

# Improving Debugging For Optimized Rust Code

Master Thesis

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# Overview

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

# What is debugging

- The process of finding and resolving errors, flaws, or faults.
- Debugging techniques:
  - Back tracking
  - Testing
  - Control flow analysis
  - And many more
- Debugging is very useful for embedded systems.

# What is a Debugger

- A Debugger is a debugging tool.
- Control over the debugged computer program.
- Some of the most common control features:
  - Continue/Start/Run
  - Stop/Halt
  - Restart
  - Step
  - Set and remove breakpoint.

# What is a Debugger

- Visualization of the debugged target state.
- Some of the most common visualization features:
  - Evaluate variables
  - Stack trace, unwinding call stack
  - Show machine and Assembly code
  - Show relevant source code.

# Unoptimized Vs Optimized code

- Unoptimized:
  - All variables stored in memory.
  - Very similar to source code.
  - Slow to execute.
  - Easy to debug.
- Optimized:
  - Faster to execute.
  - Some Variables temporarily stored in registry.
  - Some functions are inlined.
  - Difficult to debug.

# Motivation

- Unoptimized Rust code is too slow.
- Debugging embedded systems.
- GDB and LLDB do not work very well.
- Write a debugger in Rust.

# DWARF

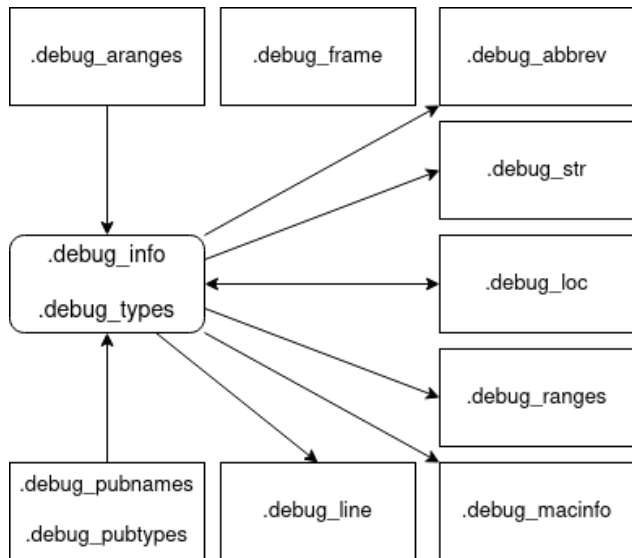






- Debugging with Attributed Record Formats(DWARF)
- Debug information format
- Rust uses DWARF version 4
- DWARF is divided into 12 sections
- Executable and Linkable Format(ELF)

# DWARF Sections



# Debug Information Entry(DIE)

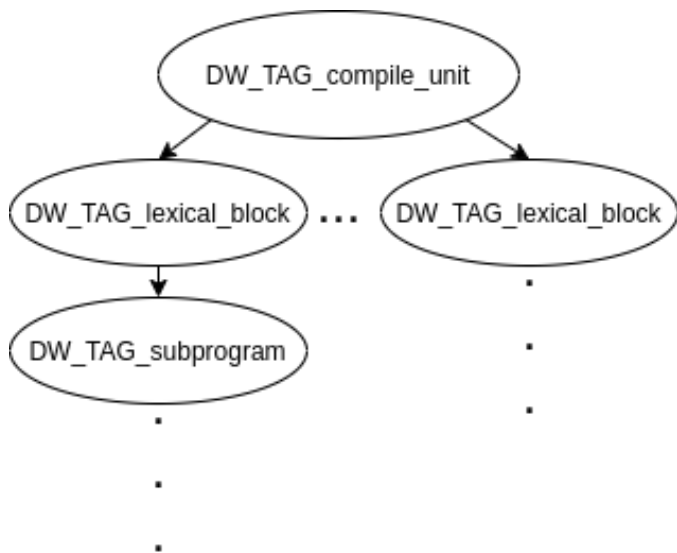
- Debug Information Entry(DIE).
- DWARF Attributes.
- DWARF DIE example from the .debug\_info section.

```
<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

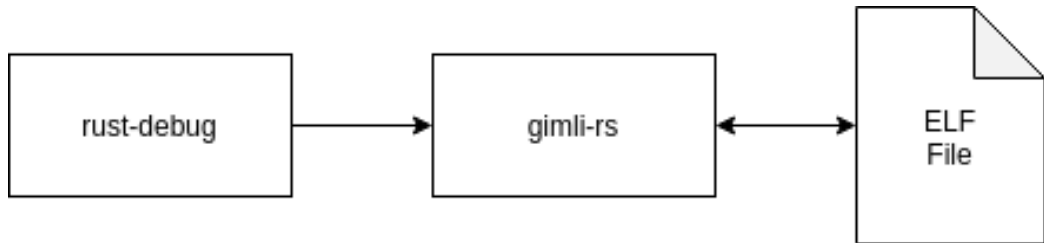
- Stack of subroutine activation's.
- A subroutine activation consists of:
  - Code location where the subroutine stopped
  - Preserved register values
  - Canonical Frame Address (CFA)
- The needed information is in section `.debug_frame`

# 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					

# Debugging library rust-debug

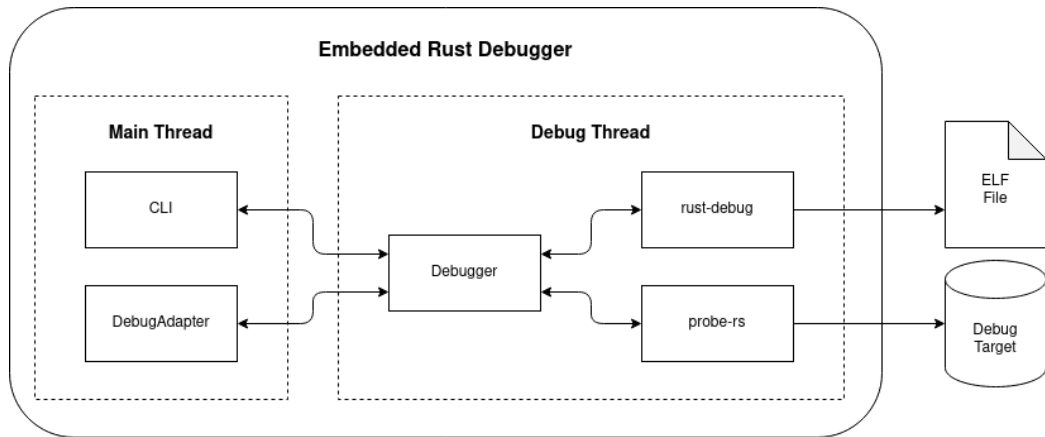


# Debugging library rust-debug

## Features

- Virtually Unwinding Stack and Stack trace
- Evaluating Variables
- Finding breakpoint location
- Retrieving source location information from a DIE
- And more

# Embedded Rust Debugger(ERD)



# 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