What Lies Beneath?

A tour of the dark gritty underbelly of OpenJDK

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What Lies Beneath?

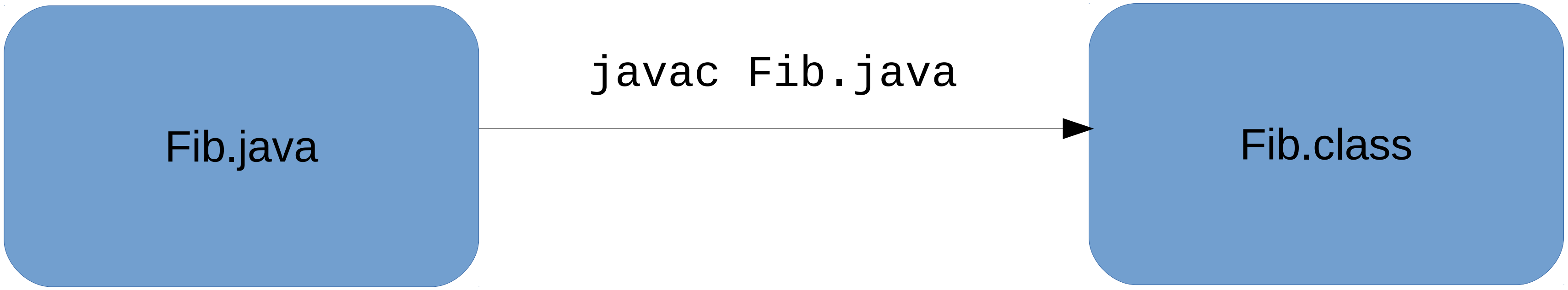
- Bytecode
- Template Interpreter
- C1 JIT Compiler
- C2 JIT Compiler
- Special Tricks
- Questions

We start with everyone's favorite Java program.

```
class Fib {
    static int fib(int x) {
       if ((x == 1) || (x == 2))
          return 1;
       else return (fib(x-1) + fib(x-2));
    }

    public static void main(String args[]) {
        int arg = Integer.parseInt(args[0]);
        System.out.println("Fib of " + arg + " = " + fib(arg));
    }
}
```

What you see.



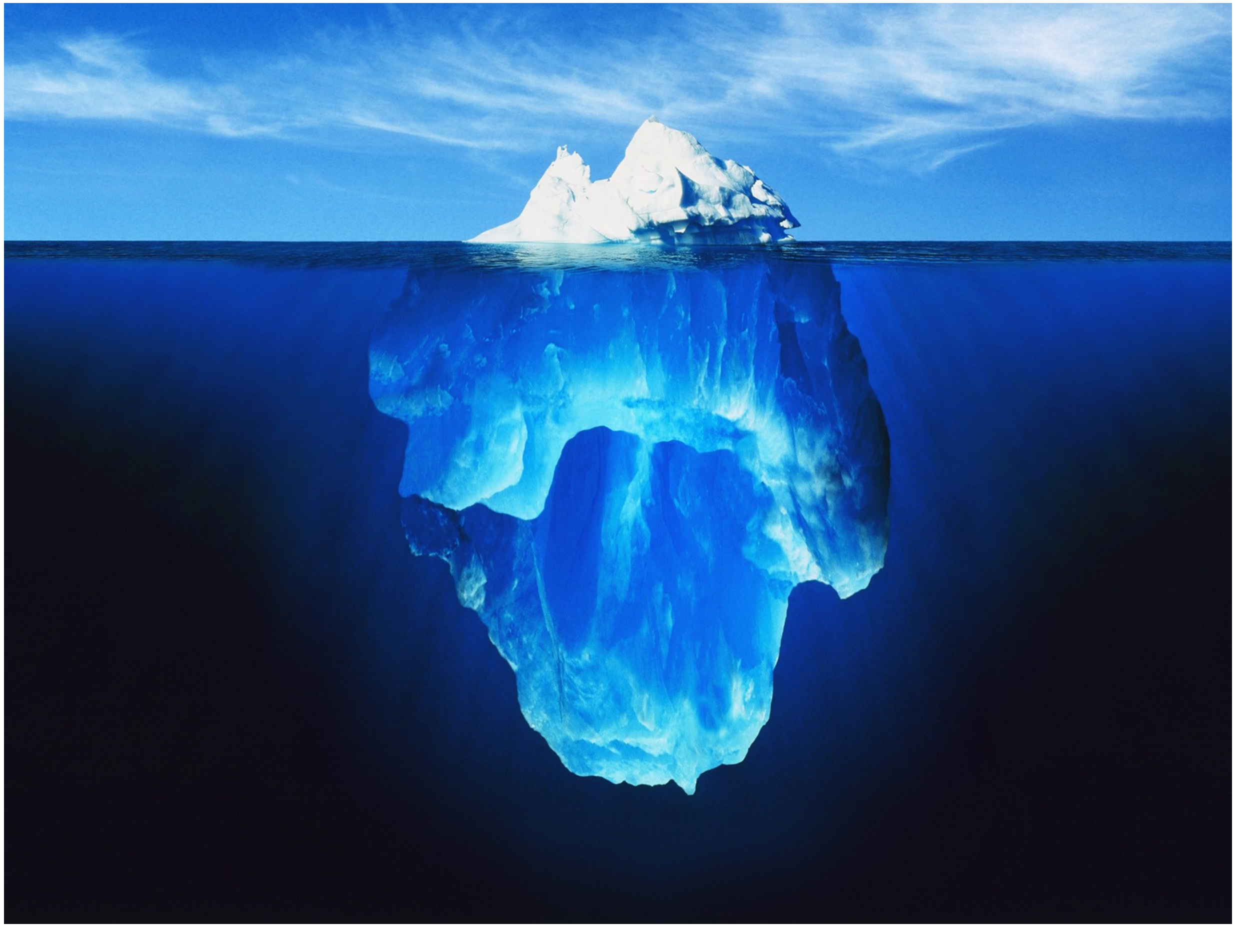
Fib.java

`javac Fib.java`

Fib.class

```
java Fib 17
Fib of 17 = 1597
```

There's a lot happening below the surface.



- **Bytecode**
- Template Interpreter
- C1 JIT Compiler
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javac generates Java Bytecode

```
static int fib(int);
    flags: ACC_STATIC
    Code:
      stack=3, locals=1, args_size=1
         0: iload_0                     13: iconst_1
         1: iconst_1                    14: isub
         2: if_icmpeq     10            15: invokestatic  #2 // Method fib:(I)I
         5: iload_0                     18: iload_0
         6: iconst_2                    19: iconst_2
         7: if_icmpne     12            20: isub
        10: iconst_1                    21: invokestatic  #2 // Method fib:(I)I
        11: ireturn                     24: iadd
        12: iload_0                     25: ireturn
```

Bytecode verification

- Abstract interpretation
  - Interpret the program except instead of values you are calculating the types of the stack and the locals at each instruction.
  - Merge points require merging types.

Bytecode Abstract Interpretation

```
static int fib(int);
    flags: ACC_STATIC
    Code:
      stack=3, locals=1, args_size=1        stack=[], locals = [int]
         0: iload_0                         stack = [int], locals=[int]
         1: iconst_1                        stack = [1, int]
         2: if_icmpeq     10                stack = []
         5: iload_0                         stack = [int]
         6: iconst_2                        stack = [2, int]
         7: if_icmpne     12                stack = []
        10: iconst_1                        stack = [1]
        11: ireturn                         . . .
            . . .
```

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Template Interpreter

- Intrepreter only execution

```
$ java -Xint -XX:+PrintInterpreter Fib 17
```

- Use of `PrintInterpreter` requires
  - `hsdis-amd64.so`
- For product release jvms must also unlock
  - `-XX:+UnlockDiagnosticVMOptions`

hsdis-amd64.so

- Download hsdis lib from
  - `https://kenai.com/projects/base-hsdis/downloads`
- e.g.for Linux
  - `$ wget https://kenai.com/projects/base-hsdis/downloads/download/linux-hsdis-amd64.so`
- use correct name
  - `$ mv linux-hsdis-amd64.so hsdis-amd64.so`
  - ensure it is in your LD_LIBRARY_PATH
  - or copy it to `${JAVA_HOME}/jre/lib/amd64`

Template Interpreter

```
static int fib(int);
    flags: ACC_STATIC
    Code:
      stack=3, locals=1, args_size=1
         0: iload_0
         1: iconst_1
         2: if_icmpeq     10
         5: iload_0
         6: iconst_2
         7: if_icmpne     12
        10: iconst_1
        11: ireturn
            . . .
```

```
iload_0  26 iload_0  [0x7f077902b040,
0x7f077902b0a0]  96 bytes

 0x7f077902b040: push   %rax
 0x7f077902b041: jmpq   0x7f077902b070
 0x7f077902b046: sub    $0x8,%rsp
 0x7f077902b04a: vmovss %xmm0,(%rsp)
 0x7f077902b04f: jmpq   0x7f077902b070
 0x7f077902b054: sub    $0x10,%rsp
 0x7f077902b058: vmovsd %xmm0,(%rsp)
 0x7f077902b05d: jmpq   0x7f077902b070
 0x7f077902b062: sub    $0x10,%rsp
 0x7f077902b066: mov    %rax,(%rsp)
 0x7f077902b06a: jmpq   0x7f077902b070
 0x7f077902b06f: push   %rax
 0x7f077902b070: mov    (%r14),%eax
 0x7f077902b073: movzbl 0x1(%r13),%ebx
 0x7f077902b078: inc    %r13
 0x7f077902b07b: mov    $0x7f078ff6af00,%r10
 0x7f077902b085: jmpq   *(%r10,%rbx,8)
```

Template Interpreter

```
static int fib(int);
    flags: ACC_STATIC
    Code:
      stack=3, locals=1, args_size=1
         0: iload_0
         1: iconst_1
         2: if_icmpeq     10
         5: iload_0
         6: iconst_2
         7: if_icmpne     12
        10: iconst_1
        11: ireturn
            . . .
```

```
iconst_1  4 iconst_1  [0x7f0779029a60,
0x7f0779029ac0]  96 bytes

  0x7f0779029a60: push   %rax
  0x7f0779029a61: jmpq   0x7f0779029a90
  0x7f0779029a66: sub    $0x8,%rsp
  0x7f0779029a6a: vmovss %xmm0,(%rsp)
  0x7f0779029a6f: jmpq   0x7f0779029a90
  0x7f0779029a74: sub    $0x10,%rsp
  0x7f0779029a78: vmovsd %xmm0,(%rsp)
  0x7f0779029a7d: jmpq   0x7f0779029a90
  0x7f0779029a82: sub    $0x10,%rsp
  0x7f0779029a86: mov    %rax,(%rsp)
  0x7f0779029a8a: jmpq   0x7f0779029a90
  0x7f0779029a8f: push   %rax
  0x7f0779029a90: mov    $0x1,%eax
  0x7f0779029a95: movzbl 0x1(%r13),%ebx
  0x7f0779029a9a: inc    %r13
  0x7f0779029a9d: mov    $0x7f078ff6af00,%r10
  0x7f0779029aa7: jmpq   *(%r10,%rbx,8)
```

Template Interpreter

```
static int fib(int);
    flags: ACC_STATIC
    Code:
      stack=3, locals=1, args_size=1
         0: iload_0
         1: iconst_1
         2: if_icmpeq     10
         5: iload_0
         6: iconst_2
         7: if_icmpne     12
        10: iconst_1
        11: ireturn
            . . .
```

- Profile which branch taken
  - MethodData holds profile counters

Template Interpreter

```
         . . .
     13: iconst_1
     14: isub
     15: invokestatic  #2 // Method
fib:(I)I
     18: iload_0
     19: iconst_2
     20: isub
     21: invokestatic  #2 // Method
fib:(I)I
     24: iadd
     25: ireturn
```

- Need to load class?
- Fetch new MethodData
- Build call frame
  - args become locals
  - push/reload locals reg
  - push/reload method reg
  - push/reload bcp reg
- Profile call

Interpreter Performance

```
$ time java -Xint Fib 42
Fib of 42 = 267914296

real 0m41.312s
user 0m41.143s
sys  0m0.152s
```

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- **C1 JIT Compiler**
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C1 JIT Compiler

- Client compiler
  - for short running desktop applications
- Relatively Standard Optimising Compiler
  - see the Dragon Book (and the code :-)

```
$ java -XX:+PrintIR2 -XX:+PrintCFG2  -XX:
+PrintAssembly -XX:CompileOnly=Fib -XX:
+CommentedAssembly -XX:TieredStopAtLevel=2 -XX:
+DebugNonSafepoints Fib 24
```

  - n.b. most options are debug build only

```
PrintIR2 PrintCFG2 CommentedAssembly
TieredStopAtLevel DebugNonSafepoints
```

How to build a debug jdk8

- Obtain forest

```
$ hg clone http://hg.openjdk.java.net/jdk8u/jdk8u
$ cd jdk8u
$ bash get_source.sh
```

- Configure build

```
$ ./configure –-with-debug-level=slowdebug
    --with-boot-jdk=/usr/lib/jvm/java-1.7.0
```

  - you will need to install a lot of packages!

- Make the jvm images

```
$ make images
```

C1 CFG before code generation

```
CFG before code generation

B17 [0, 0] -> B18 sux: B18
B18 (S) [0, 0] -> B0 dom B17 sux: B0 pred: B17
B0 (SV) [0, 2] -> B2 B1 dom B18 sux: B2 B1 pred: B18
B2 (V) [7, 9] -> B4 B3 dom B0 sux: B4 B3 pred: B0
B4 (V) [14, 2] -> B8 B7 dom B2 sux: B8 B7 pred: B2
B7 (V) [5, 20] -> B5 dom B4 sux: B5 pred: B4
B8 (V) [7, 9] -> B10 B9 dom B4 sux: B10 B9 pred: B4
B9 (V) [12, 20] -> B5 dom B8 sux: B5 pred: B8
B10 (V) [14, 20] -> B5 dom B8 sux: B5 pred: B8
B5 (V) [20, 2] -> B14 B13 dom B4 sux: B14 B13 pred: B7 B9 B10Stack:
 0  i32 [ i6 i6 i41]
B14 (V) [7, 9] -> B16 B15 dom B5 sux: B16 B15 pred: B5
B15 (V) [12, 26] -> B11 dom B14 sux: B11 pred: B14
B16 (V) [14, 26] -> B11 dom B14 sux: B11 pred: B14
B13 (V) [5, 26] -> B11 dom B5 sux: B11 pred: B5
B11 (V) [26, 27] dom B5 pred: B13 B15 B16Stack:
 0  i32
 1  i61 [ i6 i6 i70]

B3 (V) [12, 13] dom B2 pred: B2
B1 (V) [5, 6] dom B0 pred: B0
```

C1 IR B10: fib(x – 1) + fib(x-2)

```
IR before code generation
  . . .
B10 (V) [14, 20] -> B5 dom B8 sux: B5 pred: B8
empty stack
inlining depth 1
__bci__use__tid____instr____________________________________
  16   1    i34    i15 - i6
. 17   0    v35    profile NULL Fib.fib)
. 17   1    i36    invokestatic(i34)
                   Fib.fib(I)I
  22   1    i38    i15 - i10
. 23   0    v39    profile NULL Fib.fib)
. 23   1    i40    invokestatic(i38)
                   Fib.fib(I)I
                   stack [0:i36]
. 26   1    i41    i36 + i40
. 20   0     42    goto B5
                   stack [0:i41]
  . . .
```

C1 Assembly B10

```
;;  block B10 [14, 20]

 0x7f7db4dfc3bf: mov    %esi,0x44(%rsp)
 0x7f7db4dfc3c3: mov    $0x7f7db21a8670,%rbx
   ;   {metadata(method data for {method}
  {0x7f7db21a83a8} 'fib' '(I)I' in 'Fib')}
 0x7f7db4dfc3cd: addq   $0x1,0x170(%rbx)
 0x7f7db4dfc3d5: mov    %rdi,%rbx
 0x7f7db4dfc3d8: dec    %ebx
 0x7f7db4dfc3da: mov    %rbx,%rsi
   ;*invokestatic fib
   ; - Fib::fib@17 (line 8)
   ; - Fib::fib@17 (line 8)

 0x7f7db4dfc3dd: mov    %edi,0x40(%rsp)
 0x7f7db4dfc3e7: callq  0x7f7db4cd5300
   ; OopMap{off=428}
   ;*invokestatic fib
   ; - Fib::fib@17 (line 8)
   ; - Fib::fib@17 (line 8)
   ;   {static_call}
 0x7f7db4dfc3ec: mov    $0x7f7db21a8670,%rsi
   ;   {metadata(method data for {method}
  {0x7f7db21a83a8} 'fib' '(I)I' in 'Fib')}
```

```
0x7f7db4dfc3f6: addq   $0x1,0x180(%rsi)
0x7f7db4dfc3fe: mov    0x40(%rsp),%edi
0x7f7db4dfc402: sub    $0x2,%edi
0x7f7db4dfc405: mov    %rdi,%rsi
  ;*invokestatic fib
  ; - Fib::fib@23 (line 8)
  ; - Fib::fib@17 (line 8)

0x7f7db4dfc408: mov    %eax,0x48(%rsp)
0x7f7db4dfc40f: callq  0x7f7db4cd5300
  ; OopMap{off=468}
  ;*invokestatic fib
  ; - Fib::fib@23 (line 8)
  ; - Fib::fib@17 (line 8)
  ;   {static_call}
0x7f7db4dfc414: mov    0x48(%rsp),%esi
0x7f7db4dfc418: add    %eax,%esi
0x7f7db4dfc41a: mov    %rsi,%rdi
  ;*iload_0
  ; - Fib::fib@20 (line 8)
0x7f7db4dfc41d: mov    0x44(%rsp),%esi
```

C1 Performance

```
$ time java Fib 42
Fib of 42 = 267914296

real 0m1.059s
user 0m0.944s
sys  0m0.131s
```

What Lies Beneath?

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C2 JIT Compiler

- Server compiler
  - for long running server applications
- Optimising Compiler Specially for JITting
  - see Global Code Motion Global Value Numbering, Click, PLDI95
    - (and especially the code ;-)

```
$ java -XX:+PrintCompilation -XX:+PrintIdeal -XX:
+PrintOptoAssembly  -XX:+PrintAssembly -XX:
+TieredCompilation -XX:CompileOnly=Fib.fib Fib 24
```

- n.b. these options are debug build only

```
PrintOptoAssembly PrintIdeal
```

C2 JIT Compiler

Highly efficient in time and space

- Sea of Nodes for IR
  - 1 graph models data, control, memory, io dependencies
  - Dataflow graph equivalent to SSA form
  - Dependencies alone impose node order
- Bytecode to HIR – abstract computation graph
  - Many Ideal graph transforms in fixed phases
  - 0(N log(N)) per phase for N bytecodes (including inlined)
- HIR to MIR – transform to MachineNodes
  - ADLC : pattern based translation
- Deopt + Recompile adaptive compilation

C2 JIT Nodes

- Hierarchy of Node classes
  - All have id (int), ins & outs (int[]), opcode, type
  - Most ins/outs are typed dataflows
    - AddNode, IAddNode, ConstNode, MemNode
      - n.b. may be multiple outs (multiple uses of data)
  - A few nodes have Ctrl/Mem/AbIO type for some ins
    - IfNode, JmpNode, CatchNode, RegionNode, PhiNode
    - MemNode, LoadNode, MergeMemNode
- Notable methods
    - Ideal() - normal form e.g. (IAdd IConst(0), X) ==> X
    - Value() - node value's type

C2 JIT Types

- Class Type models Node value types
  - Type class hierarchy

```
                 Type
              /   |   \
Double   Float   Int     Long     Ptr
                                /  |  \
               RawPtr  OopPtr   KlassPtr  MetaDataPtr
                       /    \
                 InstPtr    AryPtr
```

- TypeFlow analysis => weaken/strengthen type
- occurences model unconstrained (Bottom), constant, range or overconstrained (Top) values
  - see Cliff Click's blog for full details (including bug!)

PrintCompilation

```
$ time java -XX:+PrintCompilation -XX:CompileOnly=Fib.fib Fib 48
    454    1       3       Fib::fib (26 bytes)
    462    2       4       Fib::fib (26 bytes)
    468    1       3       Fib::fib (26 bytes)   made not entrant
Fib of 48 = 512559680

real    0m14.311s
user    0m14.251s
sys     0m0.108s

$ time java -XX:+PrintCompilation -XX:-TieredCompilation
-XX:CompileOnly=Fib.fib Fib 48
    539    1             Fib::fib (26 bytes)
Fib of 48 = 512559680

real    0m14.394s
user    0m14.311s
sys     0m0.114s
```

C2 PrintIdeal

```
 36 IfTrue  ===  35  [[ 56 ]] #1 !jvms: Fib::fib @ bci:7
 54 CmpI    === _  43  22  [[ 55 ]]  !jvms: Fib::fib @ bci:2 Fib::fib @
bci:15
 55 Bool    === _  54  [[ 56 ]] [ne] !jvms: Fib::fib @ bci:2 Fib::fib @
bci:15
 63 CmpI    === _  43  32  [[ 64 ]]  !jvms: Fib::fib @ bci:7 Fib::fib @
bci:15
 56 If  ===  36  55  [[ 57  58 ]] P=0.809012, C=224255.000000 !jvms:
Fib::fib @ bci:2 Fib::fib @ bci:15
 32 ConI    ===  0  [[ 33  63  136 ]]  #int:2
 127    CmpI    === _  72  22  [[ 128 ]]  !jvms: Fib::fib @ bci:2 Fib::fib
@ bci:21
 136    CmpI    === _  72  32  [[ 137 ]]  !jvms: Fib::fib @ bci:7 Fib::fib
@ bci:21
 64 Bool    === _  63  [[ 65 ]] [ne] !jvms: Fib::fib @ bci:7 Fib::fib @
bci:15
 57 IfTrue  ===  56  [[ 65 ]] #1 !jvms: Fib::fib @ bci:2 Fib::fib @ bci:15
 58 IfFalse ===  56  [[ 62 ]] #0 !jvms: Fib::fib @ bci:2 Fib::fib @ bci:15
 67 IfFalse ===  65  [[ 62 ]] #0 !jvms: Fib::fib @ bci:7 Fib::fib @ bci:15
    . . .
```

C2 PrintIdeal

```
 62 Region  ===  62  67  58  [[ 62  46 ]]  !jvms: Fib::fib @ bci:10
Fib::fib @ bci:15
    . . .
 46 Region  ===  46  100  62  [[ 46  50  47  48  129 ]]  !jvms: Fib::fib @
bci:15
    . . .
  50    Phi ===  46  111  22  [[ 164  186  146 ]]  #int !jvms: Fib::fib @
bci:15
 48 Phi ===  46  95  7  [[ 120  146 ]]  #memory  Memory: @BotPTR *+bot,
idx=Bot; !jvms: Fib::fib @ bci:15
  47    Phi ===  46  94  6  [[ 146  119 ]]  #abIO !jvms: Fib::fib @ bci:15
  . . .
 129    If  ===  46  128  [[ 130  131 ]] P=0.809011, C=247266.000000 !
jvms: Fib::fib @ bci:2 Fib::fib @ bci:21
  . . .
 146    CallStaticJava  ===  139  47  48  8  1 ( 90  1  50  72 ) [[ 147
148  149  151 ]] # Static  Fib::fib int ( int ) Fib::fib @ bci:15 Fib::fib
@ bci:21 !jvms: Fib::fib @ bci:15 Fib::fib @ bci:21
  . . .
 188    Rethrow ===  107  108  109  8  9 exception 110  [[ 0 ]]
 187    Return  ===  13  14  15  8  9 returns 17  [[ 0 ]]
  0 Root    ===  0  187  188  [[ 0  1  3  22  32  42  73  91  163 ]] inner
```

C2 PrintOptoAssembly

```
{method}
 - this oop:          0x7f1087c003a8
 - method holder:     'Fib'
 - constants:         0x7f1087c00070 constant pool [56] {0x7f1087c00070}
for 'Fib' cache=0x7f1087c004e8
 - access:            0x81000008  static
 - name:              'fib'
 - signature:         '(I)I'
 - max stack:         4
 - max locals:        1
 - size of params:    1
 - method size:       12
 - vtable index:      -2
 - i2i entry:         0x7f108d01eb00
 - adapters:          AHE@0x7f10900eb270: 0xa0000000 i2c: 0x7f108d148420
c2i: 0x7f108d148559 c2iUV: 0x7f108d14852c
 - compiled entry     0x7f108d148559
 - code size:         26
 - code start:        0x7f1087c00388
 - code end (excl):   0x7f1087c003a2
 - method data:       0x7f1087c00670
 - checked ex length: 0
 - linenumber start:  0x7f1087c003a2
 - localvar length:   0
```

C2 PrintOptoAssembly

```
#
#  int ( int )
#
#r018 rsi   : parm 0: int
# -- Old rsp -- Framesize: 48 --
#r191 rsp+44: in_preserve
#r190 rsp+40: return address
#r189 rsp+36: in_preserve
#r188 rsp+32: saved fp register
#r187 rsp+28: pad2, stack alignment
#r186 rsp+24: pad2, stack alignment
#r185 rsp+20: Fixed slot 1
#r184 rsp+16: Fixed slot 0
#r195 rsp+12: spill
#r194 rsp+ 8: spill
#r193 rsp+ 4: spill
#r192 rsp+ 0: spill
#
abababab   N1: #    B1 <- B12 B22  Freq: 1
abababab
```

C2 PrintOptoAssembly

```
000   B1: # B3 B2 <- BLOCK HEAD IS JUNK   Freq: 1
000     # stack bang (216 bytes)
        pushq   rbp # Save rbp
        subq    rsp, #32    # Create frame

00c     movl    [rsp + #0], RSI # spill
00f     cmpl    RSI, #1
012     je,s   B3  P=0.191038 C=7878.000000
012
014   B2: # B13 B3 <- B1  Freq: 0.808962
014     cmpl    RSI, #2
017     jne,s   B13  P=0.617919 C=6373.000000
017
019   B3: # B12 <- B2 B1  Freq: 0.500127
019     movl    RAX, #1 # int
01e     jmp,s   B12
01e
020   B4: # B11 <- B7 B6  Freq: 0.249995
020     movl    RAX, #1 # int
025     jmp,s   B11
025
027   B5: # B6 <- B14 B13  Freq: 0.25
027     movl    R11, #1 # int
        . . .
```

C2 PrintOptoAssembly

```
        . . .
037   B8: # B20 B9 <- B7  Freq: 0.249868
037     movl    [rsp + #8], R11 # spill
03c     movl    RSI, [rsp + #4] # spill
        nop     # 3 bytes pad for loops and calls
043     call,static  Fib::fib
        # Fib::fib @ bci:15  L[0]=RBP
        # Fib::fib @ bci:21  L[0]=_ STK[0]=rsp + #8
        # OopMap{off=72}
048
048   B9: # B21 B10 <- B8  Freq: 0.249863
        # Block is sole successor of call
048     movl    RBP, RAX    # spill
04a     movl    RSI, [rsp + #0] # spill
04d     addl    RSI, #-4    # int
        nop     # 3 bytes pad for loops and calls
053     call,static  Fib::fib
        # Fib::fib @ bci:21  L[0]=_ STK[0]=RBP
        # Fib::fib @ bci:21  L[0]=_ STK[0]=rsp + #8
        # OopMap{off=88}
058
058   B10: #    B11 <- B9  Freq: 0.249858
        # Block is sole successor of call
058     addl    RAX, RBP    # int
05a     movl    R11, [rsp + #8] # spill
        . . .
```

C2 PrintOptoAssembly

```
        . . .
05f   B11: #    B12 <- B10 B4  Freq: 0.499853
05f     addl    RAX, R11    # int
062
062   B12: #    N1 <- B11 B3  Freq: 0.99998
062     addq    rsp, 32 # Destroy frame
        popq   rbp
        testl  rax, [rip + #offset_to_poll_page] # Safepoint: poll for GC

06d     ret
        . . .
0c9   B20: #    B22 <- B8  Freq: 2.49975e-06
0c9     # exception oop is in rax; no code emitted
0c9     movq    RSI, RAX    # spill
0cc     jmp,s   B22
0cc
0ce   B21: #    B22 <- B9  Freq: 2.49863e-06
0ce     # exception oop is in rax; no code emitted
0ce     movq    RSI, RAX    # spill
0ce
0d1   B22: #    N1 <- B18 B19 B20 B21  Freq: 9.99472e-06
0d1     addq    rsp, 32 # Destroy frame
        popq   rbp

0d6     jmp     rethrow_stub
```

C2 PrintAssembly

```
Decoding compiled method 0x00007f4e791fec90:
Code:
[Entry Point]
[Verified Entry Point]
[Constants]
  # {method} {0x00007f4e73c003a8} 'fib' '(I)I' in 'Fib'
  # parm0:    rsi       = int
  #           [sp+0x30]  (sp of caller)
  ;; N1: #  B1 <- B12 B22  Freq: 1

  ;; B1: #  B3 B2 <- BLOCK HEAD IS JUNK   Freq: 1

  0x00007f4e791fee00: mov    %eax,-0x16000(%rsp)
  0x00007f4e791fee07: push   %rbp
  0x00007f4e791fee08: sub    $0x20,%rsp         ;*synchronization entry
                                                ; - Fib::fib@-1 (line 3)

  0x00007f4e791fee0c: mov    %esi,(%rsp)
  0x00007f4e791fee0f: cmp    $0x1,%esi
  0x00007f4e791fee12: je     0x00007f4e791fee19  ;*if_icmpeq
                                                ; - Fib::fib@2 (line 3)

  . . .
```

C2 PrintAssembly

```
;; B8: #  B20 B9 <- B7  Freq: 0.249975

0x00007f4e791fee37: mov    %r11d,0x8(%rsp)
0x00007f4e791fee3c: mov    0x4(%rsp),%esi
0x00007f4e791fee40: nop
0x00007f4e791fee41: nop
0x00007f4e791fee42: nop
0x00007f4e791fee43: callq  0x00007f4e79106300  ; OopMap{off=72}
                                              ;*invokestatic fib
                                              ; - Fib::fib@15 (line 5)
                                              ; - Fib::fib@21 (line 5)
                                              ;   {static_call}
;; B9: #  B21 B10 <- B8  Freq: 0.24997

0x00007f4e791fee48: mov    %eax,%ebp
0x00007f4e791fee4a: mov    (%rsp),%esi
0x00007f4e791fee4d: add    $0xfffffffffffffffc,%esi  ;*isub
                                              ; - Fib::fib@20 (line 5)
                                              ; - Fib::fib@21 (line 5)

0x00007f4e791fee50: nop
0x00007f4e791fee51: nop
0x00007f4e791fee52: nop
0x00007f4e791fee53: callq  0x00007f4e79106300  ; OopMap{off=88}
                                              ;*invokestatic fib
                                                . . .
```

C2 PrintAssembly

```
  ;; B22: # N1 <- B18 B19 B20 B21  Freq: 9.999e-06

  0x00007f4e791feed1: add    $0x20,%rsp
  0x00007f4e791feed5: pop    %rbp
  0x00007f4e791feed6: jmpq   0x00007f4e791faea0  ;   {runtime_call}
  0x00007f4e791feedb: hlt
  0x00007f4e791feedc: hlt
  0x00007f4e791feedd: hlt
  0x00007f4e791feede: hlt
  0x00007f4e791feedf: hlt
[Stub Code]
  0x00007f4e791feee0: mov    $0x0,%rbx          ;   {no_reloc}
  0x00007f4e791feeea: jmpq   0x00007f4e791feeea  ;   {runtime_call}
  0x00007f4e791feeef: mov    $0x0,%rbx          ;   {static_stub}
  0x00007f4e791feef9: jmpq   0x00007f4e791feef9  ;   {runtime_call}
  0x00007f4e791feefe: mov    $0x0,%rbx          ;   {static_stub}
  0x00007f4e791fef08: jmpq   0x00007f4e791fef08  ;   {runtime_call}
  0x00007f4e791fef0d: mov    $0x0,%rbx          ;   {static_stub}
  0x00007f4e791fef17: jmpq   0x00007f4e791fef17  ;   {runtime_call}
[Exception Handler]
  0x00007f4e791fef1c: jmpq   0x00007f4e79004ee0  ;   {runtime_call}
[Deopt Handler Code]
  0x00007f4e791fef21: callq  0x00007f4e791fef26
  0x00007f4e791fef26: subq   $0x5,(%rsp)
  0x00007f4e791fef2b: jmpq   0x00007f4e791072e0  ;   {runtime_call}
  . . .
```

What Lies Beneath?

- Bytecode
- Template Interpreter
- C1 JIT Compiler
- C2 JIT Compiler
- **Special Tricks**
- Questions

On Stack Replacement

- Compile and jump into a hot method
  - e.g. a big loop

```
for (idx = 0; idx < limit; idx++) {
    // do something complex lots of times
}

while (condition) {
    // do something complex lots of times
}
```

- Compile from OSR point

  with current locals as inputs (e.g. `idx, limit`)

- Swap interpreted frame for compiled frame!

Deoptimisation

- Jump out into the interpreter and recompile
  - e.g. a cold path is entered
    - C1/C2 generate deopt trap on cold paths
      - saves on code size and compile time
      - n.b. -Xcomp wtih -Tiered == deopt-a-lot (all paths are cold)
  - e.g. access to not yet-loaded class
    - C1/C2 generate deopt trap for this case
      - bet on never if it was not loaded by interpreter
- Swap compiled frame for interpreted frame!
  - several frames if deopt is for inlined code!
  - locals need to be restored to local area(s)!

Safepoint Checks

- Do we need to stop the world?
  - for a GC/GC phase? or other VM housekeeping?
    - e.g. clear out deoptimised methods
- Checks happen at strategic points
  - after callouts to VM stubs/helpers
  - before return
  - at loop back edges

Safepoint Checks

```
062   B12: #    N1 <- B11 B3  Freq: 0.99998
062     addq    rsp, 32 # Destroy frame
        popq   rbp
        testl  rax, [rip + #offset_to_poll_page]    # Safepoint: poll for GC

06d     ret
```

- Check by reading well known address
  - Poll page is mprotected -r when Safepoint needed
  - Signal handler identifies SEGV address
    - returns from signal into stub code
  - Stub code pushes frame for callout to VM
    - return address of frame is instruction after testl

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- **Questions**