Introduction to Compilers and Stages of Compilation

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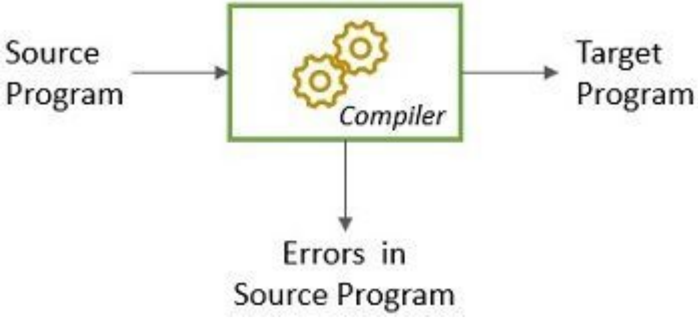
Agenda

- What are compilers?
- Usage and scope
- Compilers Today
- Stakeholders in the compiler industry
- What do compiler engineers work on?
- LLVM and its significance. What is LLVM IR and why we need it?
- Hands-on with LLVM
- Diving into the source code
- A few pointers
- Reach Us

What are Compilers?

- Translating computer code written in one language (source) to another (target).
- The target language may be low-level such as assembly, object code etc. Or it may be high-level such as Babel.
- Compilers also provide optimizations (see: Don't Help the Compiler) and error handling.



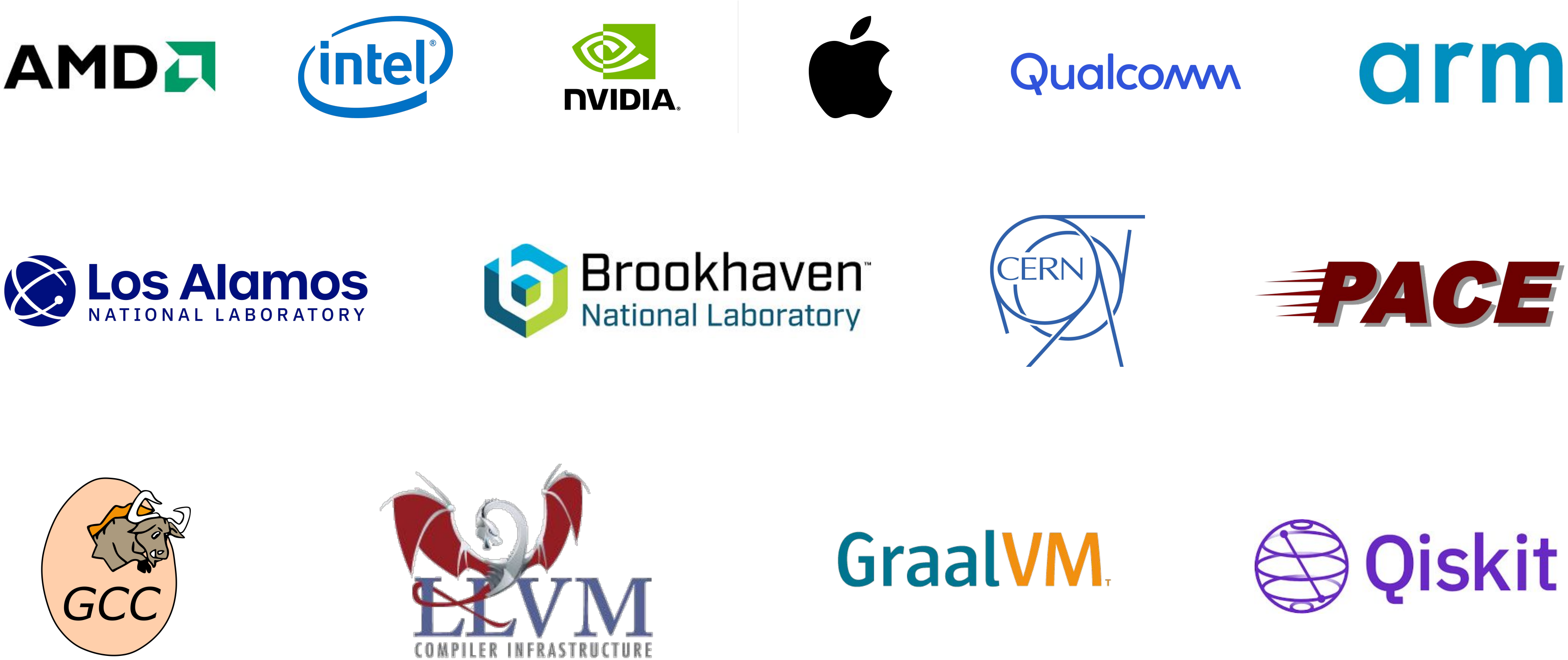
Usage and Scope

- Domain specific and device specific processing. Eg. Halide is a DSL for image processing and computational photography.
- Tools such as linters (clang-tidy), code formatters (ClangFormat), code completion (Intellisense), static analysis (Clang Static Analyzer), Debuggers etc.
- High Performance Computing (HPC) makes use of optimizing compilers for applications related to weather modelling, healthcare, physics simulations etc.
- Translating HDL’s (Hardware Description Languages) to the schematic of circuits and EDA tools. Eg: LLVM-CIRCT.

Compilers Today

- Many compilers exist for C/C++/Fortran as these are the main HPC languages.
- Open Source compilers as Clang/LLVM and GCC.
- Proprietary compilers such as ICC, AOCC, PGI, Cray Compiler, ARM etc.
- Many new languages - Rust and Julia have features such as memory safety, multiple dispatch and optional typing. These communities are very active.
- Upcoming compilers such as F18.
- Machine learning techniques such as RL are being explored for compiler optimizations.

Stakeholders In the Compiler Industry


AMD
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CERN
PACE
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LLVM COMPILER INFRASTRUCTURE
GraalVM
Qiskit

What do Compiler Engineers work on?

- **Optimizations**: figuring out ways to extract the maximum performance out of a system. Examples include vectorization, inlining, loop unrolling etc.
- **Implementing new features**: every few years new features are added to C++. The standards need to be implemented by compiler engineers.
- **Verification/Validation**: compilers need to be tested thoroughly for correctness as developers rely on them. This process includes lots of scripting, debugging etc.
- **Research**: research into new kinds of tools, techniques and processes is going on all the time as new hardware and software paradigms come to the fore. Example: llvm-bolt (from facebook).

What is LLVM and Why is it so important?

- Created by Vikram Adve and Chris Lattner in 2000 at UIUC. Originally LLVM stood for Low Level Virtual Machine.
- It is a **modular** set of compiler and toolchain technologies that can be used to create a frontend for any programming language and a Backend for any ISA.
- It currently has support for languages such as C, C++, Fortran, Rust, Objective C/C++, Julia, Haskell, Halide, Common LISP, Scala and many others.
- It has a permissive open source license that enables collaboration and commercial use.
- LLVM IR serves as a portable, high level assembly language that makes many of these optimizations and modularity possible.

Hands On with LLVM

Getting LLVM

- To use LLVM for compilation - https://releases.llvm.org/download.html
- To dive into the source of LLVM - https://llvm.org/docs/CMake.html

  -
    ```
    cmake -G "Ninja"  \
    -DCMAKE_BUILD_TYPE=Release \
    -DLLVM_TARGETS_TO_BUILD="X86" \
    -DLLVM_ENABLE_PROJECTS="clang" \
    -DLLVM_ENABLE_ASSERTIONS=ON \
    -DLLVM_ENABLE_LLD=On \
    -DCMAKE_EXPORT_COMPILE_COMMANDS=On ../llvm
    ```

Hands On with LLVM (Using LLVM for compilation)

Compiling Hello World

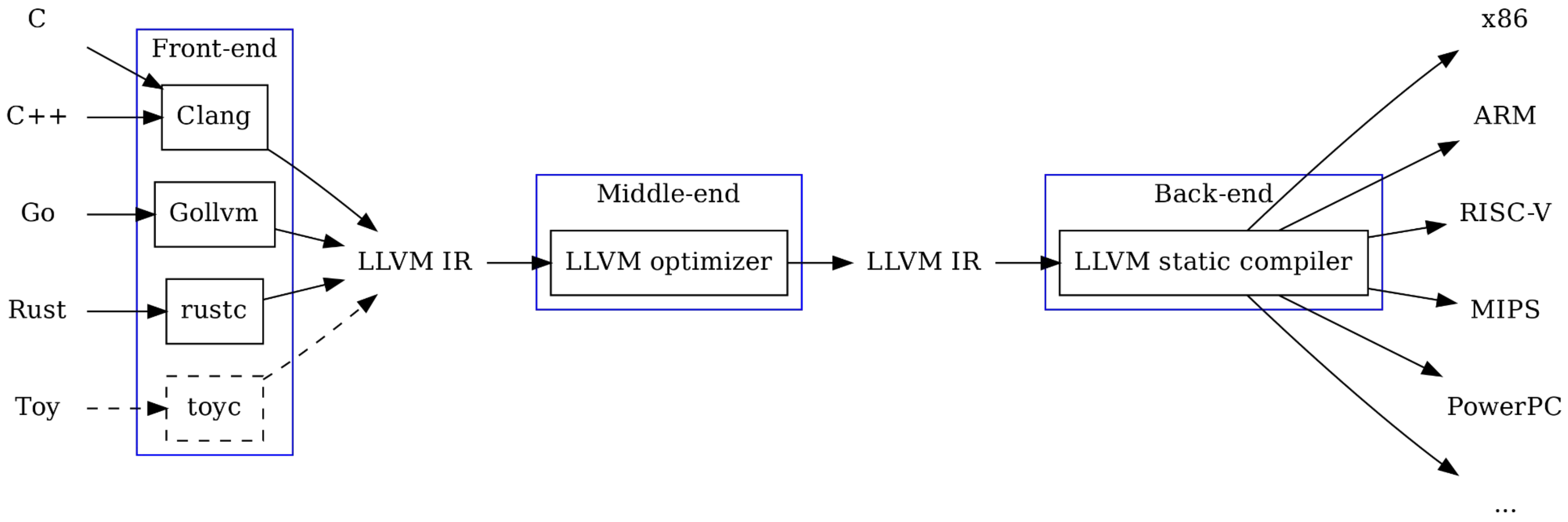


Image Credits: https://blog.gopheracademy.com/advent-2018/llvm-ir-and-go/

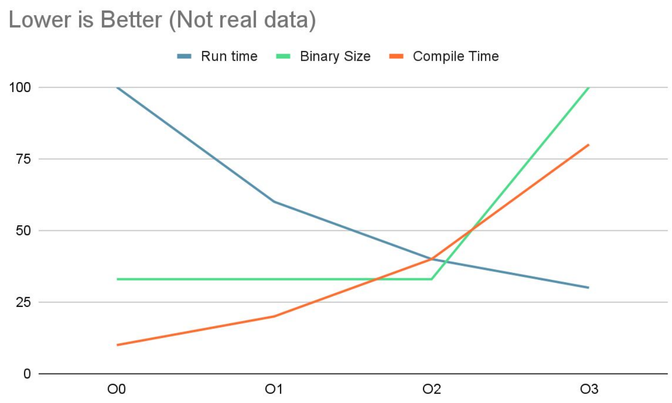
Frontend with C/C++ (Language Dependent)

Input: C file, Output: LLVM IR File

- Preprocessing
  - `clang -E example.c`
  - Replace all #defines, #includes etc. with code
  - example
- AST and semantics
  - `clang -Xclang -ast-dump example.c`
  - example
- IR Generation
  - `clang -Xclang -disable-O0-optnone -S -emit-llvm example.c`
  - example

Middle end (Language and Machine Independent)

Input: LLVM IR File, Output: Optimized LLVM IR File



More options for different compilation speeds, binary size, and execution speeds

example

Middle end (Language and Machine Independent)

Input: LLVM IR File, Output: Optimized LLVM IR File

- Run transformations
  - `opt -dce -S sample.ll`
  - `opt -passes='dce' -S sample.ll`
  - example
- Run analysis
  - `opt -passes='print<scalar-evolution>' -disable-output sample.ll`
  - example
- Pass pipeline
  - `opt -passes='pass1,pass2' /tmp/a.ll -S`
- Many options related to passes and debugging them in `opt-15 --help`

Backend (Machine Dependent)

- Assembler (llc -march=”x86”): example
- Linker: ld, lld, gold etc.
- Tooling such as LLVM MCA (machine code analyzer). An example is here.
- Tools such as Godbolt have an analysis mode to give you machine code level information on code execution. example.
- Timeline mode (-timeline -mcpu=name) can give Decode, execute and wait information for each instruction. example
- We’re still beginners when it comes to backend stuff, so feel free to research this at your own pace!

Diving into the source code

Subprojects

- >15 subprojects in the monorepo llvm/llvm-project
- 2 incubated projects

To get involved, two main questions -

- What to work on?
- How to work on it?

Diving into the source code (answering the WHAT)

What can we do? (Not exhaustive, there are many more things to do)

- Implement new and missing language constructs
  - https://clang.llvm.org/cxx_status.html
- Fix bugs in existing language constructs
  - https://github.com/llvm/llvm-project/issues
- Implement new static analysis tools on clang for C/C++ programs
  - https://clang.llvm.org/docs/RAVFrontendAction.html
  - https://clang.llvm.org/docs/LibASTMatchersReference.html
- Find new optimizations from Research and bring them to the LLVM Project.
  - https://scholar.google.com/scholar?q=llvm&hl=en&as_sdt=0,5
- Implement/Improve static analysis tools (sanitizers etc)
  - https://clang.llvm.org/docs/ThreadSanitizer.html
  - https://clang.llvm.org/docs/MemorySanitizer.html
- Work on MLIR, LLDB, Flang, Bolt, Libc and all the other subprojects.
  - Very similar skill set is required for all the projects, and all of them are very exciting.
- Open Projects at LLVM
  - https://llvm.org/OpenProjects.html
  - https://mlir.llvm.org/getting_started/openprojects/

Diving into the source code (answering the HOW)

After deciding what to do, discuss how to do it.

- Discussion forum - https://discourse.llvm.org/
- Discord - https://discord.gg/xS7Z362

For example -

- https://discourse.llvm.org/t/rfc-improving-clang-s-diagnostics/62584
- https://discourse.llvm.org/t/rfc-introduce-ml-program-dialect-and-top-level-ops-proposal-v2/60907
- https://discourse.llvm.org/t/rfc-a-unified-lto-bitcode-frontend/61774/32

Feel free to reach out to us.

Some pointers for working on LLVM

- Use assertions, a lot of them.
- The dump() function.
- Don't be scared of arc/phabricator. It has a short and steep learning curve.
- Use intellisense/ctags - the codebase is massive.
- Add tests for everything. If you don’t know where, ask someone.
- Read the documentation/comments in code and also comment your code.
- Use cmake options efficiently to reduce build times.

Reach Us

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calendar	calendar