Automatically Retrofitting JIT Compilers

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https://tratt.net/laurie/

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yk

```
$ diff -u lua-5.5.0/src yklua/src | diffstat -f 0
 Makefile  |   15       14 +    1 -     0 !
 ldo.c     |   46       44 +    2 -     0 !
 lfunc.c   |   27       27 +    0 -     0 !
 lfunc.h   |    7        7 +    0 -     0 !
 lgc.c     |    6        6 +    0 -     0 !
 llimits.h |    2        1 +    1 -     0 !
 lobject.h |   18       18 +    0 -     0 !
 loslib.c  |   15       15 +    0 -     0 !
 lparser.c |  115      115 +    0 -     0 !
 lparser.h |    4        3 +    1 -     0 !
 lstate.c  |    6        6 +    0 -     0 !
 lstate.h  |    7        7 +    0 -     0 !
 luac.c    |   10       10 +    0 -     0 !
 lundump.c |   10       10 +    0 -     0 !
 lvm.c     |  116      114 +    2 -     0 !
 15 files changed, 397 insertions(+), 7 deletions(-)
```

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 ldo.c     |   46       44 +    2 -      0 !
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 llimits.h |    2        1 +    1 -      0 !
 lobject.h |   18       18 +    0 -      0 !
 loslib.c  |   15       15 +    0 -      0 !
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 lstate.c  |    6        6 +    0 -      0 !
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 luac.c    |   10       10 +    0 -      0 !
 lundump.c |   10       10 +    0 -      0 !
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```

- *VM*:

- *VM*: System containing one or more language implementations

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- *Interpreter*:

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*https://tratt.net/laurie/blog/2023/distinguishing_an_interpreter_from_a_compiler.html

- *VM*: System containing one or more language implementations
- *Interpreter*: Simple language implementation*
- *JIT compiler*:

*https://tratt.net/laurie/blog/2023/distinguishing_an_interpreter_from_a_compiler.html

- *VM*: System containing one or more language implementations
- *Interpreter*: Simple language implementation*
- *JIT compiler*: Language implementation that observes a running program, optimises, and compiles portions to machine code

*https://tratt.net/laurie/blog/2023/distinguishing_an_interpreter_from_a_compiler.html

I: Why?

My program is slow

Drop in a faster language implementation

Cinder; IronPython; Jython;

Cinder; IronPython; Jython;
Nuitka; Psyco; Pyjion;

Cinder; IronPython; Jython;
Nuitka; Psyco; Pyjion;
PyPy; Pyston; S6;

Cinder; IronPython; Jython;
Nuitka; Psyco; Pyjion;
PyPy; Pyston; S6;
Shed Skin; Stackless; Starkiller;

Cinder; IronPython; Jython;
Nuitka; Psyco; Pyjion;
PyPy; Pyston; S6;
Shed Skin; Stackless; Starkiller;
TrufflePython; Unladen Swallow;

Cinder; IronPython; Jython;
Nuitka; Psyco; Pyjion;
PyPy; Pyston; S6;
Shed Skin; Stackless; Starkiller;
TrufflePython; Unladen Swallow;
WPython; Zippy

JIT compiling VMs are:

JIT compiling VMs are:

hard

JIT compiling VMs are:

hard
expensive

JIT compiling VMs are:

hard
expensive
maybe incompatible

JIT compiling VMs are:

hard
expensive
maybe incompatible
difficult to evolve

Automation:

Automation: RPython and Truffle

Automation: RPython and Truffle

Host:

Automation: RPython and Truffle

Host: RPython / Java

Automation: RPython and Truffle

Host: RPython / Java

Guest:

Automation: RPython and Truffle

Host: RPython / Java
Guest: Lua, Ruby, Python, CPU sim, etc.

II: How?

The C interpreter is the source of truth

Generate a *meta-tracing* JIT compiler
from C interpreters

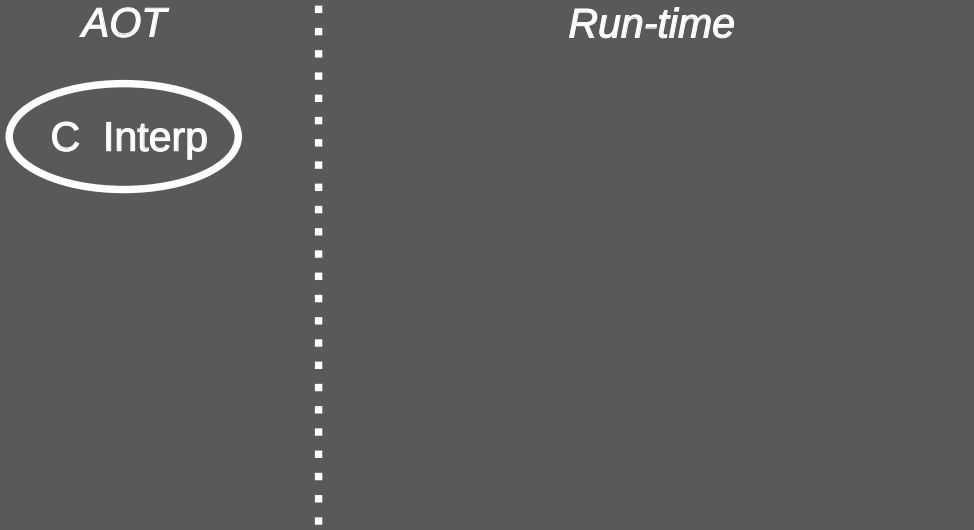
Tracing: manually record *hot loops* at run-time

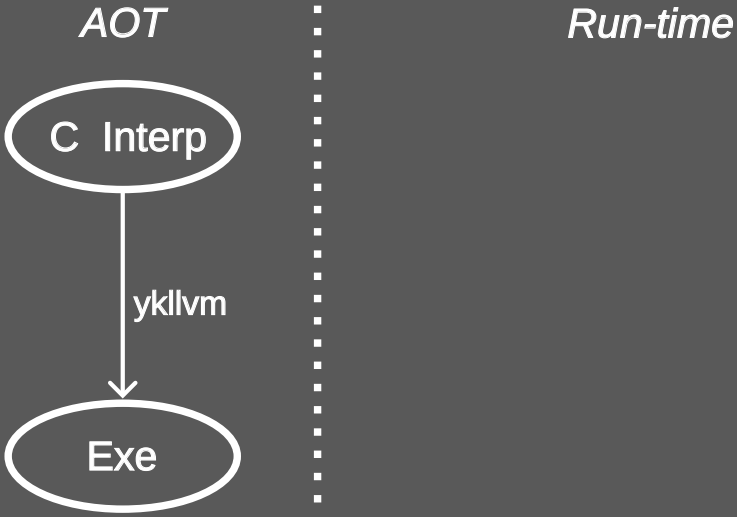
Tracing: manually record *hot loops* at run-time

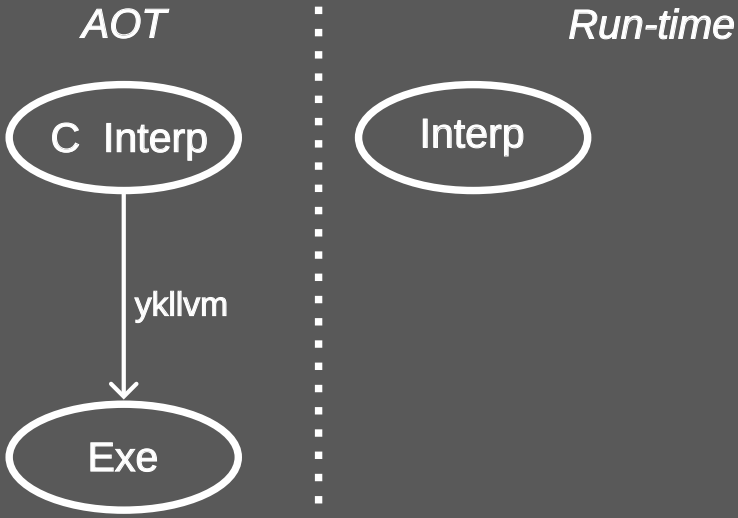
Meta-tracing: record the interpreter executing loops at run-time

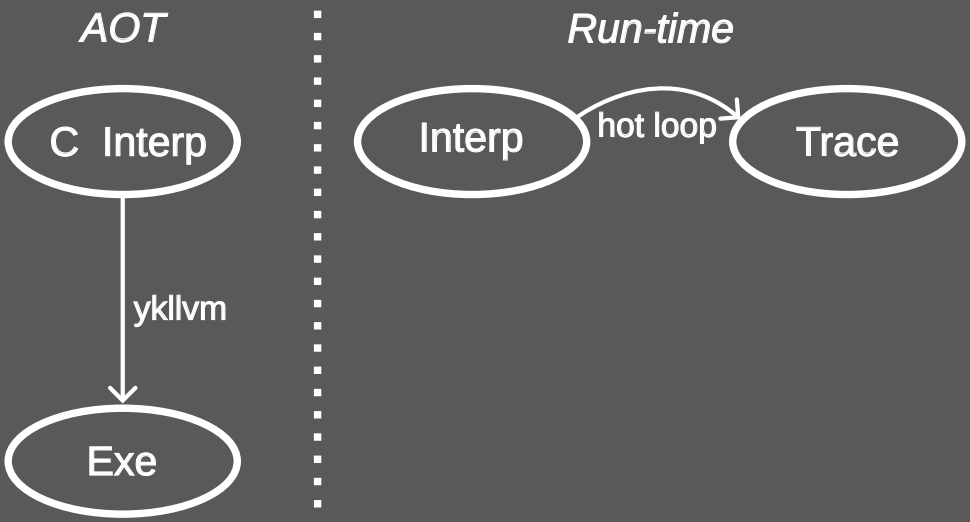
AOT

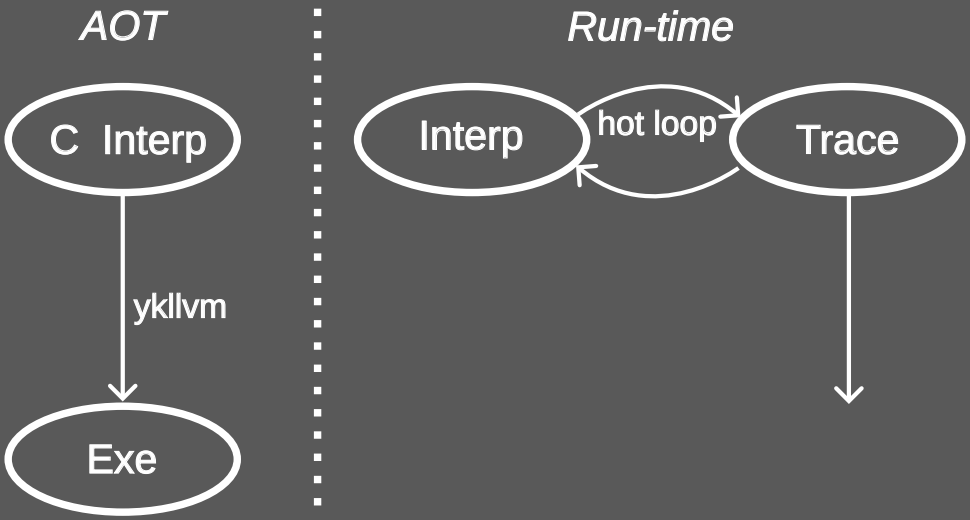
Run-time

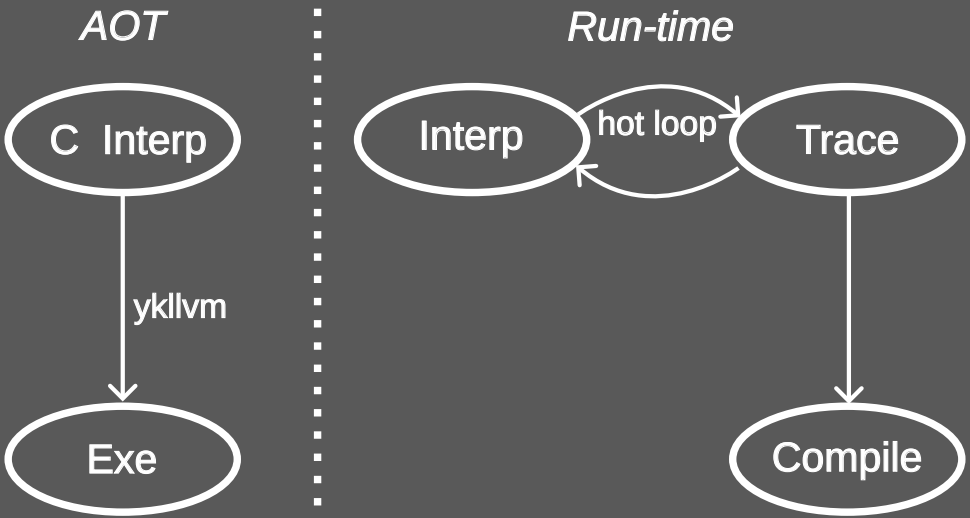

AOT
Run-time
C Interp

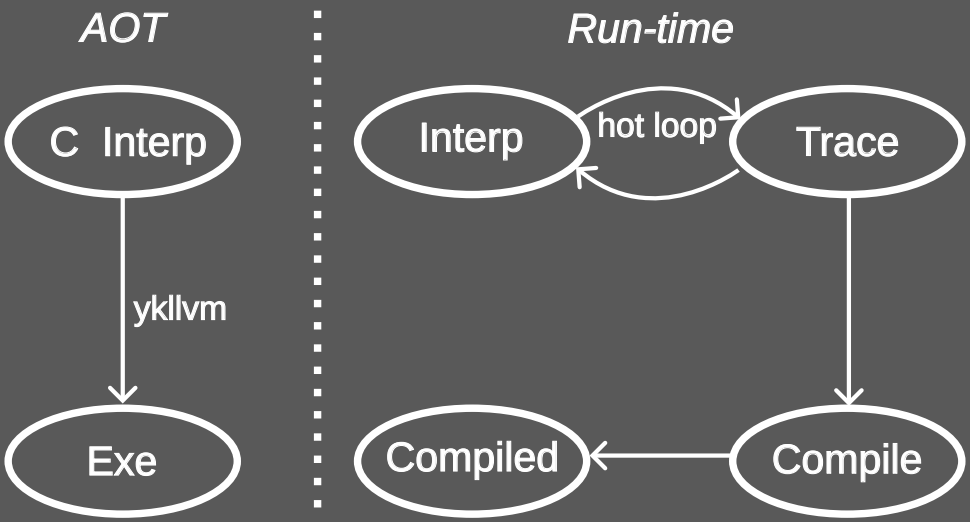

AOT
Run-time
C Interp
yklllvm
Exe

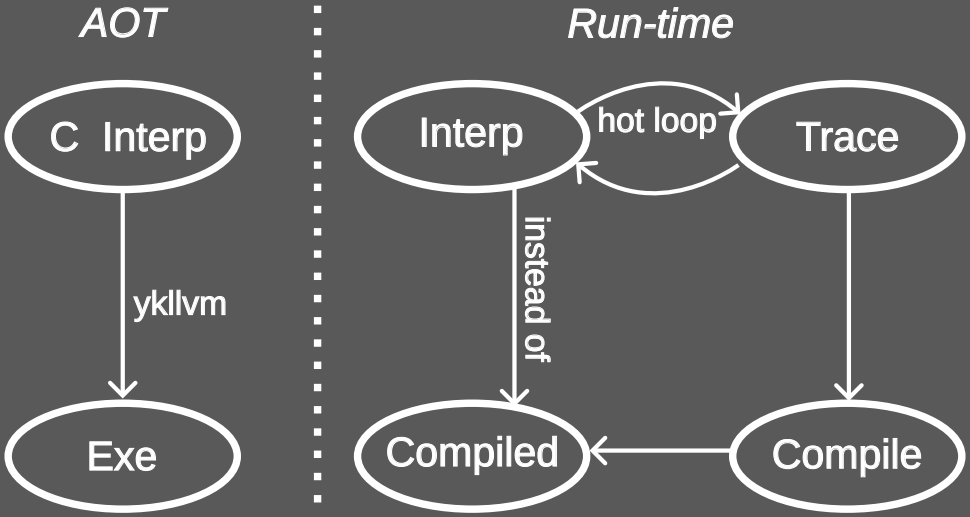

AOT
Run-time
C Interp
Interp
yklIvm
Exe

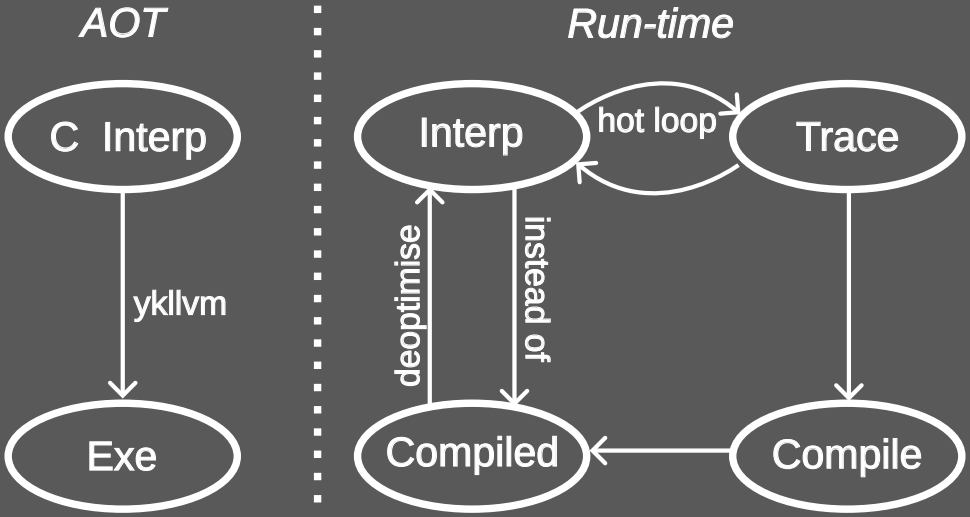

AOT
Run-time
C Interp
ykllvm
Exe
Interp
hot loop
Trace


AOT
Run-time
C Interp
yk|lvm
Exe
Interp
hot loop
Trace


AOT
Run-time
C Interp
ykllvm
Exe
Interp
hot loop
Trace
Compile


AOT
Run-time
C Interp
yklllvm
Exe
Interp
hot loop
Trace
Compiled
Compile


AOT
Run-time
C Interp
yklIvm
Exe
Interp
hot loop
Trace
instead of
Compiled
Compile


AOT
Run-time
C Interp
yk|lvm
Exe
Interp
hot loop
Trace
deoptimise
instead of
Compiled
Compile

```
while (true) {




}
```

```
Instruction *code = ...;

while (true) {




}
```

```
Instruction *code = ...;
int pc = 0;

while (true) {
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {




  }
}
```

```
Instruction *code = ...;
int pc = 0;

while (true) {
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP:




  }
}
```

```
Instruction *code = ...;
int pc = 0;
Value **stack = ...;
while (true) {
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP: push(lookup(GET_OPVAL()));




  }
}
```

```
Instruction *code = ...;
int pc = 0;
Value **stack = ...;
while (true) {
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP: push(lookup(GET_OPVAL())); pc++; break;




  }
}
```

```
Instruction *code = ...;
int pc = 0;
Value **stack = ...;
while (true) {
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP: push(lookup(GET_OPVAL())); pc++; break;
    case OP_ADD:



  }
}
```

```
Instruction *code = ...;
int pc = 0;
Value **stack = ...;
while (true) {
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP: push(lookup(GET_OPVAL())); pc++; break;
    case OP_ADD: push(pop() + pop()); pc++; break;



  }
}
```

```
Instruction *code = ...;
int pc = 0;
Value **stack = ...;
while (true) {
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP: push(lookup(GET_OPVAL())); pc++; break;
    case OP_ADD: push(pop() + pop()); pc++; break;
    case OP_JLE:


  }
}
```

```
Instruction *code = ...;
int pc = 0;
Value **stack = ...;
while (true) {
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP: push(lookup(GET_OPVAL())); pc++; break;
    case OP_ADD: push(pop() + pop()); pc++; break;
    case OP_JLE:
      if (pop() <= 0) pc += GET_OPVAL(i) else pc++;
      break;
  }
}
```

Guest

```
if x > 0:
  y = y + 3
```

Guest

```
if x > 0:
  y = y + 3
```

Tracing

```
OP_LOOKUP("x")
guard true, pop() > 0
OP_LOOKUP("y")
OP_INT(3)
OP_ADD
OP_SET("y")
```

Guest

```
if x > 0:
  y = y + 3
```

Tracing

```
OP_LOOKUP("x")
guard true, pop() > 0
OP_LOOKUP("y")
OP_INT(3)
OP_ADD
OP_SET("y")
```

Meta-tracing

```
push(lookup("x")); pc++;
guard true, pop() > 0; pc++;
push(lookup("y")); pc++;
push(3); pc++;
push(pop() + pop()); pc++;
set("y", pop()); pc++;
```

```
push(lookup("x"));
```

```
push(lookup("x"));
```

Inlined

```
guard true, *used < *capacity;
storage[*used] = elem;
*used += 1;
```

How does yk convert C code into a meta-tracing compiler?

How does yk convert C code into a meta-tracing compiler?

ykllvm

```
cc -o vm.o vm.c
ld -o vm vm.o
```

```
cc -o vm.o vm.c
ld -o vm vm.o

`yk-config release --cc` -o vm.o vm.c
`yk-config release --cc --ldflags` -o vm vm.o
```

```
Instruction *code = ...;
int pc = 0;
Value **stack = ...;
while (true) {

  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP:

      push(lookup(GET_OPVAL())); pc++; break;
    case OP_ADD:

      push(pop() + pop()); pc++; break;
  }
}
```

```
Instruction *code = ...;
int pc = 0;
Value **stack = ...;
while (true) {
  __yk_record(0);
  Instruction i = code[pc];
  switch (GET_OPCODE(i)) {
    case OP_LOOKUP:
      __yk_record(1);
      push(lookup(GET_OPVAL())); pc++; break;
    case OP_ADD:
      __yk_record(2);
      push(pop() + pop()); pc++; break;
  }
}
```

Convert LLVM’s IR for the interpreter into yk IR

```
359:                                              ; preds = %341
  %360 = load ptr, ptr %355, align 8, !tbaa !11
  %361 = load ptr, ptr %352, align 8, !tbaa !11
  %362 = call ptr @luaH_getshortstr(ptr noundef %361, ptr noundef %360) #18
  %363 = getelementptr inbounds nuw i8, ptr %362, i64
  %364 = load i8, ptr %363, align 8, !tbaa !9
  %365 = and i8 %364, 15
  %366 = icmp eq i8 %365, 0
  br i1 %366, label %371, label %367
367:                                              ; preds = %359
  %368 = load i64, ptr %362, align 8, !tbaa !11
  store i64 %368, ptr %345, align 8, !tbaa !11
  %369 = load i8, ptr %363, align 8, !tbaa !9
  %370 = getelementptr inbounds nuw i8, ptr %345, i64 8
  store i8 %369, ptr %370, align 8, !tbaa !9
  br label %3329
371:                                              ; preds = %341, %359
  %372 = phi ptr [ %362, %359 ], [ null, %341 ]
  store ptr %203, ptr %171, align 8, !tbaa !11
  %373 = load ptr, ptr %172, align 8, !tbaa !11
  store ptr %373, ptr %13, align 8, !tbaa !11
  call void @luaV_finishget(ptr noundef nonnull %0, ptr noundef nonnull %352, ptr n
  %374 = load volatile i32, ptr %173, align 8, !tbaa !11
  br label %3329
```

```
 bb47:
  %47_0: ptr = ptr_add %46_2, 8
  %47_1: i8 = load %47_0
  %47_2: i8 = and %47_1, 15i8
  %47_3: i1 = eq %47_2, 0i8
  condbr %47_3, bb49, bb48 [statepoint: 396i64, (%0_0, %0_2, %0_5, %0_6, ...
bb48:
  %48_0: i64 = load %46_2
  *%45_3 = %48_0
  %48_2: i8 = load %47_0
  %48_3: ptr = ptr_add %45_3, 8
  *%48_3 = %48_2
  br bb812
bb49:
  %49_0: ptr = phi bb47 -> %46_2, bb45 -> 0x0
  *%6_10 = %29_0
  %49_2: ptr = load %11_5
  *%0_21 = %49_2
  call luaV_finishget(%0_0, %45_10, %45_13, %45_3, %49_0) [statepoint: 397i64,
  br bb50
```

Executable = normal machine code + serialised IR

How does yk optimise a program?

How does yk optimise a program?

1. Inlining.

How does yk optimise a program?

1. Inlining.
2. Standard(ish) compiler optimisations.

How does yk optimise a program?

1. Inlining.
2. Standard(ish) compiler optimisations.
3. Interpreter hints.

```
push(lookup("x")); pc++
guard true, pop() > 0; pc++
push(lookup("y")); pc++
push(3); pc++
push(pop() + pop()); pc++
set("y", pop()); pc++
```

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push(lookup("x")); pc++
guard true, pop() > 0; pc++
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set("y", pop()); pc++
```
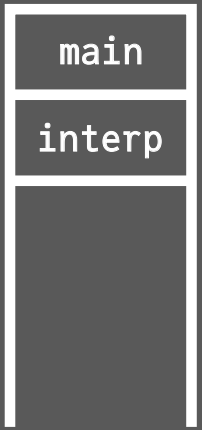
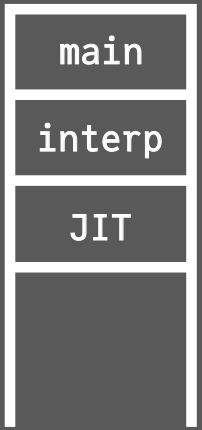
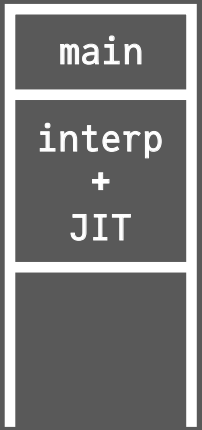
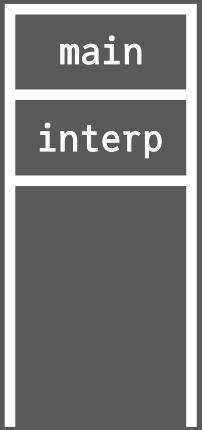


main


main
interp


main
interp
JIT


main
interp
+
JIT


main
interp

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  %47_3: i1 = eq %47_2, 0i8
  condbr %47_3, bb49, bb48 [statepoint: 396i64, (%0_0, %0_2, %0_5, %0_6, ...
bb48:
  %48_0: i64 = load %46_2
  *%45_3 = %48_0
  %48_2: i8 = load %47_0
  %48_3: ptr = ptr_add %45_3, 8
  *%48_3 = %48_2
  br bb812
bb49:
  %49_0: ptr = phi bb47 -> %46_2, bb45 -> 0x0
  *%6_10 = %29_0
  %49_2: ptr = load %11_5
  *%0_21 = %49_2
  call luaV_finishget(%0_0, %45_10, %45_13, %45_3, %49_0) [statepoint: 397i64,
  br bb50
```

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bb47:
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  %47_3: i1 = eq %47_2, 0i8
  condbr %47_3, bb49, bb48 [statepoint: 396i64, (%0_0, %0_2, %0_5, %0_6, ...
bb48:
  %48_0: i64 = load %46_2
  *%45_3 = %48_0
  %48_2: i8 = load %47_0
  %48_3: ptr = ptr_add %45_3, 8
  *%48_3 = %48_2
  br bb812
bb49:
  %49_0: ptr = phi bb47 -> %46_2, bb45 -> 0x0
  *%6_10 = %29_0
  %49_2: ptr = load %11_5
  *%0_21 = %49_2
  call luaV_finishget(%0_0, %45_10, %45_13, %45_3, %49_0) [statepoint: 397i64,
  br bb50
```

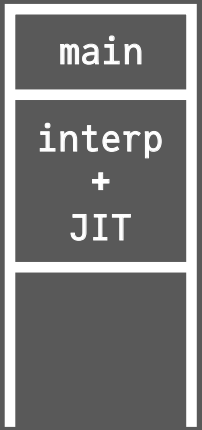
```
%0_0:
```

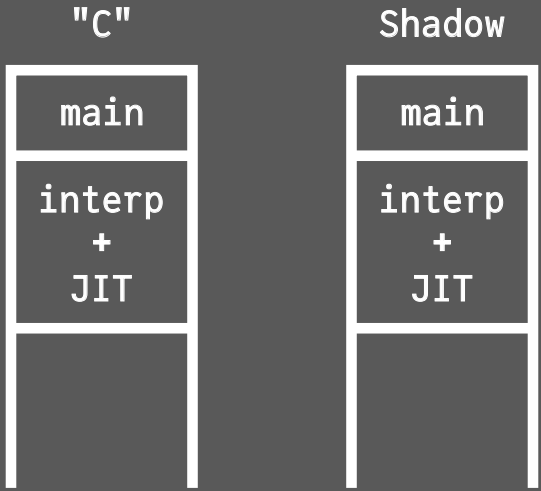
```
%0_0: [Stack(0x40)
```

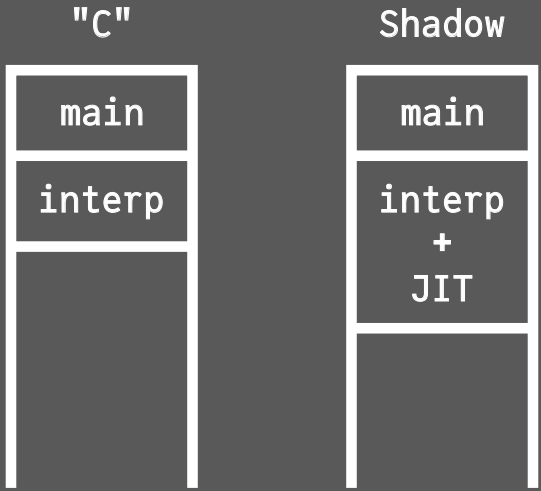
```
%0_0: [Stack(0x40), RAX]
```

```
%0_0: [Stack(0x40), RAX]
%0_1: [Const(9)]
```

```
%0_0: [Stack(0x40), RAX]
%0_1: [Const(9)]
%0_2: [RCX, RDX]
```


main
interp
+
JIT


"C"
main
interp
+
JIT
Shadow
main
interp
+
JIT


"C"
main
interp
Shadow
main
interp
+
JIT

```
while i > 0 do
  x = ...
  i = i - 1
end
print(x)
```

```
while i > 0 do
  x = ...
  i = i - 1
end
print(x)
```

Is this a loop?

```
while i > 0 do
  x = ...
  i = i - 1
end
print(x)
```

Is this a loop?

AOT:

```
while i > 0 do
  x = ...
  i = i - 1
end
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```

Is this a loop?

AOT: yes

```
while i > 0 do
  x = ...
  i = i - 1
end
print(x)
```

Is this a loop?

AOT: yes

Run-time:

```
while i > 0 do
  x = ...
  i = i - 1
end
print(x)
```

Is this a loop?

AOT: yes

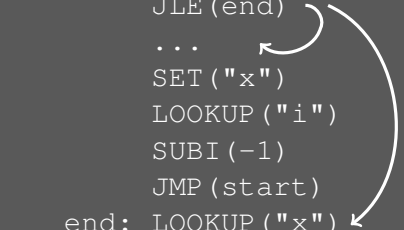
Run-time: maybe

```
        while i > 0 do
          x = ...
          i = i - 1
        end
        print(x)

start:  LOOKUP("i")
        JLE(end)
        ...
        SET("x")
        LOOKUP("i")
        SUBI(-1)
        JMP(start)
  end:  LOOKUP("x")
        PRINT()
```

```
while i > 0 do
  x = ...
  i = i - 1
end
print(x)
```

```
start: LOOKUP("i")
       JLE(end)
       ...
       SET("x")
       LOOKUP("i")
       SUBI(-1)
       JMP(start)
  end: LOOKUP("x")
       PRINT()
```

```
        while i > 0 do
          x = ...
          i = i - 1
        end
        print(x)

start:  LOOKUP("i")
        JLE(end)
        ...
        SET("x")
        LOOKUP("i")
        SUBI(-1)
        JMP(start)
  end:  LOOKUP("x")
        PRINT()
```



III: What’s next?

1. Support more LLVM IR (e.g. vectors).

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2. More optimisations (e.g. escape analysis).
3. More interpreters (WIP micropython).

https://github.com/ykjit/yk