Array Access Analysis by llvmpy

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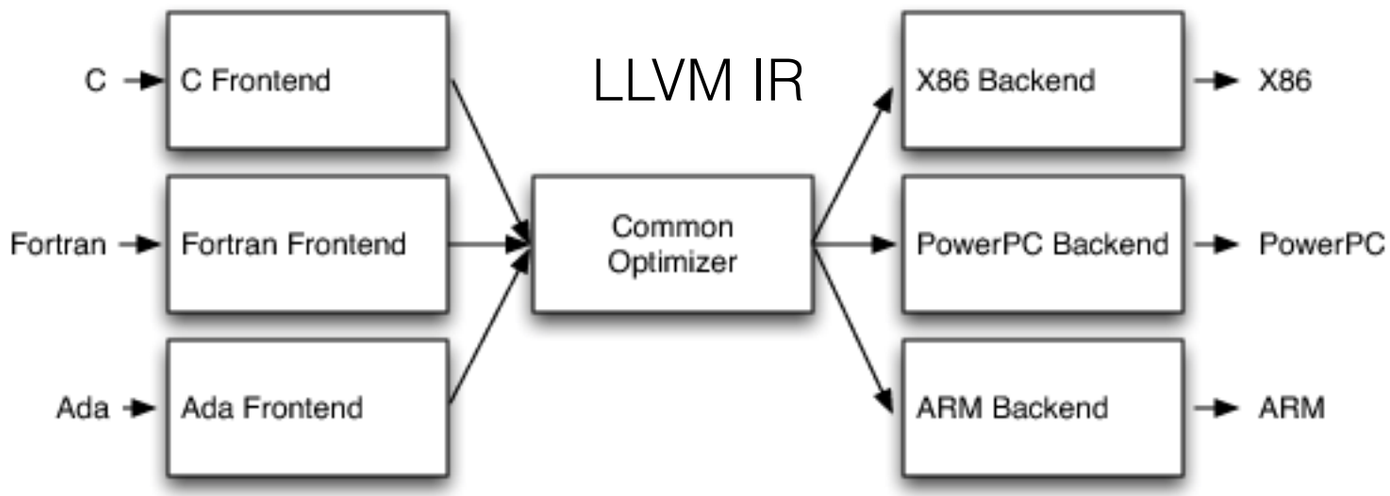
LLVM infrastructure

- Three Phase Design of LLVM infrastructure[1]



LLVM Intermediate Representation (IR)

- Features:
  - Three address form
  - Static single assignment
  - low-level RISC like instruction set with high-level type information
- Example:

```
int max(int a, int b) {
        if (a > b)
                return a;
        else
                return b;
}
```

```
define i32 @max(i32 %a, i32 %b) #0 {
  %1 = alloca i32, align 4
  %2 = alloca i32, align 4
  %3 = alloca i32, align 4
  store i32 %a, i32* %2, align 4
  store i32 %b, i32* %3, align 4
  %4 = load i32* %2, align 4
  %5 = load i32* %3, align 4
  %6 = icmp sgt i32 %4, %5
  br i1 %6, label %7, label %9

; <label>:7                                       ; preds = %0
  %8 = load i32* %2, align 4
  store i32 %8, i32* %1
  br label %11

; <label>:9                                       ; preds = %0
  %10 = load i32* %3, align 4
  store i32 %10, i32* %1
  br label %11

; <label>:11                                      ; preds = %9, %7
  %12 = load i32* %1
  ret i32 %12
}
```

LLVM API

- Features:
  - C++ implementation
  - templates and pointers are everywhere

```
for (Function::iterator b = F.begin(), be = F.end(); b != be; ++b) {
      for (BasicBlock::iterator i = b->begin(), ie = b->end(); i != ie; ++i) {
    if (CallInst* callInst = dyn_cast<CallInst>(&*i)) {
              if (callInst->getCalledFunction() == targetFunc)
        ++callCounter;
    }
  }
}
```

LLVM API

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```
for (Function::iterator b = F.begin(), be = F.end(); b != be; ++b) {
      for (BasicBlock::iterator i = b->begin(), ie = b->end(); i != ie; ++i) {
        if (CallInst* callInst = dyn_cast<CallInst>(&*i)) {
                if (callInst->getCalledFunction() == targetFunc)
          ++callCounter;
        }
      }
    }
```

- LLVMPY

```
for bb in f.basic_blocks:
      for istr in bb.instructions:
          if istr.opcode == OPCODE_CALL:
               if its.operands[0] == targetFunc:
                    callCounter=callCounter+1
```

Array access analysis of GPU kernel program

- Kernel Program
  - blockIdx
  - threadIdx

```
__global__ void add( int *a, int *b, int *c ) {
        int tid = threadIdx.x; // handle the data at this index
        if (tid < N)
        c[tid] = a[tid] + b[tid];
}
```

- Array Access Analysis
  - Extract the index
    - tid -> threadIdx.x
  - Calculate the range
    - thread block |- 0 -|- 1 -|- 2 -|…
    - threads |-0-|-1-|-2-|-3-|-4-|-5-|-6-|-7-|-8-|-9-|10|11|…
    - array |-0-|-1-|-2-|-3-|-4-|-5-|-6-|-7-|-8-|-9-|10|11|…

Implementation

- Algorithm (Array index analysis)
  - locating array access instruction ‘getelementptr’
  - construct prefix expression by define-use chain
  - construct infix expresion from prefix expression

- Algorithm (Induction variable analysis)
  - locating store to induction variable instructions
  - construct expression

- Algorithm (Constrain analysis)
  - locating the basic blocks contain array access
  - construct Execution Path Tree from control flow graph
  - extract branch conditions to constrains

Test

- MatrixMul

```
Array access analysis result=============
A = a + wA * ty + tx
B = b + wB * ty + tx
C = wB * 32 * by + 32 * bx + wB * ty + tx

induction variables analysis result======
a = wA * 32 * blockIdx.y
a = a + 32
b = 32 * blockIdx.x
b = b + 32 * wB

constrains analysis result===============
full execution path:
Start From Basic Block 0 : [[0]]
Start From Basic Block 1 : [[1, 0], [1, 7, 6, 3, 2, 1], [1, 7, 6, 3, 5, 4, 3]]
Start From Basic Block 2 : [[2, 1, 0], [2, 1, 7, 6, 3, 2], [2, 1, 7, 6, 3, 2, 5, 4, 3]]
Start From Basic Block 3 : [[3, 5, 4, 3], [3, 2, 1, 0], [3, 2, 1, 7, 6, 3]]
Start From Basic Block 4 : [[4, 3, 5, 4], [4, 3, 2, 1, 0], [4, 3, 2, 1, 7, 6, 3]]
Start From Basic Block 5 : [[5, 4, 3, 5], [5, 4, 3, 2, 1, 0], [5, 4, 3, 2, 1, 7, 6, 3]]
Start From Basic Block 6 : [[6, 3, 5, 4, 3], [6, 3, 2, 1, 0], [6, 3, 2, 1, 7, 6]]
Start From Basic Block 7 : [[7, 6, 3, 2, 1, 7], [7, 6, 3, 5, 4, 3], [7, 6, 3, 2, 1, 0]]
Start From Basic Block 8 : [[8, 1, 0], [8, 1, 7, 6, 3, 2, 1], [8, 1, 7, 6, 3, 5, 4, 3]]
execution path of a,b:[2, 1, 0]
execution path of c:[8, 1, 0]
a,b constrains: a <= wA * 32 * blockIdx.y + wA - 1
 c constrains: a > wA * 32 * blockIdx.y + wA - 1
```

- Reference:
  - [1] Chris Lattner. The Architecture of Open Source Applications: LLVM.