Optimizing Bril with STOKE

Kei Imada

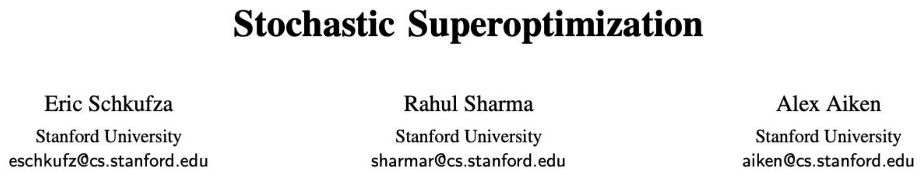
Agenda

- Background
  - STOKE
  - Bril
- Optimizing Bril with STOKE
  - Overview
  - Multiphase Optimization
- Evaluation
- Future Work

~~STOKE~~ Stork

Background

STOKE



Stochastic Superoptimization

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Random walk on x86 assembly programs with

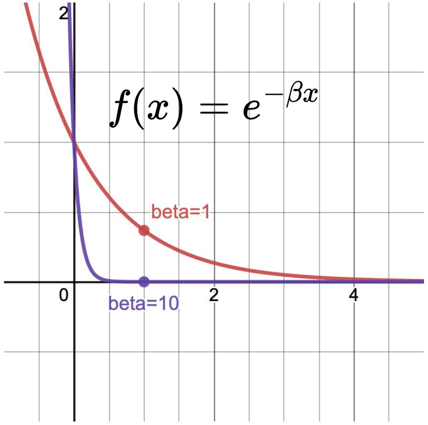
- Opcode (**add** x y → **mul** x y)
- Operand (add **x** y → add **a** y)
- Swap (line x ↔ line y)
- Instruction (add x y → random instr)

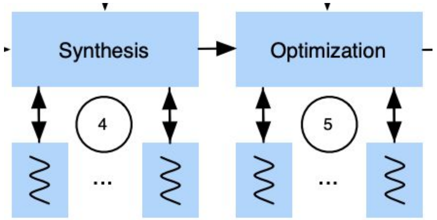
Accept with probability $e^{-\beta \frac{\mathrm{cost(next\_program)}}{\mathrm{cost(program)}}}$

Beta: higher=stricter acceptance

Two phases

- Synthesis: $\mathrm{cost}(x) = \mathrm{eq}(x), \beta = \beta_{\mathrm{min}}$
- Optimization: $\mathrm{cost}(x) = \mathrm{eq}(x) + \mathrm{perf}(x), \beta = \beta_{\mathrm{max}}$





Bril

Language for Cornell CS6120

Inspired from LLVM IR

Statically typed

Basic arithmetic operations + other extensions

https://github.com/sampsyo/bril

```
# clobber.bril
@main(a: int, b: int): int {
  # (a + b) * (a + b)
  sum1: int = add a b;
  sum2: int = add a b;
  prod1: int = mul sum1 sum2;

  # Clobber both sums.
  sum1: int = const 0;
  sum2: int = const 0;

  # Use the sums again.
  sum3: int = add a b;
  prod2: int = mul sum3 sum3;

  ret prod2;
}
```

Optimizing **Bril** with ST**OKE**

BLOKE

Optimizing BPF with STOKE

```
# clobber.bril
@main(a: int, b: int): int {
  sum1: int = add a b;
  sum2: int = add a b;
  prod1: int = mul sum1 sum2;
  sum1: int = const 0;
  sum2: int = const 0;
  sum3: int = add a b;
  prod2: int = mul sum3 sum3;
  ret prod2;
}
```

```
# clobber.bril
@main(a: int, b: int): int {
  sum1: int = add a b;
  sum2: int = add a b;
  prod1: int = mul sum1 sum2;
  sum1: int = const 0;
  sum2: int = const 0;
  sum3: int = add a b;
  prod2: int = mul sum3 sum3;
  ret prod2;
}
```

```
# 229.73 seconds
@main(a: int, b: int): int {
  sum3: int = add a b;
  prod2: int = mul sum3 sum3;
  ret prod2;
  nop;
  sum1: int = add a a;
  x4: bool = fge x2 x2;
  sum2: int = mul a sum1;
  nop;
}
```

BLOKE

STOKE on Bril

Same mutation operations

Similar cost functions

STOKE Mutations

Opcode (**add** x y → **mul** x y)

Operand (add **x** y → add **a** y)

Swap (line x ↔ line y)

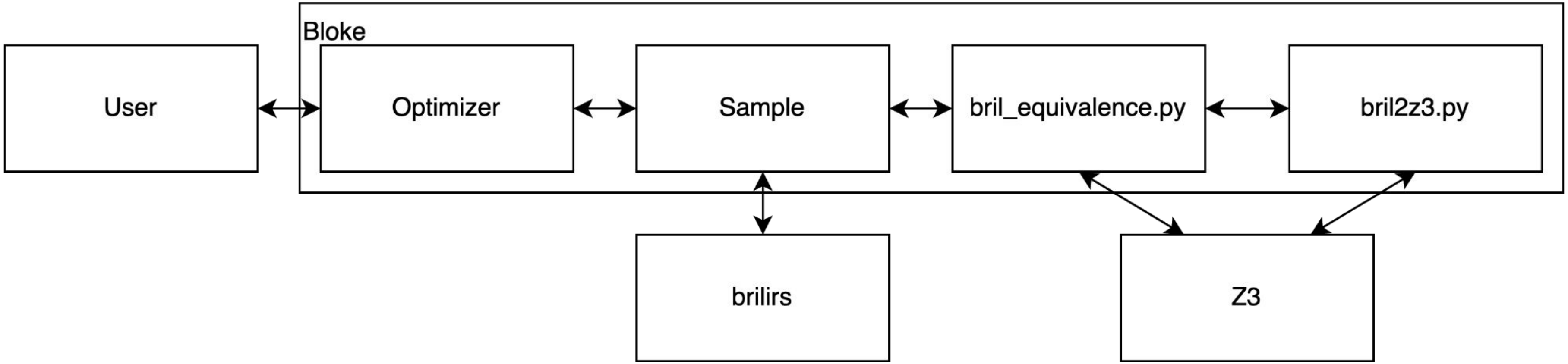
Instruction (add x y → random instr)

```
@main(a: int, b: int): int {
  sum1: int = add a b;
  sum2: int = add a b;
  prod1: int = mul sum1 sum2;
  sum1: int = const 0;
  sum2: int = const 0;
  sum3: int = add a b;
  prod2: int = mul sum3 sum3;
  ret prod2;
}
```

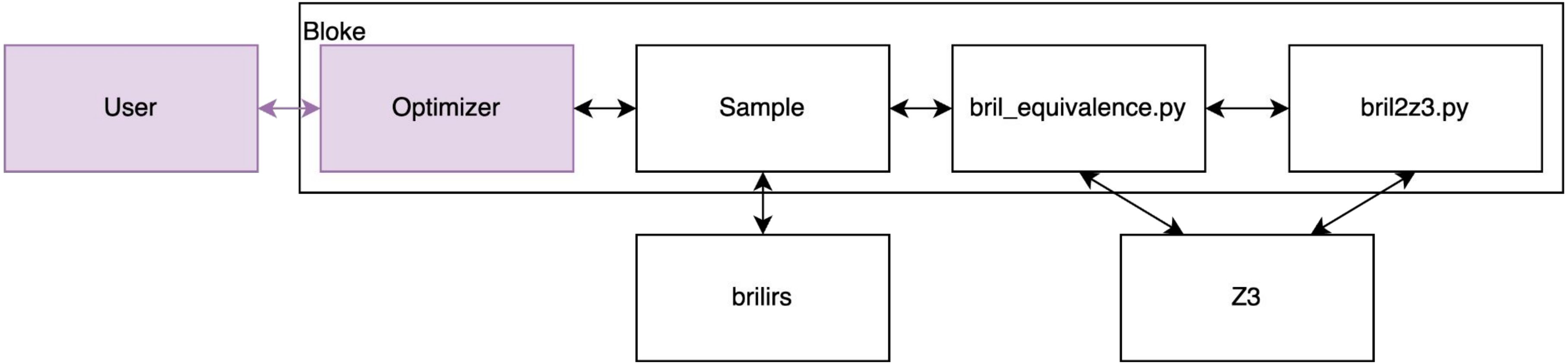
BLOKE

```
@main(a: int, b: int): int {
  nop;
  nop;
  sum3: int = add a b;
  nop;
  nop;
  nop;
  prod2: int = mul sum3 sum3;
  ret prod2;
}
```

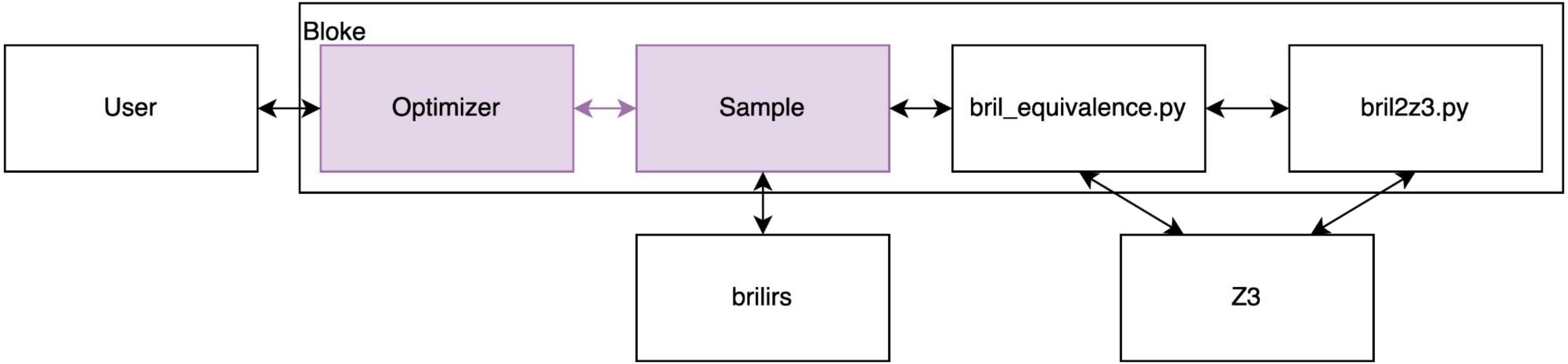
Architecture



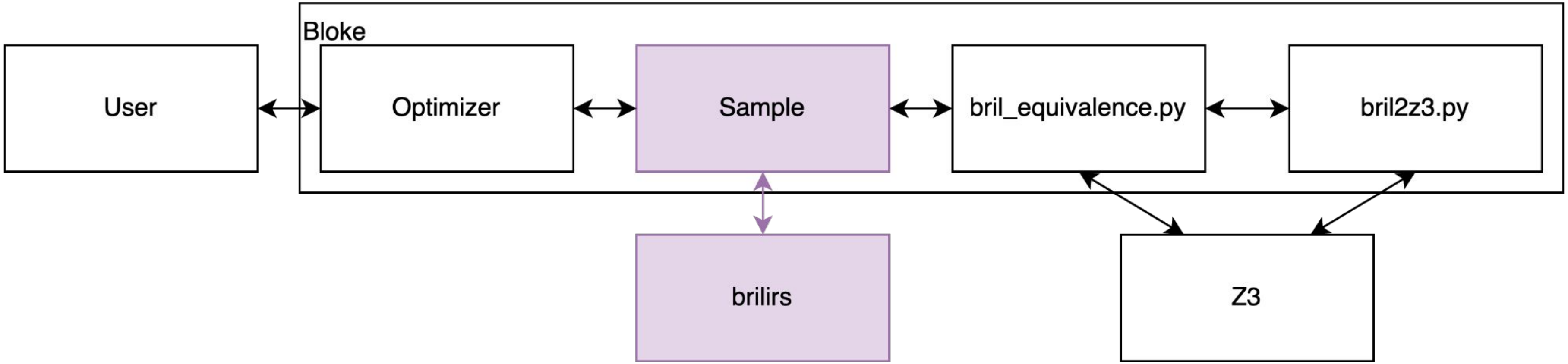
Architecture



Architecture



Architecture



Bloke

User

Optimizer

Sample

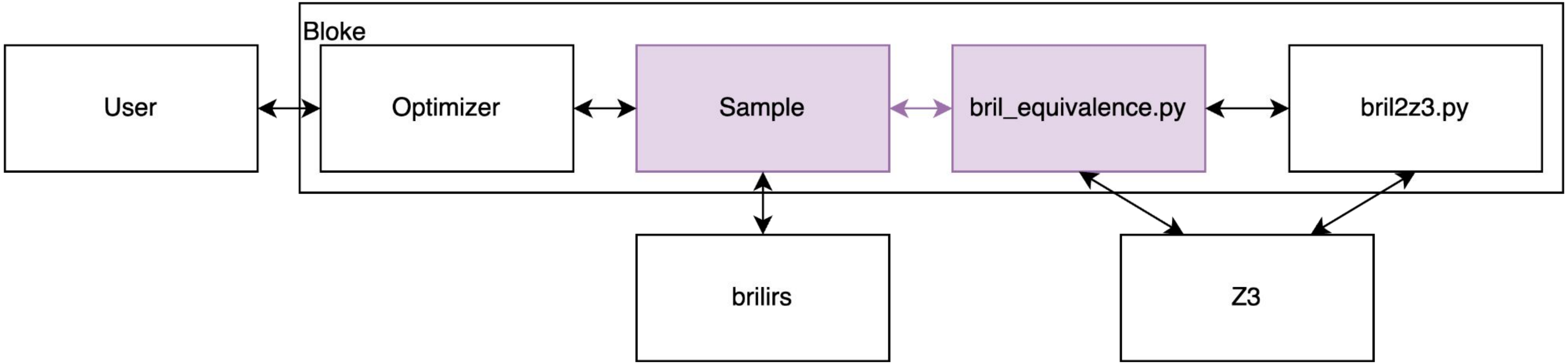
bril_equivalence.py

bril2z3.py

brilirs

Z3

Architecture



Bloke

User

Optimizer

Sample

bril_equivalence.py

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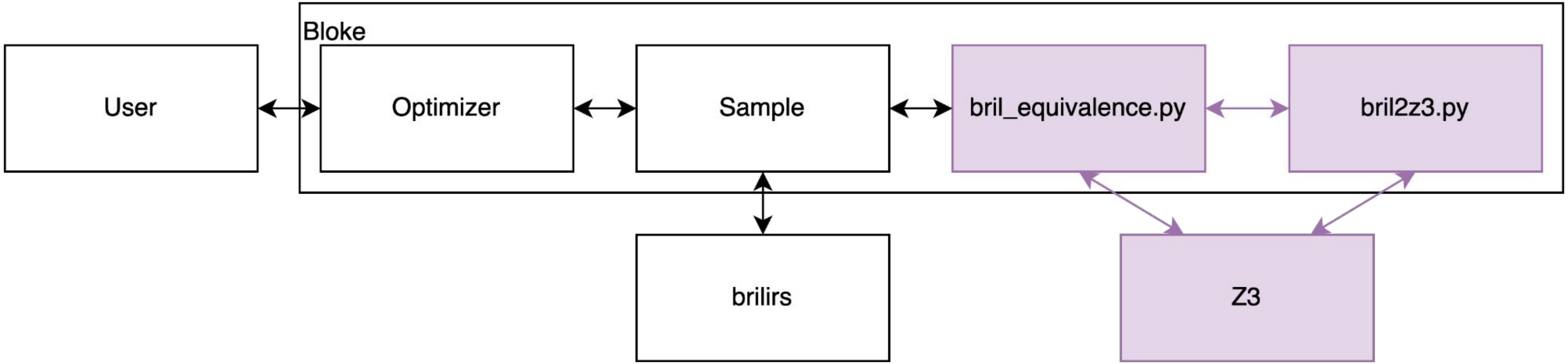
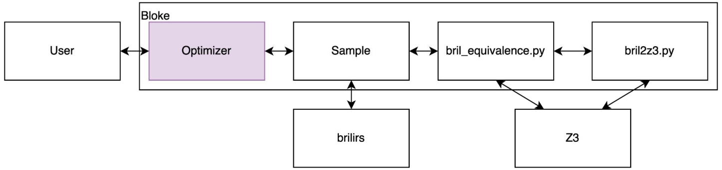
brilirs

Z3

Architecture



Multiphase Optimization



Recall: STOKE has two phases

Synthesis and optimization

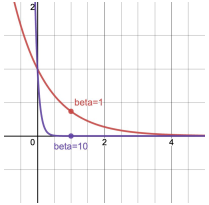
Recall: Beta = acceptance strictness

Gamma: performance cost weight

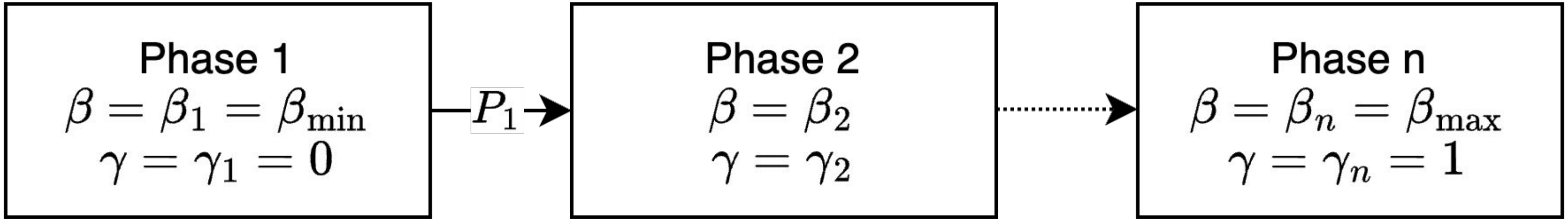
$$e^{-\beta\frac{\text{cost(next\_program)}}{\text{program}}}$$

$$\text{cost}(x) = \text{eq}(x), \beta = \beta_{\text{min}}$$

$$\text{cost}(x) = \text{eq}(x) + \text{perf}(x), \beta = \beta_{\text{max}}$$



$$\text{cost}(x) = \text{eq}(x) + \gamma \cdot \text{perf}(x)$$



Phase 1

$\beta = \beta_1 = \beta_{\text{min}}$

$\gamma = \gamma_1 = 0$

P_1

Phase 2

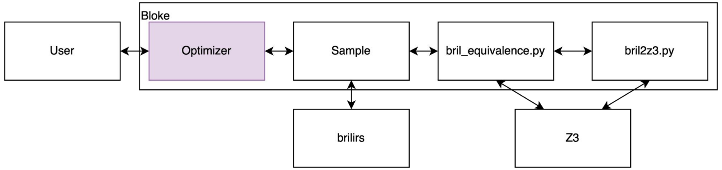
$\beta = \beta_2$

$\gamma = \gamma_2$

Phase n

$\beta = \beta_n = \beta_{\text{max}}$

$\gamma = \gamma_n = 1$



Bloke

User

Optimizer

Sample

bril_equivalence.py

bril2z3.py

brilirs

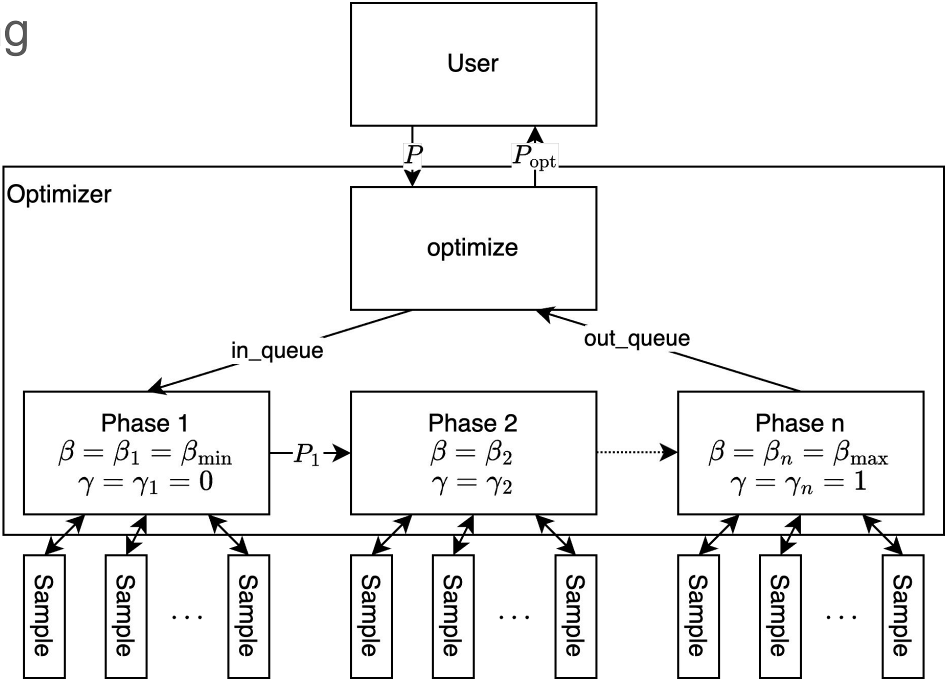
Z3

Optimizer Architecture

Python multiprocessing + threading

Each phase is a thread

Communicate with queues



User

P

P_{opt}

Optimizer

optimize

in_queue

out_queue

Phase 1
$\beta = \beta_1 = \beta_{\min}$
$\gamma = \gamma_1 = 0$

P_1

Phase 2
$\beta = \beta_2$
$\gamma = \gamma_2$

Phase n
$\beta = \beta_n = \beta_{\max}$
$\gamma = \gamma_n = 1$

Sample Sample … Sample

Sample Sample … Sample

Sample Sample … Sample

Evaluation

Benchmarks

Many existing Bril benchmarks have loops :(

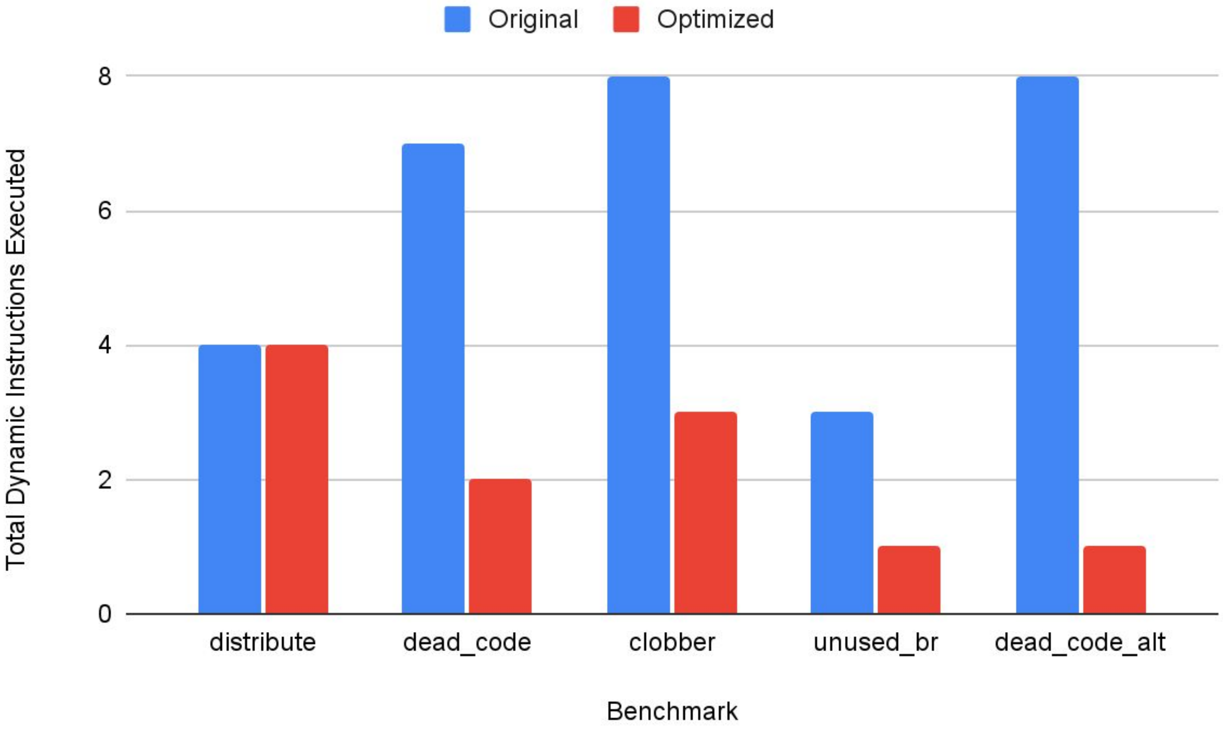
Most existing benchmarks have currently unsupported operations :(

- Print, Call, Memory, etc

So I made my own programs

- Toy examples

Optimized Code Performance



Optimized Code Performance

```
# distribute.bril: a*b+a*c
@main(a: int, b: int, c: int): int
{
  x1: int = mul a b;
  x2: int = mul a c;
  x3: int = add x1 x2;
  ret x3;
}
# dead_code.bril
@main(x: int): int {
  one: int = const 1;
  x: int = add x one;
  x: int = add x one;
  x: int = add x one;
  x: int = add x one;
  x: int = add x one;
  ret one;
}
```

```
# 10.68 seconds
@main(a: int, b: int, c: int): int {
  x1: int = mul a b;
  x2: int = mul a c;
  x3: int = add x1 x2;
  ret x3;
}

# 277.86 seconds
@main(x: int): int {
  one: int = const 1;
  ret one;
  x: int = add x one;
  x: int = add x one;
  x: int = add x one;
  jmp;
  x: int = add x one;
}
```

Optimized Code Performance

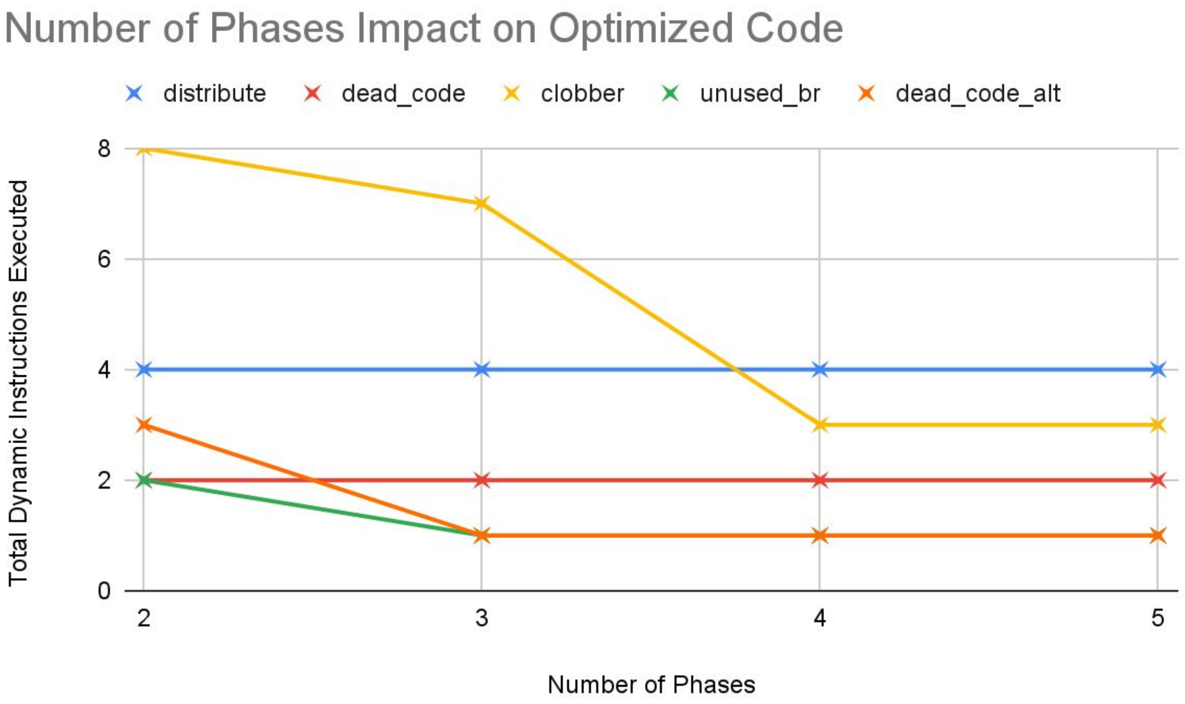
```
# unused_br.bril
@main(a: int, b: int): int {
  true: bool = const true;
  br true .then .else;
.then:
  ret a;
.else:
  ret b;
}
```

```
# 228.13 seconds
@main(a: int, b: int): int {
  ret a;
  br true .then .else;
.then:
  true: bool = const true;
.else:
  ret b;
}
```

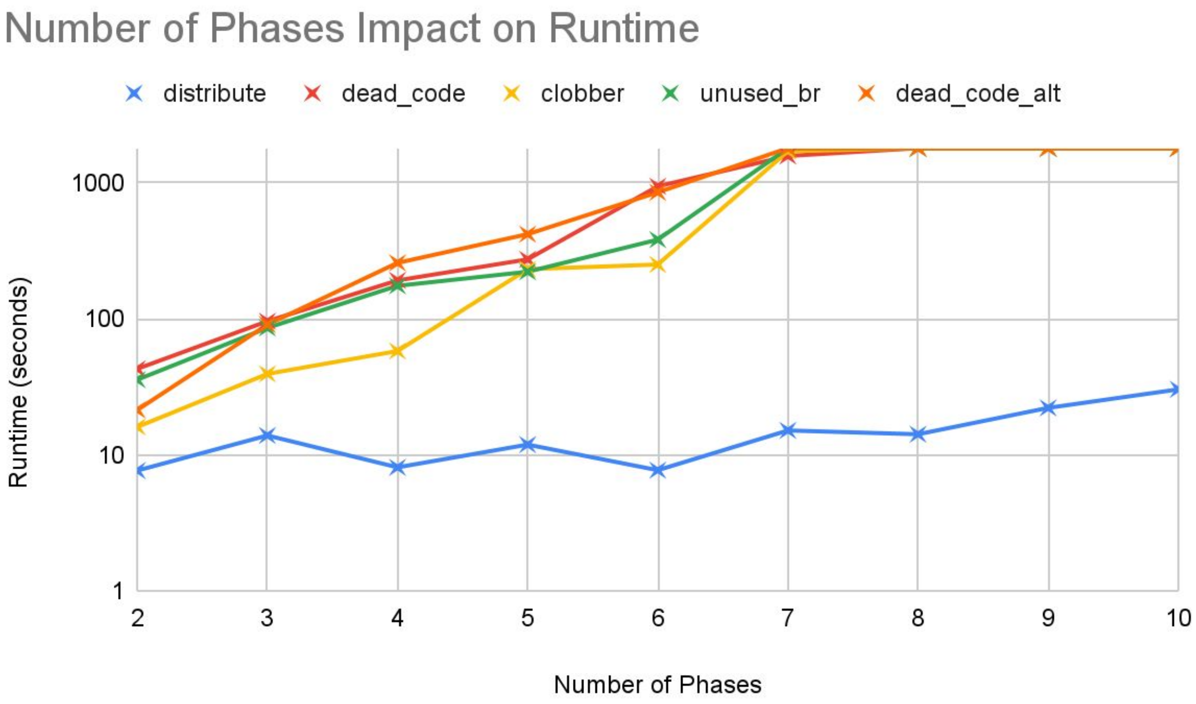
```
# dead_code_alt.bril
@main(x: int): int {
  one: int = const 1;
  y: int = id x;
  x: int = add x one;
  x: int = add x one;
  x: int = add x one;
  x: int = add x one;
  x: int = add x one;
  ret y;
}
```

```
# 418.19 seconds
@main(x: int): int {
  ret x;
  x: int = add x one;
  x: int = add x one;
  x3: bool = fle x0 x1;
  y: int = id x;
  x: int = mul x x;
  x: int = sub x x;
  x5: bool = lt x one;
}
```

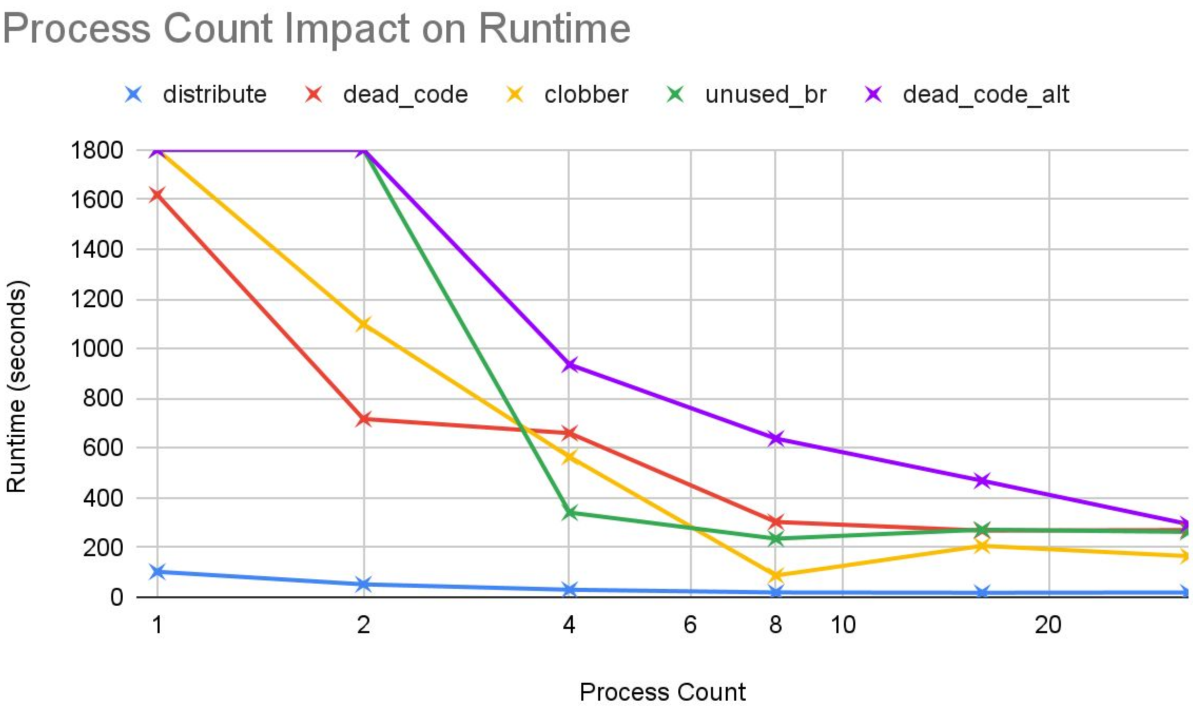
Multiphase Optimized Code Performance



Multiphase Performance



Scalability



Future Work

More benchmarks

Support more Bril operations in Z3

- Print statements with theory of arrays
- Pointers and memory access
- Function calls
- Speculation

Trace optimizations and JIT compilation

Allow some loops with loop-invariant synthesis

Optimizer optimizations

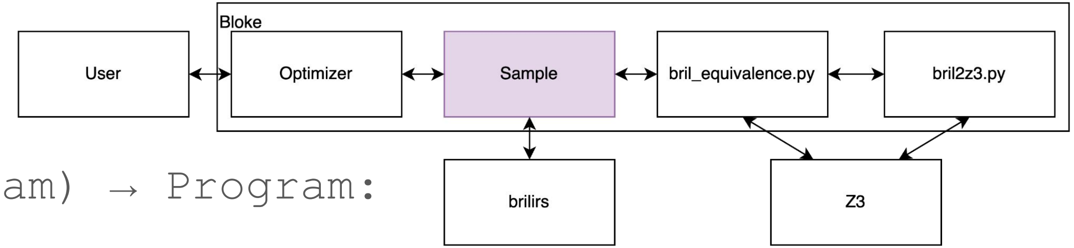
MPI for distributed BLOKE

~~BLOKE~~ Blork

?

Backup

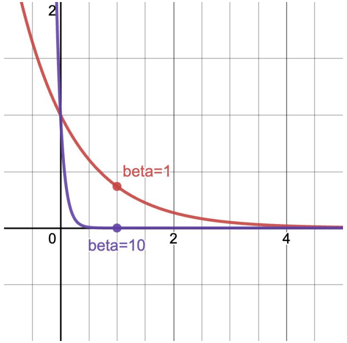
Sample



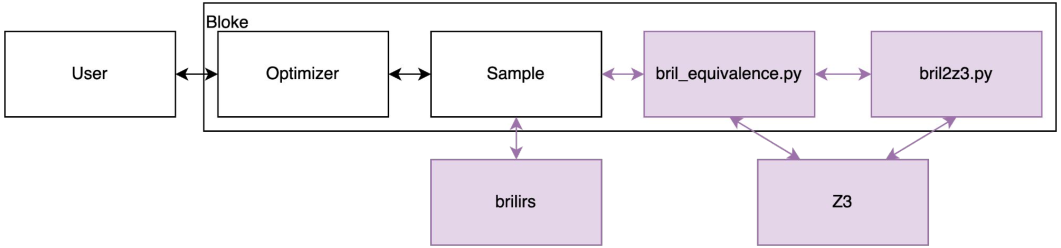
```
def sample(program: Program) → Program:
    next_program ← mutated program
    return next_program with probability $e^{-\beta \frac{\text{cost(next\_program)}}{\text{cost(program)}}}$
    otherwise return program
```

Recall: beta is the acceptance strictness

$$f(x) = e^{-\beta x}$$



Equivalence cost



Lift loop-free programs to Z3

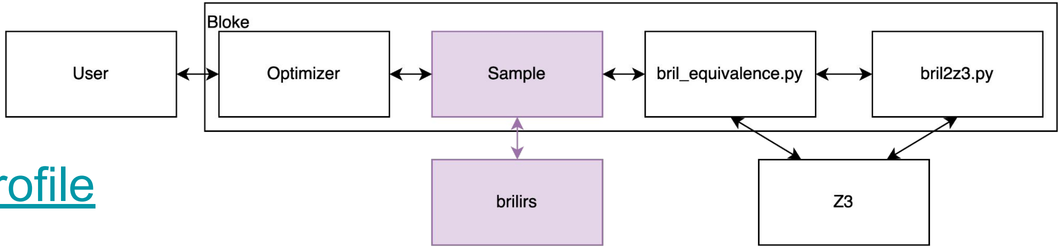
Program x not equivalent to x_0 iff $\exists i[x(i) \neq x_0(i)]$

Z3 is expensive and running brilirs on test cases is cheaper

Counter-example guided equivalence cost function

$$\mathrm{eq}(x) = \begin{cases} \mathrm{validation}(x) & \text{if} \quad \mathrm{validation}(x) > 0 \\ \mathrm{verification}(x) & \text{otherwise} \end{cases}$$

Performance cost



Bril interpreters have -p flag to profile

Total dynamic instructions executed

If interpreter produces an error, use approximate performance

$$\text{total\_dyn\_inst}_{\text{approx}}(x, i) = \text{len}(x[\text{instrs}]) - x[\text{number of nops}]$$

$$\text{total\_dyn\_inst}(x, i) = \begin{cases} \infty & \text{if } \; x \; \text{ has a loop} \\ \text{total\_dyn\_inst}_{\text{approx}}(x) & \text{if } \; x \; \text{ errors on input } \; i \\ x(i)[\text{total\_dyn\_inst}] & \text{otherwise} \end{cases}$$

$$\text{perf}(x) = \text{max}_i\{\text{total\_dyn\_inst}(x, i)\}$$

Bril2Z3

Static single assignment (SSA) form

Bril types

- Integer: 64-bit bitvector
- Float: 64-bit floating point

Z3 datatypes to model Bril return types

Bril Modifications

Python bindings for brilirs

Allow “main” function to return an integer

- Treat as return code

brili and brilirs no longer profiles nops