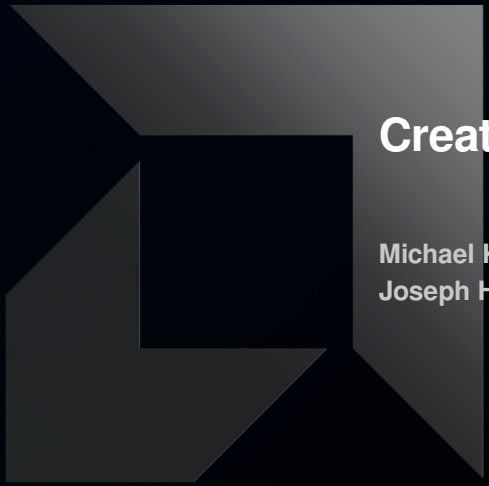


Creating an LLVM Runtime

Michael Kruse *(michael.kruse@amd.com)*,
Joseph Huber *(joseph.huber@amd.com)*

AMD
together we advance_

Outline

Introduction

Let’s Create a Runtime

Are We Done Yet?

Outline

Introduction

- Why This Tutorial?
- History
- Rationale
- Goal

Let's Create a Runtime

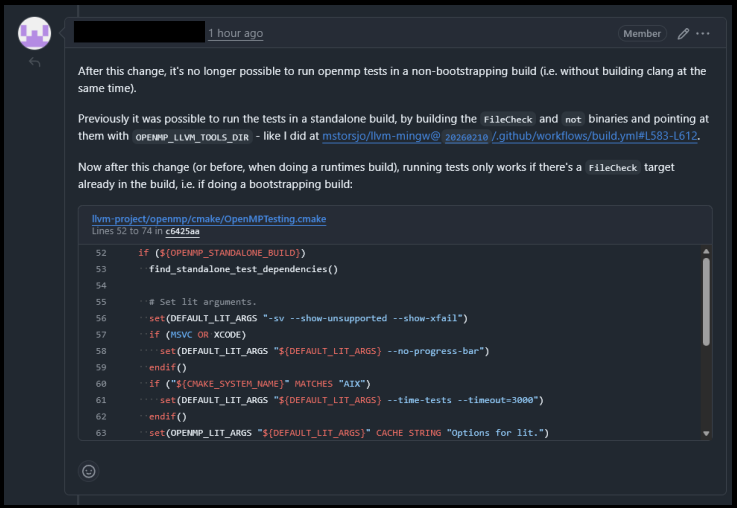
Are We Done Yet?

About Me

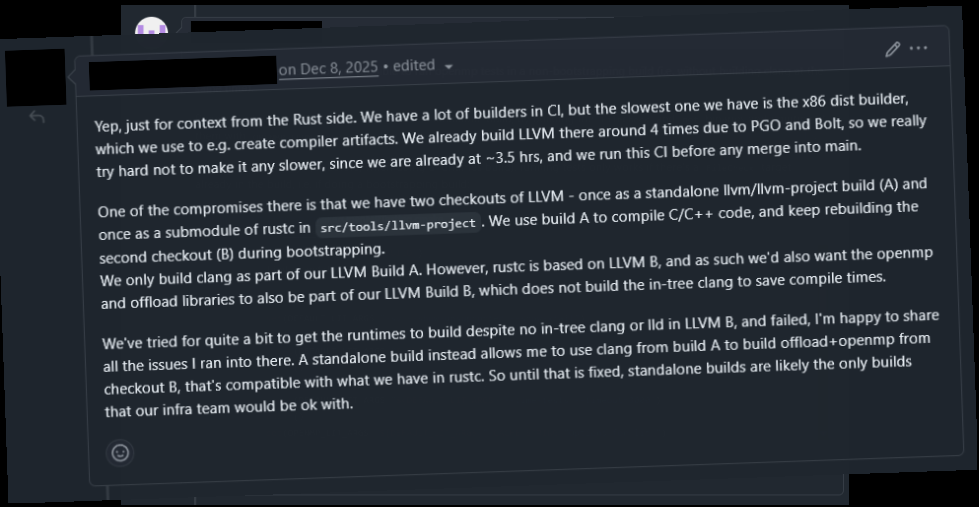
- At AMD since 2024
- Working on
  - Fortran
  - OpenMP®
  - GPGPU Offloading
  - Loops
- Converted Flang's runtime to use the `LLVM_ENABLE_RUNTIMES` system

https://youtu.be/AGrInJLxJ0Q

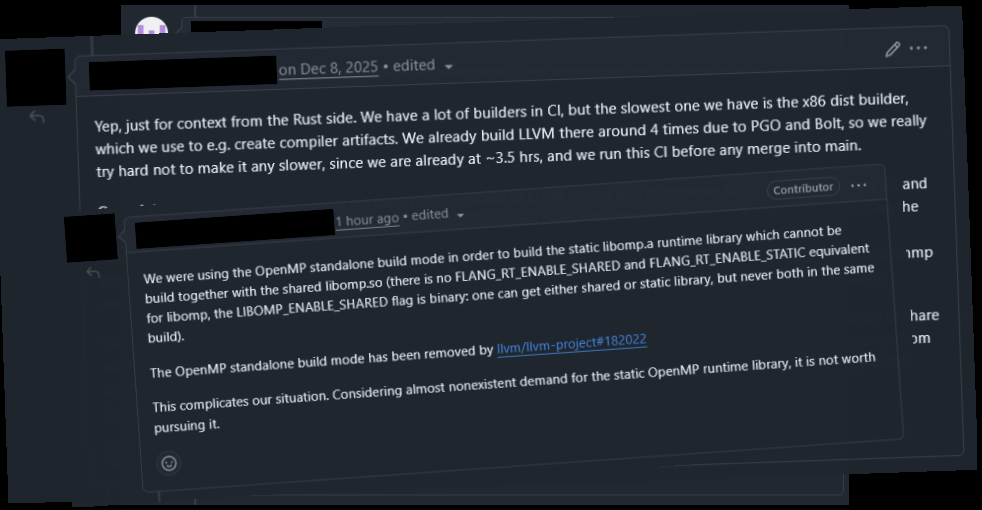
Why This Tutorial



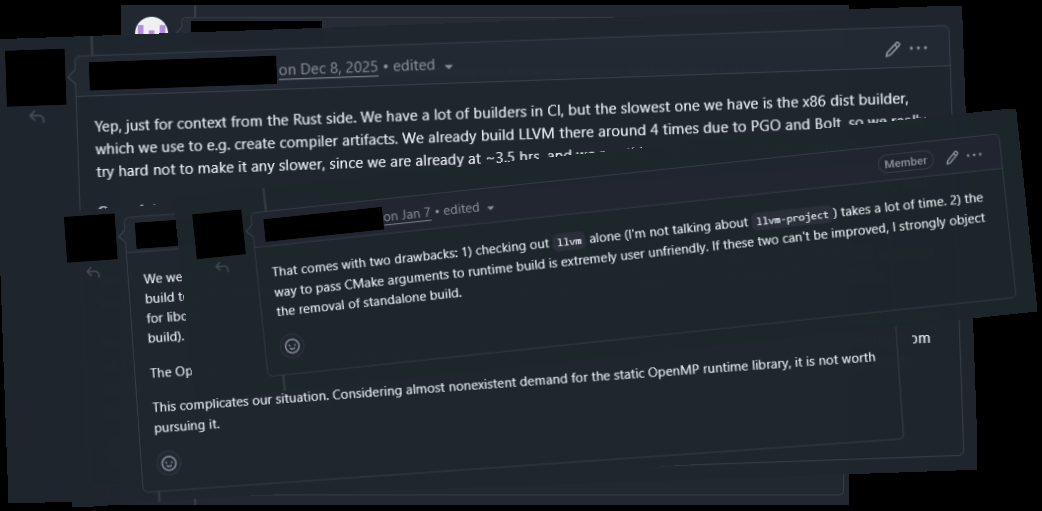
Why This Tutorial



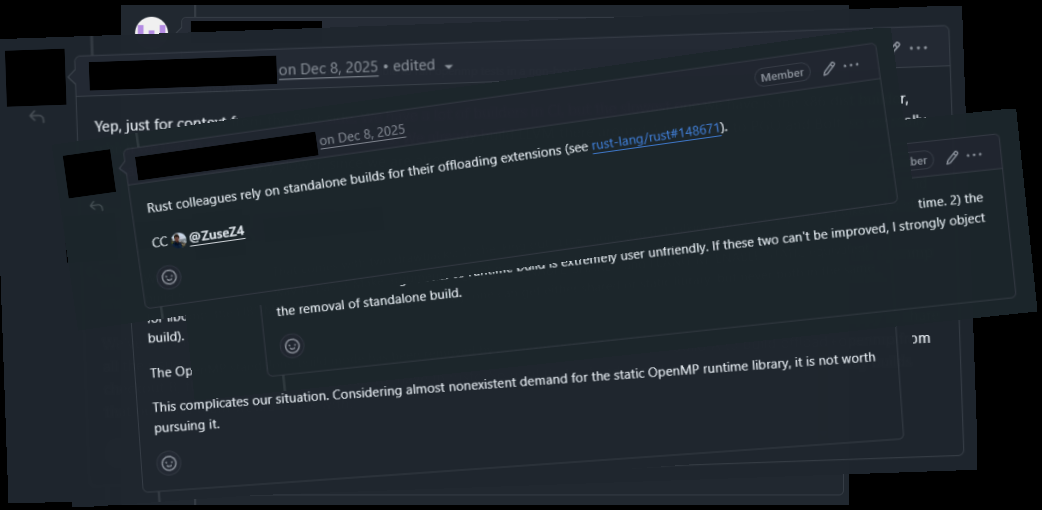
Why This Tutorial



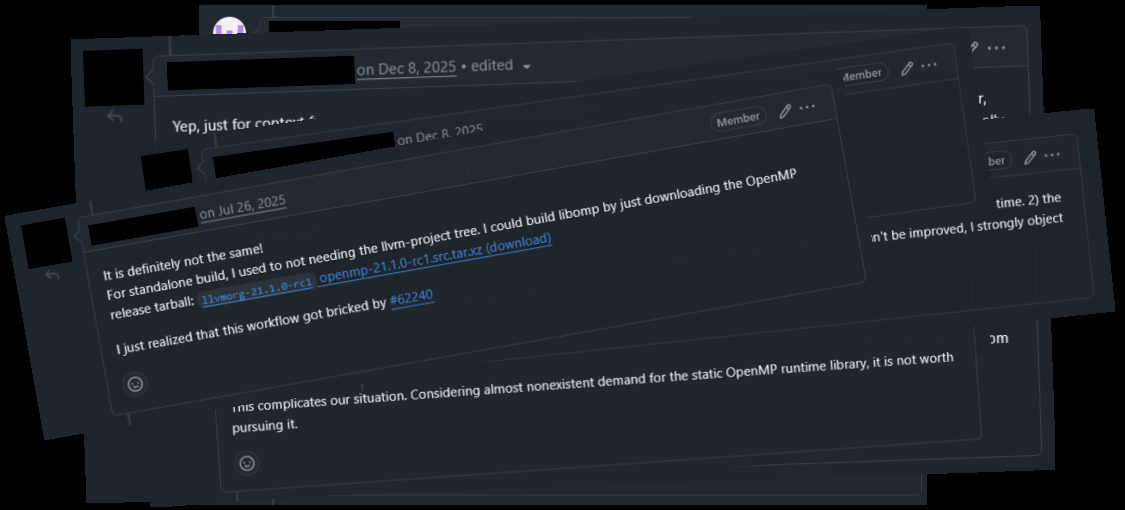
Why This Tutorial



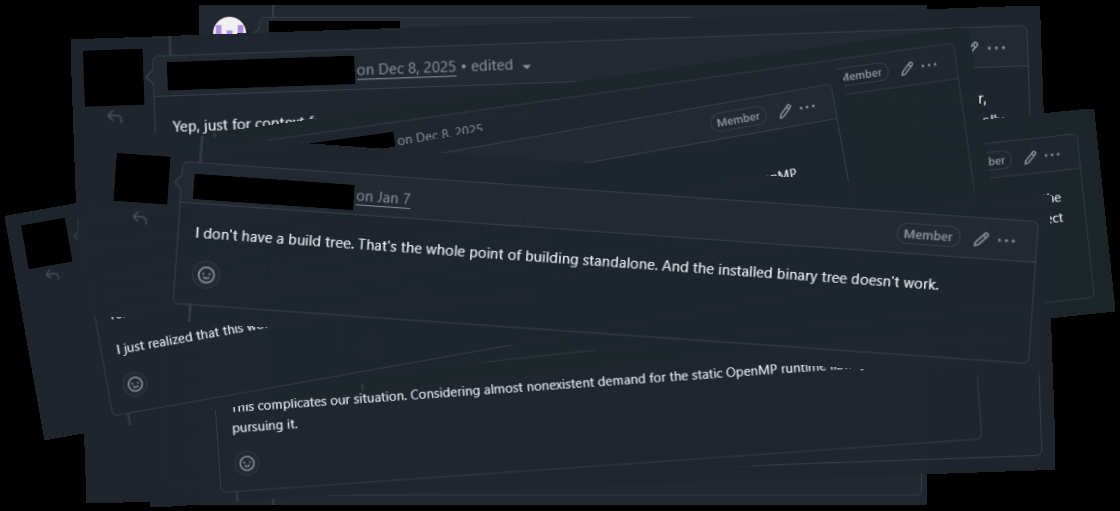
Why This Tutorial



Why This Tutorial



Why This Tutorial



History

1. Initially, each subproject had its own SVN repository
   - Subprojects categorized as “tools” (clang: 2009), “runtime” (libprofile), and “projects” (e.g., llvm-gcc)
   - An example project boilerplate existed

[1] https://reviews.llvm.org/D20992
[2] https://lists.llvm.org/pipermail/llvm-dev/2020-October/145997.html
[3] https://reviews.llvm.org/D26365
[4] https://reviews.llvm.org/D132478

History

1. Initially, each subproject had its own SVN repository
   - Subprojects categorized as “tools” (clang: 2009), “runtime” (libprofile), and “projects” (e.g., llvm-gcc)
   - An example project boilerplate existed
2. “runtime” subdirectory disappears with dysfunct PGO removal (2013)

[1] https://reviews.llvm.org/D20992
[2] https://lists.llvm.org/pipermail/llvm-dev/2020-October/145997.html
[3] https://reviews.llvm.org/D26365
[4] https://reviews.llvm.org/D132478

History

1. Initially, each subproject had its own SVN repository
   - Subprojects categorized as “tools” (clang: 2009), “runtime” (libprofile), and “projects” (e.g., llvm-gcc)
   - An example project boilerplate existed
2. “runtime” subdirectory disappears with dysfunct PGO removal (2013)
3. Desire to separate runtimes[1,2] (2016–2020)
   - Somewhat different from compile-time utils/tools/compilers

[1] https://reviews.llvm.org/D20992
[2] https://lists.llvm.org/pipermail/llvm-dev/2020-October/145997.html
[3] https://reviews.llvm.org/D26365
[4] https://reviews.llvm.org/D132478

History

1. Initially, each subproject had its own SVN repository
   - Subprojects categorized as “tools” (clang: 2009), “runtime” (libprofile), and “projects” (e.g., llvm-gcc)
   - An example project boilerplate existed
2. “runtime” subdirectory disappears with dysfunct PGO removal (2013)
3. Desire to separate runtimes[1,2] (2016–2020)
   - Somewhat different from compile-time utils/tools/compilers
4. Introduction of `LLVM_ENABLE_PROJECTS`[3] (2016)
5. Introduction of `LLVM_ENABLE_RUNTIMES`[4] (2022)
   - First for libc++

[1] `https://reviews.llvm.org/D20992`
[2] `https://lists.llvm.org/pipermail/llvm-dev/2020-October/145997.html`
[3] `https://reviews.llvm.org/D26365`
[4] `https://reviews.llvm.org/D132478`

Rationale

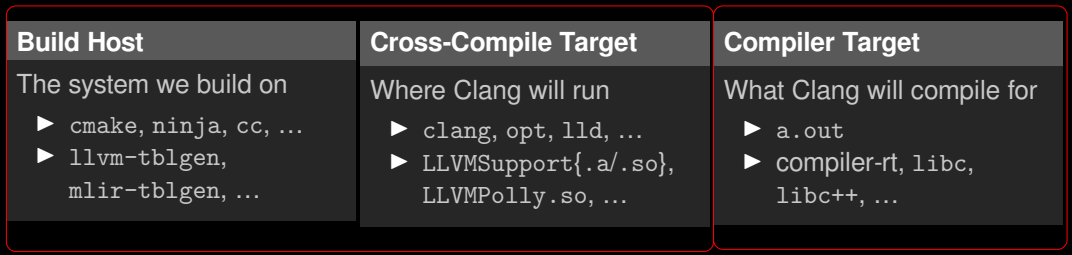
Why `LLVM_ENABLE_RUNTIMES`?

Build Host	Cross-Compile Target	Compiler Target
The system we build on ► `cmake`, `ninja`, `cc`, ... ► `llvm-tblgen`, `mlir-tblgen`, ...	Where Clang will run ► `clang`, `opt`, `lld`, ... ► `LLVMSupport{.a/.so}`, `LLVMPolly.so`, ...	What Clang will compile for ► `a.out` ► compiler-rt, `libc`, `libc++`, ...

- Automate multiple build-steps
  - Instead of: Build clang → build compiler-rt for x86_64 → build compiler-rt for arm64 → ...
- Reduce per-runtime boilerplate/differences between build modes
- Runtimes compiled (Stage 2) using just-built Clang

Rationale

Why `LLVM_ENABLE_RUNTIMES`?



- Automate multiple build-steps
  - Instead of: Build clang → build compiler-rt for x86_64 → build compiler-rt for arm64 → ...
- Reduce per-runtime boilerplate/differences between build modes
- Runtimes compiled (Stage 2) using just-built Clang

Tutorial Runtime

What is our tutorial runtime going to do?

Our Runtime

```
void _dublin_hello_world() {
  puts("Dia daoibh, a dhomhain!\n");
}
```

- Use LLVM™ best-practices
- Linux® only
- Prioritize conciseness and principles over
  - … features
  - … comments
  - … unrelated boilerplate
- Point out shortcomings of the current system

Outline

Setup

https://github.com/Meinersbur/llvm-dublin/tree/dublin-0-main

- README.md
  - Update Readme for tutorial
- .gitignore
  - Make git ignore `install*` subdirs
    (like `build*` already is)

$HOME/bin/cmake

```
/usr/bin/cmake -G Ninja                                \
               -D CMAKE_C_COMPILER_LAUNCHER=ccache     \
               -D CMAKE_CXX_COMPILER_LAUNCHER=ccache   \
               -D CMAKE_DISABLE_PRECOMPILE_HEADERS=ON \
               "$@"
```

Register with the LLVM™ Build System

https://github.com/Meinersbur/llvm-dublin/tree/dublin-1-basic

- llvm/CMakeLists.txt
- runtimes/CMakeLists.txt
  - Allow LLVM_ENABLE_RUNTIME=dublin
- dublin/CMakeLists.txt
- dublin/CODE_OWNERS.TXT
- dublin/LICENSE.TXT
  - Subproject boilerplate

Step 2: Build a Library Artifact

- `lib/Dublin/dublin.c`
- `include/dublin/Dublin/dublin.h`
  - Library sources
- `lib/Dublin/CMakeLists.txt`
  - Build instructions for `libdublin.a`

Standard Subproject Layout

An Example That Uses the Library

https://github.com/Meinersbur/llvm-dublin/tree/dublin-3-example

- examples/dublin-hello/dublin-hello.c
  - Example source
- examples/dublin-hello/CMakeLists.txt
  - Example build instructions

Common What To Build Options

- `DUBLIN_INCLUDE_<component>`
  - Executes `add_subdirectory(<component>)`
  - `ninja <component>` can be used
  - Defaults to `LLVM_INCLUDE_<component>`

- `DUBLIN_BUILD_<component>`
  - `ninja all` also builds `<component>`
  - Generally, steers which target use `ALL`/`EXCLUDE_FROM_ALL`
  - Defaults to `LLVM_BUILD_<component>`

Build Modes

- `CMakeLists.txt`
  - Detect unsupported legacy build modes

Build Modes

Legacy Build Modes

As project: `cmake -S <llvm-project>/llvm -D LLVM_ENABLE_PROJECTS=dublin`
Standalone: `cmake -S <llvm-project>/dublin`

- Intended to be superseded by runtimes build modes[1]
- If your build infrastructure still uses this, please consider updating
- Even “standalone” mode needs files from sibling directories
  A consequence of the monorepository

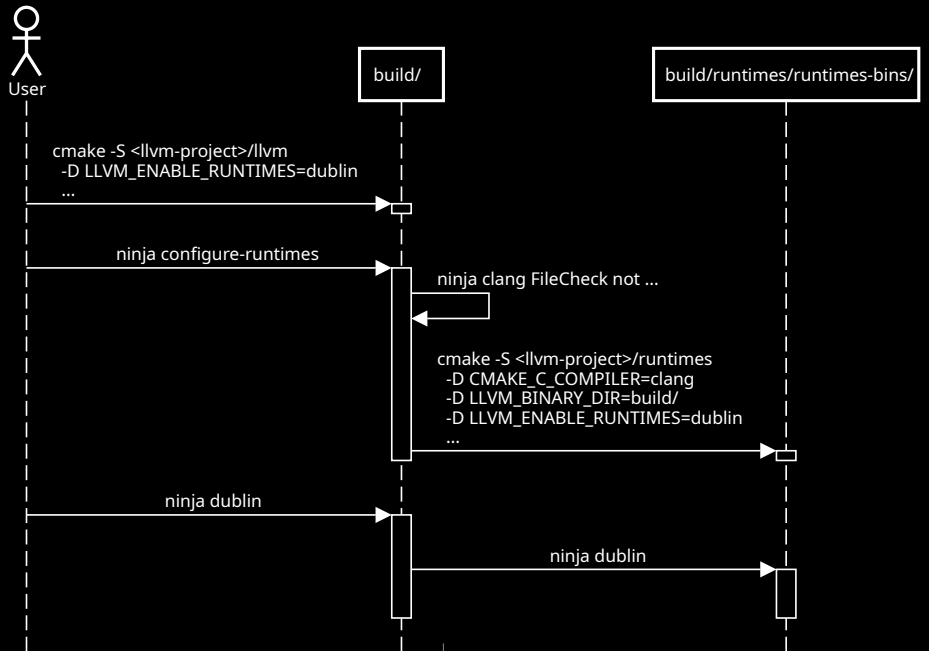
Runtimes Build Modes

Bootstrapping: `cmake -S <llvm-project>/llvm -D LLVM_ENABLE_RUNTIMES=dublin`
Default/Standalone: `cmake -S <llvm-project>/runtimes -D LLVM_ENABLE_RUNTIMES=dublin`

- Shared boilerplate code in `<llvm-project>/runtimes/CMakeLists.txt`

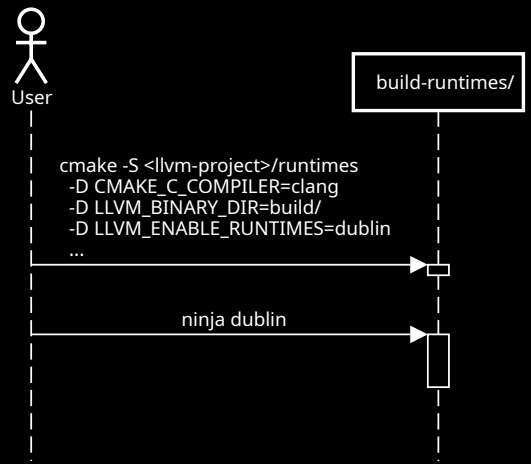
[1] https://lists.llvm.org/pipermail/llvm-dev/2020-October/145997.html

Bootstrapping Runtimes Build Mode



Default/Standalone Runtimes Build Mode

Skip the Middleman



Default/Standalone Runtimes Build Mode

runtimes/CMakeLists.txt

```
project(Runtimes C CXX ASM)

find_package(LLVM HINT ${LLVM_BINARY_DIR})
# more boilerplate code

foreach (runtime ${LLVM_ENABLE_RUNTIMES})
  add_subdirectory(${runtime})
endforeach ()
```

CMake Cache Files

https://github.com/Meinersbur/llvm-dublin/tree/dublin-5-cachefiles

- `cmake/caches/runtimes-bins.cmake`
  - Pre-populated CMake parameters as a bootstrapping build would set them

Artifact Output Location

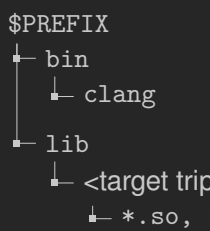
https://github.com/Meinersbur/llvm-dublin/tree/dublin-6-location

- CMakeLists.txt, cmake/Modules/GetToolchainDirs.cmake
  - Determine standard locations
- lib/Dublin/CMakeLists.txt
  - Set artifact output location

Library Locations

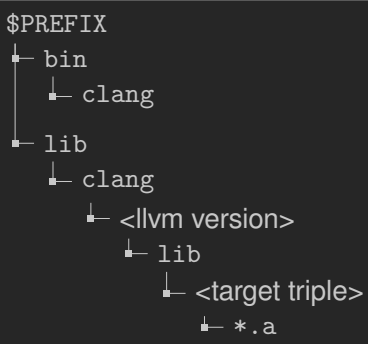
`LLVM_ENABLE_PER_TARGET_RUNTIME_DIR=ON`

Installation Prefix Dir



- Accessible to any compiler when installed (including e.g., gcc)

Resource Dir



- Accessible to only this version of Clang (and Flang)

Installation

https://github.com/Meinersbur/llvm-dublin/tree/dublin-7-install

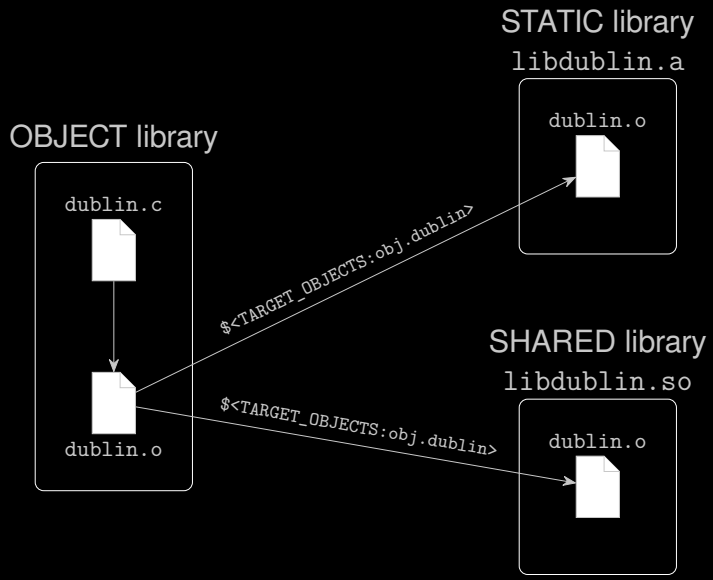
- `CMakeLists.txt`
  - Set install output location
- `lib/Dublin/CMakeLists.txt`
  - Library installation
- `include/CMakeLists.txt`
  - Header installation

Shared and Static Libraries

https://github.com/Meinersbur/llvm-dublin/tree/dublin-8-shared

- `cmake/Modules/AddDublin.cmake`
  - If building Shared and Static library, use an OBJECT library
  - Wrapper around CMake's native `add_library`
  - `AddLLVM`'s `llvm_add_library` main service is linking to LLVM™ libraries
    Target triple confusion. Do not use.
- `lib/Dublin/CMakeLists.txt`
  - Use `AddDublin.cmake` instead of `add_library`

OBJECT Libraries



Regression Testing

https://github.com/Meinersbur/llvm-dublin/tree/dublin-9-test

- dublin/test/Dublin/dublin-hello.c
  - The regression test:
    - Build the source
    - Link to libdublin(.a/.so)
    - Run
    - Expect output: “Dia daoibh, a dhomhain!”
- dublin/test/CMakeLists.txt
  - Testing boilerplate
- dublin/test/lit.cfg.py
- dublin/test/lit.site.cfg.py.in
  - llvm-lit configuration
    - How to find regression tests (lit.formats.ShTest)
    - Setup execution environment
    - Forward build configuration

Unittests

https://github.com/Meinersbur/llvm-dublin/tree/dublin-10-unittest

- `unittests/Dublin/DublinTest.cpp`
  - Google Test-based test code
- `test/Unit/lit.cfg.py`
- `test/Unit/lit.site.cfg.py.in`
  - `llvm-lit` configuration
    How to find unittests (`lit.formats.GoogleTest`)

Sphinx Docs

https://github.com/Meinersbur/llvm-dublin/tree/dublin-11-docs

- `docs/index.md`
  - The documentation
- `docs/conf.py`
- `docs/CMakeLists.txt`
  - Sphinx configuration
- `docs/_theme`
  - HTML boilerplate

Doxygen Docs

https://github.com/Meinersbur/llvm-dublin/tree/dublin-12-doxygen

- `lib/Dublin/dublin.c`
  - Add Doxygen comment
- `docs/doxygen-mainpage.dox`
  - Doxygen frontpage content
- `docs/doxygen.cfg.in`, `docs/CMakeLists.txt`
  - Doxygen configuration

Cross-Compilation

https://github.com/Meinersbur/llvm-dublin/tree/dublin-13-cross

No modifications necessary !

Cross-Compilation

- `-D LLVM_RUNTIME_TARGETS="default;aarch64-linux-gnu"`
  Compile runtimes also for arm64
- `-D RUNTIMES_CMAKE_ARGS=-DLLVM_USE_LINKER=lld`
  Ubuntu's default `ld.bfd` does not support arm64

Cross-Compilation

```
$builddir/
└─ runtimes/
   ├─ runtimes-bins/
   │  └─ CMakeCache.txt
   └─ runtimes-aarch64-linux-gnu-bins/
      └─ CMakeCache.txt
```

- `LLVM_RUNTIME_TARGETS=default`
  - ≈ `x86_64-unknown-linux-gnu`
  - Executable on host
  - NOT necessarily same ABI as LLVM™ (e.g., incompatible `LLVMSupport.a`)
- `LLVM_RUNTIME_TARGETS=aarch64-linux-gnu`
  - Cross-compilation target

Accelerator Offloading

https://github.com/Meinersbur/llvm-dublin/tree/dublin-14-offload

- CMakeLists.txt
- cmake/Modules/AddDublin.cmake
  - Accommodate limitations of GPGPU targets
- examples/dublin-openmp
- examples/dublin-hip
- examples/dublin-cuda
  - Use of GPGPU-side `libdublin.a` from various offload languages

Depending on Other LLVM™ Libraries / C++

https://github.com/Meinersbur/llvm-dublin/tree/dublin-15-deps

- lib/Dublin/dublin.cpp
- include/dublin/Dublin/dublin.h
- examples/dublin-hello/dublin-hello.cpp
  - Convert to C++
- cmake/Modules/AddDublin.cmake
- ../third-party/unittest/CMakeLists.txt
  - Link to libc++, regardless of compiler default

Compiler-RT Builtins

Outline

Introduction

Let’s Create a Runtime

Are We Done Yet?

- More Topics
- Build System Improvements

Not Covered Topics

- Platform Introspection
  `check_source_compiles`
- Platform Support
  Windows®/MacOS/AIX/Fuchsia/…
- Multilib
  `lib32`/`lib64`
- Versioning
  `libdublin.a.1.1`
- Export libraries
  `find_package(Dublin)`
- Continuous Integration
- Fortran
- …

Potential Runtimes Build Improvements

- Inform LLVM™ developers and OS distributions
  (Build modes) developer documentation missing, runtime template

Potential Runtimes Build Improvements

- Inform LLVM™ developers and OS distributions
  (Build modes) developer documentation missing, runtime template
- Make `RUNTIMES_*` options discoverable

```
set(RUNTIMES_CMAKE_ARGS "" CACHE STRING "Help")
```

Potential Runtimes Build Improvements

- Inform LLVM™ developers and OS distributions
  (Build modes) developer documentation missing, runtime template
- Make `RUNTIMES_*` options discoverable
  `set(RUNTIMES_CMAKE_ARGS "" CACHE STRING "Help")`
- Unify the CMake code of all runtimes
  Boilerplate diverged significantly since the SVN days

Potential Runtimes Build Improvements

- Inform LLVM™ developers and OS distributions
  (Build modes) developer documentation missing, runtime template
- Make `RUNTIMES_*` options discoverable
  `set(RUNTIMES_CMAKE_ARGS "" CACHE STRING "Help")`
- Unify the CMake code of all runtimes
  Boilerplate diverged significantly since the SVN days
- Fat libraries support
  MacOS Universal Binaries, `arm64ec`, Offload, …

Potential Runtimes Build Improvements

- Inform LLVM™ developers and OS distributions
  (Build modes) developer documentation missing, runtime template
- Make `RUNTIMES_*` options discoverable
  `set(RUNTIMES_CMAKE_ARGS "" CACHE STRING "Help")`
- Unify the CMake code of all runtimes
  Boilerplate diverged significantly since the SVN days
- Fat libraries support
  MacOS Universal Binaries, `arm64ec`, Offload, …
- Avoid special cases
  - GPGPU targets
  - `LLVM_RUNTIME_TARGETS=default`
  - Compiler-RT “builtins”

Potential Runtimes Build Improvements

- Inform LLVM™ developers and OS distributions
  (Build modes) developer documentation missing, runtime template
- Make `RUNTIMES_*` options discoverable
  `set(RUNTIMES_CMAKE_ARGS "" CACHE STRING "Help")`
- Unify the CMake code of all runtimes
  Boilerplate diverged significantly since the SVN days
- Fat libraries support
  MacOS Universal Binaries, `arm64ec`, Offload, …
- Avoid special cases
  - GPGPU targets
  - `LLVM_RUNTIME_TARGETS=default`
  - Compiler-RT “builtins”
- Writing runtimes in C++
  Option whether to use default stdlib or libc++

Potential Runtimes Build Improvements

- Inform LLVM™ developers and OS distributions
  (Build modes) developer documentation missing, runtime template
- Make `RUNTIMES_*` options discoverable
  `set(RUNTIMES_CMAKE_ARGS "" CACHE STRING "Help")`
- Unify the CMake code of all runtimes
  Boilerplate diverged significantly since the SVN days
- Fat libraries support
  MacOS Universal Binaries, `arm64ec`, Offload, …
- Avoid special cases
  - GPGPU targets
  - `LLVM_RUNTIME_TARGETS=default`
  - Compiler-RT “builtins”
- Writing runtimes in C++
  Option whether to use default stdlib or libc++
- Get rid of `LLVM_ENABLE_PER_TARGET_RUNTIME_DIR`

Potential Runtimes Build Improvements

- Inform LLVM™ developers and OS distributions
  (Build modes) developer documentation missing, runtime template
- Make `RUNTIMES_*` options discoverable
  `set(RUNTIMES_CMAKE_ARGS "" CACHE STRING "Help")`
- Unify the CMake code of all runtimes
  Boilerplate diverged significantly since the SVN days
- Fat libraries support
  MacOS Universal Binaries, `arm64ec`, Offload, …
- Avoid special cases
  - GPGPU targets
  - `LLVM_RUNTIME_TARGETS=default`
  - Compiler-RT “builtins”
- Writing runtimes in C++
  Option whether to use default stdlib or libc++
- Get rid of `LLVM_ENABLE_PER_TARGET_RUNTIME_DIR`
- QEMU (`CMAKE_CROSSCOMPILING_EMULATOR`)
- …

Disclaimer

The information presented in this document is for informational purposes only and may contain technical inaccuracies, omissions, and typographical errors. The information contained herein is subject to change and may be rendered inaccurate for many reasons, including but not limited to product and roadmap changes, component and motherboard version changes, new model and/or product releases, product differences between differing manufacturers, software changes, BIOS flashes, firmware upgrades, or the like. Any computer system has risks of security vulnerabilities that cannot be completely prevented or mitigated. AMD assumes no obligation to update or otherwise correct or revise this information. However, AMD reserves the right to revise this information and to make changes from time to time to the content hereof without obligation of AMD to notify any person of such revisions or changes.

THIS INFORMATION IS PROVIDED “AS IS.” AMD MAKES NO REPRESENTATIONS OR WARRANTIES WITH RESPECT TO THE CONTENTS HEREOF AND ASSUMES NO RESPONSIBILITY FOR ANY INACCURACIES, ERRORS, OR OMISSIONS THAT MAY APPEAR IN THIS INFORMATION. AMD SPECIFICALLY DISCLAIMS ANY IMPLIED WARRANTIES OF NON-INFRINGEMENT, MERCHANTABILITY, OR FITNESS FOR ANY PARTICULAR PURPOSE. IN NO EVENT WILL AMD BE LIABLE TO ANY PERSON FOR ANY RELIANCE, DIRECT, INDIRECT, SPECIAL, OR OTHER CONSEQUENTIAL DAMAGES ARISING FROM THE USE OF ANY INFORMATION CONTAINED HEREIN, EVEN IF AMD IS EXPRESSLY ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

AMD, the AMD Arrow logo, and combinations thereof are trademarks of Advanced Micro Devices, Inc. Other product names used in this publication are for identification purposes only and may be trademarks of their respective companies.

LLVM is a trademark of LLVM Foundation. The OpenMP name and the OpenMP logo are registered trademarks of the OpenMP Architecture Review Board. Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries. Windows is a registered trademark of Microsoft Corporation in the US and/or other countries. Other names used herein are for identification purposes only and may be trademarks of their respective companies


AMD