.
- There are many different debugging techniques
- A debugger is a tool for debugging.
    - Used for controlling debugged target.
        - Start
        - Stop
        - Reset
        - Step
        - Breakpoints
    - Used to retrieve and visualize debug information.
        - Evaluate variable
        - Stack trace
        - And more

Unoptimized Vs Optimized Rust Code

- Rust is a programming language.
- Unoptimized Rust Code
  - Slow to run compared to other languages and optimized Rust code.
  - The machine code is very similar to the source code.
  - Values of variables are stored in memory on the stack.
  - Easy to debug.
- Optimized Rust Code
  - Fast compared to unoptimized code.
  - The machine code is very different form source code.
  - Values of variables have short life spans because they are stored in registers.
  - Hard to debug.

Problems

- Hard to debug because of short life spans of values.
- Existing debuggers like GDB often say that variables are optimized out.
- Existing debuggers also gives wrong result, this is especially true for LLDB.
- Both LLDB and GDB are hard to use for beginners.

Solution and motivation

- Research if better and more debug information can be generated.
    - Why? Because debuggers are restricted by the amount of debug information generated.
- Create a debugger for embedded systems that solve the mentioned problems.
    - Why? Because debuggers are very useful for embedded systems.
        - Small enough that the system can fully be understood.
        - They often have high requirements to meet.
        - Important that the optimized code work correctly.
    - Unoptimized code is to slow.
    - Written is Rust to use the benefits of Rust.

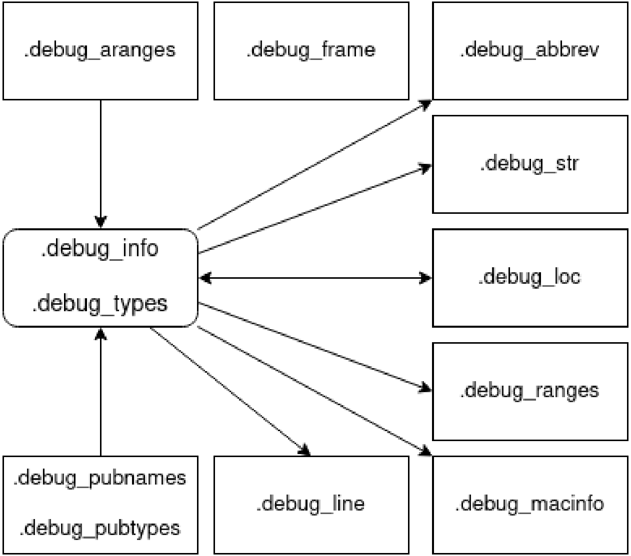
DWARF

DWARF

DWARF

- Debugging with Attributed Record Formats(DWARF)
- Debug information format
- Rust uses DWARF version 4
- DWARF is divided into 12 sections
- Executable and Linkable Format(ELF)

DWARF Sections



Debug Information Entry(DIE)

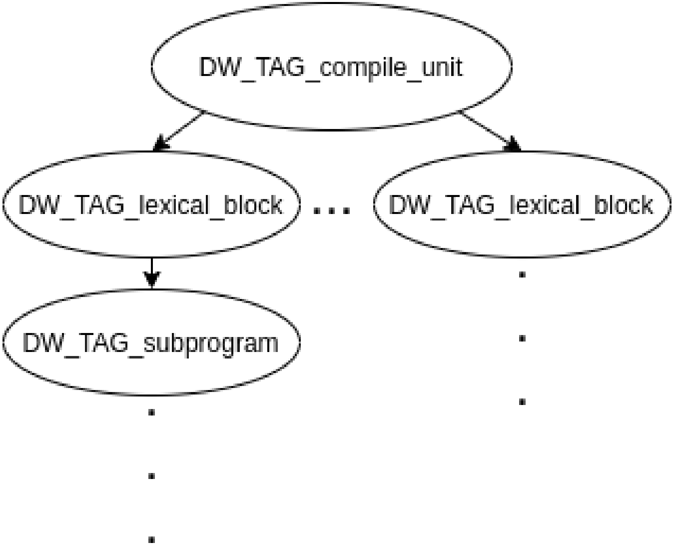
- Debug Information Entry(DIE).
- DWARF Attributes.
- DWARF DIE example from the .debug_info section.

```
<8><241>: Abbrev Number: 9 (DW_TAG_variable)
   <242>   DW_AT_location    : 2 byte block: 7d 3c     (DW_OP_breg13 (r13): 60)
   <245>   DW_AT_name        : (indirect string, offset: 0x40466): ptr
   <249>   DW_AT_decl_file   : 1
   <24a>   DW_AT_decl_line   : 591
   <24c>   DW_AT_type        : <0x1069>
```

Compilation unit

- Computer program is divided into compilation units.
- Each compilation unit contains a DIE tree.

Compilation unit



Evaluating a variable

- Find the current compilation unit.
- Find the current subprogram die.
- Find the searched variable die.
- Two parts to evaluating a variable:
    - Finding the location of the variable
    - Parsing the value into the correct type

Evaluating the location of a variable

```
<2><4321>: Abbrev Number: 16 (DW_TAG_subprogram)
   <4322>   DW_AT_low_pc       : 0x8000fca
   <4326>   DW_AT_high_pc      : 0x2c
   <432a>   DW_AT_frame_base   : 1 byte block: 57       (DW_OP_reg7 (r7))
   <432c>   DW_AT_linkage_name: (indirect string, offset: 0x473b8): _ZN24nucleo_r
   <4330>   DW_AT_name         : (indirect string, offset: 0x64a52): my_function
   <4334>   DW_AT_decl_file    : 1
   <4335>   DW_AT_decl_line    : 194
   <4336>   DW_AT_type         : <0x6233>
<3><433a>: Abbrev Number: 17 (DW_TAG_formal_parameter)
   <433b>   DW_AT_location     : 2 byte block: 91 7e    (DW_OP_fbreg: -2)
   <433e>   DW_AT_name         : (indirect string, offset: 0x11d94): val
   <4342>   DW_AT_decl_file    : 1
   <4343>   DW_AT_decl_line    : 194
   <4344>   DW_AT_type         : <0x6233>
```

Parsing the type of a variable

```
<1><6233>: Abbrev Number: 34 (DW_TAG_base_type)
   <6234>   DW_AT_name        : (indirect string, offset: 0x2a125): i16
   <6238>   DW_AT_encoding    : 5       (signed)
   <6239>   DW_AT_byte_size   : 2
```

Virtually Unwinding Call Stack

- Stack of subroutine activation's.
- A subroutine activation consists of:
  - Code location were the subroutine stopped
  - Preserved register values
  - Canonical Frame Address (CFA)
- The needed information is in section .debug_frame

Virtually Unwinding Subroutine Activation's

1. Find the Common Information Entry (CIE)
2. Find the Frame Description Entry (FDE)
3. Unwind CFA and register values.
4. Repeat for all activation's.

```
LOC CFA R0 R1 ... RN
L0
L1
...
LN
```

Comparing Evaluation Of Rust Enums

Rust Source Code

```
let mut test_enum3 = TestEnum::Struct(TestStruct { flag: true, num: 123 });
```

ERD

```
test_enum3 = TestEnum { < OptimizedOut >}
```

GDB Version 11.0.90

```
(gdb) p test_enum3
$ 1 = nucleo_rtic_blinking_led::TestEnum::ITest(<optimized out>)
```

Comparing Evaluation Of Rust Enums

Rust Source Code

```
let mut test_enum3 = TestEnum::Struct(TestStruct { flag: true, num: 123 });
```

LLDB Version 13.0.0

```
(nucleo_rtic_blinking_led::TestEnum) test_enum3 = {
  ITest = (0 = 0)
  UTest = (0 = 0)
  Struct = {
    0 = (flag = false, num = 0)
  }

  Non = {}
}
```

Comparing Evaluation Of Rust Enums

Rust Source Code

let mut test_struct = TestStruct { flag: true, num: 123 };

ERD

test_struct = TestStruct { num::123, flag::< OptimizedOut >}

GDB Version 11.0.90

(gdb) p test_struct
$ 1 = nucleo_rtic_blinking_led::TestStruct {flag: <sybthetic pointer>, num: 123}

LLDB Version 13.0.0

(nucleo_rtic_blinking_led::TestEnum) test_struct = (flag = false, num = 123)

Comparing Evaluation Of Rust Enums

Rust Source Code

```
let mut test_u16: u16 = 500;
```

ERD

test_u16 = <OutOfRange>

GDB Version 11.0.90

```
(gdb) p test_u16
$ 1 = <optimized out>
```

LLDB Version 13.0.0

```
(unsigned short) test_u16 = <variable not available>
```

Conclusion

- Able to do some small improvements.
- ERD lacks some of the features that LLDB and GDB has.
- Contributed with a Debugging library for Rust.
- ERD is written in Rust.
- Still a lot that needs to be done.

Future Work

- Display last known value.
- Evaluating expressions in ERD.
- Display more information about the target system.

Demo

Thank you for listening