NASH

an experimental

TRACING JIT VM

for

GNU GUILE

TRACING JIT

ASSUMPTIONS

- Programs spend most of their runtime in loops.
- Several iterations of the same loop are likely to take similar code paths.

TERMINOLOGY

Trace: Recorded instruction sequence.

Fragment: Artifact made from a trace.

Guard: A test inserted to native code.

GNU GUILE

Guile compiles Scheme source code to *bytecode*

```scheme
(define (mandelbrot x y)
  (let ((cr (- y 0.5))
        (ci x)
        (zi 0.0)
        (zr 0.0))
    (let lp ((i 0) (zr zr) (zi zi))
      (if (< *max-iterations* i)
        0
        (let ((zi2 (* zi zi))
              (zr2 (* zr zr)))
          (if (< *bailout* (+ zi2 zr2))
              i
              (lp (+ i 1)
                  (+ (- zr2 zi2) cr)
                  (+ (* 2.0 zr zi) ci))))))))
```

Bytecode has flat structure.

Bytecode contains labels for jump destination.

```
Disassembly of mandelbrot at #x2a8:

   0    (assert-nargs-ee/locals 3 9)
   1    (static-ref 11 3087)
   3    (sub 11 9 11)
   4    (make-short-immediate 9 2)
   5    (static-ref 8 3093)
   7    (toplevel-box 7 3093 2925 2923 #t)
  12    (box-ref 7 7)
  13    (static-ref 6 3097)
  15    (mov 5 8)
  16    (mov 4 8)
  17    (mov 8 9)
L1:
  18    (br-if-< 7 8 #f 26)
  21    (mul 3 4 4)
  22    (mul 2 5 5)
  23    (toplevel-box 1 3089 2909 2897 #t)
  28    (box-ref 1 1)
  29    (add 0 3 2)
  30    (br-if-< 1 0 #f 12)
  33    (add/immediate 8 8 1)
  34    (sub 3 2 3)
  35    (add 3 3 11)
  36    (mul 5 6 5)
  37    (mul 5 5 4)
  38    (add 5 5 10)
  39    (mov 4 5)
  40    (mov 5 3)
  41    (br -23)
L2:
  42    (mov 10 8)
  43    (return-values 2)
L3:
  44    (mov 10 9)
  45    (return-values 2)
```

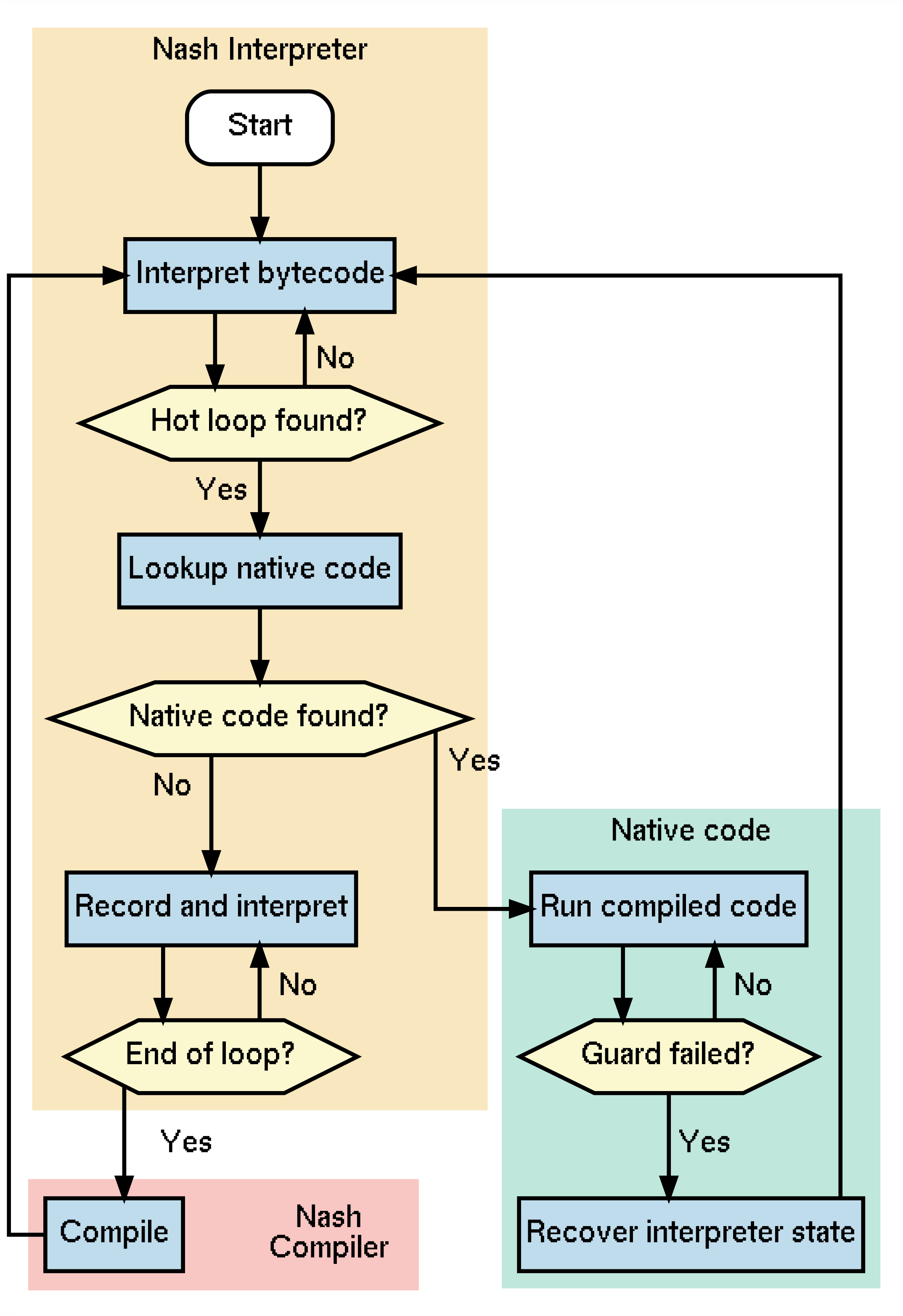
Compiled bytecode instructions are interpreted by a C function.

... which is called *VM-engine*.

VM-engine could be viewed as a huge `switch` ... `case` statement.

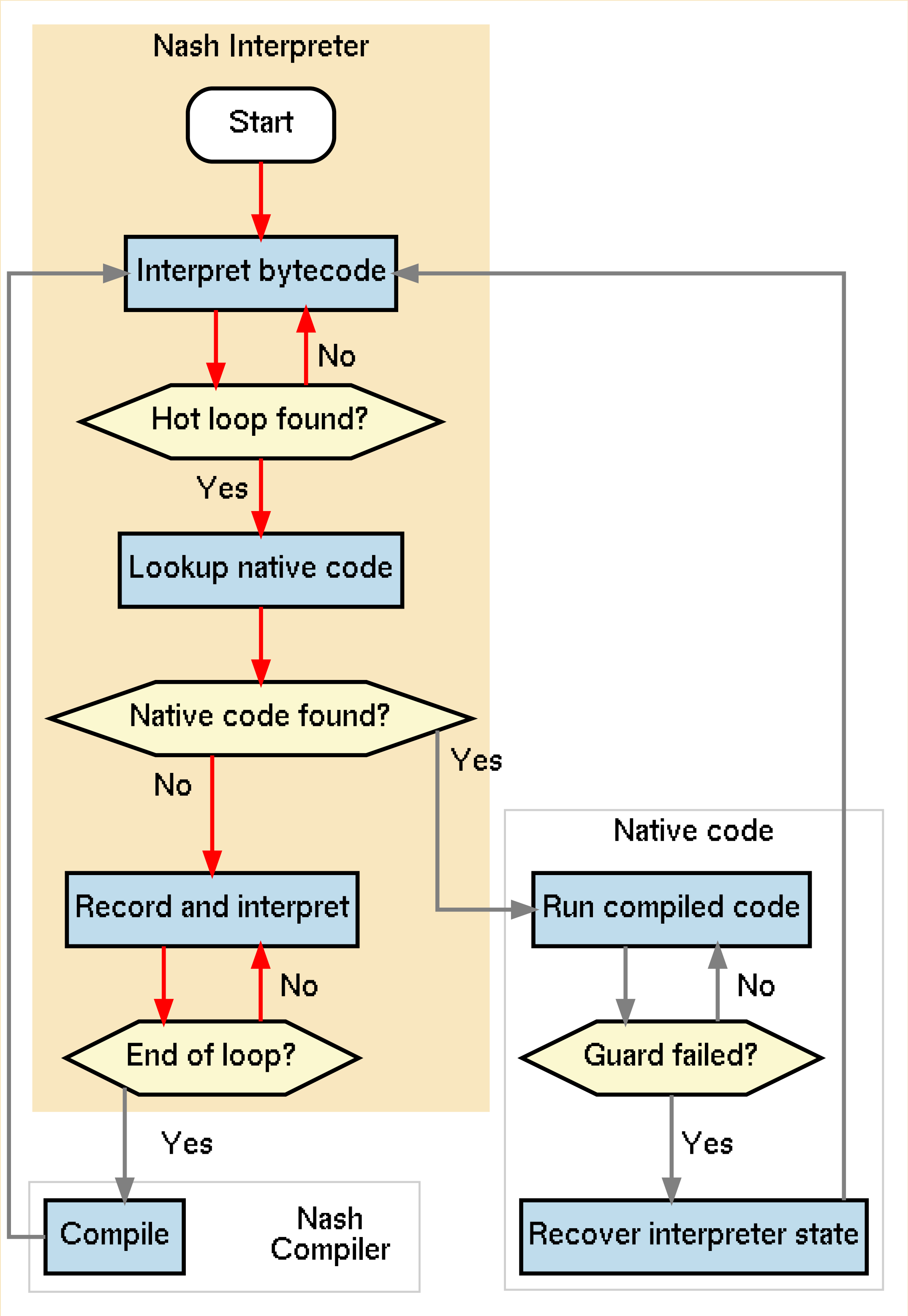
```
static SCM
VM_NAME (scm_i_thread *thread, struct scm_vm *vp,
         scm_i_jmp_buf *registers, int resume) {
  ...
  VM_DEFINE_OP (1, call, ...) {
    ...
  }
  VM_DEFINE_OP (2, call-label, ...) {
    ...
  }
  VM_DEFINE_OP (3, tail_call, ...) {
    ...
  }
  ...
}
```

NASH OVERVIEW



Key components:

- Interpreter
- Compiler
- Native code



User programs start from the interpreter.

Interpreter observes each bytecode instruction, seeks for hot loops.

When a hot loop was detected, the interpreter looks up accompanying native code.

If no native code were found, the interpreter starts recording the instructions in the loop.

```
Disassembly of mandelbrot at #x2a8:

   0    (assert-nargs-ee/locals 3 9)
   1    (static-ref 11 3087)
   3    (sub 11 9 11)
   4    (make-short-immediate 9 2)
   5    (static-ref 8 3093)
   7    (toplevel-box 7 3093 2925 2923 #t)
  12    (box-ref 7 7)
  13    (static-ref 6 3097)
  15    (mov 5 8)
  16    (mov 4 8)
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L1:
  18    (br-if-< 7 8 #f 26)
  21    (mul 3 4 4)
  22    (mul 2 5 5)
  23    (toplevel-box 1 3089 2909 2897 #t)
  28    (box-ref 1 1)
  29    (add 0 3 2)
  30    (br-if-< 1 0 #f 12)
  33    (add/immediate 8 8 1)
  34    (sub 3 2 3)
  35    (add 3 3 11)
  36    (mul 5 6 5)
  37    (mul 5 5 4)
  38    (add 5 5 10)
  39    (mov 4 5)
  40    (mov 5 3)
  41    (br -23)
L2:
  42    (mov 10 8)
  43    (return-values 2)
L3:
  44    (mov 10 9)
  45    (return-values 2)
```

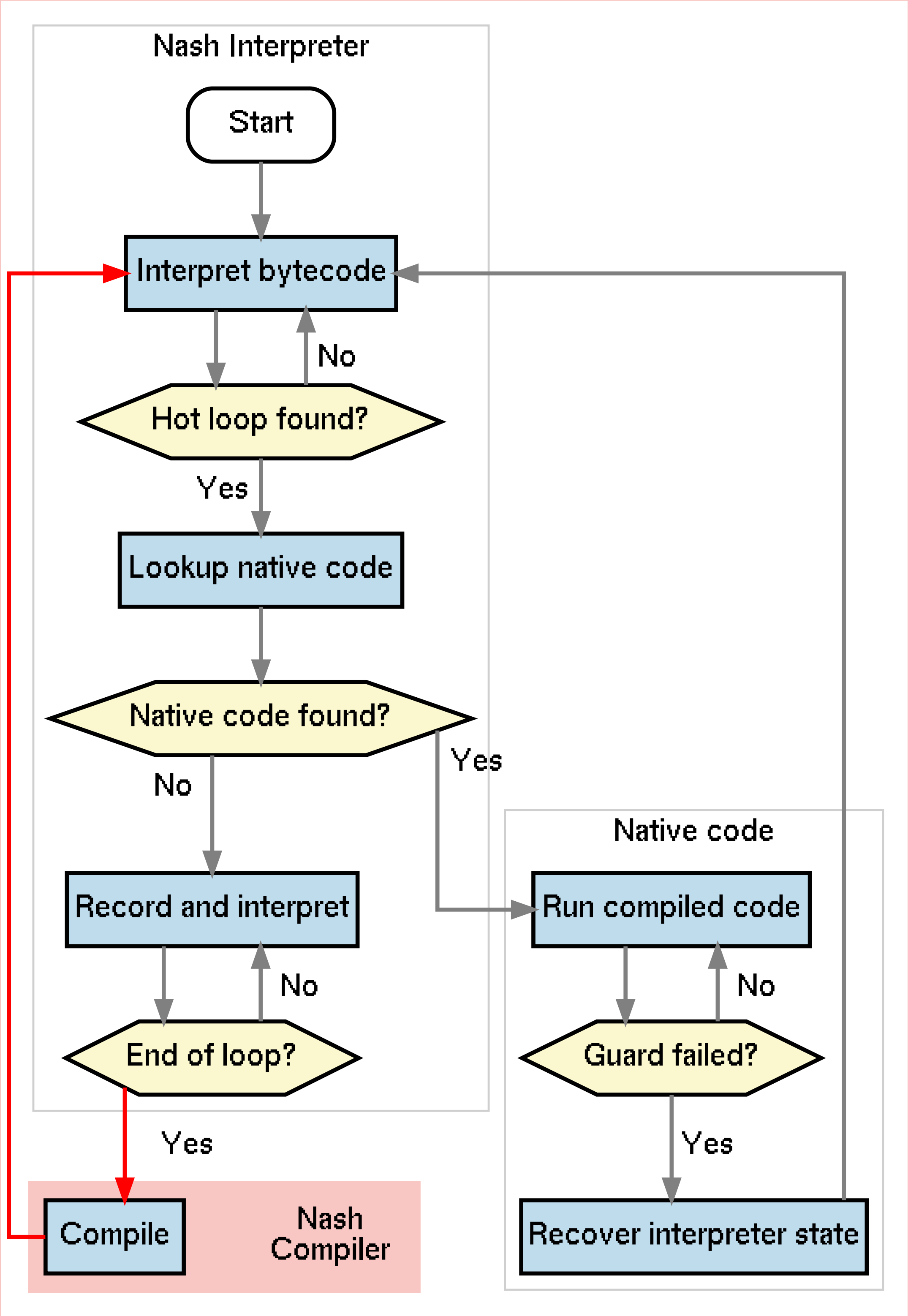
IP 41 (br -23) is a backward jump instruction.

The interpreter jumps back to IP 18 (br-if-7 8 #f 20), which is marked as L1, the label one.

Then the interpreter records the instructions between IP 18 and 41.

Recorded trace:

```
;;; trace 1: bytecode 16
7f39397e92f0  (br-if-< 7 8 #f 26)
7f39397e92fc  (mul 3 4 4)
7f39397e9300  (mul 2 5 5)
7f39397e9304  (toplevel-box 1 3089 2909 2897 #t)
7f39397e9318  (box-ref 1 1)
7f39397e931c  (add 0 3 2)
7f39397e9320  (br-if-< 1 0 #f 12)
7f39397e932c  (add/immediate 8 8 1)
7f39397e9330  (sub 3 2 3)
7f39397e9334  (add 3 3 11)
7f39397e9338  (mul 5 6 5)
7f39397e933c  (mul 5 5 4)
7f39397e9340  (add 5 5 10)
7f39397e9344  (mov 4 5)
7f39397e9348  (mov 5 3)
7f39397e934c  (br -23)
```



The recorded instructions are then passed to compiler.

Compiler is written in Scheme.

Uses *A-normal form* IR.

Uses *GNU Lightning* as assembler backend.

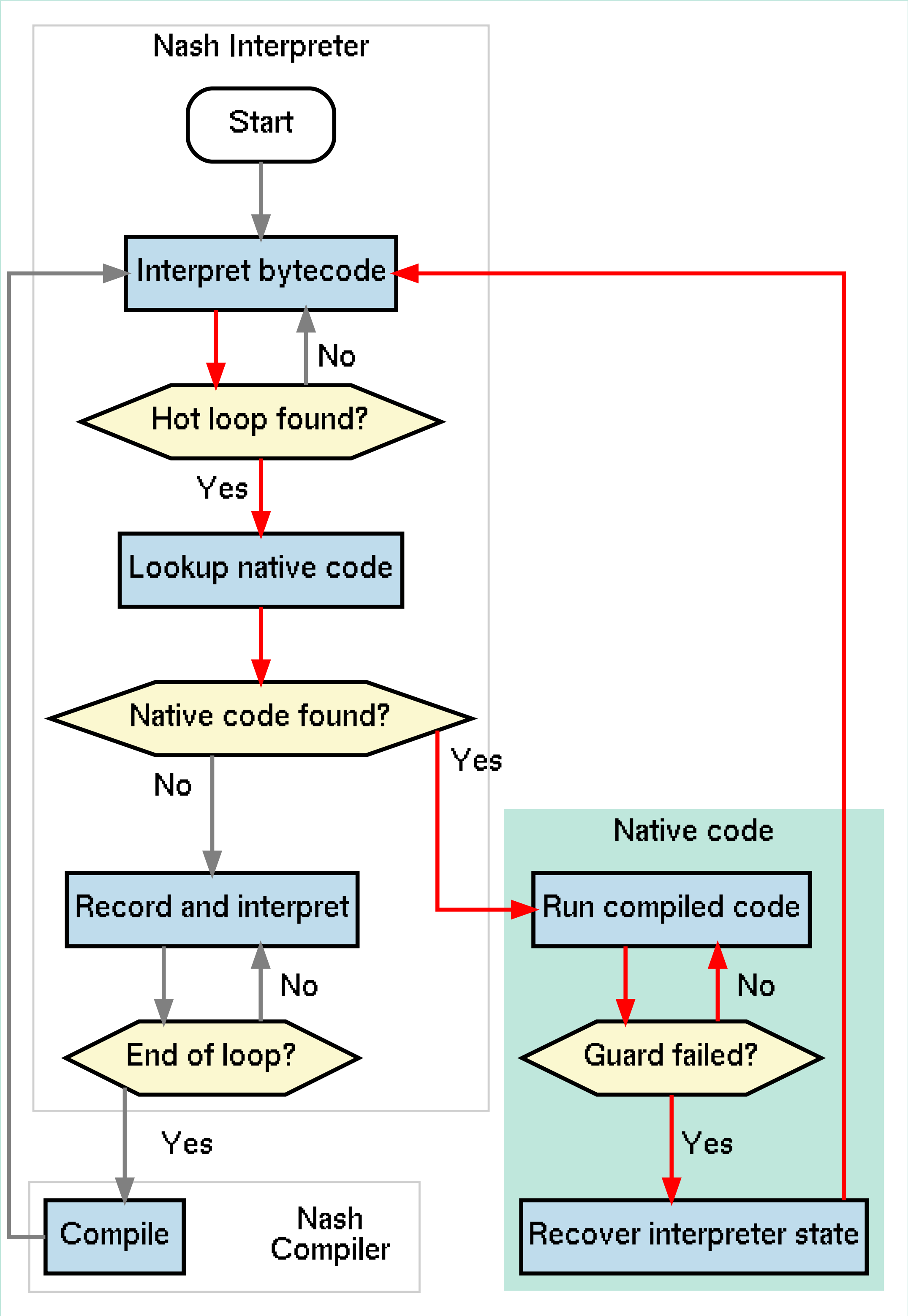
```
;;; trace 1: bytecode 16
7f39397e92f0  (br-if-< 7 8 #f 26)
7f39397e92fc  (mul 3 4 4)
7f39397e9300  (mul 2 5 5)
7f39397e9304  (toplevel-box 1 3089 2909 2897 #t)
7f39397e9318  (box-ref 1 1)
7f39397e931c  (add 0 3 2)
7f39397e9320  (br-if-< 1 0 #f 12)
7f39397e932c  (add/immediate 8 8 1)
7f39397e9330  (sub 3 2 3)
7f39397e9334  (add 3 3 11)
7f39397e9338  (mul 5 6 5)
7f39397e933c  (mul 5 5 4)
7f39397e9340  (add 5 5 10)
7f39397e9344  (mov 4 5)
7f39397e9348  (mov 5 3)
7f39397e934c  (br -23)
```

IR contains a prologue section and a loop body section.

Prologue section loads locals from *the stack*, the stack is shared with the interpreter.

IR to native code compilation is done in almost straight forward manner.

```
;;; trace 1: anf
(lambda ()
  (let* ((_   (%snap 0))
         (v0  (%sref/f 0 2))
         (v2  (%sref/f 2 2))
         (v3  (%sref/f 3 2))
         (v4  (%sref/f 4 2))
         (v5  (%sref/f 5 2))
         (v6  (%sref/f 6 2))
         (v7  (%sref 7 1))
         (v8  (%sref 8 1))
         (v10  (%sref/f 10 2))
         (v11  (%sref/f 11 2)))
    (loop v0 v1 v2 v3 v4 v5 v6 v7 v8 v10 v11)))
(lambda (v0 v1 v2 v3 v4 v5 v6 v7 v8 v10 v11)
  (let* ((_   (%snap 1 v0 v1 v2 v3 v4 v5 v8))
         (_   (%ge v7 v8))
         (v3  (%fmul v4 v4))
         (v2  (%fmul v5 v5))
         (v1  (%cref 15967664 1))
         (v0  (%fadd v3 v2))
         (_   (%snap 2 v0 v1 v2 v3 v4 v5 v8))
         (_   (%typeq v1 2))
         (f2  (%cref/f v1 2))
         (_   (%fge f2 v0))
         (_   (%snap 3 v0 v1 v2 v3 v4 v5 v8))
         (v8  (%addov v8 4))
         (v3  (%fsub v2 v3))
         (v3  (%fadd v3 v11))
         (v5  (%fmul v6 v5))
         (v5  (%fmul v5 v4))
         (v5  (%fadd v5 v10))
         (v4  v5)
         (v5  v3))
    (loop v0 v1 v2 v3 v4 v5 v6 v7 v8 v10 v11)))
```



After compilation, the control flow goes back to the interpreter.

The interpreter will find the native code of the loop from the next iteration.

Native code runs until guard fails. The guard failure triggers a *bailout code*.

Bailout code recovers VM state and passes back the control of user program to the intepreter.

IR of recorded trace

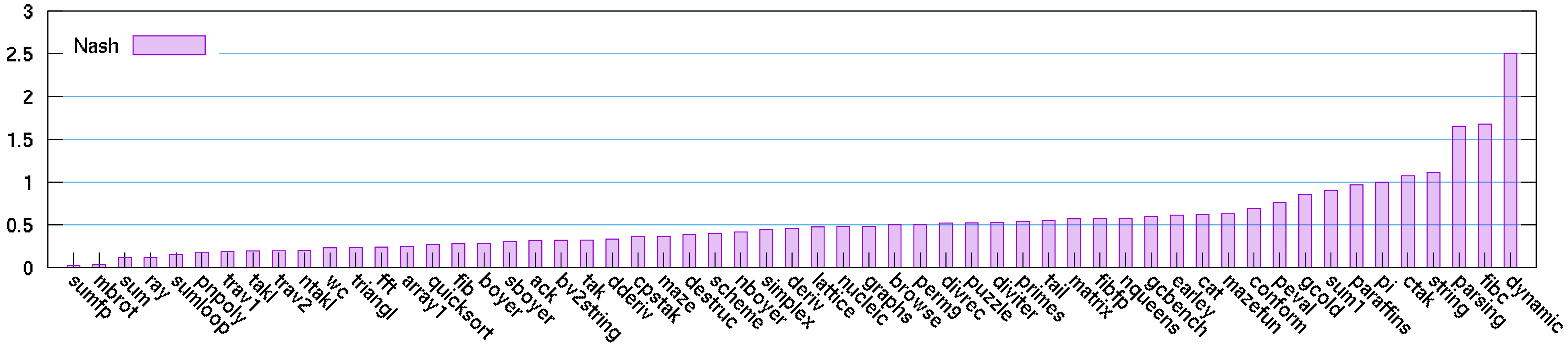
```
;;; trace 1: anf
(lambda ()
  (let* ((_    (%snap 0))
         (v0   (%sref/f 0 2))
         (v2   (%sref/f 2 2))
         (v3   (%sref/f 3 2))
         (v4   (%sref/f 4 2))
         (v5   (%sref/f 5 2))
         (v6   (%sref/f 6 2))
         (v7   (%sref 7 1))
         (v8   (%sref 8 1))
         (v10  (%sref/f 10 2))
         (v11  (%sref/f 11 2)))
    (loop v0 v1 v2 v3 v4 v5 v6 v7 v8 v10 v11)))
(lambda (v0 v1 v2 v3 v4 v5 v6 v7 v8 v10 v11)
  (let* ((_    (%snap 1 v0 v1 v2 v3 v4 v5 v8))
         (_   (%ge v7 v8))
         (v3   (%fmul v4 v4))
         (v2   (%fmul v5 v5))
         (v1   (%cref 15967664 1))
         (v0   (%fadd v3 v2))
         (_   (%snap 2 v0 v1 v2 v3 v4 v5 v8))
         (_   (%typeq v1 2))
         (f2   (%cref/f v1 2))
         (_   (%fge f2 v0))
         (_   (%snap 3 v0 v1 v2 v3 v4 v5 v8))
         (v8   (%addov v8 4))
         (v3   (%fsub v2 v3))
         (v3   (%fadd v3 v11))
         (v5   (%fmul v6 v5))
         (v5   (%fmul v5 v4))
         (v5   (%fadd v5 v10))
         (v4   v5)
         (v5   v3))
    (loop v0 v1 v2 v3 v4 v5 v6 v7 v8 v10 v11)))
```

Native code of loop body (x86-64)

```
;;; trace 1: ncode 624
...
loop:
0x01ee61c8 cmp    r14,r15
0x01ee61cb jl     0x01efe028    ->1
0x01ee61d1 movsd  xmm13,xmm14
0x01ee61d6 mulsd  xmm13,xmm14
0x01ee61db movsd  xmm12,xmm15
0x01ee61e0 mulsd  xmm12,xmm15
0x01ee61e5 mov    r9,QWORD PTR ds:0x1cac5a8
0x01ee61ed movsd  xmm11,xmm13
0x01ee61f2 addsd  xmm11,xmm12
0x01ee61f7 test   r9,0x6
0x01ee61fe jne    0x01efe030
0x01ee6204 mov    rax,QWORD PTR [r9]
0x01ee6207 and    rax,0xffff
0x01ee620d cmp    rax,0x217
0x01ee6213 jne    0x01efe030
0x01ee6219 movsd  xmm10,QWORD PTR [r9+0x10]
0x01ee621f ucomisd xmm11,xmm10
0x01ee6224 ja     0x01efe030    ->2
0x01ee622a mov    r11,r15
0x01ee622d add    r11,0x4
0x01ee6231 jo     0x01efe038
0x01ee6237 mov    r15,r11
0x01ee623a movsd  xmm8,xmm13
0x01ee623f movsd  xmm13,xmm12
0x01ee6244 subsd  xmm13,xmm8
0x01ee6249 addsd  xmm13,xmm5
0x01ee624e mulsd  xmm15,xmm7
0x01ee6253 mulsd  xmm15,xmm14
0x01ee6258 addsd  xmm15,xmm6
0x01ee625d movsd  xmm14,xmm15
0x01ee6262 movsd  xmm15,xmm13
0x01ee6267 jmp    0x01ee61c8    ->loop
...
```

BENCHMARKS

Total time normalized to Guile bytecode interpreter



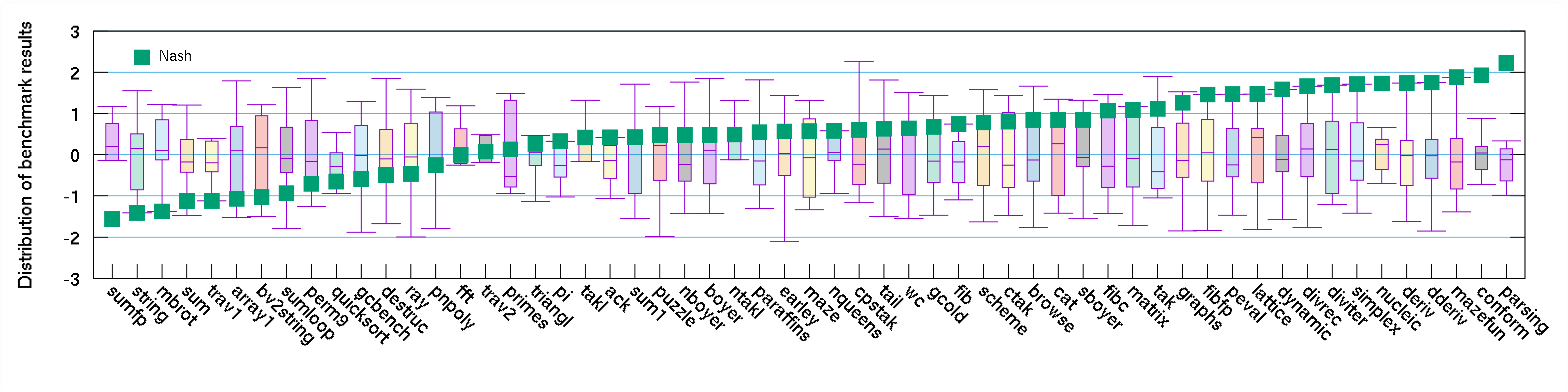
	sumfp	mbrot	sum	ctak	string	parsing	fibc	dynamic	GM
Nash	0.024	0.034	0.119	1.073	1.115	1.654	1.678	2.506	0.400

"sumfp" and "mbrot" contain loops with floting point number arithmetic.

"string" and "fibc" mostly use procedures implemented in C.

"parsing" and "dynamic" contain large amount of data-driven conditional branches.

Geometric standard scores of the benchmark suite from 10 Scheme native code compilers



	Chez	Bigloo	Ikarus	Pycket	Gambit	Larceny	Racket	Nash	Chicken	MIT
GM	0.148	0.236	0.244	0.252	0.274	0.301	0.324	0.400	0.448	0.486

Nash showed the best score in "string", but Guile bytecode interpreter was faster.

"parsing" was the slowest benchmark for Nash, but the score of Pycket was not so bad.

PROS AND CONS OF NASH

Significant improvement in tight loop with floating point arithmetic.

No need to use "fl+", "fx+", ... etc.

Not much differences in procedures implemented in C.

Not much suited for programs with large amount of conditional branches, e.g.: parser, interpreter, and compiler.

JIT warming up time.

QUESTIONS?

THANK YOU

http://github.com/8c6794b6/guile-tjit