

Improving Debugging For Optimized Rust Code

Master Thesis

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What is debugging?

- Debugging is the process of finding and 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 values of variables
 - 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 from source code.
 - Values of variables have short life spans because they are stored in registers.
 - Hard to debug.

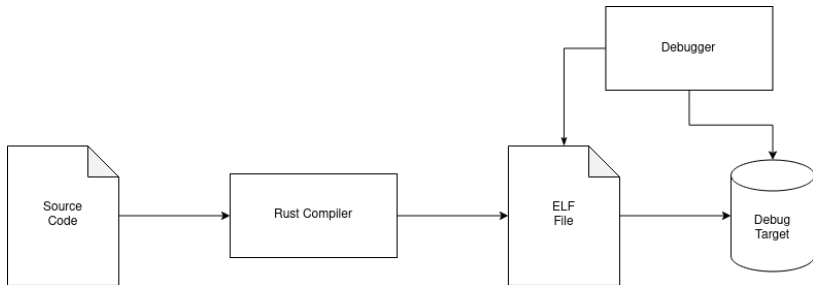
Problems

- 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.
 - They often have high requirements to meet.
 - Important that the optimized code work correctly.
 - Small enough that the system can fully be understood.

How dose debuggers work?



DWARF

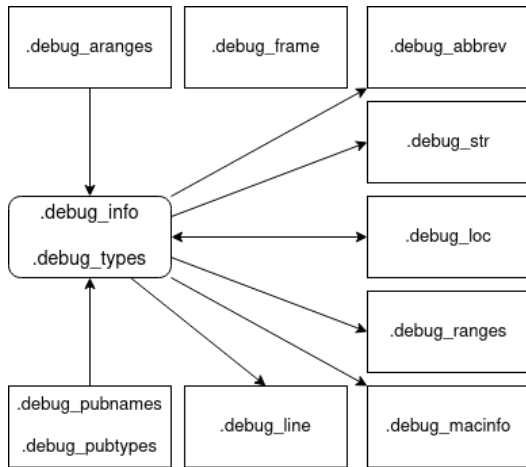




How to get the debug information?

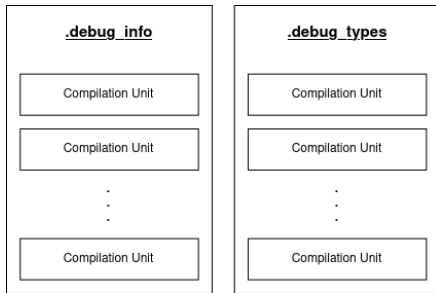
- DWARF is used to understand how the source and machine code relates to each other.
- ELF contains the Debugging with Attributed Record Formats(DWARF).
- Rust uses DWARF version 4.
- Dwarf is divided into 12 sections.

DWARF Sections



Compilation unit

1. Sections `.debug_info` and `.debug_types` contain a number of compilation units.
2. A compilation unit can be a program or a library.
3. Each compilation unit contains all the related debug information for that unit.
4. Each compilation unit contains a tree of DIEs.



Debug Information Entry(DIE)

- Debug Information Entry(DIE).
 - All DIEs have a DWARF TAG.
 - DIEs also contain a number of DWARF attributesa.
- 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>
```

An example on how to use DWARF

- How can DWARF be used to evaluate the value of a variable?
 - Two things are needed from DWARF.
 - Location of the value in the debug target.
 - The type of the variable.

Evaluating a variable

- Read the current code location from the debug target.
- Find the current compilation unit using the current code location.
- Find the current subprogram DIE using the current code location.
- Find the searched variable DIE in the sub tree of the subprogram DIE.

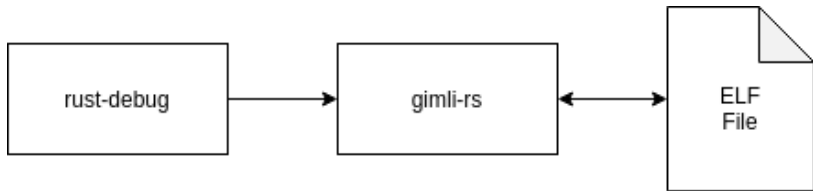
Evaluating the location of a variable

```
<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
```


Debugging library rust-debug

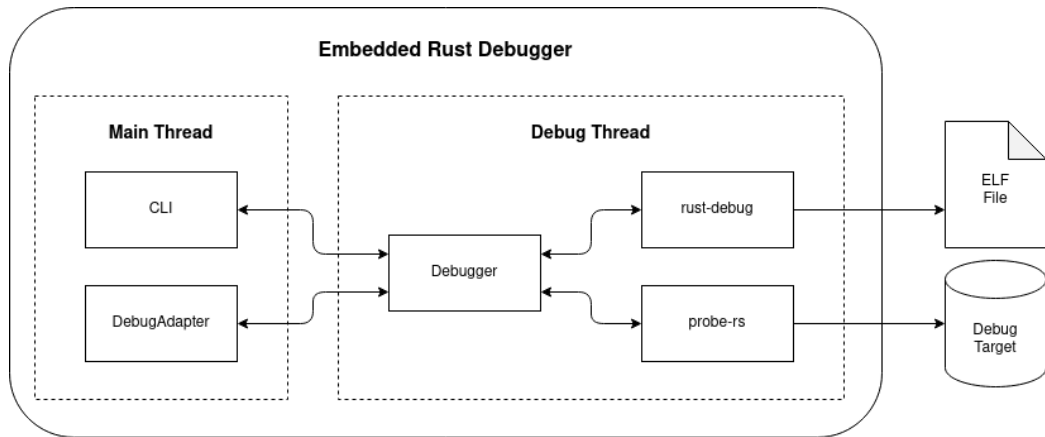


Debugging library rust-debug

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)



Result

- Evaluated the result by comparing ERD to GDB and LLDB.
- Compiled an example blink program with different optimization.
- The blink program has an inline assembly breakpoint set.
- To ensure that the program stops at the same location each time.
- Added some different types of variables to test the debugger.

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

- Was not able to generate better or more debug information.
- 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.
- Improved somewhat on the user experience.
- Still a lot that needs to be done.

Future Work

- Display last known value.
- Evaluating expressions.
- Improving user experience.

Questions?