Polly - Polyhedral optimization in LLVM

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Motivation

- Most polyhedral tools are limited to a specific programming language $\Rightarrow$ programming-language-specific techniques (like Java or Haskell.)
- Even for this language, relevant code needs to match specific syntax that rarely appears in existing code. (disallowing any pointer arithmetic or higher level language constructs like C++ iterators)
- May apply incorrect transformations, e.g., implicit type casts, integer wrapping or aliasing in C are mostly ignored

What is Polly

- A project to enable polyhedral optimizations in LLVM
- automatically detects and transforms relevant program parts in a language-independent and syntactically transparent way

  $\Rightarrow$ supports programs written in most common programming languages (not only for C/C++) and constructs
- provides a state-of-the-art polyhedral library with full support for **Z-polyhedra**, advanced data dependency analysis and support for external optimizers.
- Polly includes integrated SIMD and OpenMP code generation
- Through LLVM, machine code for CPUs and GPU accelerators, C source code and even hardware descriptions can be targeted

Related Work

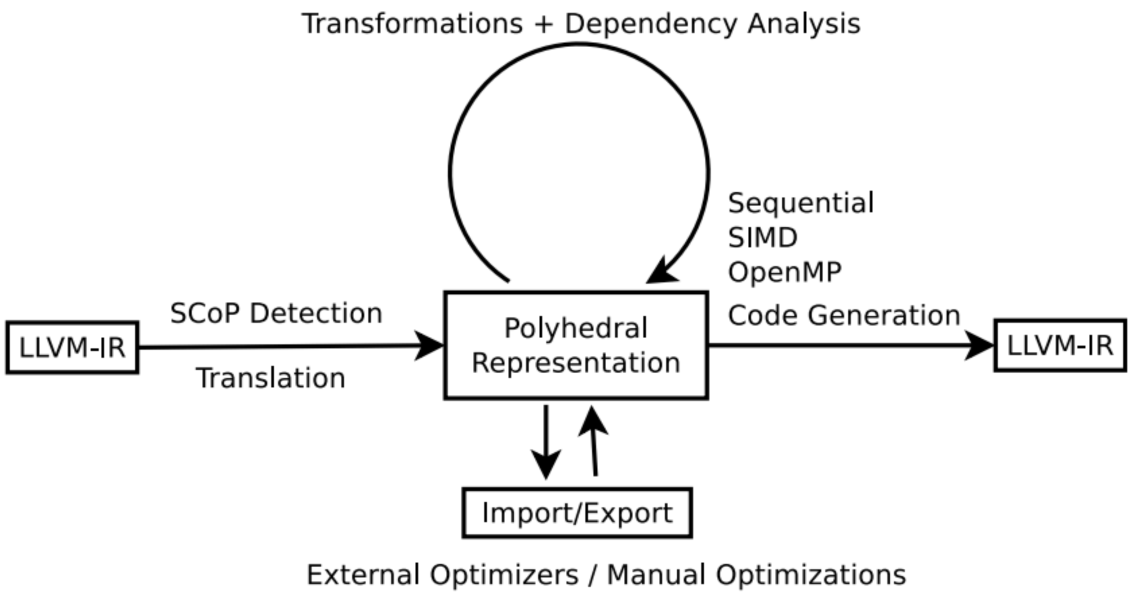
Low-level virtual machine (LLVM)

- a set of tools and libraries to build a compiler
- Based on a language and platform-independent intermediate representation (IR)
- provides 1) state-of-the-art analyses, 2) optimizations and 3) target code generation
- LLVM-IR is a very low-level representation of a program, which
  - does **not** have loops, and has **no** arrays or affine expressions,
  - Has jumps and gotos but pointer arithmetic and three address form operations.

- Optimizations that transform multiplications into shifts or a sequence of additions are very common
- understanding the effects of calculations on LLVM-IR is difficult $\Rightarrow$ LLVM provides an analysis called scalar evolution, which calculates closed form expressions for all scalar integer variables in a program

Details

- Polly accepts LLVM-IR as input and take LLVM-IR as output,
    - $\Rightarrow$ it is programming language independent and transparently supports constructs
        - like C++ iterators, pointer arithmetic or goto based loops
    - Front end: translates from LLVM-IR into a polyhedral representation
    - Middle end: transforms and optimizes this representation
    - Back end: translates it back to LLVM-IR



LLVM-IR to Polyhedral Model

1. Region-based SCoP detection
    - static control parts (SCoPs), the classical domain of polyhedral optimizations
    - A *region* is a subgraph of the control flow graph (CFG) that is connected to the remaining graph by only two edges, an entry edge and an exit edge.
    - A *canonical region* is a region that cannot be constructed by merging two adjacent smaller regions.
    - Target: find the maximal non-canonical regions that form valid SCoPs.
2. Semantic SCoPs
    - arbitrary control flow structures are valid (has the semantics of a SCoP) if they can be written as a well-structured set of for-loops and if-conditions with affine expressions in lower and upper bounds and in the operands of the comparisons
    - **Assumption of Polly ???**

Polyhedral Model

1. The integer set library
2. Composable polyhedral transformations
    - Polly uses the classical polyhedral description that describes a SCoP as a set of statements each defined by
        1. domain: the set of values the induction variables surrounding the statement enumerate.
        2. schedule: a relation which, when applied to the domain, yields the execution times of the statement’s operations (not affine functions) $\Rightarrow$the composition of transformations is simply the composition of the relations/schedule representing the schedules, no modifications of the domain
        3. a set of memory accesses.
3. Export/Import

Polyhedral Model to LLVM-IR

- uses **CLooG** , polyhedral representation $\Rightarrow$ a generic AST $\Rightarrow$ LLVM-IR

1. Detecting parallel loops
    - detects parallelism **after** generating the generic AST
    - for each generated for-loop, calculates if it can be executed in parallel
2. Trivially SIMDizable loops
    - A trivially SIMDizable loop is a loop that is 1) parallel, 2)does not have any control flow statements in its body and 3) has a number of iterations that is in the order of magnitude of the SIMD vector width
    - find such a loop on the generic AST, instead of translated to loop structrue, to a **set of vector instructions** with a width corresponding to the number of loop iterations.
    - introduce SIMD vector code