Enabling Dataflow Optimization for Quantum Programs

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What is MLIR?

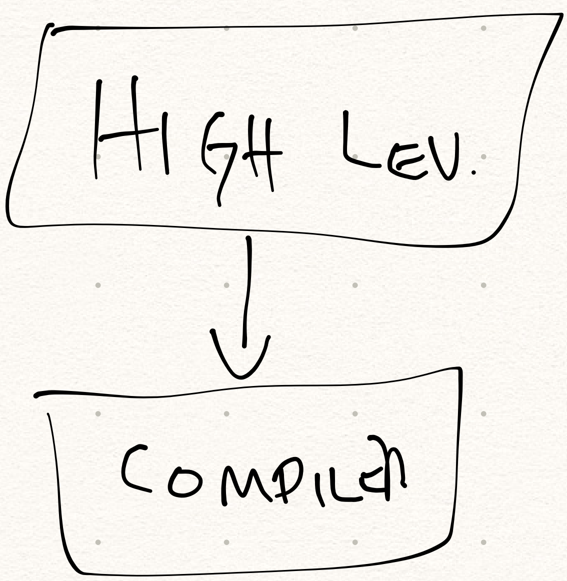
- "A novel approach to building reusable and extensible compiler infra."

MLIR: A Compiler Infrastructure for the End of Moore's Law

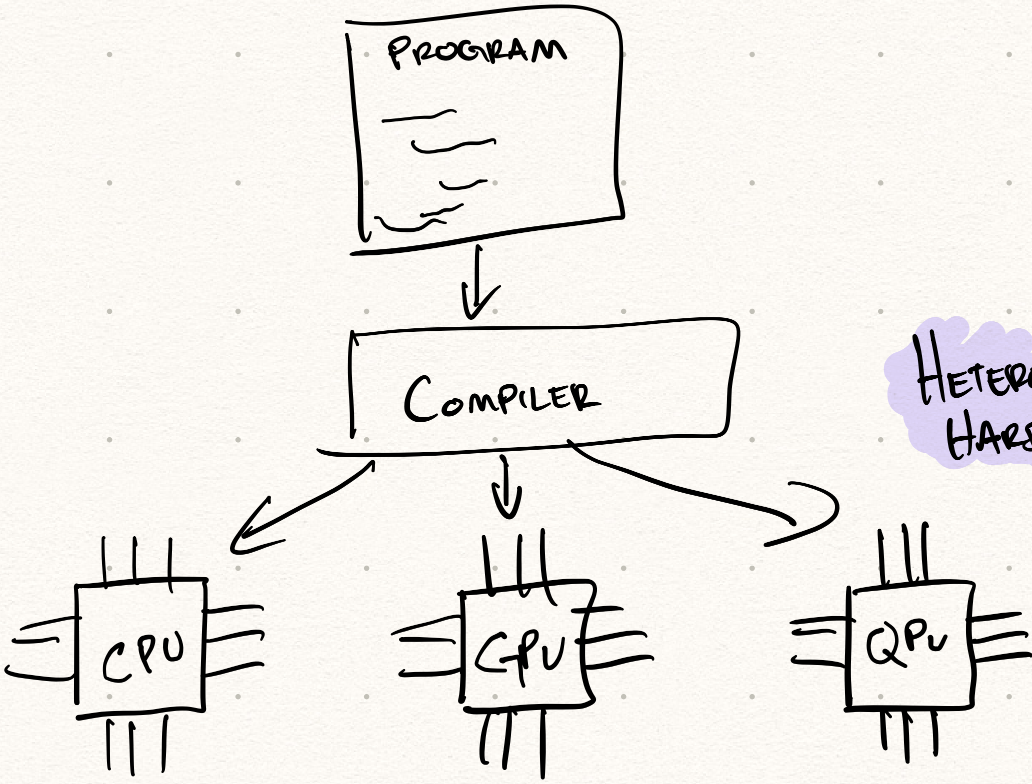
Chris Lattner * Google
Mehdi Amini Google
Uday Bondhugula IISc
Albert Cohen Google
Andy Davis Google
Jacques Pienaar Google
River Riddle Google
Tatiana Shpeisman Google
Nicolas Vasilache Google
Oleksandr Zinenko Google

Goals

- Address software fragmentation
- Compilation for heterogeneous hardware
- Reduce cost of building domain specific compilers
- Combine existing compilers



HETEROGENEOUS HARDWARE



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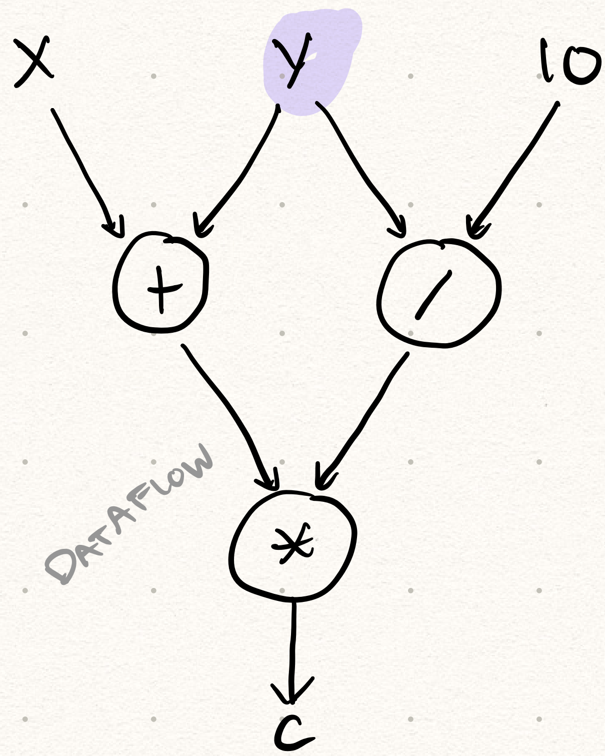
$A := X + Y$

$B := Y / 10$

$C := A * B$

IMPERATIVE



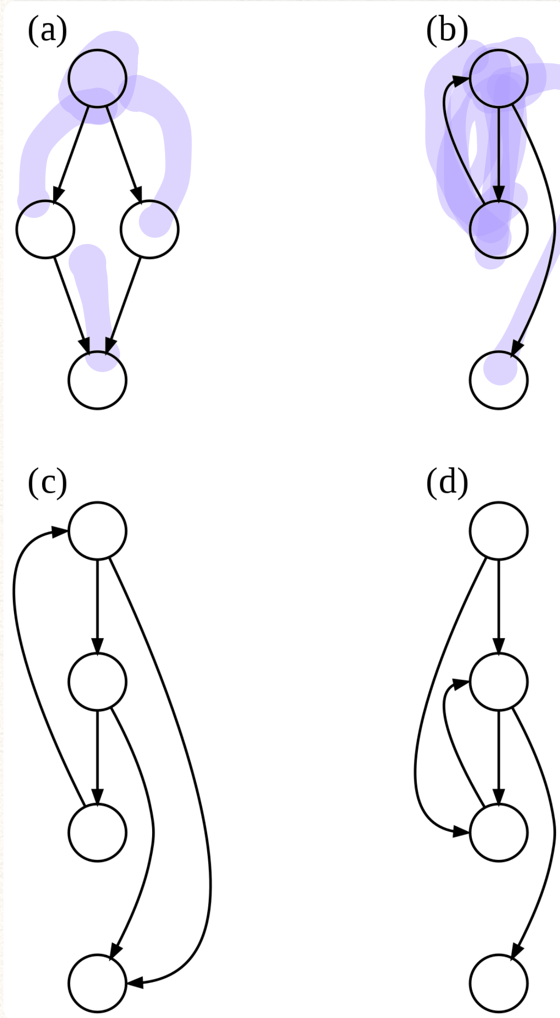
$ CAT FILE.TXT | SORT | UNIQ | WC -l

c = Circuit()

CNOT(q_1, q_2)

H(q_1)

Control Flow Diagrams



Dataflow Optimizations

```
IF b = 4
    a := 5
ELSE
    a := 3

IF a < 4
    COMPUTE(a)
```

Static Single-Assignment

$$
\begin{aligned}
y &:= 1 \\
y &:= 2 \\
x &:= y
\end{aligned}
\qquad\qquad
\begin{aligned}
y_1 &:= 1 \\
y_2 &:= 2 \\
x_1 &:= y_2
\end{aligned}
$$

```
if (cond)
    x = 6
else
    x = 4
y = x*2
```

$\longrightarrow$

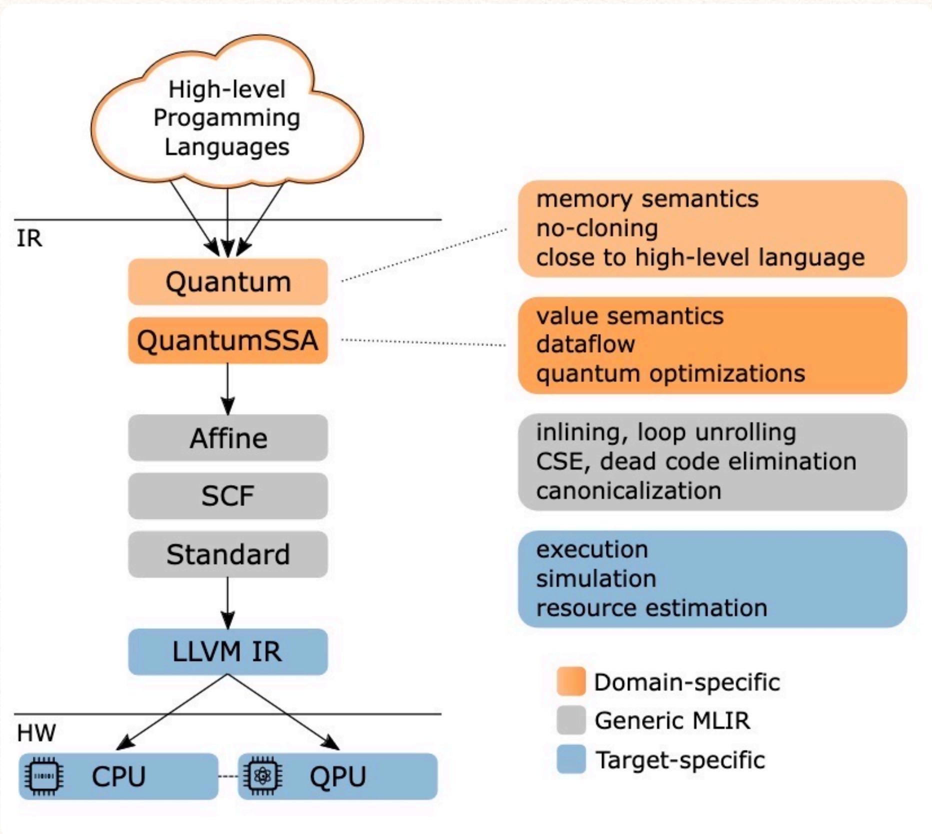
```
if (cond)
    x1 = 6
else
    x2 = 4
x3 = phi(x1,x2)
y1 = x3*2
```

QIRO

- WE ARE OFTEN USED TO THINKING OF QUANTUM OPERATIONS AS "SIDE EFFECTS"

- QUANTUM DATA OFTEN TREATED DIFFERENTLY THAN CLASSICAL DATA

- QIRO CONTAINS 2 MLIR DIALECTS
  - FIRST THAT IS "EASY" TO LOWER INTO
  - SECOND THAT EXPOSES DATAFLOW EXPLICITLY



Quantum

unique register reference

```
%r = q.allocreg(8)
q.CX %r[%i], %r[%j]
q.H %r[2]
q.CX %r[%k], %r[%h]
```

qubit register indexing

partial eval.

Quantum

```
%r = q.allocreg(8)
q.CX %r[0], %r[1]
q.H %r[2]
q.CX %r[0], %r[1]
```

identical static indices

lowering

QuantumSSA

register access becomes extract/combine block

```
%q0_0, %q1_0, %rem0 = qs.extract %r_0[0, 1]
%q0_1, %q1_1 = qs.CX %q0_0, %q1_0
%r_1 = qs.combine %rem0[0, 1], %q0_1, %q1_1

%q2_0, %rem1 = qs.extract %r_1[2]
%q2_1 = qs.H %q2_0
%r_2 = qs.combine %rem1[2], %q2_1

%q0_2, %q1_2, %rem2 = qs.extract %r_2[0, 1]
%q0_3, %q1_3 = qs.CX %q0_2, %q1_2
%r_3 = qs.combine %rem2[0, 1], %q0_3, %q1_3
```

qubit indices to extract

produce new state

consume qubit state

dataflow

QuantumSSA

```
%q0_0, %q1_0, %rem0 = qs.extract %r_0[0, 1]
%q0_1, %q1_1 = qs.CX %q0_0, %q1_0

%q2_0, %rem1 = qs.extract %rem0[0]
%q2_1 = qs.H %q2_0
%rem2 = qs.combine %rem1[0], %q2_1

%q0_2, %q1_2 = qs.CX %q0_1, %q1_1
%r_3 = qs.combine %rem2[0, 1], %q0_2, %q1_2
```

data dependence is explicit

eliminated by pattern rewrite

MLIR in Quantum

InQuIR: Intermediate Representation for Interconnected Quantum Computers

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A MLIR Dialect for Quantum Assembly Languages

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QSSA: An SSA-based IR for Quantum Computing

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Enabling Retargetable Optimizing Compilers for Quantum Accelerators via a Multi-Level Intermediate Representation

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