



开源基础设施的下一个十年

The Next Decade of Open Infrastructure

Revisiting GraalVM-based unified runtime for eBPF & WebAssembly

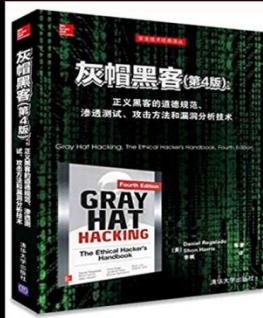


李枫 Koo

独立开发者(Indie developer)

Who Am I

- The main translator of the book «Gray Hat Hacking The Ethical Hacker's Handbook, Fourth Edition» (ISBN: 9787302428671) & «Linux Hardening in Hostile Networks, First Edition» (ISBN: 9787115544384)



- Pure software development for ~15 years
- Actively participate in various activities of the open source community
- <https://github.com/XianBeiTuoBaFeng2015/MySlides/tree/master/Conf>
- <https://github.com/XianBeiTuoBaFeng2015/MySlides/tree/master/LTS>
- Recently, focus on infrastructure of Cloud/Edge Computing, AI, Virtualization, Program Runtimes, Network, 5G, RISC-V, EDA...

Agenda

I. Background

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-

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- Recent changes

II. eBPF on GraalVM

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III. Wasm on GraalVM

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- Sulong-based implementation

IV. GaaS for Cloud Native

- Containers vs WASI on K8s

- Serverless with GraalVM

- DSLs

- .Net on GraalVM

- Go on GraalVM



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I. Background

1) Tech Stack

Please may refer to corresponding part in my previous talks as below for related content:

- "GraalVM-based unified runtime for eBPF & Wasm" at GOTC 2021 (Shenzhen).
- "AOT compilation based Wasm compiler and runtime for Serverless Edge computing" at OpenInfra Days China 2021 (Beijing).





2) Review (previous talk on this topic)

- "GraalVM-based unified runtime for eBPF & Wasm" at GOTC 2021 (Shenzhen).

Testbed

- **X64 Laptop**

A Dell Laptop with Fedora 34 + Kernel 5.13.4 + 14GB Memory (6GB DDR4 + 8GB Swap).

Dev Env

```
[mydev@myfedora /]$ uname -a
Linux myfedora 5.13.4-200.fc34.x86_64 #1 SMP Tue Jul 20 20:27:29 UTC 2021 x86_64 x86_64 x86_64 GNU/Linux
[mydev@myfedora /]$
[mydev@myfedora /]$ java --version
openjdk 11.0.12 2021-07-20
OpenJDK Runtime Environment GraalVM CE 21.2.0 (build 11.0.12+6-jvmci-21.2-b08)
OpenJDK 64-Bit Server VM GraalVM CE 21.2.0 (build 11.0.12+6-jvmci-21.2-b08, mixed mode, sharing)
[mydev@myfedora /]$
[mydev@myfedora /]$ gcc -v
Using built-in specs.
COLLECT_GCC=gcc
COLLECT_LTO_WRAPPER=/usr/libexec/gcc/x86_64-redhat-linux/11/lto-wrapper
OFFLOAD_TARGET_NAMES=nvptx-none
OFFLOAD_TARGET_DEFAULT=1
Target: x86_64-redhat-linux
Configured with: ../configure --enable-bootstrap --enable-languages=c,c++,fortran,objc,obj-c++,ada,go,d,lto --prefix=/usr --mandir=/usr/share/man --infodir=/usr/share/info --with-bugurl=http://bugzilla.redhat.com/bugzilla --enable-shared --enable-threadsposix --enable-checking=release --enable-multilib --with-system-zlib --enable-cxa_atexit --disable-libunwind-exceptions --enable-gnu-unique-object --enable-linker-build-id --with-gcc-major-version-only --with-linker-hash-style=gnu --enable-plugin --enable-initfini-array --with-isle=/builddir/build/BUILD/gcc-11.1.1-20210531/obj-x86_64-redhat-linux/isl-install --enable-offload-targets=nvptx-none --without-cuda-driver --enable-gnu-indirect-function --enable-cet --with-tune=generic --with-arch_32=i686 --build=x86_64-redhat-linux
Thread model: posix
Supported LTO compression algorithms: zlib zstd
gcc version 11.1.1 20210531 (Red Hat 11.1.1-3) (GCC)
[mydev@myfedora /]$
[mydev@myfedora /]$ clang -v
clang version 12.0.0 (Fedora 12.0.0-2.fc34)
Target: x86_64-unknown-linux-gnu
Thread model: posix
InstalledDir: /bin
Found candidate GCC installation: /bin/../lib/gcc/x86_64-redhat-linux/11
Found candidate GCC installation: /usr/lib/gcc/x86_64-redhat-linux/11
Selected GCC installation: /usr/lib/gcc/x86_64-redhat-linux/11
Candidate multilib: .@m64
Candidate multilib: 32;@m32
Selected multilib: .@m64
[mydev@myfedora /]$
[mydev@myfedora /]$ mvn -v
Apache Maven 3.6.3 (Red Hat 3.6.3-8)
Maven home: /usr/share/maven
Java version: 11.0.12, vendor: GraalVM Community, runtime: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java11-21.2.0
Default locale: en_US, platform encoding: UTF-8
OS name: "linux", version: "5.13.4-200.fc34.x86_64", arch: "amd64", family: "unix"
[mydev@myfedora /]$
[mydev@myfedora /]$ rust -V
-bash: rust: command not found
[mydev@myfedora /]$ rustc -V
rustc 1.53.0 (Fedora 1.53.0-1.fc34)
[mydev@myfedora /]$
[mydev@myfedora /]$ go version
go version go1.16.5 linux/amd64
[mydev@myfedora /]$
```

uBPF on GraalVM

On GraalVM CE Java11-21.2.0:

- Successfully ported project **BPF-Graal-Truffle**(<https://github.com/mattmurante/bpf-graal-truffle> except for AOT part and some test cases.
- Successfully built **uBPF**(<https://github.com/iovisor/ubpf>) to LLVM bitcode and run on GraalVM.



WASM on GraalVM

On GraalVM CE Java11-21.2.0:

- Successfully run some basic tests with the official solution **GraalWasm**(<https://github.com/oracle/graal/tree/master/wasm>),
but failed with the Polyglot case...



Issues

On GraalVM CE Java11-21.2.0:

- Most of the uBPF implementations do not support ARM.
 - The GraalVM LLVM toolchain does not work as expected for some cases.
 - ...
-



3) Recent changes

RPi4 Testbed (new)

- Fedora 34 + Kernel 5.14.10 + 16GB Memory (8GB LPDDR4 + 8GB Swap).
Dev Env:

```
[mydev@fedora /]$ uname -a
Linux fedora 5.14.10-200.fc34.aarch64 #1 SMP Thu Oct 7 20:33:59 UTC 2021 aarch64 aarch64 aarch64 GNU/Linux
[mydev@fedora /]$
[mydev@fedora /]$ gcc -v
Using built-in specs.
COLLECT_GCC=/usr/bin/gcc
COLLECT_LTO_WRAPPER=/usr/libexec/gcc/aarch64-redhat-linux/11/lto-wrapper
Target: aarch64-redhat-linux
Configured with: ../configure --enable-bootstrap --enable-languages=c,c++,fortran,objc,obj-c++,ada,go,lto --prefix=/usr --mandir=/usr/share/man --infodir=/usr/share/info --with-bugurl=http://bugzilla.redhat.com/bugzilla --enable-shared --enable-threads=posix --enable-checking=release --enable-multilib --with-system-zlib --enable-cxa_atexit --disable-libunwind-exceptions --enable-gnu-unique-object --enable-linker-build-id --with-gcc-major-version-only --with-linker-hash-style=gnu --enable-plugin --enable-initfini-array --with-isl=/builddir/build/BUILD/gcc-11.2.1-20210728/obj-aarch64-redhat-linux/isl-install --enable-gnu-indirect-function --build=aarch64-redhat-linux
Thread model: posix
Supported LTO compression algorithms: zlib zstd
gcc version 11.2.1 20210728 (Red Hat 11.2.1-1) (GCC)
[mydev@fedora /]$
[mydev@fedora /]$ clang -v
clang version 12.0.1 (Fedora 12.0.1-1.fc34)
Target: aarch64-unknown-linux-gnu
Thread model: posix
InstalledDir: /usr/bin
Found candidate GCC installation: /usr/bin/../lib/gcc/aarch64-redhat-linux/11
Found candidate GCC installation: /usr/lib/gcc/aarch64-redhat-linux/11
Selected GCC installation: /usr/lib/gcc/aarch64-redhat-linux/11
Candidate multilib: .:@m64
Selected multilib: .:@m64
[mydev@fedora /]$ 
[mydev@fedora /]$ rustc -V
rustc 1.55.0 (c8dfcfe04 2021-09-06)
[mydev@fedora /]$
[mydev@fedora /]$ cargo -V
cargo 1.55.0 (32da73ab1 2021-08-23)
[mydev@fedora /]$
[mydev@fedora /]$ rustup -V
rustup 1.24.3 (ce5817a94 2021-05-31)
info: This is the version for the rustup toolchain manager, not the rustc compiler.
info: The currently active `rustc` version is `rustc 1.55.0 (c8dfcfe04 2021-09-06)`
[mydev@fedora /]$
[mydev@fedora /]$ ll ~/.rustup/toolchains
total 0
drwxr-xr-x. 1 mydev mydev 64 Oct 12 13:02 ./
drwxr-xr-x. 1 mydev mydev 96 Oct 12 13:02 ../
drwxr-xr-x. 1 mydev mydev 42 Oct 12 13:02 stable-aarch64-unknown-linux-gnu/
[mydev@fedora /]$ 

[mydev@fedora /]$ java --version
openjdk 17 2021-09-14
OpenJDK Runtime Environment GraalVM CE 21.3.0-dev (build 17+35-jvmci-21.3-b04)
OpenJDK 64-Bit Server VM GraalVM CE 21.3.0-dev (build 17+35-jvmci-21.3-b04, mixed mode, sharing)
[mydev@fedora /]$
[mydev@fedora /]$ gu list
-----
```

ComponentId	Version	Component name	Stability	Origin
graalvm	21.3.0-dev	GraalVM Core	Supported	
espresso	21.3.0-dev	Java on Truffle	Experimental	
js	21.3.0-dev	Graal.js	Experimental	
llvm-toolchain	21.3.0-dev	LLVM.org toolchain	Experimental	
native-image	21.3.0-dev	Native Image	Experimental	
wasm	21.3.0-dev	GraalWasm	Experimental	



X64 Laptop Testbed

- A Dell Laptop with Fedora 34 + Kernel 5.14.10 + 14GB Memory (6GB DDR4 + 8GB Swap).

Dev Env:

```
[mydev@myfedora /]$ uname -a
Linux myfedora 5.14.10-200.fc34.x86_64 #1 SMP Thu Oct 7 20:49:53 UTC 2021 x86_64 x86_64 x86_64 GNU/Linux
[mydev@myfedora /]$
[mydev@myfedora /]$ gcc -v
GraalVM wrapper script for clang
GraalVM version: Development Build
running: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/lib/llvm/bin/clang -v
clang version 12.0.1 (GraalVM.org llvmlorg-12.0.1-3-g6e0a5672bc-bgf11ed69a5a 6e0a5672bc058d882dce3d56f90b72b64a6870d7)
Target: x86_64-unknown-linux-gnu
Thread model: posix
InstalledDir: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/lib/llvm/bin
Found candidate GCC installation: /usr/lib/gcc/x86_64-redhat-linux/11
Selected GCC installation: /usr/lib/gcc/x86_64-redhat-linux/11
Candidate multilib: .;@m64
Candidate multilib: 32;@m32
Selected multilib: .;@m64
[mydev@myfedora /]$
[mydev@myfedora /]$ clang -v
GraalVM wrapper script for clang
GraalVM version: Development Build
running: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/lib/llvm/bin/clang -v
clang version 12.0.1 (GraalVM.org llvmlorg-12.0.1-3-g6e0a5672bc-bgf11ed69a5a 6e0a5672bc058d882dce3d56f90b72b64a6870d7)
Target: x86_64-unknown-linux-gnu
Thread model: posix
InstalledDir: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/lib/llvm/bin
Found candidate GCC installation: /usr/lib/gcc/x86_64-redhat-linux/11
Selected GCC installation: /usr/lib/gcc/x86_64-redhat-linux/11
Candidate multilib: .;@m64
Candidate multilib: 32;@m32
Selected multilib: .;@m64
[mydev@myfedora /]$
[mydev@myfedora /]$ rustc -V
rustc 1.55.0 (c8dfcce04 2021-09-06)
[mydev@myfedora /]$
[mydev@myfedora /]$ cargo -V
cargo 1.55.0 (32da73ab1 2021-08-23)
[mydev@myfedora /]$
[mydev@myfedora /]$ rustup -V
rustup 1.24.3 (ce5817a94 2021-05-31)
info: This is the version for the rustup toolchain manager, not the rustc compiler.
info: The currently active `rustc` version is `rustc 1.55.0 (c8dfcce04 2021-09-06)`
[mydev@myfedora /]$
[mydev@myfedora /]$ ll ~/.rustup/toolchains
total 8
drwxrwxr-x. 7 mydev mydev 4096 Oct 10 12:49 nightly-x86_64-unknown-linux-gnu
drwxrwxr-x. 7 mydev mydev 4096 Oct 10 12:22 stable-x86_64-unknown-linux-gnu
[mydev@myfedora /]$
```

```
[mydev@myfedora /]$ java --version
openjdk 17 2021-09-14
OpenJDK Runtime Environment GraalVM CE 21.3.0-dev (build 17+35-jvmci-21.3-b04)
OpenJDK 64-Bit Server VM GraalVM CE 21.3.0-dev (build 17+35-jvmci-21.3-b04, mixed mode, sharing)
[mydev@myfedora /]$
[mydev@myfedora /]$ gu list
ComponentId      Version      Component name      Stability      Origin
-----
graalvm          21.3.0-dev   GraalVM Core      Supported
espresso         21.3.0-dev   Java on Truffle  Experimental
js                21.3.0-dev   Graal.js        Experimental
llvm-toolchain   21.3.0-dev   LLVM.org toolchain  Experimental
native-image     21.3.0-dev   Native Image    Experimental
python           21.3.0-dev   Graal.Python   Experimental
wasm             21.3.0-dev   GraalWasm       Experimental
[mydev@myfedora /]$
```

Java 17

- <https://www.infoq.com/news/2021/09/java17-released/>
- <https://openjdk.java.net/projects/jdk/17/>
- **Features**

- 306: Restore Always-Strict Floating-Point Semantics
- 356: Enhanced Pseudo-Random Number Generators
- 382: New macOS Rendering Pipeline
- 391: macOS/AArch64 Port
- 398: Deprecate the Applet API for Removal
- 403: Strongly Encapsulate JDK Internals
- 406: Pattern Matching for switch (Preview)
- 407: Remove RMI Activation
- 409: Sealed Classes
- 410: Remove the Experimental AOT and JIT Compiler
- 411: Deprecate the Security Manager for Removal
- 412: Foreign Function & Memory API (Incubator)
- 414: Vector API (Second Incubator)
- 415: Context-Specific Deserialization Filters

- **Faster LTS and free JDK with Java 17**



Krustlet

- For Krustlet on RPi4, you may refer to my previous talk:
**"Cloud-Hypervisor on ARM" at the Rust China Meetup 2021
(Hangzhou)**
-



II. eBPF on GraalVM

Dev Env(X64 Laptop)



CHINA
OpenInfra Days

1) rBPF

1.1 Overview

- <https://github.com/qmonnet/rbpf>

Rust(user-space) virtual machine and JIT compiler for eBPF programs.

Languages



- Rust 99.5%
- Batchfile 0.5%

- Base on IOVisor uBPF

```
[mydev@myfedora rbpf-master]$ tree src
src
├── asm_parser.rs
├── assembler.rs
├── disassembler.rs
├── ebpf.rs
├── helpers.rs
├── insn_builder.rs
├── jit.rs
└── lib.rs
    └── verifier.rs
```



```
[mydev@myfedora ubpf-master]$ tree ubpf
ubpf
├── asm_parser.py
├── assembler.py
├── disassembler.py
└── __init__.py

0 directories, 4 files
[mydev@myfedora ubpf-master]$
[mydev@myfedora ubpf-master]$
[mydev@myfedora ubpf-master]$ tree vm
vm
├── ebpf.h
└── inc
    └── ubpf.h
├── Makefile
├── test.c
├── ubpf_int.h
├── ubpf_jit_x86_64.c
├── ubpf_jit_x86_64.h
└── ubpf_loader.c
    └── ubpf_vm.c
```



■ More

<https://github.com/qmonnet/rbpf/blob/master/Cargo.toml>

```
1 [package]
2
3 # Project metadata
4 name = "rbpf"
5 version = "0.1.0"
6 authors = ["Quentin Monnet <quentin.monnet@netronome.com>"]
7
8 # Additional metadata for packaging
9 description = "Virtual machine and JIT compiler for eBPF programs"
10 repository = "https://github.com/qmonnet/rbpf"
11 readme = "README.md"
12 keywords = ["BPF", "eBPF", "interpreter", "JIT", "filtering"]
13 license = "Apache-2.0/MIT"
14
15 # Packaging directives
16 include = [
17     "src/**",
18     "examples/**",
19     "tests/**",
20     "bench/**",
21     "LICENSE**",
22     "Cargo.toml",
23 ]
24
25 [dependencies]
26
27 combine = "2.5"
28 libc = "0.2"
29 time = "0.1"
30 byteorder = "1.2"
31
32 [dev-dependencies]
33
34 elf = "0.0.10"
35 json = "0.11"
```

■ A library, and no official executable.



■ <https://docs.rs/rbpf/0.1.0/rbpf/>

Crate rbpf

[-][src]

[-] Virtual machine and JIT compiler for eBPF programs.

Modules

assembler	This module translates eBPF assembly language to binary.
disassembler	Functions in this module are used to handle eBPF programs with a higher level representation, for example to disassemble the code into a human-readable format.
rbpf	This module contains all the definitions related to eBPF, and some functions permitting to manipulate eBPF instructions.
helpers	This module implements some built-in helpers that can be called from within an eBPF program.
insn_builder	Module provides API to create eBPF programs by Rust programming language

Structs

EbpfVmFixedMbuff	A virtual machine to run eBPF program. This kind of VM is used for programs expecting to work on a metadata buffer containing pointers to packet data, but it internally handles the buffer so as to save the effort to manually handle the metadata buffer for the user.
EbpfVmMbuff	A virtual machine to run eBPF program. This kind of VM is used for programs expecting to work on a metadata buffer containing pointers to packet data.
EbpfVmNoData	A virtual machine to run eBPF program. This kind of VM is used for programs that do not work with any memory area—no metadata buffer, no packet data either.
EbpfVmRaw	A virtual machine to run eBPF program. This kind of VM is used for programs expecting to work directly on the memory area representing packet data.

Type Definitions

Helper	eBPF helper function.
JitProgram	eBPF Jit-compiled program.
Verifier	eBPF verification function that returns an error if the program does not meet its requirements.

Sample

```
■ extern crate rbpf;

fn main() {
    let prog = &[
        0x71, 0x10, 0x02, 0x00, 0x00, 0x00, 0x00, 0x00, // ldxh r0, [r1+2]
        0x95, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00 // exit
    ];

    // Let's use some data.
    let mem = &mut [
        0xaa, 0xbb, 0x11, 0xcc, 0xdd
    ]; Some(prog)

    // This is an eBPF VM for programs reading from a given memory area (it
    // directly reads from packet data) VM
    let mut vm = rbpf::EbpfVmRaw::new(prog).unwrap();

    // This time we JIT-compile the program.
    vm.jit_compile().unwrap();

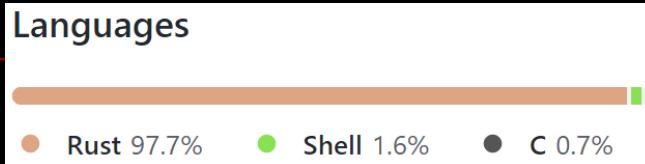
    // Then we execute it. For this kind of VM, a reference to the packet data
    // must be passed to the function that executes the program.
    unsafe { assert_eq!(vm.execute_program_jit(mem).unwrap(), 0x11); }
}
```



1.2 Solana rBPF

- <https://github.com/solana-labs/rbpf>

A derivative of rBPF, but with more features.



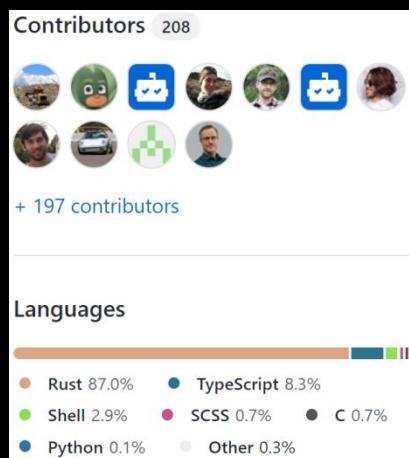
- Solana

Web-Scale Blockchain for fast, secure, scalable, decentralized apps and marketplaces.

[https://en.wikipedia.org/wiki/Solana_\(blockchain_platform\)](https://en.wikipedia.org/wiki/Solana_(blockchain_platform))

<https://solana.com/solana-whitepaper.pdf>

<https://github.com/solana-labs/solana>





API

- https://docs.rs/solana_rbpf/0.2.14/solana_rbpf/

[Create solana_rbpf](#)

[-][src]

[-] Virtual machine and JIT compiler for eBPF programs.

Modules

aligned_memory	Aligned memory
assembler	This module translates eBPF assembly language to binary.
call_frames	Call frame handler
disassembler	Functions in this module are used to handle eBPF programs with a higher level representation, for example to disassemble the code into a human-readable format.
ebpf	This module contains all the definitions related to eBPF, and some functions permitting to manipulate eBPF instructions.
elf	This module relocates a BPF ELF
error	This module contains all the definitions related to eBPF, and some functions permitting to manipulate eBPF instructions.
fuzz	This module defines memory regions
insn_builder	Module provides API to create eBPF programs by Rust programming language
memory_region	This module defines memory regions
static_analysis	Static Byte Code Analysis
syscalls	This module implements some built-in syscalls that can be called from within an eBPF program.
user_error	This module defines an example user error definition
verifier	This “verifier” performs simple checks when the eBPF program is loaded into the VM (before it is interpreted or JIT-compiled). It has nothing to do with the much more elaborated verifier inside Linux kernel. There is no verification regarding the program flow control (should be a Direct Acyclic Graph) or the consistency for registers usage (the verifier of the kernel assigns types to the registers and is much stricter).
vm	Virtual machine and JIT compiler for eBPF programs.

Macros

question_mark	Error handling for SyscallObject::call methods
-------------------------------	--

Src

```
[mydev@myfedora Rust]$ tree -L 3 solana-rbpf-main
solana-rbpf-main
├── benchmarks
│   ├── elf_loader.rs
│   ├── jit_compile.rs
│   ├── memory_mapping.rs
│   └── vm_execution.rs
├── build.rs
├── Cargo.lock
└── Cargo.toml
├── cli
│   ├── Cargo.lock
│   ├── Cargo.toml
│   └── src
│       └── main.rs
├── clippy.toml
├── examples
│   ├── disassemble.rs
│   ├── to_json.rs
│   └── uptime.rs
├── LICENSE-APACHE
└── LICENSE-MIT
├── misc
│   ├── rbpf_256.png
│   ├── rbpf.ico
│   └── rbpf.png
└── README.md
├── scripts
│   ├── cargo-for-all-lock-files.sh
│   ├── increment-cargo-version.sh
│   ├── read-cargo-variable.sh
│   └── semver.sh
└── src
    ├── aligned_memory.rs
    ├── asm_parser.rs
    ├── assembler.rs
    ├── call_frames.rs
    ├── disassembler.rs
    ├── ebpf.rs
    ├── elf.rs
    ├── error.rs
    ├── fuzz.rs
    ├── helpers.rs
    ├── nsn_builder.rs
    ├── jit.rs
    ├── ldr.rs
    ├── memory_region.rs
    ├── static_analysis.rs
    ├── syscalls.rs
    ├── user_error.rs
    ├── verifier.rs
    ├── vm.rs
    └── x86.rs
    └── tests
        ├── assembler.rs
        ├── disassembler.rs
        └── elfs
            ├── elf.ld
            ├── elfs.sh
            ├── empty_rodata.c
            ├── empty_rodata.so
            ├── empty_so
            ├── emptyfile_file.so
            ├── noop.c
            ├── noop.so
            ├── noro.c
            ├── noro.so
            ├── pass_stack_reference.c
            ├── pass_stack_reference.so
            ├── relative_call.c
            ├── relative_call.so
            ├── reloc.c
            ├── reloc.so
            ├── scratch_registers.c
            ├── scratch_registers.so
            ├── syscall
            ├── syscall.h
            └── unresolved_syscall.c
            └── unresolved_syscall.so
    └── misc.rs
    └── ubpf_execution.rs
    └── ubpf_verifier.rs
└── test_utils
    ├── Cargo.lock
    ├── Cargo.toml
    └── src
        └── lib.rs
```

1.2.1 Build for GraalVM

- <https://www.graalvm.org/reference-manual/llvm/Compiling/>

- <https://michaelbh.com/blog/graalvm-and-rust-1/>

- ...

- ```
export GRAALVM_LLVM_TOOLCHAIN=$(lli --print-toolchain-path)
export PATH=$GRAALVM_LLVM_TOOLCHAIN:$PATH
```

```
[mydev@myfedora solana-rbpf-main]$ cd cli;cargo rustc -vv --release -- --emit=llvm-bc
```

```
...
```

```
Compiling rbpf_cli v0.2.14 (/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli)
 Running `CARGO=/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/bin/cargo CARGO_BIN_NAME=rbpf_cli CARGO_CRATE_NAME=rbpf_cli CARGO_MANIFEST_DIR=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli CARGO_PKG_AUTHORS='Solana Maintainers <maintainers@solana.foundation>' CARGO_PKG_DESCRIPTION='CLI to test and analyze eBPF programs' CARGO_PKG_HOMEPAGE='https://solana.com/' CARGO_PKG_LICENSE='CARGO_PKG_LICENSE_FILE=' CARGO_PKG_NAME='rbpf_cli' CARGO_PKG_REPOSITORY='https://github.com/solana-labs/rbpf' CARGO_PKG_VERSION='0.2.14' CARGO_PKG_VERSION_MAJOR='0' CARGO_PKG_VERSION_MINOR='2' CARGO_PKG_VERSION_PATCH='14' CARGO_PKG_VERSION_PRE='-' CARGO_PRIMARY_PACKAGE='1' LD_LIBRARY_PATH='/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps:/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib' rustc --crate-name rbpf_cli --edition=2018 src/main.rs --error-format=json --json-diagnostic-rendered-ansi --create-type bin --emit=dep-info,link -C opt-level=3 -C embed-bitcode=no -C metadata=cfa6eb874f5bde -C extra-filename=_cfa6eb874f5bde --out-dir /opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps --dependency=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana_rbpf=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libsolana_rbpf-a8561c5c06ce2a7f.rlib --extern test_utils=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libtest_utils-29fbba2308ae929a.rlib`
```

error[E0308]: mismatched types
 --> src/main.rs:197:63
 |
197 | let mut vm = EbpfVm::new(executable.as\_ref(), &mut mem, [&heap\_region]).unwrap();
 | ^^^^^^^^^^ expected `u8`, found struct `MemoryRegion`

For more information about this error, try `rustc --explain E0308`.
error: could not compile `rbpf\_cli` due to previous error

Caused by:
process didn't exit successfully: `CARGO=/home/mydev/.rustup/toolchains/stable-x86\_64-unknown-linux-gnu/bin/cargo CARGO\_BIN\_NAME=rbpf\_cli CARGO\_CRATE\_NAME=rbpf\_cli CARGO\_MANIFEST\_DIR=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli CARGO\_PKG\_AUTHORS='Solana Maintainers <maintainers@solana.foundation>' CARGO\_PKG\_DESCRIPTION='CLI to test and analyze eBPF programs' CARGO\_PKG\_HOMEPAGE='https://solana.com/' CARGO\_PKG\_LICENSE='CARGO\_PKG\_LICENSE\_FILE=' CARGO\_PKG\_NAME='rbpf\_cli' CARGO\_PKG\_REPOSITORY='https://github.com/solana-labs/rbpf' CARGO\_PKG\_VERSION='0.2.14' CARGO\_PKG\_VERSION\_MAJOR='0' CARGO\_PKG\_VERSION\_MINOR='2' CARGO\_PKG\_VERSION\_PATCH='14' CARGO\_PKG\_VERSION\_PRE='-' CARGO\_PRIMARY\_PACKAGE='1' LD\_LIBRARY\_PATH='/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps:/home/mydev/.rustup/toolchains/stable-x86\_64-unknown-linux-gnu/lib' rustc --crate-name rbpf\_cli --edition=2018 src/main.rs --error-format=json --json-diagnostic-rendered-ansi --create-type bin --emit=dep-info,link -C opt-level=3 -C embed-bitcode=no -C metadata=cfa6eb874f5bde -C extra-filename=\_cfa6eb874f5bde --out-dir /opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps --dependency=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana\_rbpf=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libsolana\_rbpf-a8561c5c06ce2a7f.rlib --extern test\_utils=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libtest\_utils-29fbba2308ae929a.rlib` (exit status: 1)

```
...
```

- Applied a workaround solution, and passed the build

```
[mydev@myfedora solana-rbpf-main]$ git diff
diff --git a/cli/src/main.rs b/cli/src/main.rs
index cbaa055..68ab9f1 100644
--- a/cli/src/main.rs
+++ b/cli/src/main.rs
@@ -194,7 +194,7 @@ fn main() {
 .unwrap()
 };
 let heap_region = MemoryRegion::new_from_slice(&heap, ebpf::MM_HEAP_START, 0, true);
- let mut vm = EbpfVm::new(executable.as_ref(), &mut mem, &heap_region).unwrap();
+ let mut vm = EbpfVm::new(executable.as_ref(), &mut mem, &mut []).unwrap();
 for (hash, name) in analysis.executable.get_syscall_symbols() {
 vm.bind_syscall_context_object(Box::new(MockSyscall { name: name.clone() }), Some(*hash))
 .unwrap();
}
[mydev@myfedora solana-rbpf-main]$
```

```
Compiling rbpf_cli v0.2.14 (/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf_main/cli)
 Running CARGO=/home/mdevy/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/bin/cargo CARGO_BIN_NAME=rbpf_cli CARGO_CRATE_NAME=rbpf_cli CARGO_MANIFEST_DIR=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf_main/cli CARGO_PKG_AUTHORS='Solana Maintainers <maintainers@solana.foundation>' CARGO_PKG_DESCRIPTION='CLI to test and analyze eBPF programs' CARGO_PKG_HOMEPAGE='https://solana.com/' CARGO_PKG_LICENSE='CARGO_PKG_LICENSEFILE=' CARGO_PKG_NAME=rbpf_cli CARGO_PKG_REPOSITORY='https://github.com/solana-labs/rbpf' CARGO_PKG_VERSION=0.2.14 CARGO_PKG_VERSION_MAJOR=0 CARGO_PKG_VERSION_MINOR=2 CARGO_PKG_VERSION_PATCH=14 CARGO_PKG_VERSION_PRE='' CARGO_PRIMARY_PACKAGE=1 LD_LIBRARY_PATH=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf_main/cli/target/release/deps:/home/mdevy/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/` rustc --crate-name rbpf_cli --edition=2018 src/main.rs --error-format=json --json=diagnostic-rendered-ansi --crate-type bin --emit=dep-info,link -C opt-level=3 -C embed-bitcode=no --emit=llvm-bc -C metadata=ca3fa6eb74f5bde -C extra-filename=ca3fa6eb74f5bde --out-dir /opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf_main/cli/target/release/deps --extern clap=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf_main/cli/target/release/deps/libclap-9b8ddf82e3ceb4c3_rlib -extern solana_rbpf=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf_main/cli/target/release/deps/libsolana_rbpf-a8561c5c06ce2a7f.rlib -extern test_utils=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf_main/cli/target/release/deps/libtest_utils-29fbba2308ae929a.rlib
warning: unused variable: `heap_region`
 --> src/main.rs:196:9
196 | let heap_region = MemoryRegion::new_from_slice(&heap, ebpf::MM_HEAP_START, 0, true);
| ^^^^^^^^^^^ help: if this is intentional, prefix it with an underscore: _heap_region
| =
| = note: `#[warn(unused_variables)]` on by default

warning: `rbpf_cli` (bin "rbpf_cli") generated 1 warning
Finished release [optimized] targets(s) in 1m 30s
```

## Check the generated LLVM bitcode file

```
[mydev@myfedora solana-rbpf-main]$ find . -name "*.bc"
./cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc
[mydev@myfedora solana-rbpf-main]$

[mydev@myfedora solana-rbpf-main]$ ll cli/target/release/deps |grep -i rbpf_cli
-rwxrwxr-x. 2 mydev mydev 7316848 Oct 12 03:00 rbpf_cli-ca3fa6eb874f5bde
-rw-rw-r--. 1 mydev mydev 2719460 Oct 12 03:00 rbpf_cli-ca3fa6eb874f5bde.bc
-rw-rw-r--. 1 mydev mydev 429 Oct 12 03:00 rbpf_cli-ca3fa6eb874f5bde.d
[mydev@myfedora solana-rbpf-main]$

[mydev@myfedora solana-rbpf-main]$ file cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc
cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc: LLVM IR bitcode
[mydev@myfedora solana-rbpf-main]$

[mydev@myfedora solana-rbpf-main]$ which lli
/opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/bin/lli
[mydev@myfedora solana-rbpf-main]$

[mydev@myfedora solana-rbpf-main]$ lli cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc
External LLVMFunction _ZN68$_LT$std..thread..local..AccessError$u20$as$u20$core..fmt..DebugGT3fmt17h2580b118015fe02eE cannot be found.
 at <llvm> <LoadModulesNode>(cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc:1:0)
[mydev@myfedora solana-rbpf-main]$

[mydev@myfedora solana-rbpf-main]$ lli --lib $(rustc --print sysroot)/lib/libstd-* cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc
External LLVMFunction _ZN57$_LT$goblin..error..Error$u20$as$u20$core..fmt..DebugGT3fmt17h16af9ba9418a9f49E cannot be found.
 at <llvm> <LoadModulesNode>(cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc:1:0)
[mydev@myfedora solana-rbpf-main]$

[mydev@myfedora solana-rbpf-main]$ lli --lib $(rustc --print sysroot)/lib/* cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc
ERROR: no main function found
```



```
[mydev@myfedora solana-rbpf-main]$ which llvm-dis
/bin/llvm-dis
[mydev@myfedora solana-rbpf-main]$ llvm-dis ./cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.bc
[mydev@myfedora solana-rbpf-main]$
[mydev@myfedora solana-rbpf-main]$ ll ./cli/target/release/deps |grep -i rbpf_cli
-rwxrwxr-x. 1 mydev mydev 7316848 Oct 12 08:31 rbpf_cli-ca3fa6eb874f5bde
-rw-rw-r--. 1 mydev mydev 2719460 Oct 12 08:31 rbpf_cli-ca3fa6eb874f5bde.bc
-rw-rw-r--. 1 mydev mydev 429 Oct 12 08:31 rbpf_cli-ca3fa6eb874f5bde.d
-rw-rw-r--. 1 mydev mydev 13678930 Oct 12 08:32 rbpf_cli-ca3fa6eb874f5bde.ll
[mydev@myfedora solana-rbpf-main]$
[mydev@myfedora solana-rbpf-main]$ vim rbpf_cli-ca3fa6eb874f5bde.ll
; Function Attrs: nonlazybind
define i32 @main(i32 %0, i8** %1) unnamed_addr #22 {
top:
%_8.i = alloca i64*, align 8
%_2 = sext i32 %0 to i64
%_3 = bitcast i64** %_8.i to i8*
call void @_G llvm.lifetime.start.p0i8(i64 %_8, i8* nonnull %_3)
%_4 = bitcast i64** %_8.i to void (**)
store void (*) @_ZN8rbpf_cli4main17h1c9a3afce3a7be1E, void ()** %_4, align 8
%_5._0.i = bitcast i64** %_8.i to {}
%_4.i = call i64 @_ZN3std2rt19lang_start_internal17h7e2ceec890d4a4d3E(%* nonnull align 1 %_5._0.i, [3 x i64]* noalias i8*, [0 x i8] %>>@vtable.5 to [3 x i64*]), i64 %_2, i8** %1)
call void @_G llvm.lifetime.end.p0i8(i64 %_8, i8* nonnull %_3)
%_5 = trunc i64 %_4.i to i32
ret i32 %5
}
```

Rethought about the build process and retried with `llvm-link`

```
[mydev@myfedora solana-rbpf-main]$ cd cli;cargo rustc -vv --release --emit=llvm-bc -C linker=llvm-link
```

```

x-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libstd-008055cc7d873802.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libpanic_unwind-06f01ac2578bda94.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/libminiz_oxide-f9a3c3274a1835e0.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/libbadler-d4ccb754ee9f4ada.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libobject-95c14e1cie3ebccc4.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libaddr2line-d489fc0a872880c.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libbgmili-75f07df0b18fea39.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libhashbrown-6b1498909d375a785.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/rustlib_std_workspace_alloc-cd15fa674775d1.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libunwind-74be3a03788ba2.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/liballoc-ac23a75f6f42004.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libcore-4beb03d0563c439.rlib" "-Wl,-end-group" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libcompiler_builtins-dd7db1bec69ff24.rlib" "-Wl,-Bdynamic" "-lgcc_s" "-util" "-lthread" "-lm" "-ldl" "-Wl,-eh-frame-hdr" "-Wl,-znoexecstack" "-L" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/rustlib/_0". "-Wl,-zrelro" "-Wl,-znow" "-Wl,-O1" "-nodefaultlibs"

= note: llvm-link: Unknown command line argument '-m64'. Try: 'llvm-link --help'
llvm-link: Did you mean '-mv60'?
llvm-link: Unknown command line argument '-Wl,--as-needed'. Try: 'llvm-link --help'
llvm-link: Did you mean '--only-needed'?
llvm-link: Unknown command line argument '-L'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-L'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-Wl,-Bstatic'. Try: 'llvm-link --help'
llvm-link: Did you mean '-stats'?
llvm-link: Unknown command line argument '-Wl,--start-group'. Try: 'llvm-link --help'
llvm-link: Did you mean '--start-before'?
llvm-link: Unknown command line argument '-Wl,--end-group'. Try: 'llvm-link --help'
llvm-link: Did you mean '--ppc-gen-isel'?
llvm-link: Unknown command line argument '-Wl,-Bdynamic'. Try: 'llvm-link --help'
llvm-link: Did you mean '-efi-limit'?
llvm-link: Unknown command line argument '-lgcc_s'. Try: 'llvm-link --help'
llvm-link: Did you mean '-stats'?
llvm-link: Unknown command line argument '-util'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-lrt'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-lpthread'. Try: 'llvm-link --help'
llvm-link: Did you mean '--threads'?
llvm-link: Unknown command line argument '-lm'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-ldl'. Try: 'llvm-link --help'
llvm-link: Did you mean '-d'?
llvm-link: Unknown command line argument '-lc'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-Wl,--eh-frame-hdr'. Try: 'llvm-link --help'
llvm-link: Did you mean '--slp-vectorize-hor'?
llvm-link: Unknown command line argument '-Wl,-znoexecstack'. Try: 'llvm-link --help'

llvm-link: Did you mean '--asan-stack'?
llvm-link: Unknown command line argument '-L'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-Wl,--gc-sections'. Try: 'llvm-link --help'
llvm-link: Did you mean '--remarks-section'?
llvm-link: Unknown command line argument '-pie'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-Wl,-zrelro'. Try: 'llvm-link --help'
llvm-link: Did you mean '--icp-lto'?
llvm-link: Unknown command line argument '-Wl,-znow'. Try: 'llvm-link --help'
llvm-link: Did you mean '--icp-lto'?
llvm-link: Unknown command line argument '-Wl,-O1'. Try: 'llvm-link --help'
llvm-link: Did you mean '-S'?
llvm-link: Unknown command line argument '-nodefaultlibs'. Try: 'llvm-link --help'
llvm-link: Did you mean '--arm-default-it'?

warning: `rbpf_cli` (bin "rbpf_cli") generated 1 warning
error: could not compile `rbpf_cli` due to previous error; 1 warning emitted

Caused by:
process didn't exit successfully: `CARGO=/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/bin/cargo CARGO_BIN_NAME=rbpf_cli CARGO_CRATE_NAME=rbpf_cli CARGO_MANIFEST_DIR=/opt/MyWorkSpace/MyProj/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli CARGO_PKG_AUTHORS='Solana Maintainers <maintainers@solana.foundation>' CARGO_PKG_DESCRIPTION='CLI to test and analyze eBPF programs' CARGO_PKG_HOMEPAGE='https://solana.com/' CARGO_PKG_LICENSE=' CARGO_PKG_LICENSE_FILE=' CARGO_PKG_NAME=rbpf_cli CARGO_PKG_REPOSITORY='https://github.com/solana-labs/rbpf' CARGO_PKG_VERSION='0.2.14' CARGO_PKG_VERSION_MAJOR='0' CARGO_PKG_VERSION_MINOR='2' CARGO_PKG_VERSION_PATCH='14' CARGO_PKG_VERSION_PRE='-' CARGO_PRIMARY_PACKAGE='1' LD_LIBRARY_PATH='/opt/MyWorkSpace/MyProj/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps:/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib:/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/C linker=llvm-link C metadata=ca3fa6eb874f5bde C extra-filename=ca3fa6eb874f5bde -out-dir /opt/MyWorkSpace/MyProj/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps -L dependency=/opt/MyWorkSpace/MyProj/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps --extern clap=/opt/MyWorkSpace/MyProj/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libsolana_rbpf-a85615c06ce2af.rlib --extern test_utils=/opt/MyWorkSpace/MyProj/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libtest_utils-29fbfa208ae929a.rlib` (exit status: 1)

```



## Retried again with graalvm-native-ld

```
[mydev@myfedora solana-rbpf-main]$ cd cli;cargo rustc -vv --release -- --emit=llvm-bc -C linker=graalvm-native-ld
```

■ ■ ■

```
= note: "graalvm-native-ld" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.rbpf_cli-4acc1348-cgu.0.rcgu.o" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde.28z5049uh5oxjp8.rcgu.o" "-as-needed" "-L" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libsolana_rbpf-a8561c5c06ce2a7f.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libtoboggan-f6547dbd6fc5274.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libplain-9cf2783e4a624b7.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libtibame-48e89880817f3e4a.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libthiserror-f962c2f3898502f3d.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/librand_pcg-7b44b5cceee8c87.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/librand_chacha-e5ddb3045ffd2930.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/librand_core-fic5eif91b11idb5.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libgetrandom-bfa928846ba53421.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/liblog-304cf0d24df483f7.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libcibash-32-9a20b3c35288b62d.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libcombine-041aa59fc545c87b.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libunreachable-310d11f7f9e78769.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libmemchr-df05dabdd40cda.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libteerider-5b2414249b1003de.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libyesterde-b870dcd9348c883e.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libclap-98bddf2e3ceb4c3.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libbsrsm-fac52b3a2457907.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libbshash-05065d333cee63ff.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libtextwrap-f0b6f18c4440824ed.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libvec_map-42adc353562c5416.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libtermcolor-f463b3a83d6ca5e3.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libunicode_width-3bf99c6b04d3f3e20.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libhashbrown-1740255a0c675020.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/liblazystatic-fe3fb0d817d3d7.rlib" "--start-group" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libstd-008055cc7d873802.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/libpanic_unwind-06fe01ac2578bda94.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libminiz_oxide-f9a3c3274a183e0.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/libadler-48a50512b6642a98.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/liblubicode_width-3bf99c6b04d3f3e20.rlib" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libdbr2line-d489f0ca872880cc.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/librustc_de_mangle-e530649c9a06e3c6.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libhashbrown-6b148909d375a785.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/librustc_std_workspace_alloc-cd15fa647f4775d1.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/librustc_std_workspace_core-557ba8776e04d182.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/liballoc-ac23a75ff42004e.rlib" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libcortex-a8eb03d503c439.rlib" "--end-group" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libcompiler_builtins-dd7db1bec6999f24.rlib" "--Dynamic" "lgcc_s" "ltilt" "-l" "lptrace" "-lm" "-lc" "-eh-frame-hdr" "-znoexecstack" "-L" "/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib/libc" "-o" "/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/rbpf_cli-ca3fa6eb874f5bde" "--gc-sections" "-pie" "-zrelro" "-znow" "-O1"
```

```
= note: ld.lld: error: unable to find library -lgcc_s
 ld.lld: error: unable to find library -lutil
 ld.lld: error: unable to find library -lrt
 ld.lld: error: unable to find library -lpthread
 ld.lld: error: unable to find library -lm
 ld.lld: error: unable to find library -ldl
 ld.lld: error: unable to find library -lc
```

```
warning: `rbpf_cli` (bin "rbpf_cli") generated 1 warning
error: could not compile `rbpf_cli` due to previous error; 1 warning emitted
```

Caused by:

```
process didn't exit successfully: `CARGO=/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/bin/cargo CARGO_BIN_NAME=rbpf_cli CARGO_CRATE_NAME=rbpf_cli CARGO_MANIFEST_DIR=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli CARGO_PKG_AUTHORS='Solana Maintainers <maintainers@solana.foundation>' CARGO_PKG_DESCRIPTION='CLI to test and analyze eBPF programs' CARGO_PKG_HOMEPAGE='https://solana.com/' CARGO_PKG_LICENSE=' CARGO_PKG_LICENSE_FILE=' CARGO_PKG_NAME=rbpf_cli CARGO_PKG_REPOPOSITORY='https://github.com/solana-labs/rbpf' CARGO_PKG_VERSION=0.2.14 CARGO_PKG_VERSION_MAJOR=0 CARGO_PKG_VERSION_MINOR=2 CARGO_PKG_VERSION_PATCH=14 CARGO_PKG_VERSION_PRE=' CARGO_PRIMARY_PACKAGE=1 LD_LIBRARY_PATH='/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps:/home/mydev/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib/rustc --crate-name rbpf_cli --edition=2018 src/main.rs --error-format=json --json=diagnostic-rendered-ansi --crate-type bin --emit=dep-info,link -C opt-level=3 -C embed-bitcode=no --emit=llvm-bc -C linker=graalvm-native-ld -C metadata=ca3fa6eb874f5bde -C extra-filename+=ca3fa6eb874f5bde --out-dir /opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps -L dependency=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps -extern solana_rbpf=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libsolana_rbpf-f-a8561c5c06ce2a7f.rlib -extern test_utils=/opt/MyWorkSpace/MyProjs/Runtime/GraalVM/eBPF/uBPF/Rust/solana-rbpf-main/cli/target/release/deps/libtest_utils-29fbba2308ae929a.rlib` (exit status: 1)
```



## 2) Summary

A more finely-grained control is needed against build Rust-based project for GraalVM...

### Cargo Make

#### ■ <https://github.com/sagiegurari/cargo-make>

The cargo-make task runner enables to define and configure sets of tasks and run them as a flow.

A task is a command, script, rust code or other sub tasks to execute.

Tasks can have dependencies which are also tasks that will be executed before the task itself.

With a simple toml based configuration file, you can define a multi platform build script that can run build, test, generate documentation, run bench tests, run security validations and more, executed by running a single command.



#### Installation

In order to install, just run the following command

```
cargo install --force cargo-make
```

This will install cargo-make in your `~/.cargo/bin`.

Make sure to add `~/.cargo/bin` directory to your PATH variable.

You will have two executables available: `cargo-make` and `makers`

- `cargo-make` - This is a cargo plugin invoked using `cargo make ...`
- `makers` - A standalone executable which provides same features and cli arguments as cargo-make but is invoked directly and not as a cargo plugin.

See [Cli Options](#) section for full CLI instructions.

#### Binary Release

Binary releases are available in the [github releases page](#).

The following binaries are available for each release:

- `x86_64-unknown-linux-musl`
- `x86_64-apple-darwin`
- `x86_64-pc-windows-msvc`
- `arm-unknown-linux-gnueabihf`

## ■ customize a Cargo.toml for rBPF(only for illustration purposes)

```
...
[tasks.build-asm_parser]
command = "cargo"
args = ["rustc", "-vv", "release", "--", "--emit=llvm-bc", "asm_parser.rs"]

[tasks.build-ebpf]
command = "rustc"
args = ["-v", "--emit=llvm-bc", "ebpf.rs"]

[tasks.build-helpers]
command = "rustc"
args = ["-v", "--emit=llvm-bc", "helpers.rs"]

[tasks.build-insn_builder]
command = "rustc"
args = ["-v", "--emit=llvm-bc", "insn_builder.rs"]

[tasks.build-assembler]
command = "rustc"
args = ["-v", "--emit=llvm-bc", "assembler.rs"]

[tasks.build-disassembler]
command = "rustc"
args = ["-v", "--emit=llvm-bc", "disassembler.rs"]

[tasks.build-verifier]
command = "rustc"
args = ["-v", "--emit=llvm-bc", "verifier.rs"]

[tasks.build-lib]
command = "rustc"
args = ["-v", "--emit=llvm-bc", "lib.rs"]

[tasks.build-jit]
command = "rustc"
args = ["-v", "--emit=llvm-bc", "jit.rs"]

[tasks.build-rbpf]
dependencies = [
 "build-asm_parser",
 "build-ebpf",
 "build-helpers",
 "build-insn_builder",
 "build-assembler",
 "build-disassembler",
 "build-verifier",
 "build-lib",
 "build-jit"
]
```

1

...



## Customize rustc/cargo

■ <https://github.com/rust-lang/rust>

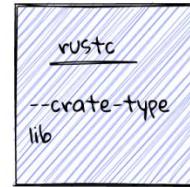
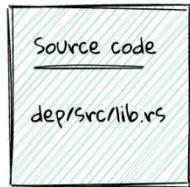
|                     |                                                                                                                                      |              |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------|--------------|
| .github             | Work around CI issue with windows sdk 10.0.20348.0.                                                                                  | last month   |
| compiler            | Auto merge of #89791 - matthiaskrgr:rollup-1lhxh5b, r=matthiaskrgr                                                                   | 17 hours ago |
| library             | Auto merge of #89770 - jkugelman:must-use-from-and-into, r=joshsriplett                                                              | 8 hours ago  |
| src                 | Auto merge of #89770 - jkugelman:must-use-from-and-into, r=joshsriplett                                                              | 8 hours ago  |
| .editorconfig       | Add .editorconfig                                                                                                                    | 8 months ago |
| .gitattributes      | Remove rustfmt tests from top-level .gitattributes                                                                                   | 4 months ago |
| .gitignore          | Simplify build system for rustdoc-gui test crates                                                                                    | 3 months ago |
| .gitmodules         | Update to the final LLVM 13.0.0 release                                                                                              | 11 days ago  |
| .mailmap            | Rollup merge of #88179 - steffahn:mailmap, r=Mark-Simulacrum                                                                         | 2 months ago |
| CODE_OF_CONDUCT.md  | Remove the code of conduct; instead link <a href="https://www.rust-lang.org/conduct.html">https://www.rust-lang.org/conduct.html</a> | 2 years ago  |
| CONTRIBUTING.md     | Make opening sentence friendlier for new contributors                                                                                | 7 months ago |
| COPYRIGHT           | Rebase to the llvm-project monorepo                                                                                                  | 3 years ago  |
| Cargo.lock          | Rollup merge of #89288 - rusticstuff:lld_wrapper, r=Mark-Simulacrum                                                                  | 5 days ago   |
| Cargo.toml          | Greatly reduce amount of debuginfo compiled for bootstrap itself                                                                     | 2 days ago   |
| LICENSE-APACHE      | Remove appendix from LICENCE-APACHE                                                                                                  | 2 years ago  |
| LICENSE-MIT         | LICENSE-MIT: Remove inaccurate (misattributed) copyright notice                                                                      | 4 years ago  |
| README.md           | Rollup merge of #85504 - liigo:patch-13, r=Mark-Simulacrum                                                                           | 3 months ago |
| RELEASES.md         | Remove task::ready! from 1.56.0 release notes                                                                                        | 22 hours ago |
| config.toml.example | bootstrap: add config option for nix patching                                                                                        | 10 days ago  |
| configure           | Enforce Python 3 as much as possible                                                                                                 | 2 years ago  |
| rustfmt.toml        | Fix tidy                                                                                                                             | 2 months ago |
| triagebot.toml      | Rollup merge of #80543 - LeSeulArtichaut:notify-close, r=spastorino                                                                  | last month   |
| x.py                | Choose the version of python at runtime (portable version)                                                                           | 9 months ago |



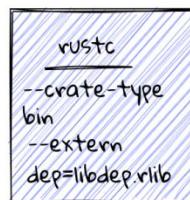
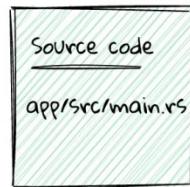
## Customize a linker

- rust-ld is the default linker for rustc
- <https://confused.ai/posts/rust-bpf-target>

The dep crate gets compiled as a rust library



And then the app crate gets compiled, linking to the libdep.rlib library



The compiled app crate (app.\*.o) and the compiled dep crate (libdep.rlib) need to be linked to generate the final executable

<https://github.com/aya-rs/bpf-linker>

<https://llvm.org/docs/CommandGuide/llvm-link.html>

## *Customize the GraalVM LLVM Toolchain*

```
[mydev@myfedora solana-rbpf-main]$ lli --print-toolchain-path
/opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin
[mydev@myfedora solana-rbpf-main]$ tree /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin
/opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin
├── ar -> graalvm-native-binutil
├── c++ -> graalvm-native-clang++
├── cc -> graalvm-native-clang
├── clang -> graalvm-native-clang
├── clang++ -> graalvm-native-clang++
├── g++ -> graalvm-native-clang++
├── gcc -> graalvm-native-clang
├── graalvm-clang -> graalvm-native-clang
├── graalvm-clang++ -> graalvm-native-clang++
└── graalvm-native-binutil
 ├── graalvm-native-clang
 └── graalvm-native-clang++
 └── graalvm-native-ld
 ├── ld -> graalvm-native-ld
 ├── ld64 -> graalvm-native-ld
 ├── ld.lld -> graalvm-native-ld
 └── lld -> graalvm-native-ld
 └── llvm-ar -> graalvm-native-binutil
 └── llvm-nm -> graalvm-native-binutil
 └── llvm-objcopy -> graalvm-native-binutil
 └── llvm-objdump -> graalvm-native-binutil
 └── llvm-ranlib -> graalvm-native-binutil
 └── llvm-readelf -> graalvm-native-binutil
 └── llvm-readobj -> graalvm-native-binutil
 └── llvm-strip -> graalvm-native-binutil
 └── nm -> graalvm-native-binutil
 └── objcopy -> graalvm-native-binutil
 └── objdump -> graalvm-native-binutil
 └── ranlib -> graalvm-native-binutil
 └── readelf -> graalvm-native-binutil
 └── readobj -> graalvm-native-binutil
 └── rustc.bak
 └── strip -> graalvm-native-binutil

0 directories, 33 files
[mydev@myfedora solana-rbpf-main]$
```





# III. Wasm on GraalVM

## 1) GraalVM-native implementation

### 1.1 GraalWasm

*(Retried the Polyglot sample on X64 Laptop)*

```
[mydev@myfedora wasm]$ git status
On branch master
Your branch is up to date with 'origin/master'.

Untracked files:
 (use "git add <file>..." to include in what will be committed)
 src/org.graalvm.wasm.test/src/org/graalvm/wasm/test/WasmPolyglotTest1.java
 src/org.graalvm.wasm.test/src/org/graalvm/wasm/test/main.wasm

nothing added to commit but untracked files present (use "git add" to track)
[mydev@myfedora wasm]$
[mydev@myfedora wasm]$ mx --dy /truffle,/compiler build
JAVA_HOME: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev
...
[mydev@myfedora wasm]$ mx --dy /compiler,/truffle --jdk jvmci unittest WasmPolyglotTest1
...
WARNING: Unsupported class files listed in /opt/MyWorkSpace/MyProjs/Runtime/GraalVM/Official/graal-master/wasm/mxbuild/jdk17/unittest/graal-compiler-micro-benchmarks.jar.jdk17.excludedclasses
JUnitCore
JUnit version 4.12
.E
test(WasmPolyglotTest1)
java.nio.file.NoSuchFileException: main.wasm
 at java.base/sun.nio.fs.UnixException.translateToIOException(UnixException.java:92)
 at java.base/sun.nio.fs.UnixException.rethrowAsIOException(UnixException.java:106)
 at java.base/sun.nio.fs.UnixException.rethrowAsIOException(UnixException.java:111)
 at java.base/sun.nio.fs.UnixFileProvider.newByteChannel(UnixFileSystemProvider.java:219)
 at java.base/java.nio.FileChannel.open(FileChannel.java:380)
 at java.base/java.nio.FileChannel$WrappingFileChannel.open(FileChannel.java:432)
 at java.base/java.nio.FileChannel.openAllBytes(FileChannel.java:3288)
 at WasmPolyglotTest1.test(WasmPolyglotTest1.java:13)
 at java.base/jdk.internal.reflect.NativeMethodAccessorImpl.invoke0(Native Method)
 at java.base/jdk.internal.reflect.NativeMethodAccessorImpl.invoke(NativeMethodAccessorImpl.java:77)
 at java.base/jdk.internal.reflect.DelegatingMethodAccessorImpl.invoke(DelegatingMethodAccessorImpl.java:43)
 at java.base/java.lang.reflect.Method.invoke(Method.java:568)
 at org.junit.runners.model.FrameworkMethod$1.runReflectiveCall(FrameworkMethod.java:50)
 at org.junit.internal.runners.model.ReflectiveCallable.run(ReflectiveCallable.java:12)
 at org.junit.runners.model.FrameworkMethod.invokeExplosively(FrameworkMethod.java:47)
 at org.junit.runners.statements.InvokeMethod.evaluate(InvokeMethod.java:17)
 at org.junit.runners.ParentRunner.runLeaf(ParentRunner.java:325)
 at org.junit.runners.BlockJUnit4ClassRunner.runChild(BlockJUnit4ClassRunner.java:78)
 at org.junit.runners.BlockJUnit4ClassRunner$1.run(BlockJUnit4ClassRunner.java:57)
 at org.junit.runners.ParentRunner$2$1.evaluate(ParentRunner.java:290)
 at org.junit.runners.ParentRunner$1.schedule(ParentRunner.java:71)
 at org.junit.runners.ParentRunner.runChildren(ParentRunner.java:288)
 at org.junit.runners.ParentRunner.access$000(ParentRunner.java:58)
 at org.junit.runners.ParentRunner$2.evaluate(ParentRunner.java:268)
 at org.junit.runners.ParentRunner.run(ParentRunner.java:363)
 at org.junit.runners.Suite.runChild(Suite.java:128)
 at org.junit.runners.Suite.runChild(Suite.java:27)
 at org.junit.runners.ParentRunner$3.run(ParentRunner.java:290)
 at org.junit.runners.ParentRunner$1.schdule(ParentRunner.java:71)
 at org.junit.runners.ParentRunner.runChildren(ParentRunner.java:288)
 at org.junit.runners.ParentRunner.access$000(ParentRunner.java:58)
 at org.junit.runners.ParentRunner$2.evaluate(ParentRunner.java:268)
 at org.junit.runners.ParentRunner.run(ParentRunner.java:363)
 at org.junit.runner.JUnitCore.run(JUnitCore.java:137)
 at org.junit.runner.JUnitCore.run(JUnitCore.java:115)
 at com.oracle.mxtool.junit.MxJUnitWrapper.runRequest(MxJUnitWrapper.java:357)
 at com.oracle.mxtool.junit.MxJUnitWrapper.main(MxJUnitWrapper.java:222)
```

# change the test code:

```
[mydev@myfedora Polyglot]$ colordiff WasmPolyglotTest1.java WasmPolyglotTest3.java
9c9
< public class WasmPolyglotTest1 {

> public class WasmPolyglotTest3 {
12c12
< File file = new File("main.wasm");

> File file = new File("/opt/MyWorkSpace/MyTest/GraalVM/Polyglot/main.wasm");
[mydev@myfedora Polyglot]$
```

# **new failure:**

```
[mydev@myfedora wasm]$ git status
On branch master
Your branch is up to date with 'origin/master'.

Untracked files:
 (use "git add <file>..." to include in what will be committed)
 src/org.graalvm.wasm.test/src/org/graalvm/wasm/test/WasmPolyglotTest3.java

nothing added to commit but untracked files present (use "git add" to track)
[mydev@myfedora wasm]$
[mydev@myfedora wasm]$
[mydev@myfedora wasm]$ mx --dy /truffle,/compiler build
JAVA HOME: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev
■ ■ ■
[mydev@myfedora wasm]$ mx --dy /compiler,/truffle --jdk jvmci unittest WasmPolyglotTest3
```

```
WARNING: Unsupported class files listed in /opt/MyWorkSpace/MyProjs/Runtime/GraalVM/Official/graal-master/wasm/mxbUILD/jdk17/unittest/wasm-benchmarks.jar.jdk17.excludedclasses
MxJunitCore
JUnit version 4.12
.E
test[WasmPolyglotTest3]
java.lang.UnsupportedOperationException: Unsupported operation Value.execute(Object...) for 'org.graalvm.wasm.WasmInstance@25641d39' (language: Java, type: com.oracle.truffle.polyglot.PolyglotMap). You can ensure that the operation is supported by Value.canExecute()
 at com.oracle.truffle/com.oracle.truffle.polyglot.PolyglotEngineException.unsupported(PolyglotEngineException.java:137)
 at org.graalvm.truffle/com.oracle.truffle.polyglot.PolyglotValueDispatch.unsupported(PolyglotValueDispatch.java:126)
 at org.graalvm.truffle/com.oracle.truffle.polyglot.PolyglotValueDispatch.interopValue$AbstractExecuteNode.executeShared(PolyglotValueDispatch.java:4239)
 at org.graalvm.truffle/com.oracle.truffle.polyglot.PolyglotValueDispatch.interopValue$ExecuteNoArgsNode.executeImpl(PolyglotValueDispatch.java:4337)
 at org.graalvm.truffle/com.oracle.truffle.polyglot.PolyglotValueDispatch.interopValue$ExecuteNode.execute(PolyglotValueDispatch.java:4337)
 at org.graalvm.truffle/com.oracle.truffle.polyglot.PolyglotValueDispatch.interopValue$ExecuteNode.optimizeCallTarget(PolyglotValueDispatch.java:4337)
 at jdk.internal.vm.compiler.org.graalvm.compiler.truffle.runtime.OptimizedCallTarget.executeRootNode(OptimizedCallTarget.java:649)
 at jdk.internal.vm.compiler.org.graalvm.compiler.truffle.runtime.OptimizedCallTarget.profiled(OptimizedCallTarget.java:621)
 at jdk.internal.vm.compiler.org.graalvm.compiler.truffle.runtime.OptimizedCallTarget.callBoundary(OptimizedCallTarget.java:554)
 at jdk.internal.vm.compiler.org.graalvm.compiler.truffle.runtime.OptimizedCallTarget.invoke(OptimizedCallTarget.java:538)
 at jdk.internal.vm.compiler.org.graalvm.compiler.truffle.runtime.OptimizedCallTarget.invoke$InterOpValue$Execute(PolyglotValueDispatch.java:211)
 at org.graalvm.truffle/com.oracle.truffle.polyglot.PolyglotValueDispatch.interopValue$Execute(PolyglotValueDispatch.java:2373)
 at org.graalvm.truffle/com.oracle.truffle.polyglot.Valuedkorg.graalvm.polyglot.Value.execute(Value.java:839)
 at WasmPolyglotTest3.test[WasmPolyglotTest3.java:22]
 at java.base/jdk.internal.reflect.NativeMethodAccessorImpl.invoke0(Native Method)
 at java.base/jdk.internal.reflect.NativeMethodAccessorImpl.invoke(NativeMethodAccessorImpl.java:77)
 at java.base/jdk.internal.reflect.DelegatingMethodAccessorImpl.invoke(DelegatingMethodAccessorImpl.java:43)
 at java.base/java.lang.reflect.Method.invoke(Method.java:568)
 at org.junit.runners.model.FrameworkMethod$1.runReflectiveCall(FrameworkMethod.java:50)
 at org.junit.internal.runners.model.ReflectiveCallable.runReflectiveCall(ReflectiveCallable.java:12)
 at org.junit.runners.model.FrameworkMethod$1.evaluate(FrameworkMethod.java:47)
 at org.junit.internal.runners.statements.InvokeMethod.evaluate(InvokeMethod.java:17)
 at org.junit.runners.ParentRunner.runLeaf(ParentRunner.java:325)
 at org.junit.runners.BlockJUnit4ClassRunner.runChild(BlockJUnit4ClassRunner.java:78)
 at org.junit.runners.BlockJUnit4ClassRunner.runChild(BlockJUnit4ClassRunner.java:57)
 at org.junit.runners.ParentRunner$3.schedule(ParentRunner.java:299)
 at org.junit.runners.ParentRunner.access$000(ParentRunner.java:58)
 at org.junit.runners.ParentRunner$2.evaluate(ParentRunner.java:268)
 at org.junit.runners.ParentRunner$2.evaluate(ParentRunner.java:363)
 at org.junit.runners.ParentRunner$3.schedule(ParentRunner.java:271)
 at org.junit.runners.ParentRunner$3.run(ParentRunner.java:290)
 at org.junit.runners.ParentRunner$1.schedule(ParentRunner.java:71)
 at org.junit.runners.ParentRunner.run(ParentRunner.java:290)
 at org.junit.runners.ParentRunner.access$000(ParentRunner.java:58)
 at org.junit.runners.ParentRunner$2.evaluate(ParentRunner.java:268)
 at org.junit.runners.ParentRunner.run(ParentRunner.java:363)
 at org.junit.runner.JUnitCore.run(JUnitCore.java:137)
 at org.junit.runner.JUnitCore.run(JUnitCore.java:119)
 at org.junit.runner.JUnitCore$1.evaluate(JUnitCore.java:205)
 at com.oracle.mxtool.junit.MxUnitWrapper.main(MxUnitWrapper.java:357)
Caused by: Attached Guess Language Frames (1)
```



## 2) Sulong-based implementation

### 2.1 Wasm3

- <https://github.com/wasm3/wasm3>

**The fastest WebAssembly interpreter, and the most universal runtime.**

- Installation

Please follow the [installation instructions](#).

Wasm3 can also be used as a library for:

Python3 | Rust | C/C++ | GoLang | Zig  
 Swift | .Net | Arduino, PlatformIO, Particle

- Status

wasm3 passes the [WebAssembly spec testsuite](#) and is able to run many [WASI](#) apps.

Minimum useful system requirements: ~64Kb for code and ~10Kb RAM

wasm3 runs on a wide range of architectures ( [x86](#) , [x86\\_64](#) , [ARM](#) , [RISC-V](#) , [PowerPC](#) , [MIPS](#) , [Xtensa](#) , [ARC32](#) , ...) and platforms:

- Linux, Windows, OS X, FreeBSD, Android, iOS
- OpenWrt, Yocto, Buildroot (routers, modems, etc.)
- Raspberry Pi, Orange Pi and other SBCs
- MCUs: Arduino, ESP8266, ESP32, Particle, ... [see full list](#)
- Browsers. Yes, using WebAssembly itself!
- wasm3 can execute wasm3 (self-hosting)



## Advanced features and post-mvp proposals support

- Sign-extension operators
- Non-trapping float-to-int conversions
- Import/Export of Mutable Globals
- Structured execution tracing
- Big-Endian systems support
- Self-hosting
- Gas metering
- Multi-value
- Reference types
- Bulk memory operations
- Tail call optimization

## Motivation

### Why use a "slow interpreter" versus a "fast JIT"?

In many situations, speed is not the main concern. Runtime executable size, memory usage, startup latency can be improved with the interpreter approach. Portability and security are much easier to achieve and maintain. Additionally, development impedance is much lower. A simple library like Wasm3 is easy to compile and integrate into an existing project. (Wasm3 builds in a just few seconds). Finally, on some platforms (i.e. iOS and WebAssembly itself) you can't generate executable code pages in runtime, so JIT is unavailable.

### Why would you want to run WASM on embedded devices?

Wasm3 started as a research project and remains so by many means. Evaluating the engine in different environments is part of the research. Given that we have `Lua`, `JS`, `Python`, `Lisp`, ... running on MCUs, `WebAssembly` is actually a promising alternative. It provides toolchain decoupling as well as a completely sandboxed, well-defined, predictable environment. Among practical use cases we can list `edge computing`, `scripting`, `plugin systems`, running `IoT rules`, `smart contracts`, etc.



Scailable.



iden<sup>3</sup>



Shareup txiki.js

# Src

|                                                                                    |                   |                                                             |              |
|------------------------------------------------------------------------------------|-------------------|-------------------------------------------------------------|--------------|
|   | .github/workflows | Fix build                                                   | 4 months ago |
|   | docs              | Update Cookbook.md                                          | 4 months ago |
|   | extra             | Fix build                                                   | 4 months ago |
|   | platforms         | Fix mistake in Readme ( <a href="#">#275</a> )              | 7 days ago   |
|   | source            | Add d_m3EnableWasiTracing support for MetaWASI              | 9 days ago   |
|   | test              | WASI test fixes                                             | 6 months ago |
|   | .codespellrc      | Separate action for spellcheck                              | 7 months ago |
|   | .gitignore        | Cleanup                                                     | 7 months ago |
|   | CMakeLists.txt    | Improve Intel C Compiler support                            | 4 months ago |
|   | LICENSE           | Update LICENSE                                              | 2 years ago  |
|   | README.md         | Update README.md                                            | 4 months ago |
|  | build.zig         | Add minimal build.zig build script ( <a href="#">#247</a> ) | 4 months ago |



## ***Build from source on RPi4 for GraalVM***

- <https://github.com/wasm3/wasm3/blob/main/docs/Development.md>

```
export GRAALVM_LLVM_TOOLCHAIN=$(lli --print-toolchain-path)
export PATH=$GRAALVM_LLVM_TOOLCHAIN:$PATH
```

**cd \$SRC\_WASM3, and run the following commands:**

```
mkdir -p build
cd build
cmake ..
make -j$(nproc)
```

```
2021-10-13 06:42:27 source/CMakeFiles/m3.dir/build.make:75: update target 'source/CMakeFiles/m3.dir/m3_api_libc.c.o' due to: source/CMakeFiles/m3.dir/compiler_depend.ts source/CMakeFiles/m3.dir/./source/m3_api.libc.c
2021-10-13 06:42:27 /usr/bin/cmake -E clang-12: fatal error: the clang compiler does not support '-march=native'
make[2]: *** [source/CMakeFiles/m3.dir/build.make:76: source/CMakeFiles/m3.dir/m3_api_libc.c.o] Error 1
make[1]: *** [CMakeFiles/Makfile2:996: source/CMakeFiles/m3.dir/all] Error 2
make: *** [Makefile:136: all] Error 2
```

**check \$SRC\_WASM3/CMakeLists.txt:**

```
28 option(BUILD_NATIVE "Build with machine-specific optimisations" ON)

173 if(BUILD_NATIVE)
174 if(APPLE AND CMAKE_C_COMPILER_ID MATCHES "Clang" AND CMAKE_HOST_SYSTEM_PROCESSOR MATCHES "arm64")
175 set(CMAKE_C_FLAGS_RELEASE "${CMAKE_C_FLAGS_RELEASE} -mcpu=native")
176 else()
177 set(CMAKE_C_FLAGS_RELEASE "${CMAKE_C_FLAGS_RELEASE} -march=native")
178 endif()
179 endif()
```

**disable BUILD\_NATIVE to pass the build:**

```
[mydev@fedora wasm3-main]$ git diff
diff --git a/CMakeLists.txt b/CMakeLists.txt
index 0862181..0a22936 100755
--- a/CMakeLists.txt
+++ b/CMakeLists.txt
@@ -25,7 +25,7 @@ else()
endif()
set_property(CACHE BUILD_WASI PROPERTY STRINGS none simple uvwasi metawasi)

-option(BUILD_NATIVE "Build with machine-specific optimisations" ON)
+option(BUILD_NATIVE "Build with machine-specific optimisations" OFF)

set(OUT_FILE "wasm3")
```

**no build error this time, but meet the similar issue as before:**

```
2021-10-13 07:07:49 /opt/MyWorkSpace/Dev5W/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin/cc -Dd_m3HasUVWASI -I/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-meps-uvwxyz-src/include -I/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/. -I/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/build/_deps/libuv-Dd_m3HasTracer -Wall -Wextra -Wparentheses -Wundef -Wpointer-arith -Wstrict-aliasing=2 -Werror=implicit-function-declaration -Wno-unused-function -Wno-unused-variable -Wno-unused-parameter -Wno-12: warning: '-fuse-lld' taking a path is deprecated. Use '--ld-path' instead [-Wfuse-lld-path]
clang-12: warning: '-fuse-lld' taking a path is deprecated. Use '--ld-path' instead [-Wfuse-lld-path]
g-field-initializers -Dd_m3HasUVWASI -O3 -Wfatal-errors -fomit-frame-pointer -fno-stack-check -fno-stack-protector -flto=thin -std=c99 -MD -MT CMakeFiles/wasm3.dir/platforms/app/main.c.o -MF CMakeFiles/wasm3.dir/platforms/app/main.c.o -o CMakeFiles/wasm3.dir/platforms/app/main.c.o -c /opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/platforms/app/main.c
2021-10-13 07:07:49 Live child 0xffff80842360 [CMakeFiles/wasm3.dir/platforms/app/main.c.o] PID 256654
2021-10-13 07:07:50 Reaping winning child 0xffff80842360 PID 256654
2021-10-13 07:07:50 Removing child 0xffff80842360 from chain.
2021-10-13 07:07:50 Successfully remade target file 'CMakeFiles/wasm3.dir/platforms/app/main.c.o'.
2021-10-13 07:07:50 Considering target file '_deps/wasm3.dir/build.make'.
2021-10-13 07:07:50 File 'CMakefiles/wasm3.dir/build.make' was considered already.
2021-10-13 07:07:50 Considering target file 'source/libm3.a'.
2021-10-13 07:07:50 Looking for an implicit rule for 'source/libm3.a'.
2021-10-13 07:07:50 No implicit rule found for 'source/libm3.a'.
2021-10-13 07:07:50 Finished prerequisites of target file 'source/libm3.a'.
2021-10-13 07:07:50 No need to remake target 'source/libm3.a'.
2021-10-13 07:07:50 Considering target file '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 07:07:50 Looking for an implicit rule for '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 07:07:50 No implicit rule found for '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 07:07:50 Finished prerequisites of target file '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 07:07:50 No need to remake target '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 07:07:50 Considering target file '_deps/libuv-build/libuv_a.a'.
2021-10-13 07:07:50 Looking for an implicit rule for '_deps/libuv-build/libuv_a.a'.
2021-10-13 07:07:50 No implicit rule found for '_deps/libuv-build/libuv_a.a'.
2021-10-13 07:07:50 Finished prerequisites of target file '_deps/libuv-build/libuv_a.a'.
2021-10-13 07:07:50 No need to remake target '_deps/libuv-build/libuv_a.a'.
2021-10-13 07:07:50 Finished prerequisites of target file 'wasm3'.
2021-10-13 07:07:50 Must remake target 'wasm3'.
2021-10-13 07:07:50 CMakeFiles/wasm3.dir/build.make:99: update target 'wasm3' due to: CMakeFiles/wasm3.dir/link.txt CMakeFiles/wasm3.dir/platforms/app/main.c.o CMakeFiles/wasm3.dir/build.make so _deps/uvwasi-build/libuvwasi_a.a _deps/libuv-build/libuv_a.a
2021-10-13 07:07:50 /usr/bin/cmake -E cmake_echo_color --switch=--green --bold --progress-dir=/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/build/CMakeFiles --progress-number C executable wasm3"
2021-10-13 07:07:50 Putting child 0xffff808421e0 (wasm3) PID 256657 on the chain.
2021-10-13 07:07:50 Live child 0xffff808421e0 (wasm3) PID 256657
```

**cd build, and check the generated files:**

```
[mydev@fedora build]$ file ./wasm3
./wasm3: ELF 64-bit LSB executable, ARM aarch64, version 1 (SYSV), dynamically linked, interpreter /lib/ld-linux-aarch64.so.1, for GNU/Linux 3.7.0, with debug_info, not stripped
[mydev@fedora build]$ ls
[mydev@fedora build]$ find . -name "*o"
./MakeFiles/_OMakeTOTest-CXX/bin/CMakeFiles/foo.dir/foo.cpp.o
./MakeFiles/_OMakeTOTest-CXX/bin/CMakeFiles/foo.dir/main.cpp.o
./MakeFiles/_OMakeTOTest-C/bin/CMakeFiles/foo.dir/foo.c.o
./MakeFiles/_OMakeTOTest-C/bin/CMakeFiles/foo.dir/main.c.o
./MakeFiles/wasm3.dir/platform/app/main.c.o
./deps/uvwasi-build/Makefiles/uvwasi_L.dir/src/clocks.c.o
./deps/uvwasi-build/Makefiles/uvwasi_L.dir/src/fdtable.c.o
./deps/uvwasi-build/Makefiles/uvwasi_L.dir/src/path_resolver.c.o
./deps/uvwasi-build/Makefiles/uvwasi_B.dir/src/poll_oneoff.c.o
./deps/uvwasi-build/Makefiles/uvwasi_B.dir/src/uv_mapping.c.o
./deps/uvwasi-build/Makefiles/uvwasi_E.dir/src/uvwasi.c.o
./deps/uvwasi-build/Makefiles/uvwasi_A.dir/src/wasi_rights.c.o
./deps/uvwasi-build/Makefiles/uvwasi_A.dir/src/wasi_serdes.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/asynch.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/core.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/fs.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/fsck.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/getaddrinfo.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/getnameinfo.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/loop-watcher.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/loop.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/pipe.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/poll.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/process.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/random-devurandom.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/random.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/socket.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/tcp.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/thread.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/tty.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/udp.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/proctitle.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/linux-core.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/linux-notify.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/linux-syscalls.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/procfs-epath.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/random-getrandom.c.o
./deps/libuv-build/Makefiles/uv_a.dir/src/unix/random-sysctl-linux.c.o
```





```
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/fs-poll.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/idna.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/inet.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/random.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/strncpy.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/threadpool.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/timer.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/uv-common.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/uv-data-getter-setters.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/version.c.o
./source/CMakeFiles/m3.dir/m3_api_libc.c.o
./source/CMakeFiles/m3.dir/m3_api_wasi.c.o
./source/CMakeFiles/m3.dir/m3_api_uvwasi.c.o
./source/CMakeFiles/m3.dir/m3_api_meta_wasi.c.o
./source/CMakeFiles/m3.dir/m3_api_tracer.c.o
./source/CMakeFiles/m3.dir/m3_bind.c.o
./source/CMakeFiles/m3.dir/m3_code.c.o
./source/CMakeFiles/m3.dir/m3_compile.c.o
./source/CMakeFiles/m3.dir/m3_core.c.o
./source/CMakeFiles/m3.dir/m3_emit.c.o
./source/CMakeFiles/m3.dir/m3_env.c.o
./source/CMakeFiles/m3.dir/m3_exec.c.o
./source/CMakeFiles/m3.dir/m3_function.c.o
./source/CMakeFiles/m3.dir/m3_info.c.o
./source/CMakeFiles/m3.dir/m3_module.c.o
./source/CMakeFiles/m3.dir/m3_parse.c.o
[mydev@fedora build]$
[mydev@fedora build]$ file ./CMakeFiles/wasm3.dir/platforms/app/main.c.o
./CMakeFiles/wasm3.dir/platforms/app/main.c.o: LLVM IR bitcode
[mydev@fedora build]$
[mydev@fedora build]$ file ./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/uvwasi.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/uvwasi.c.o: LLVM IR bitcode
[mydev@fedora build]$
[mydev@fedora build]$ file ./_deps/libuv-build/CMakeFiles/uv_a.dir/src/uv-common.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/uv-common.c.o: LLVM IR bitcode
[mydev@fedora build]$
[mydev@fedora build]$ file ./source/CMakeFiles/m3.dir/m3_compile.c.o
./source/CMakeFiles/m3.dir/m3_compile.c.o: LLVM IR bitcode
[mydev@fedora build]$
```

**The final executable “wasm3” is ELF format, but all the previous compiled .o files are LLVM bitcode, there should be something wrong with the linker...**



## The indication from \$SRC\_WASM3/CMakeLists.txt:

```
30 set(OUT_FILE "wasm3")
99 add_executable(${OUT_FILE} ${app_srcs})
188 target_link_libraries(${OUT_FILE} m3)
209 target_link_libraries(${OUT_FILE} uvwasi_a uv_a)
```

### check the linker:

```
[mydev@fedora build]$ mkdir -p out
[mydev@fedora build]$
[mydev@fedora build]$ find . -name "*.a"
./CMakeFiles/_CMakeLTOTest-CXX/bin/libfoo.a
./CMakeFiles/_CMakeLTOTest-C/bin/libfoo.a
./_deps/uvwasi-build/libuvwasi_a.a
./_deps/libuv-build/libuv_a.a
./source/libm3.a
[mydev@fedora build]$
[mydev@fedora build]$ cp ./_deps/uvwasi-build/libuvwasi_a.a out
[mydev@fedora build]$ cp ./_deps/libuv-build/libuv_a.a out
[mydev@fedora build]$ cp ./source/libm3.a out
[mydev@fedora build]$ cp ./CMakeFiles/wasm3.dir/platforms/app/main.c.o out
[mydev@fedora build]$
[mydev@fedora build]$ cd out;ll
total 3088
drwxr-xr-x. 1 mydev mydev 74 Oct 13 22:39 .
drwxr-xr-x. 1 mydev mydev 140 Oct 13 22:39 ../
-rw-r--r--. 1 mydev mydev 1191958 Oct 13 22:39 libm3.a
-rw-r--r--. 1 mydev mydev 1398412 Oct 13 22:39 libuv_a.a
-rw-r--r--. 1 mydev mydev 480654 Oct 13 22:39 libuvwasi_a.a
-rw-r--r--. 1 mydev mydev 78940 Oct 13 22:39 main.c.o
[mydev@fedora out]$
[mydev@fedora out]$ lli --print-toolchain-path
/opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin
[mydev@fedora out]$
```

```
[mydev@fedora out]$ /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin/graalvm-native-ld main.c.o libm3.a libuv_a.a libuvwasi_a.a -o wasm3
ld.lld: error: undefined symbol: memset
>>> referenced by m3_api_libc.c:45 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_api_libc.c:45)
 >>> lto.tmp:(m3_libc_memset)
>>> referenced by m3_core.c:145 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_core.c:145)
 >>> lto.tmp:(m3_Realloc_Impl)
>>> referenced by m3_env.c:261 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_env.c:261)
 >>> lto.tmp:(EvaluateExpression)
>>> referenced 13 more times

ld.lld: error: undefined symbol: memmove
>>> referenced by m3_api_libc.c:60 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_api_libc.c:60)
 >>> lto.tmp:(m3_libc_memmove)
>>> referenced by m3_exec.h:717 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source./m3_exec.h:717)
 >>> lto.tmp:(op_MemCopy)
>>> referenced by stream.c:643 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/build/_deps/libuv-src/src/unix/stream.c:643)
 >>> lto.tmp:(uv_accept)
>>> referenced 1 more times

ld.lld: error: undefined symbol: stdout
>>> referenced by m3_api_libc.c:73 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_api_libc.c:73)
 >>> lto.tmp:(m3_libc_print)
>>> referenced by m3_api_libc.c:73 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_api_libc.c:73)
 >>> lto.tmp:(m3_libc_print)
>>> referenced by m3_api_libc.c:74 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_api_libc.c:74)
 >>> lto.tmp:(m3_libc_print)
>>> referenced 2 more times

ld.lld: error: undefined symbol: fwrite
>>> referenced by m3_api_libc.c:73 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_api_libc.c:73)
 >>> lto.tmp:(m3_libc_print)
>>> referenced by m3_api_libc.c:165 (/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/Official/wasm3-main/source/m3_api_libc.c:165)
 >>> lto.tmp:(m3_libc_printf)

```

## retry with llvm-link:

```
[mydev@fedora out]$ which llvm-link
/usr/bin/llvm-link
[mydev@fedora out]$ llvm-link main.c.o libm3.a libuv_a.a libuvwasi_a.a -o wasm3
error: linking module flags ['EnableSplitLTOUnit']: IDs have conflicting values in 'ArchiveModule' and 'llvm-link'
[mydev@fedora out]$
```

## LTO in \$SRC\_WASM3/CMakeLists.txt:

```
87 include(CheckIPOSupported)
121 check_ipo_supported(RESULT result)
122 if(result AND NOT WASIENV) # TODO: LTO breaks wasm imports
123 set_property(TARGET ${OUT_FILE} PROPERTY INTERPROCEDURAL_OPTIMIZATION True)
124 message("LTO: ON")
125 else()
126 message("LTO: OFF")
127 endif()
```



# debug the build:



# CHINA *OpenInfra Days*



# what behind the GraalVM LLVM toolchain:

```
[mydev@fedora wasm3-main]$ which clang
/opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin/clang
[mydev@fedora wasm3-main]$
[mydev@fedora wasm3-main]$ clang -v
GraalVM wrapper script for clang
GraalVM version: Development Build
running: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/lib/llvm/bin/clang -v
clang version 12.0.1 (GraalVM.org llvmorg-12.0.1-3-g6e0a5672bc-bf911ed69a5a 6e0a5672bc058d882dce3d56f90b72b64a6870d7
Target: aarch64-unknown-linux-gnu
Thread model: posix
InstalledDir: /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/lib/llvm/bin
Found candidate GCC installation: /usr/lib/gcc/aarch64-redhat-linux/11
Selected GCC installation: /usr/lib/gcc/aarch64-redhat-linux/11
Candidate multilib: .;@m64
Selected multilib: .;@m64
[mydev@fedora wasm3-main]$
```

```
[mydev@fedora build]$ tree /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/lib/llvm/bin
/opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/lib/llvm/bin
├── clang -> clang-12
├── clang++ -> clang
├── clang-12
├── clang-cl -> clang
├── clang-cpp -> clang
├── clang-format
├── ld64.lld -> lld
├── ld64.lld.darwinnew -> lld
├── ld.lld -> lld
└──
 llc
 lld
 lld-link -> lld
 lli
 llvm-ar
 llvm-as
 llvm-bitcode-strip -> llvm-objcopy
 llvm-config
 llvm-diff
 llvm-dis
 llvm-dlltool -> llvm-ar
 llvm-dwarfdump
 llvm-extract
 llvm-gsymutil
 llvm-ifs
 llvm-install-name-tool -> llvm-objcopy
 llvm-lib -> llvm-ar
 llvm-libtool-darwin
 llvm-link
 llvm-ml
 llvm-nm
 llvm-objcopy
 llvm-objdump
 llvm-profgen
 llvm-ranlib -> llvm-ar
 llvm-readelf -> llvm-readobj
 llvm-readobj
 llvm-reduce
 llvm-strip -> llvm-objcopy
 opt
 split-file
 wasm-ld -> lld
```

## check the link.txt and linking the wasm3 executable manually according to it:

```
[mydev@fedora wasm3-main]$ cd build/
[mydev@fedora build]$ ll
total 2676
drwxr-xr-x. 1 mydev mydev 140 Oct 13 22:39 .
drwxr-xr-x. 1 mydev mydev 210 Oct 13 22:18 ../
-rw-r--r--. 1 mydev mydev 23253 Oct 13 22:18 CMakeCache.txt
drwxr-xr-x. 1 mydev mydev 418 Oct 13 22:18 CMakeFiles/
-rw-r--r--. 1 mydev mydev 2012 Oct 13 22:18 cmake_install.cmake
drwxr-xr-x. 1 mydev mydev 142 Oct 13 22:18 _deps/
-rw-r--r--. 1 mydev mydev 24471 Oct 13 22:18 Makefile
drwxr-xr-x. 1 mydev mydev 74 Oct 13 23:30 out/
drwxr-xr-x. 1 mydev mydev 88 Oct 13 22:18 source/
-rwrxr-xr-x. 1 mydev mydev 2686776 Oct 13 22:18 wasm3*
[mydev@fedora build]$
[mydev@fedora build]$ find . -name "link.txt"
./CMakeFiles/_CMakeLTOTest-CXX/bin/CMakeFiles/foo.dir/link.txt
./CMakeFiles/_CMakeLTOTest-CXX/bin/CMakeFiles/boo.dir/link.txt
./CMakeFiles/_CMakeLTOTest-C/bin/CMakeFiles/foo.dir/link.txt
./CMakeFiles/_CMakeLTOTest-C/bin/CMakeFiles/boo.dir/link.txt
./CMakeFiles/wasm3.dir/link.txt
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/link.txt
./_deps/libuv-build/CMakeFiles/uv_a.dir/link.txt
./_deps/libuv-build/CMakeFiles/uv.dir/link.txt
./source/CMakeFiles/m3.dir/link.txt
[mydev@fedora build]$
[mydev@fedora build]$ cat ./CMakeFiles/wasm3.dir/link.txt
/opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin/cc -Dm3HasTracer -Wall -Wextra -Wparentheses -Wundef -Wpointer-arith -Wstrict-aliasing=2 -Werror=implicit-function-declaration -Wno-unused-function -Wno-unused-variable -Wno-unused-parameter -Wno-missing-field-initializers -Dm3HasUVWASI -O3 -Wfatal-errors -fomit-frame-pointer -fno-stack-check -fno-stack-protector -fno=thin -O3 CMakeFiles/wasm3.dir/platforms/app/main.c.o -o wasm3 -lm source/libm3.a _deps/uvwasi-build/libuvwasi_a.a _deps/libuv-build/libuv_a.a -lpthread -ldl -lrt
[mydev@fedora build]$
[mydev@fedora build]$ /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin/cc -Dm3HasTracer -Wall -Wextra -Wparentheses -Wundef -Wpointer-arith -Wstrict-aliasing=2 -Werror=implicit-function-declaration -Wno-unused-function -Wno-unused-variable -Wno-unused-parameter -Wno-missing-field-initializers -Dm3HasUVWASI -O3 -Wfatal-errors -fomit-frame-pointer -fno-stack-check -fno-stack-protector -fno=thin -O3 CMakeFiles/wasm3.dir/platforms/app/main.c.o -o wasm3 -lm source/libm3.a _deps/uvwasi-build/libuvwasi_a.a _deps/libuv-build/libuv_a.a -lpthread -ldl -lrt
clang-12: warning: '-fuse-ld=' taking a path is deprecated. Use '--ld-path=' instead [-Wfuse-ld-path]
clang-12: warning: '-fuse-ld=' taking a path is deprecated. Use '--ld-path=' instead [-Wfuse-ld-path]
[mydev@fedora build]$
[mydev@fedora build]$ ll
total 2676
drwxr-xr-x. 1 mydev mydev 140 Oct 13 23:32 .
drwxr-xr-x. 1 mydev mydev 210 Oct 13 22:18 ../
-rw-r--r--. 1 mydev mydev 23253 Oct 13 22:18 CMakeCache.txt
drwxr-xr-x. 1 mydev mydev 418 Oct 13 22:18 CMakeFiles/
-rw-r--r--. 1 mydev mydev 2012 Oct 13 22:18 cmake_install.cmake
drwxr-xr-x. 1 mydev mydev 142 Oct 13 22:18 _deps/
-rw-r--r--. 1 mydev mydev 24471 Oct 13 22:18 Makefile
drwxr-xr-x. 1 mydev mydev 74 Oct 13 23:30 out/
drwxr-xr-x. 1 mydev mydev 88 Oct 13 22:18 source/
-rwrxr-xr-x. 1 mydev mydev 2686776 Oct 13 23:32 wasm3*
[mydev@fedora build]$
[mydev@fedora build]$ file ./wasm3
./wasm3: ELF 64-bit LSB executable, ARM aarch64, version 1 (SYSV), dynamically linked, interpreter /lib/ld-linux-aarch64.so.1, for GNU/Linux 3.7.0, with debug_info, not stripped
```



## repatch the \$SRC\_WASM3/CMakeLists.txt:

```
[mydev@fedora wasm3-main]$ git diff
diff --git a/CMakeLists.txt b/CMakeLists.txt
index 0862181..c86a0b5 100755
--- a/CMakeLists.txt
+++ b/CMakeLists.txt
@@ -25,7 +25,7 @@ else()
endif()
set_property(CACHE BUILD_WASI PROPERTY STRINGS none simple uvwasi metawasi)

-option(BUILD_NATIVE "Build with machine-specific optimisations" ON)
+option(BUILD_NATIVE "Build with machine-specific optimisations" OFF)

set(OUT_FILE "wasm3")

@@ -84,7 +84,7 @@ message("Compiler: ${CMAKE_C_COMPILER_ID}")
message("Build Type: ${CMAKE_BUILD_TYPE}")

#include(CheckIPOSupported)
+##include(CheckIPOSupported)

set(CMAKE_C_STANDARD 99)
set(CMAKE_C_STANDARD_REQUIRED YES)
@@ -159,6 +159,7 @@ else()
 set(CMAKE_C_FLAGS "${CMAKE_C_FLAGS} -Wall -Wextra -Wparentheses -Wundef -Wpointer-arith -Wstrict-aliasing=2")
 set(CMAKE_C_FLAGS "${CMAKE_C_FLAGS} -Werror=implicit-function-declaration") # -Werror=cast-align
 set(CMAKE_C_FLAGS "${CMAKE_C_FLAGS} -Wno-unused-function -Wno-unused-variable -Wno-unused-parameter -Wno-missing-field-initializers")
+ set(CMAKE_C_FLAGS "${CMAKE_C_FLAGS} --ld-path=/usr/bin/llvm-link")
 if (CMAKE_C_COMPILER_ID MATCHES "Clang")
 # TODO: Place clang-specific options here
 elseif(CMAKE_C_COMPILER_ID MATCHES "Intel")
@@ -209,13 +210,13 @@ elseif(BUILD_WASI MATCHES "uvwasi")
 target_link_libraries(${OUT_FILE} uvwasi_a uv_a)
endif()

-check_ipo_supported(RESULT result)
-if(result AND NOT WASIENV) # TODO: LTO breaks wasm imports
- set_property(TARGET ${OUT_FILE} PROPERTY INTERPROCEDURAL_OPTIMIZATION True)
- message("LTO: ON")
-else()
- message("LTO: OFF")
-endif()
+##check_ipo_supported(RESULT result)
+##if(result AND NOT WASIENV) # TODO: LTO breaks wasm imports
+## set_property(TARGET ${OUT_FILE} PROPERTY INTERPROCEDURAL_OPTIMIZATION True)
+## message("LTO: ON")
+##else()
+## message("LTO: OFF")
+##endif()

add_subdirectory(source)
```



## rebuild:

```
2021-10-13 11:56:45 [98%] Building C object CMakeFiles/wasm3.dir/platforms/app/main.c.o
2021-10-13 11:56:45 Reaping winning child 0xfffffb8842360 PID 317628
2021-10-13 11:56:45 /opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/languages/llvm/native/bin/cc -Dd_m3HasUVWASI -I/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/wasm3-main/build/_deps/uvwasl-src/include -Dd_m3HasTracer -Wall -Wext-l-src/include -I/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/wasm3-main/source/ -I/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/wasm3-build/_deps/libuv-src/include -Dd_m3HasTracer -Wall -Wext-l-src/include -Wno-deprecated-declarations -Wno-strict-aliasing -Werror=implicit-function-declaration -Wno-unused-function -Wno-unused-variable -Wno-unused-parameter -Wno-missing-field-initializers -Ild-path=/usr/bin/llvm-link -Dd_m3HasUVWASI -O3 -Wfatal-errors -fno-frame-pointer -fno-stack-check -fno-stack-protector -std=c99 -MD -MT CMakeFiles/wasm3.dir/platforms/app/main.c.o -MF CMakeFiles/wasm3.dir/platforms/app/main.c.d -o CMakeFiles/wasm3.dir/platforms/app/main.c.o -c /opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/wasm3-main/platforms/app/main.c
2021-10-13 11:56:45 Reaping winning child 0xfffffb8842360 PID 317629
2021-10-13 11:56:45 Removing child 0xfffffb8842360 PID 317629 from chain.
2021-10-13 11:56:45 Successfully remade target file 'CMakeFiles/wasm3.dir/platforms/app/main.c.o'.
2021-10-13 11:56:45 Considering target file 'CMakeFiles/wasm3.dir/build.make'.
2021-10-13 11:56:45 File 'CMakeFiles/wasm3.dir/build.make' was considered already.
2021-10-13 11:56:45 Considering target file 'source/libm3.a'.
2021-10-13 11:56:45 Looking for an implicit rule for 'source/libm3.a'.
2021-10-13 11:56:45 No implicit rule found for 'source/libm3.a'.
2021-10-13 11:56:45 Finished prerequisites of target file 'source/libm3.a'.
2021-10-13 11:56:45 No need to remake target 'source/libm3.a'.
2021-10-13 11:56:45 Considering target file '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 11:56:45 Looking for an implicit rule for '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 11:56:45 No implicit rule found for '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 11:56:45 Finished prerequisites of target file '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 11:56:45 No need to remake target '_deps/uvwasi-build/libuvwasi_a.a'.
2021-10-13 11:56:45 Considering target file '_deps/libuv-build/libuv_a.a'.
2021-10-13 11:56:45 Unknown command line argument '-EL'. Try: '/usr/bin/llvm-link --help'
llvm-link: Did you mean '-S'?
2021-10-13 11:56:45 Looking for an implicit rule for '_deps/libuv-build/libuv_a.a'.
2021-10-13 11:56:45 No implicit rule found for '_deps/libuv-build/libuv_a.a'.
2021-10-13 11:56:45 Finished prerequisites of target file '_deps/libuv-build/libuv_a.a'.
2021-10-13 11:56:45 No need to remake target '_deps/libuv-build/libuv_a.a'.
2021-10-13 11:56:45 Finished prerequisites of target file 'wasm3'.
2021-10-13 11:56:45 Must remake target 'wasm3'.
2021-10-13 11:56:45 CMakeFiles/wasm3.dir/build.make:99: update target 'wasm3' due to: CMakeFiles/wasm3.dir/link.txt CMakeFiles/wasm3.dir/platforms/app/main.c.o CMakeFiles/wasm3.dir/build.make source/libm3.a _deps/uvwasi-build/libuvwasi_a.a _deps/libuv-build/libuv_a.a
2021-10-13 11:56:45 /usr/bin/cmake -E cmake_echo_color --switch= --green --bold --progress-dir=/opt/MyWorkSpace/MyProjs/Runtime/WASM/Impls/Wasm3/wasm3-main/build/CMakeFiles --progress-num=100 "Linking C executable wasm3"
2021-10-13 11:56:45 Putting child 0xfffffb88421e0 (wasm3) PID 317638 on the chain.
2021-10-13 11:56:45 Live child 0xfffffb88421e0 (wasm3) PID 317638
2021-10-13 11:56:45 [100%] Linking C executable wasm3
2021-10-13 11:56:45 Reaping winning child 0xfffffb88421e0 PID 317638
2021-10-13 11:56:45 /usr/bin/cmake -E cmake_link_script CMakeFiles/wasm3.dir/link.txt --verbose=
2021-10-13 11:56:45 Live child 0xfffffb88421e0 (wasm3) PID 317639
2021-10-13 11:56:45 OVERVIEW: llvm linker
2021-10-13 11:56:45
2021-10-13 11:56:45 USAGE: llvm-link [options] <input bitcode files>
2021-10-13 11:56:45 OPTIONS:
```

## let's link the “wasm3” via llvmbit code manually:

```
[mydev@fedora build]$ mkdir -p out
[mydev@fedora build]$
[mydev@fedora build]$ find . -name "*.a"
./_deps/uvwasi-build/libuvwasi_a.a
./_deps/libuv-build/libuv_a.a
./source/libm3.a
[mydev@fedora build]$
[mydev@fedora build]$ cp ./_deps/uvwasi-build/libuvwasi_a.a out
[mydev@fedora build]$ cp ./_deps/libuv-build/libuv_a.a out
[mydev@fedora build]$ cp ./source/libm3.a out
[mydev@fedora build]$
```





```
[mydev@fedora build]$ find . -name "*.o"
./CMakeFiles/wasm3.dir/platforms/app/main.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/clocks.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/fd_table.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/path_resolver.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/poll_oneoff.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/uv_mapping.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/uvwasi.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/wasi_rights.c.o
./_deps/uvwasi-build/CMakeFiles/uvwasi_a.dir/src/wasi_serdes.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/async.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/core.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/dl.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/fs.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/getaddrinfo.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/getnameinfo.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/loop-watcher.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/loop.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/pipe.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/poll.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/process.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/random-devurandom.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/signal.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/stream.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/tcp.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/thread.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/tty.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/udp.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/proctitle.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/linux-core.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/linux-inotify.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/linux-syscalls.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/procfs-exepath.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/random-getrandom.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/unix/random-sysctl-linux.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/fs-poll.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/idna.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/inet.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/random.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/strscpy.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/threadpool.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/timer.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/uv-common.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/uv-data-getter-setters.c.o
./_deps/libuv-build/CMakeFiles/uv_a.dir/src/version.c.o
./source/CMakeFiles/m3.dir/m3_api_libc.c.o
./source/CMakeFiles/m3.dir/m3_api_wasi.c.o
./source/CMakeFiles/m3.dir/m3_api_uvwasi.c.o
./source/CMakeFiles/m3.dir/m3_api_meta_wasi.c.o
./source/CMakeFiles/m3.dir/m3_api_tracer.c.o
./source/CMakeFiles/m3.dir/m3_bind.c.o
./source/CMakeFiles/m3.dir/m3_code.c.o
./source/CMakeFiles/m3.dir/m3_compile.c.o
./source/CMakeFiles/m3.dir/m3_core.c.o
./source/CMakeFiles/m3.dir/m3_emit.c.o
./source/CMakeFiles/m3.dir/m3_env.c.o
./source/CMakeFiles/m3.dir/m3_exec.c.o
./source/CMakeFiles/m3.dir/m3_function.c.o
./source/CMakeFiles/m3.dir/m3_info.c.o
./source/CMakeFiles/m3.dir/m3_module.c.o
./source/CMakeFiles/m3.dir/m3_parse.c.o
[mydev@fedora build]$
```



```
[mydev@fedora build]$ cp ./CMakeFiles/wasm3.dir/platforms/app/main.c.o out
[mydev@fedora build]$
[mydev@fedora build]$ cd out;ll
total 3084
drwxr-xr-x. 1 mydev mydev 74 Oct 13 12:09 .
drwxr-xr-x. 1 mydev mydev 130 Oct 13 12:08 ..
-rw-r--r--. 1 mydev mydev 1191238 Oct 13 12:09 libm3.a
-rw-r--r--. 1 mydev mydev 1396740 Oct 13 12:09 libuv_a.a
-rw-r--r--. 1 mydev mydev 480294 Oct 13 12:09 libuvwasi_a.a
-rw-r--r--. 1 mydev mydev 78332 Oct 13 12:09 main.c.o
[mydev@fedora out]$
[mydev@fedora out]$ llvm-link main.c.o libm3.a libuvwasi_a.a libuv_a.a -o wasm3
[mydev@fedora out]$
[mydev@fedora out]$ ll
total 5656
drwxr-xr-x. 1 mydev mydev 84 Oct 13 12:10 .
drwxr-xr-x. 1 mydev mydev 130 Oct 13 12:08 ..
-rw-r--r--. 1 mydev mydev 1191238 Oct 13 12:09 libm3.a
-rw-r--r--. 1 mydev mydev 1396740 Oct 13 12:09 libuv_a.a
-rw-r--r--. 1 mydev mydev 480294 Oct 13 12:09 libuvwasi_a.a
-rw-r--r--. 1 mydev mydev 78332 Oct 13 12:09 main.c.o
-rw-r--r--. 1 mydev mydev 2633308 Oct 13 12:10 wasm3
[mydev@fedora out]$
[mydev@fedora out]$ file ./wasm3
./wasm3: LLVM IR bitcode
[mydev@fedora out]$
[mydev@fedora out]$ which lli
/opt/MyWorkSpace/DevSW/Java/JDK/GraalVM/CE/java17-21.3.0-dev/bin/lli
[mydev@fedora out]$
[mydev@fedora out]$ lli ./wasm3
Usage:
 wasm3 [options] <file> [args...]
 wasm3 --repl [file]
Options:
 --func <function> function to run default: _start
 --stack-size <size> stack size in bytes default: 64KB
 --dump-on-trap dump wasm memory
[mydev@fedora out]$
```

Successfully launch “wasm3” on GraalVM!

## 2.2 WAMR (WebAssembly Micro Runtime)

- <https://github.com/bytecodealliance/wasm-micro-runtime>
  - Working on it, please see the result in our upcoming “Third discussion on GraalVM-based unified runtime for eBPF and WebAssembly”...
- 



### 3) Summary

- Currently, there is no universal method to “port” an existed project of eBPF or Wasm runtime to GraalVM unless it is either too simple or already “GraalVM-native”, which means we have to deal with it case by case.
- E.g., for native language based project: try to build the source code to LLVM bitcode, customize the link process to get the expected executable. You may have to resolve the failures during the build process, hack the build system or even the toolchain that used, and provide workarounds to various issues you may meet. This is a “manual” procedure until find a workable solution to meet your target, then you can automate those work with tools and scripts.
- Additional work is needed by Rust-based projects as it has its own compiler and build system.
- Be careful with “weird” behavior of the official GraalVM LLVM toolchain, especially for its linker.



# IV. GraalVM as a Service(GaaS) for Cloud Native

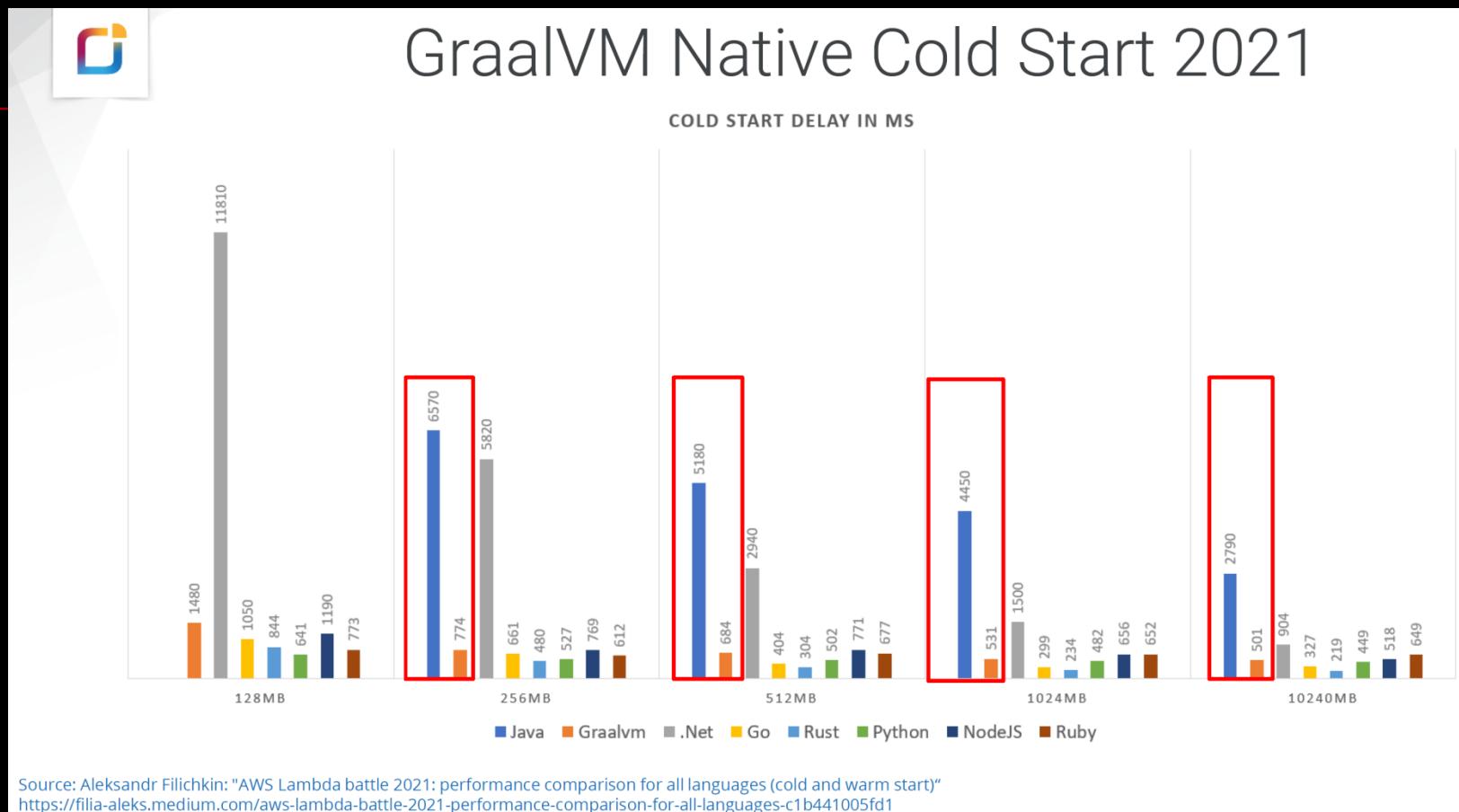
## 1) Containers vs WASI on K8s

- | Containers                                          | WASI                                              |
|-----------------------------------------------------|---------------------------------------------------|
| High startup cost.                                  | Low startup cost.                                 |
| Bigger binary files and highest memory consumption. | Smaller .wasm files and lower memory consumption. |
| Security requires high starting cost.               | High security by default.                         |
| Active open-source community.                       | Active open-source community.                     |
| Over 10 years of active development for Docker.     | WASI was only created 2 years ago.                |
| Access to multithreading.                           | Only able to run in a single thread.              |
| Access to Network.                                  | Limited network access.                           |
| Any library can be compiled to.                     | Not every library can be compiled to.             |

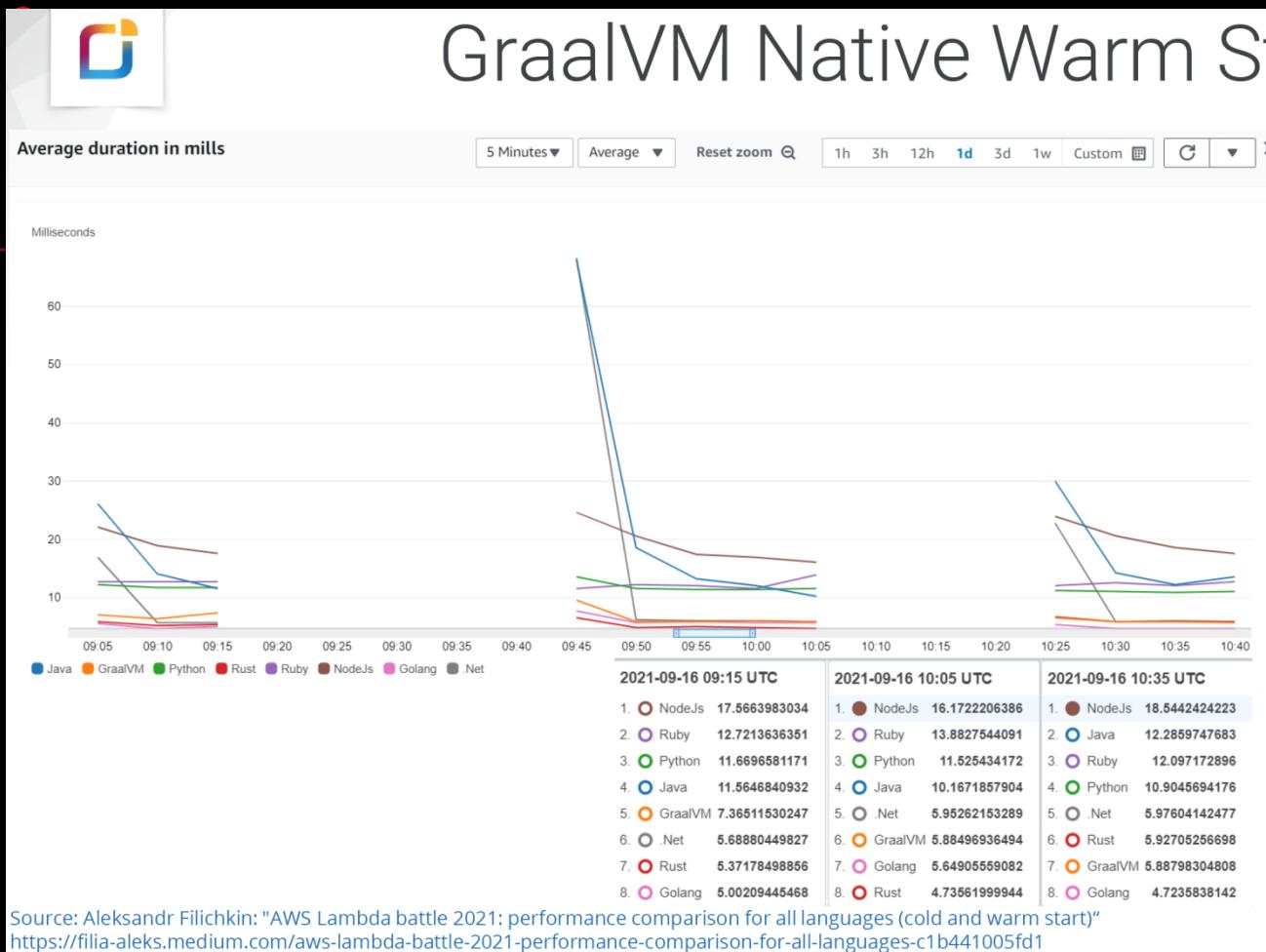
Source: “Living on the Edge: Using IoT Devices on Kubernetes WebAssembly Applications”, Kate Goldenring (Microsoft) and Rodrigo Rodrigues Lemos (Facebook), Cloud Native Wasm Day North America 2021

- <https://quarkus.io/>
- **Supersonic Subatomic Java...**
- **Spring Framework & Boot, Micronaut, and more.**

## 2) Serverless with GraalVM AWS Lambda



# GraalVM Native Warm Start 2021



# 3) DSLs

## 3.1 P4

- <https://github.com/p4lang/p4c>

```
[mydev@fedora p4c-main]$ tokei
```

| Language           | Files | Lines  | Code   | Comments | Blanks |
|--------------------|-------|--------|--------|----------|--------|
| GNU Style Assembly | 1     | 1      | 1      | 0        | 0      |
| Autoconf           | 4     | 638    | 436    | 119      | 83     |
| Automake           | 2     | 534    | 385    | 79       | 70     |
| BASH               | 7     | 873    | 562    | 189      | 122    |
| Batch              | 1     | 1      | 1      | 0        | 0      |
| C                  | 24    | 18028  | 13685  | 1831     | 2512   |
| C Header           | 360   | 88760  | 53938  | 25288    | 9534   |
| CMake              | 34    | 4000   | 2559   | 945      | 496    |
| C++                | 348   | 117653 | 87339  | 16547    | 13767  |
| C++ Header         | 4     | 171    | 99     | 35       | 37     |
| CSS                | 1     | 8      | 6      | 0        | 2      |
| Dockerfile         | 2     | 32     | 16     | 12       | 4      |
| Emacs Lisp         | 1     | 125    | 87     | 18       | 20     |
| HTML               | 1     | 21     | 15     | 6        | 0      |
| JavaScript         | 1     | 5      | 5      | 0        | 0      |
| JSON               | 72    | 5723   | 5648   | 0        | 75     |
| LLVM               | 2     | 659    | 631    | 0        | 28     |
| Makefile           | 8     | 634    | 349    | 155      | 130    |
| Module-Definition  | 9     | 3192   | 2853   | 0        | 339    |
| MSBuild            | 2     | 38     | 38     | 0        | 0      |
| Pascal             | 1     | 254    | 129    | 91       | 34     |
| Perl               | 1     | 59     | 34     | 19       | 6      |
| Protocol Buffers   | 6     | 1550   | 810    | 594      | 146    |
| Python             | 75    | 26353  | 19974  | 3097     | 3282   |
| RPM Specfile       | 72    | 8881   | 7759   | 0        | 1122   |
| ReStructuredText   | 1     | 168    | 124    | 0        | 44     |
| Shell              | 26    | 2152   | 1545   | 328      | 279    |
| TeX                | 1     | 157    | 129    | 13       | 15     |
| Plain Text         | 1076  | 22583  | 0      | 22526    | 57     |
| Visual Studio Proj | 17    | 2259   | 2259   | 0        | 0      |
| Visual Studio Sol  | 5     | 186    | 183    | 0        | 3      |
| Xcode Config       | 6     | 146    | 33     | 81       | 32     |
| XML                | 1     | 194    | 182    | 7        | 5      |
| YAML               | 1     | 71     | 59     | 1        | 11     |
| Markdown           | 90    | 41074  | 0      | 31994    | 9080   |
| - BASH             | 7     | 101    | 80     | 19       | 2      |
| - C                | 1     | 5      | 4      | 1        | 0      |
| - C++              | 2     | 38     | 37     | 1        | 0      |
| - Python           | 1     | 3      | 3      | 0        | 0      |
| (Total)            |       | 41221  | 124    | 32015    | 9082   |
| Total              | 2263  | 347330 | 201997 | 103996   | 41337  |

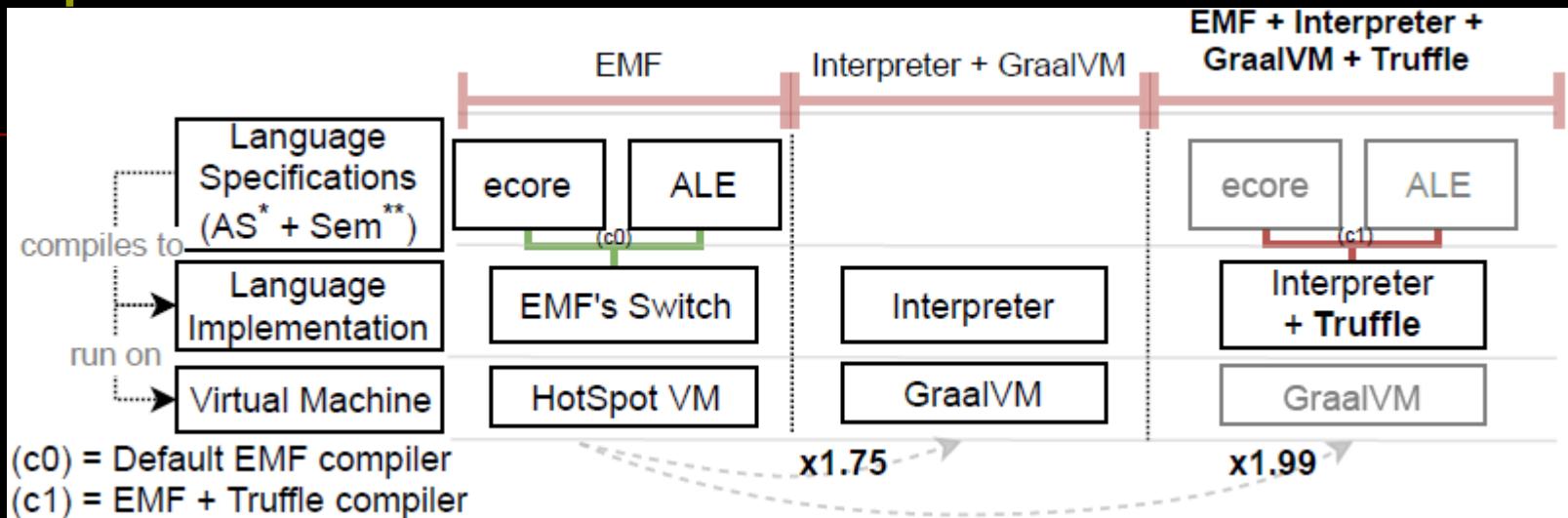
```
[mydev@fedora p4c-main]$ ll
total 112
drwxr-xr-x. 1 mydev mydev 504 Oct 13 12:19 .
drwxr-xr-x. 1 mydev mydev 106 Oct 13 12:19 ..
drwxr-xr-x. 1 mydev mydev 68 Oct 13 12:19 backends/
drwxr-xr-x. 1 mydev mydev 100 Oct 13 12:19 bazel/
-rw-r--r--. 1 mydev mydev 119 Oct 13 12:19 .bazelignore
-rwxr-xr-x. 1 mydev mydev 879 Oct 13 12:19 bootstrap.sh*
-rw-r--r--. 1 mydev mydev 9729 Oct 13 12:19 BUILD.bazel
drwxr-xr-x. 1 mydev mydev 256 Oct 13 12:19 cmake/
-rw-r--r--. 1 mydev mydev 19354 Oct 13 12:19 CMakeLists.txt
drwxr-xr-x. 1 mydev mydev 582 Oct 13 12:19 control-plane/
-rw-r--r--. 1 mydev mydev 650 Oct 13 12:19 CPPLINT.cfg
drwxr-xr-x. 1 mydev mydev 120 Oct 13 12:19 debian/
-rw-r--r--. 1 mydev mydev 893 Oct 13 12:19 Dockerfile
-rw-r--r--. 1 mydev mydev 66 Oct 13 12:19 .dockerignore
drwxr-xr-x. 1 mydev mydev 326 Oct 13 12:19 docs/
drwxr-xr-x. 1 mydev mydev 68 Oct 13 12:19 frontends/
-rwxr-xr-x. 1 mydev mydev 9584 Oct 13 12:19 .gdbinit*
drwxr-xr-x. 1 mydev mydev 152 Oct 13 12:19 .git/
drwxr-xr-x. 1 mydev mydev 58 Oct 13 12:19 .github/
-rw-r--r--. 1 mydev mydev 553 Oct 13 12:19 .gitignore
-rw-r--r--. 1 mydev mydev 404 Oct 13 12:19 .gitmodules
drwxr-xr-x. 1 mydev mydev 922 Oct 13 12:19 ir/
drwxr-xr-x. 1 mydev mydev 1338 Oct 13 12:19 lib/
-rw-r--r--. 1 mydev mydev 10172 Oct 13 12:19 LICENSE
drwxr-xr-x. 1 mydev mydev 2778 Oct 13 12:19 midend/
drwxr-xr-x. 1 mydev mydev 138 Oct 13 12:19 p4include/
-rw-r--r--. 1 mydev mydev 19096 Oct 13 12:19 README.md
drwxr-xr-x. 1 mydev mydev 90 Oct 13 12:19 test/
drwxr-xr-x. 1 mydev mydev 348 Oct 13 12:19 testdata/
drwxr-xr-x. 1 mydev mydev 238 Oct 13 12:19 tools/
-rw-r--r--. 1 mydev mydev 6 Oct 13 12:19 Version.txt
-rw-r--r--. 1 mydev mydev 975 Oct 13 12:19 WORKSPACE.bazel
[mydev@fedora p4c-main]$
```

```
[mydev@fedora p4c-main]$ find . -name "CMakeLists.txt"
./CMakeLists.txt
./backends/bmv2/CMakeLists.txt
./backends/dpdk/CMakeLists.txt
./backends/ebpf/CMakeLists.txt
./backends/graphs/CMakeLists.txt
./backends/p4test/CMakeLists.txt
./backends/ubpf/CMakeLists.txt
./control-plane/CMakeLists.txt
./frontends/CMakeLists.txt
./ir/CMakeLists.txt
./lib/CMakeLists.txt
./midend/CMakeLists.txt
./test/CMakeLists.txt
./test/frameworks/gtest/CMakeLists.txt
./test/frameworks/gtest/googletest/CMakeLists.txt
./test/frameworks/gtest/googlemock/CMakeLists.txt
./tools/driver/CMakeLists.txt
./tools/ir-generator/CMakeLists.txt
[mydev@fedora p4c-main]$
```

- Working on build it to LLVM bitcode manually...

## Automatic generation of Truffle-based interpreters for DSLs

- <https://hal.inria.fr/hal-02395867v2/document>



- [https://en.wikipedia.org/wiki/Eclipse\\_Modeling\\_Framework](https://en.wikipedia.org/wiki/Eclipse_Modeling_Framework)  
<https://www.eclipse.org/modeling/emf/>  
**Eclipse Modeling Framework**

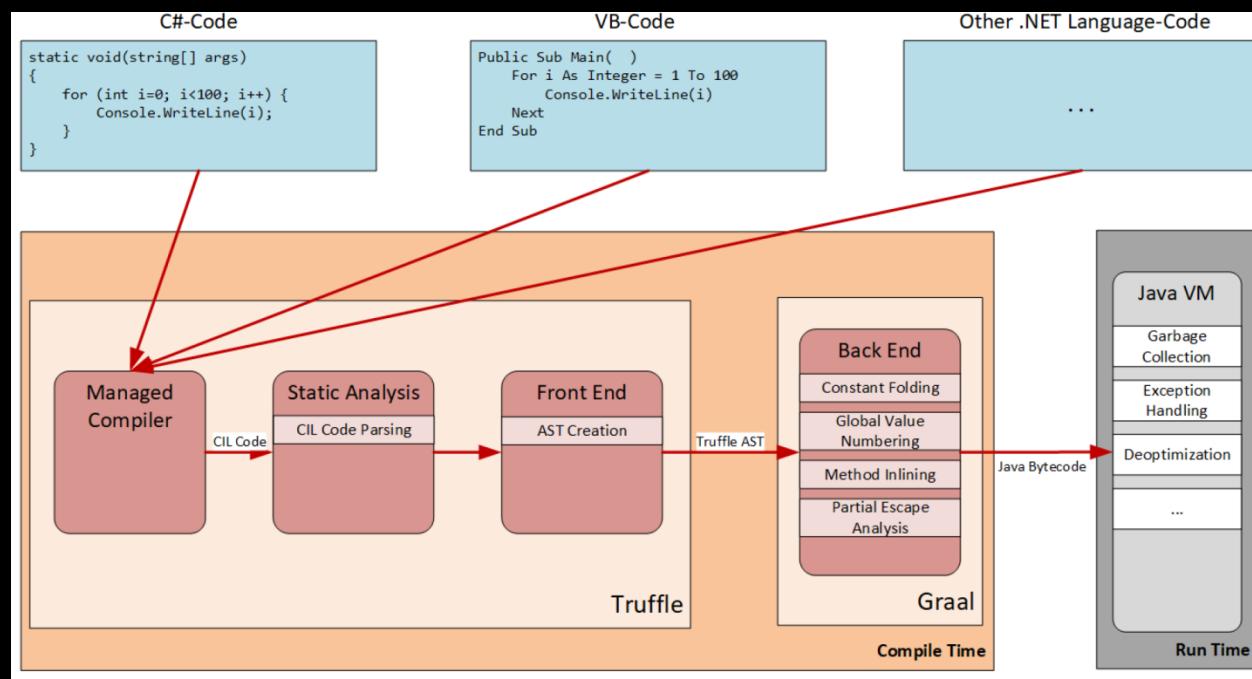


## 4) .Net on GraalVM

- <https://en.wikipedia.org/wiki/.NET>
- [https://en.wikipedia.org/wiki/Common\\_Intermediate\\_Language](https://en.wikipedia.org/wiki/Common_Intermediate_Language)

### 3.1 Truffle CIL Interpreter

- <https://githubmemory.com/repo/jagotu/BACIL>
- <https://epub.jku.at/obvulihs/download/pdf/5473678?originalFileName=true>





## 5) Go on GraalVM

### Gollvm

- <https://go.googlesource.com/gollvm>

Gollvm is an LLVM-based Go compiler. It incorporates “gofrontend” (a Go language front end written in C++ and shared with GCCGO), a bridge component (which translates from gofrontend IR to LLVM IR), and a driver that sends the resulting IR through the LLVM back end.

Gollvm is set up to be a subproject within the LLVM tools directory, similar to how things work for “clang” or “compiler-rt”: you check out a copy of the LLVM source tree, then within the LLVM tree you check out additional git repos.

How do I see the LLVM IR generated by gollvm?

The ‘llvm-goc’ command supports the -emit-llvm flag, however passing this option to a “go build” command is not practical, since the “go build” won’t be expecting the compiler to emit LLVM bitcode or assembly.

A better recipe is to run “go build” with “-x -work” to capture the commands being executed, then rerun the llvm-goc command shown adding “-S -emit-llvm”. The resulting output will be an LLVM IR dump. Example:

```
% go build -work -x mypackage.go 1> transcript.txt 2>&1
% egrep '(WORK=|llvm-goc -c)' transcript.txt
WORK=/tmp/go-build887931787
/t/bin/llvm-goc -c -g -m64 -fdebug-prefix-map=$WORK=/tmp/go-build \
-gno-record-gcc-switches -fgo-pkgpath=command-line-arguments \
-fgo-relative-import-path=/myopath/src/tmp -o $WORK/b001/_go_.o \
-I $WORK/b001/_importcfgroot_ ./mypackage.go
% /t/bin/llvm-goc -c -g -m64 -fdebug-prefix-map=$WORK=/tmp/go-build \
-gno-record-gcc-switches -fgo-pkgpath=command-line-arguments \
-fgo-relative-import-path=/myopath/src/tmp \
-I $WORK/b001/_importcfgroot_ -o mypackage.ll -S -emit-llvm \
./mypackage.go
% ls -l mypackage.ll
...
%
```

...

## 6) Lua

Many popular FOSS projects like Redis, Nginx etc are using Lua for writing module or extension.

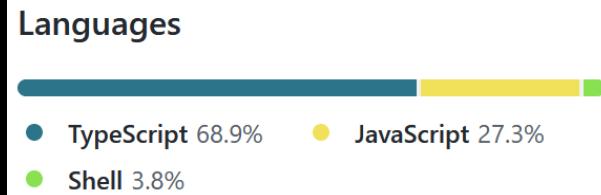
### 6.1 Lua on GraalVM

- <https://github.com/lucasallan/LuaTruffle>
- <https://github.com/Glavo/GraalLua>

### Wasmoon

- <https://github.com/ceifa/wasmoon>

A real Lua VM with JS bindings made with WebAssembly.

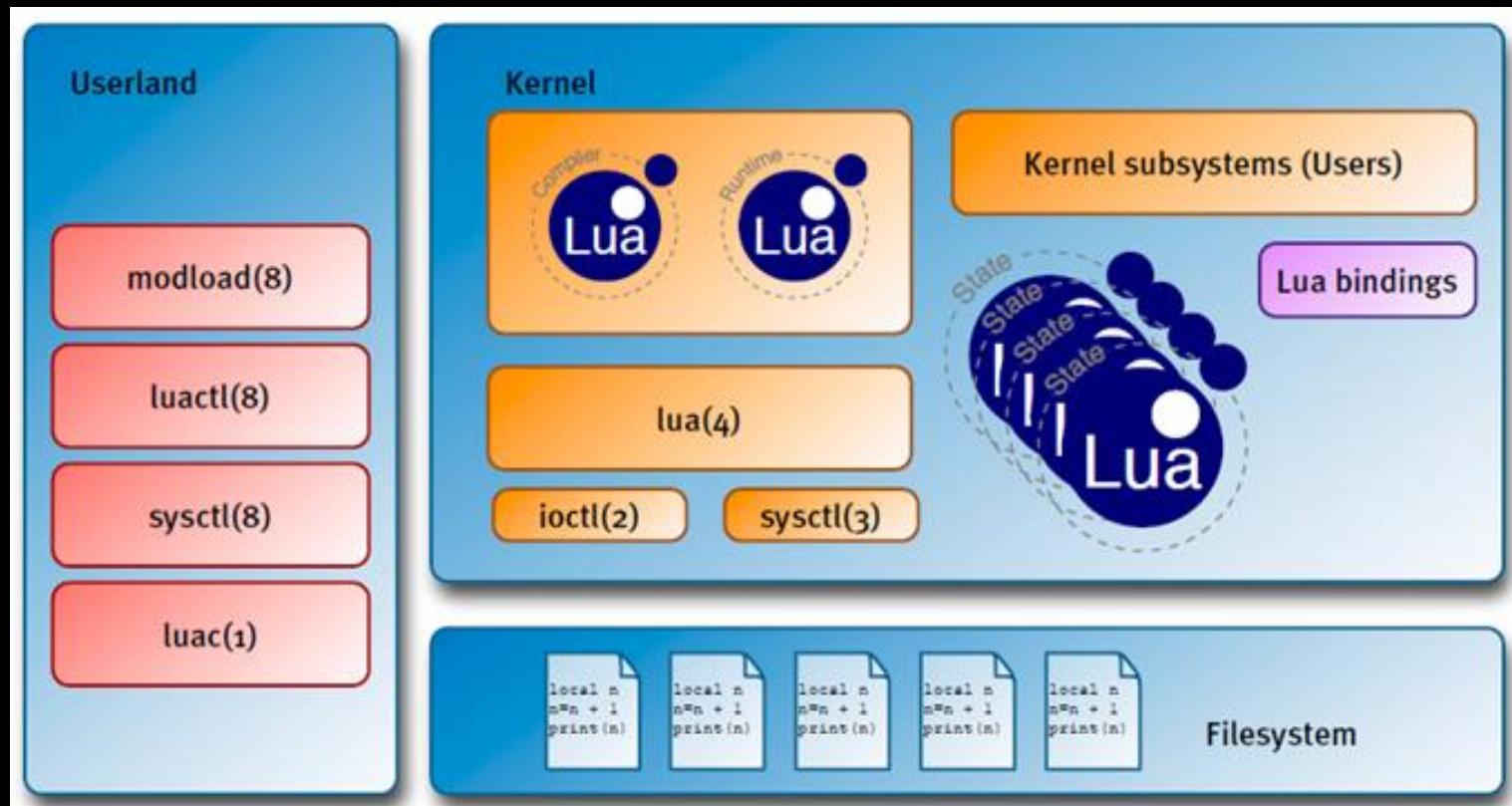




## 6.2 Lua-based In-Kernel VM

### 6.2.1 NetBSD

- **NetBSD Kernel scripting with Lua**
  - be part of NetBSD 6 (Userland)
  - be part of NetBSD 7 (Kernel)



Source: [https://archive.fosdem.org/2013/schedule/event/lua\\_in\\_the\\_netbsd\\_kernel/](https://archive.fosdem.org/2013/schedule/event/lua_in_the_netbsd_kernel/)

## 6.2.2 Linux

- <https://lwn.net/Articles/830154/> //Lua in the kernel?
- <https://github.com/luainkernel>

---

### *lunatik*

- <https://github.com/cujoai/lunatik>
- a port of the Lua interpreter to the Linux kernel

### *lunatik-ng*

- <https://github.com/lunatik-ng/lunatik-ng>

This repository contains the ongoing effort of porting the [Lunatik Lua engine](#) to current Linux kernels. There are a few differences between the original lunatik and lunatik-ng:

- Lunatik-ng works on x86\_64
- It is memory-leak free
- It can be built as loadable modules
- A few interfaces to the kernel are provided by default:
  - `buffer` for allocating memory regions in kernel space
  - `crypto` which provides bindings to the SHA1 implementation in the kernel (a more advanced interface to the kernel which allows selection of the cipher is in the works) and the random number generator.
  - `printk` as a direct binding to the kernels `printk`
  - `type` and `gc_count` as bindings to parts of the default Lua library



## KTap

### ■ <https://github.com/ktap/ktap>

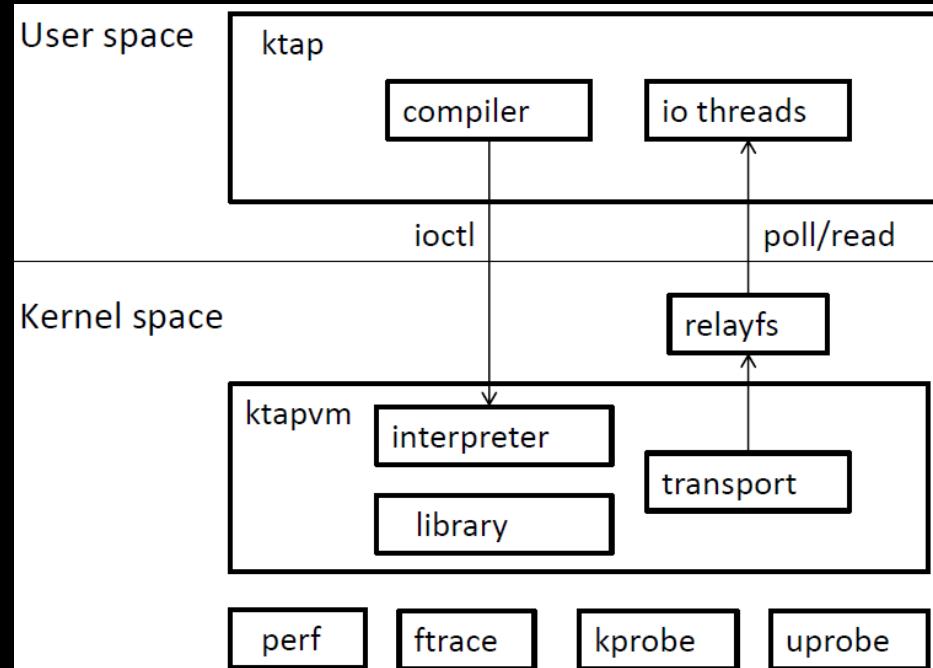
ktap is a new scripting dynamic tracing tool for Linux, it uses a scripting language and lets users trace the Linux kernel dynamically. ktap is designed to give operational insights with interoperability that allows users to tune, troubleshoot and extend the kernel and applications. It's similar to Linux Systemtap and Solaris Dtrace.

ktap has different design principles from Linux mainstream dynamic tracing language in that it's based on bytecode, so it doesn't depend upon GCC, doesn't require compiling kernel module for each script, safe to use in production environment, fulfilling the embedded ecosystem's tracing needs.

\* ktap code is based on luajit(compiler & bytecode), so carry luajit  
copyright notices in below.

LuaJIT -- a Just-In-Time Compiler for Lua. <http://luajit.org/>

### ■ Architecture



Source: “Ktap--A New Scripting Dynamic Tracing Tool For Linux”, Wei Zhang(Huawei),” LinuxCon Japan 2013

## ■ History

<https://lwn.net/Articles/551314/>

<https://lwn.net/Articles/572788/>

<https://lwn.net/Articles/595565/>

<https://lwn.net/Articles/595581/>

//Ktap—yet another kernel tracer

//Ktap almost gets into 3.13

//Ktap or BPF?

//ktap and ebpf integration





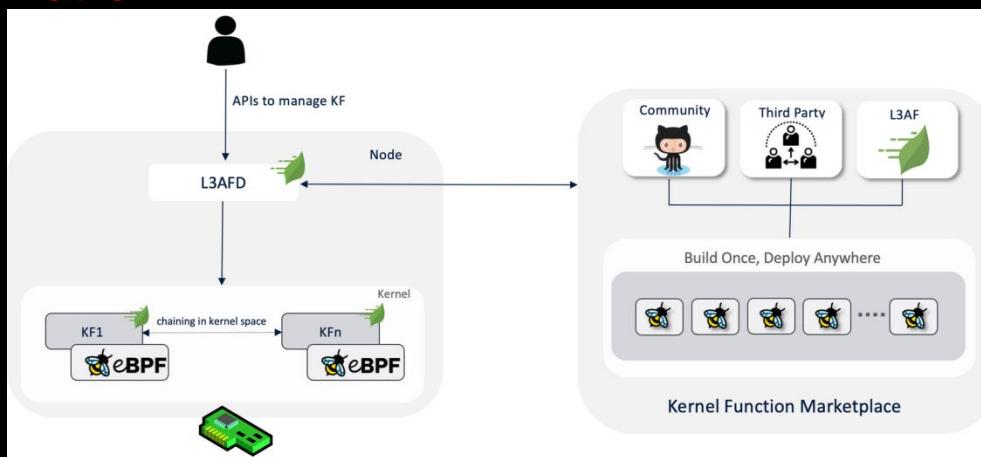
## 7) KFaaS (Kernel Functions as a Service)

- <https://www.linuxfoundation.org/press-release/walmart-moves-production-grade-networking-project-l3af-to-the-linux-foundation/>
- <https://l3af.io/>
- <https://github.com/l3af-project>

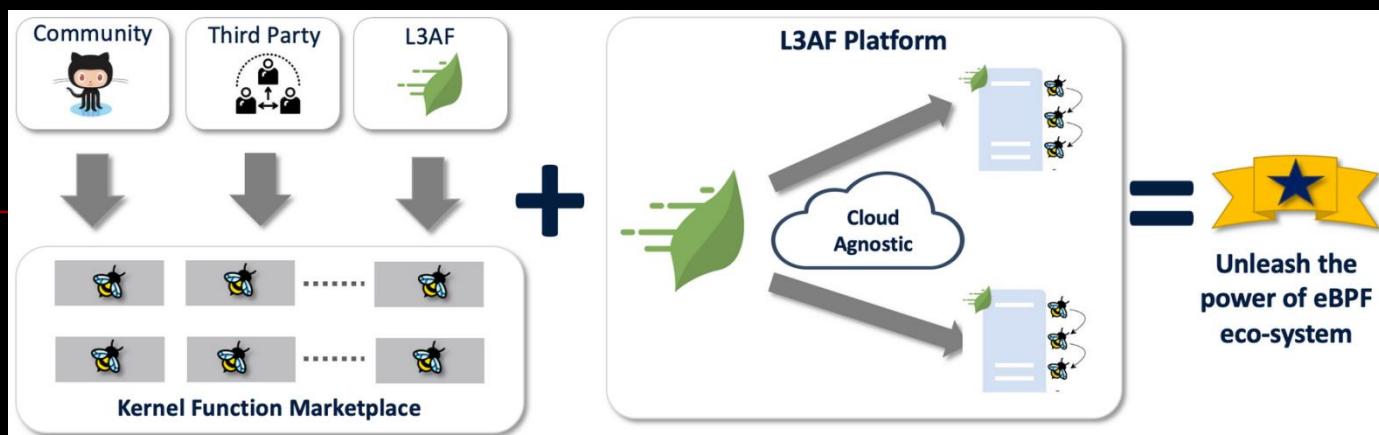
### Features

| Innovation                                                             | Empowerment                                                               | Flexibility                                                                    |
|------------------------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Industry-first "Kernel Functions as a Service"                         | Simple API to add, remove, and reorder kernel functions on the fly        | Distributed model to manage and configure kernel functions on a per-node basis |
| Multiple independent kernel functions executing in a chain             | Configurable metrics are gathered for each kernel function                | Compose kernel functions to fit business needs                                 |
| More to come, including a community-driven kernel function marketplace | Replace proprietary applications and hardware with blazing fast eBPF code | Cloud and vendor agnostic                                                      |

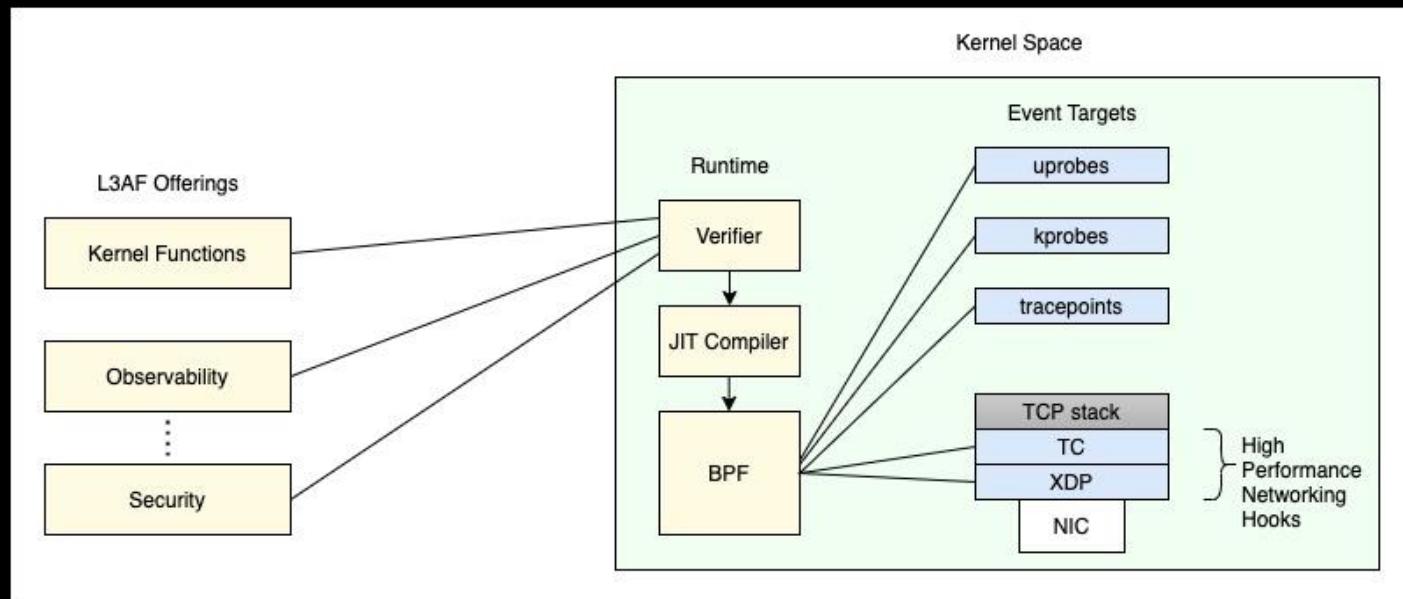
### Platform



## Vision

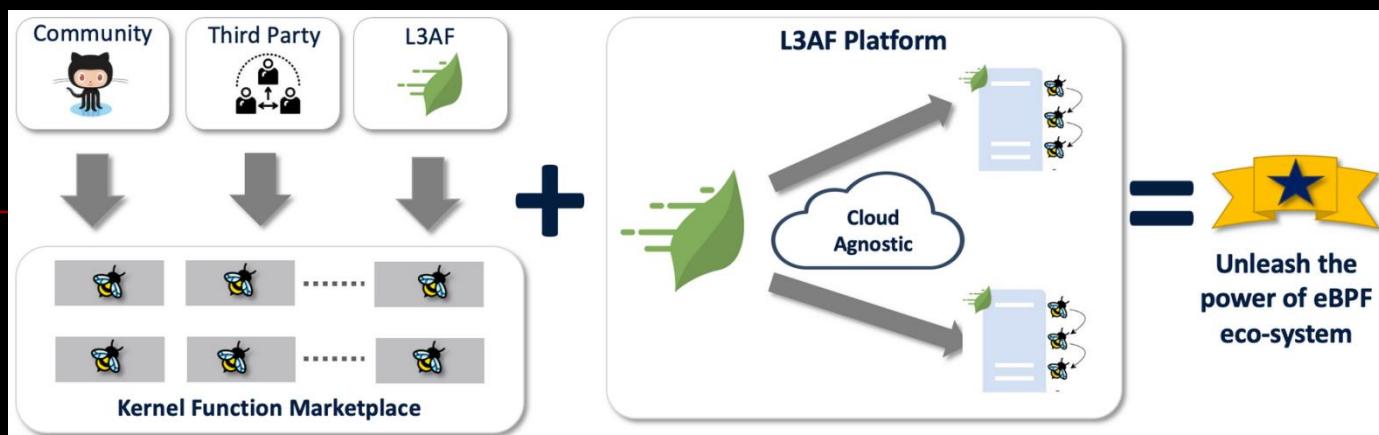


## eBPF Integration and Hooks

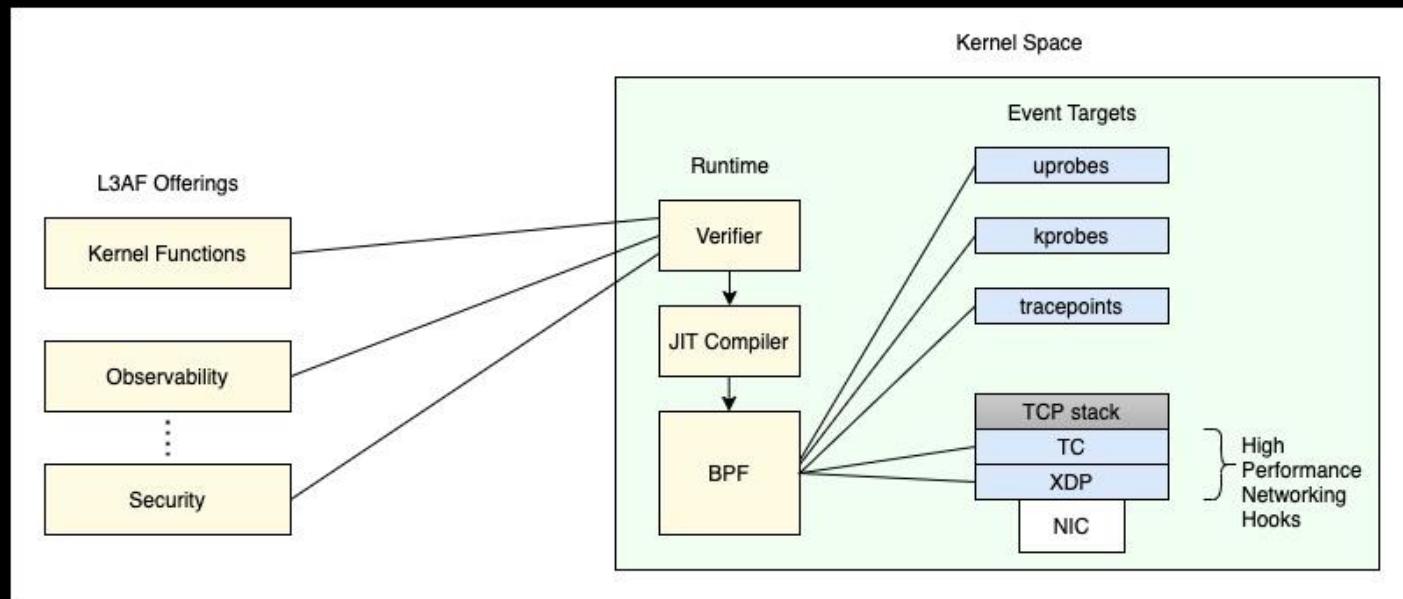


Source: <https://github.com/l3af-project/l3af-arch>

## Vision

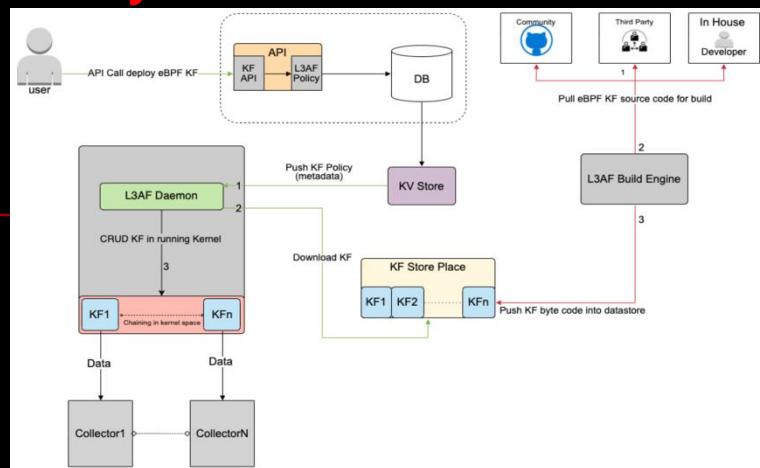


## eBPF Integration and Hooks



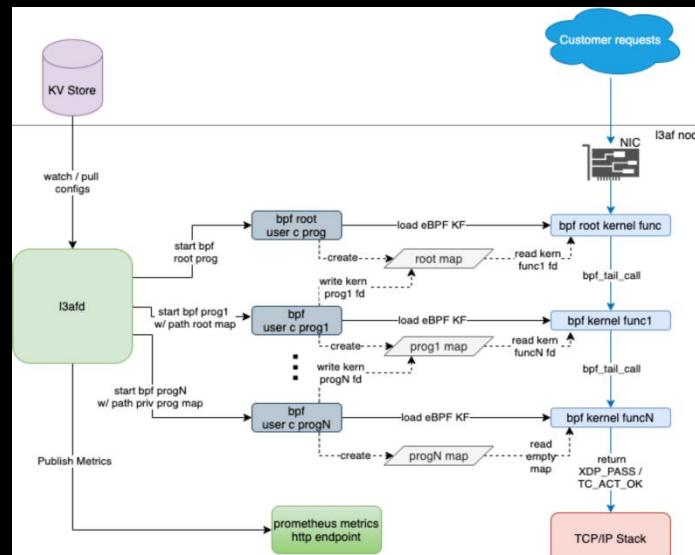
Source: <https://github.com/l3af-project/l3af-arch>

## Ecosystem



Source: <https://github.com/l3af-project/l3af-arch>

## Orchestration



Source: <https://github.com/l3af-project/l3af-arch>

# V. Wrap-up

- “Rust on GraalVM” requires more hacking!
- How about GasS(GraalVM as a Service)?
- Wasm and eBPF will certainly be the two key points of the infrastructure for tomorrow’s Cloud Computing.
- Please look forward to our follow-ups “Revisiting the eBPF-centric new approach for Hyper-Converged Infrastructure & Edge Computing” at K+ Summit(Nov 20) , “Third discussion on GraalVM-based unified runtime for eBPF and WebAssembly” and “GraalVM for Heterogeneous Parallel Computing”...



# Thanks!

Feng Li (李枫)  
hkli2012@126.com



鲜卑拓跋枫



扫一扫上面的二维码图案，加我微信



# Reference

Slides/materials from many and varied sources:

- <http://en.wikipedia.org/wiki/>
- <http://www.slideshare.net/>
- <https://github.com/cncf/toc/blob/main/DEFINITION.md>
- <https://rustrepo.com/repo/chop0-graal-bindgen-rust-foreign-function-interface>
- <https://doc.rust-lang.org/rustc/>
- <https://stackoverflow.com/questions/57812916/how-do-i-change-the-default-rustc-cargo-linker>
- [https://github.com/oracle/graal/blob/master/sulong/docs/contributor/T\\_OOLCHAIN.md](https://github.com/oracle/graal/blob/master/sulong/docs/contributor/T_OOLCHAIN.md)
- <https://github.com/oracle/graal/blob/master/truffle/docs/Languages.md>
- <https://doc.rust-lang.org/rustc/codegen-options/index.html>
- <https://doc.rust-lang.org/rustc/linker-plugin-lto.html>
- <https://www.eclipse.org/ecoretools/>
- ...