The Performance Effects of Virtual-Machine Instruction Pointer Updates 2024 update

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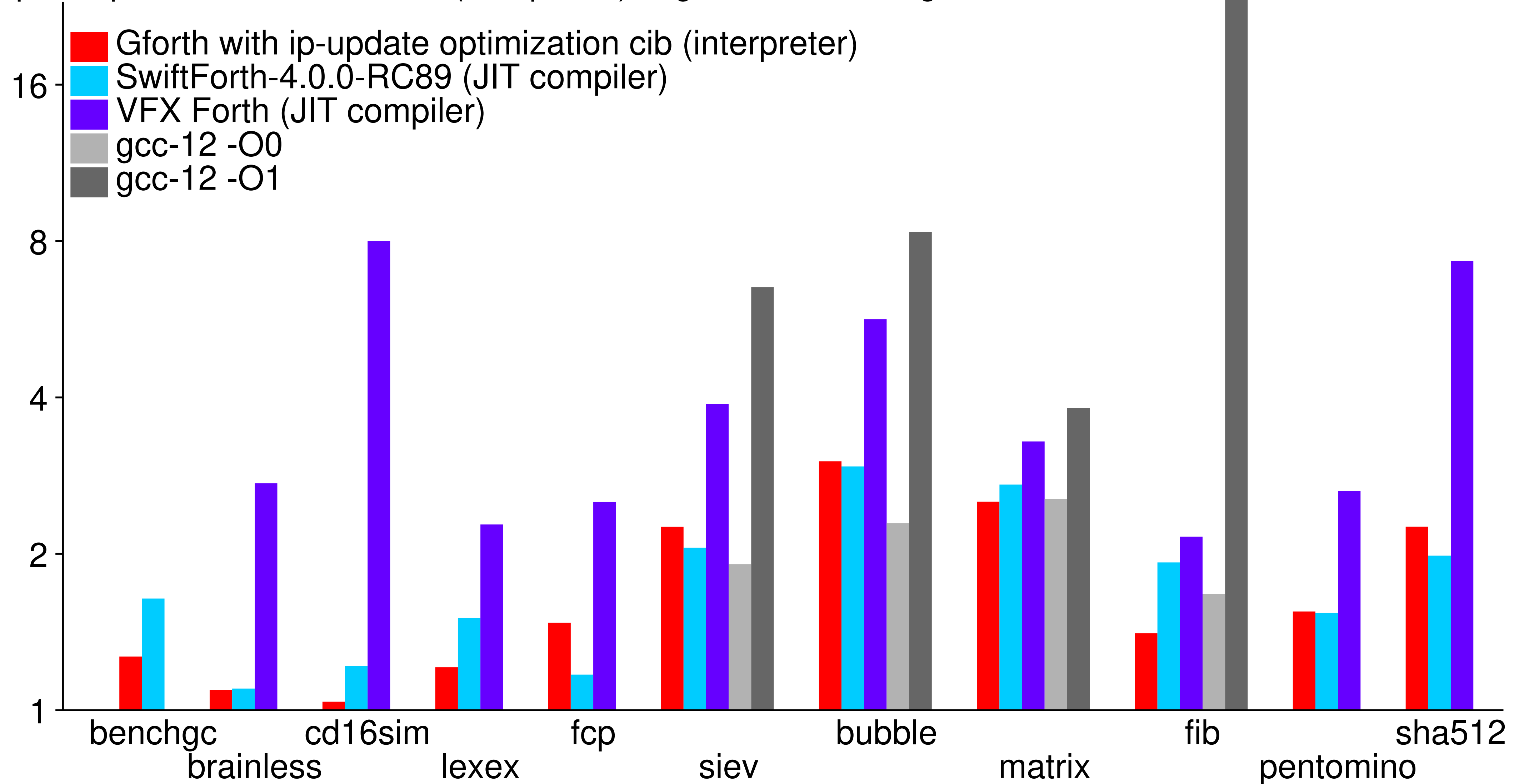
Overview

- Background: Virtual-machine interpreter with code copying
- Every VM instruction increments the VM instruction pointer (IP)
- Question: How relevant are IP updates for performance?
- Answer: on some programs critical latency path
- Method: optimize most IP updates away

Is interpreter performance relevant? What about JITs?



Running example: inner loop of `siev`

Forth Source:

```
do
  0 i c! dup +loop
```

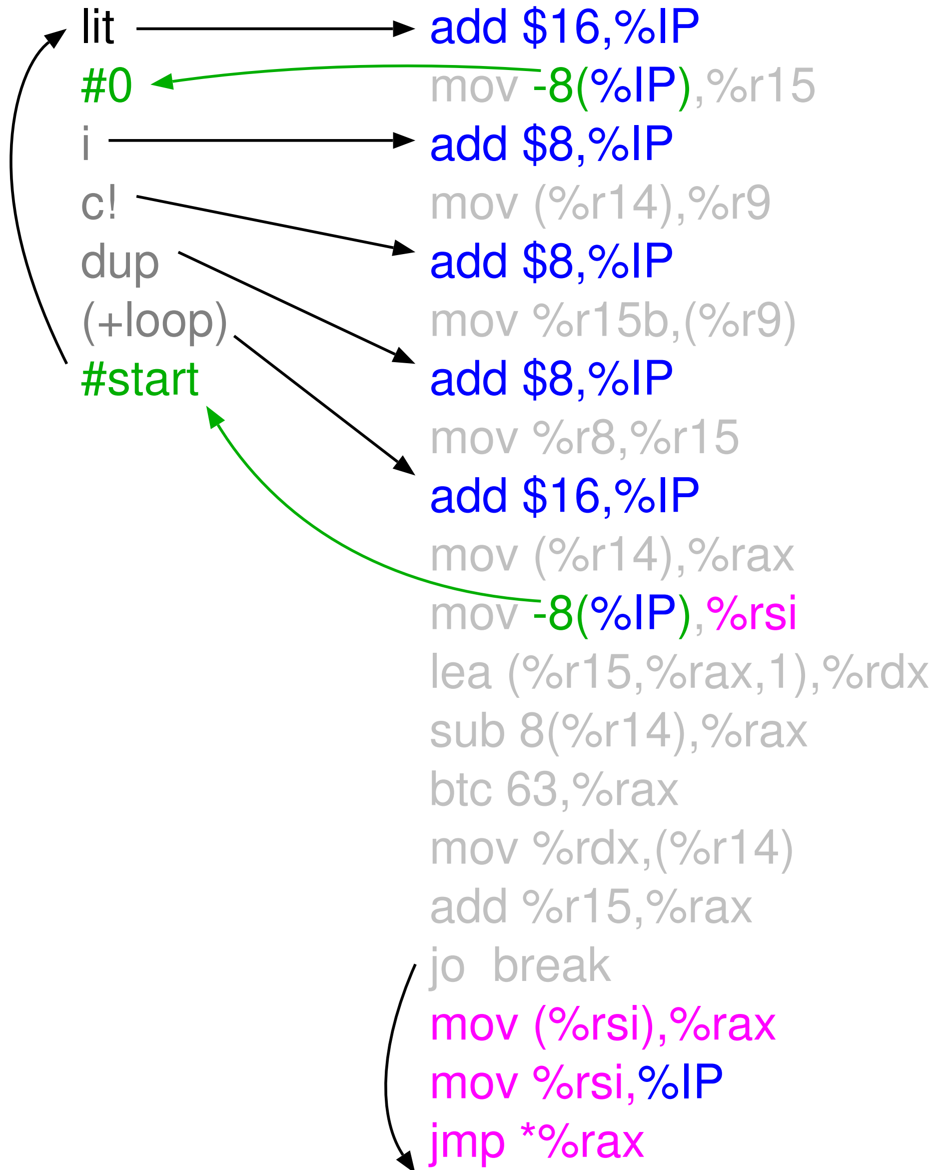
C Source:

```
for(p = ... ; p <= ... ; p += prime)
  *p = 0;
```

Virtual-Machine code (Gforth):

```
        (do)
start:  lit
        #0
        i
        c!
        dup
        (+loop)
        #start
```

Baseline: Code-copying interpreter with static stack caching



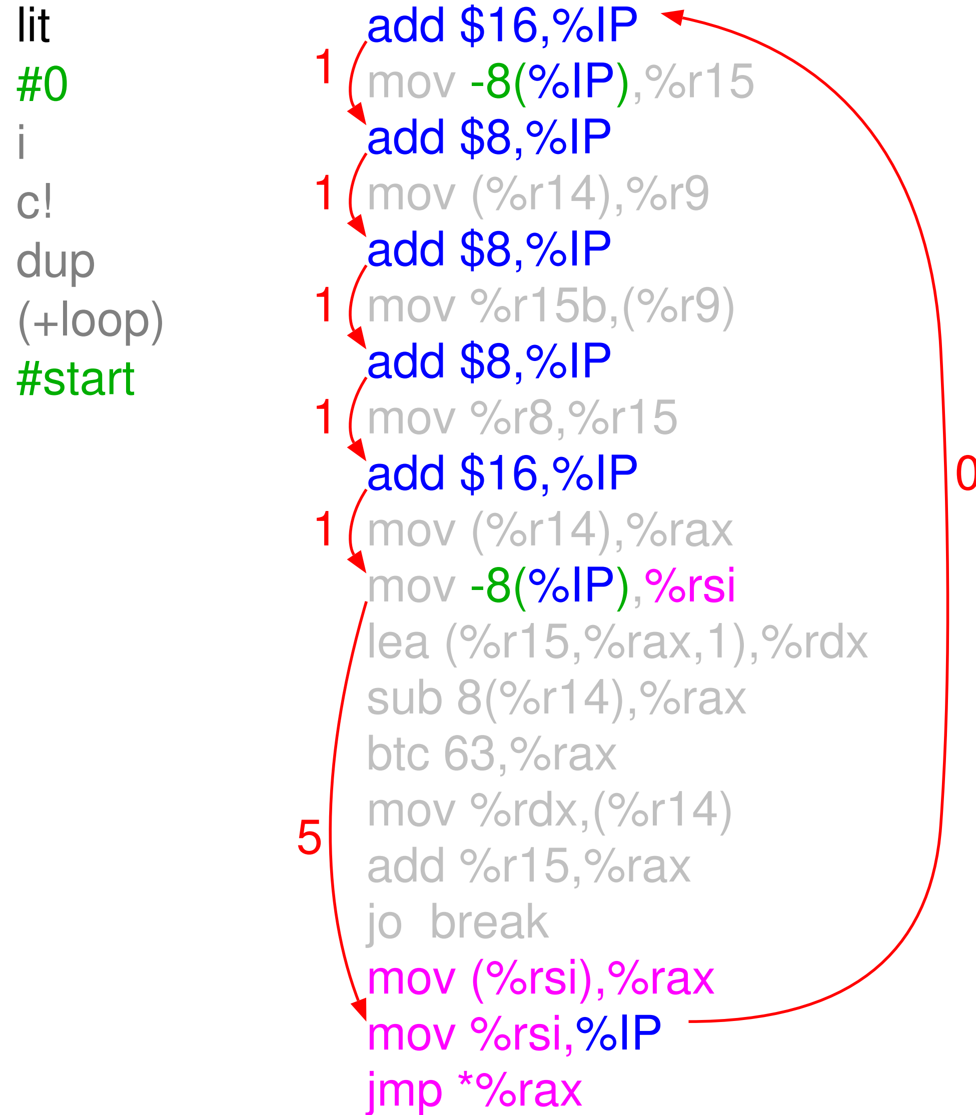
It's a JIT compiler!

+ Copies native code

It's an interpreter!

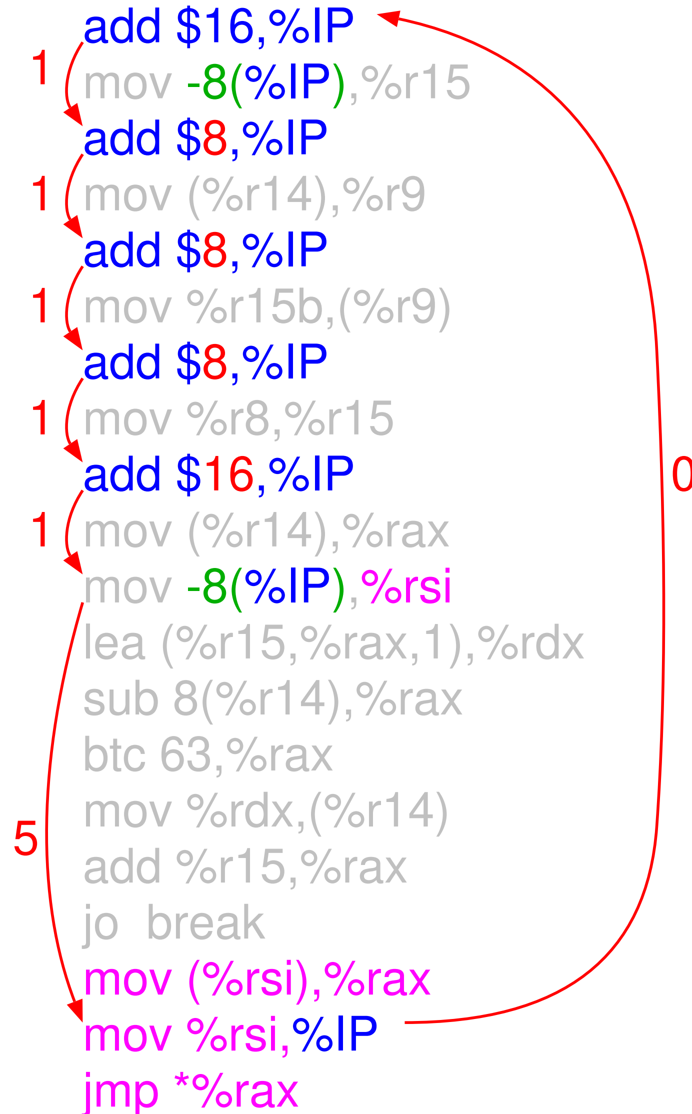
+ Portable
  gcc generates code snippets
+ Fallback option
  to threaded-code interpreter
  without code copying
+ VM code is still needed
  for immediate values
  for control flow
+ ⇒ VM instruction pointer needed

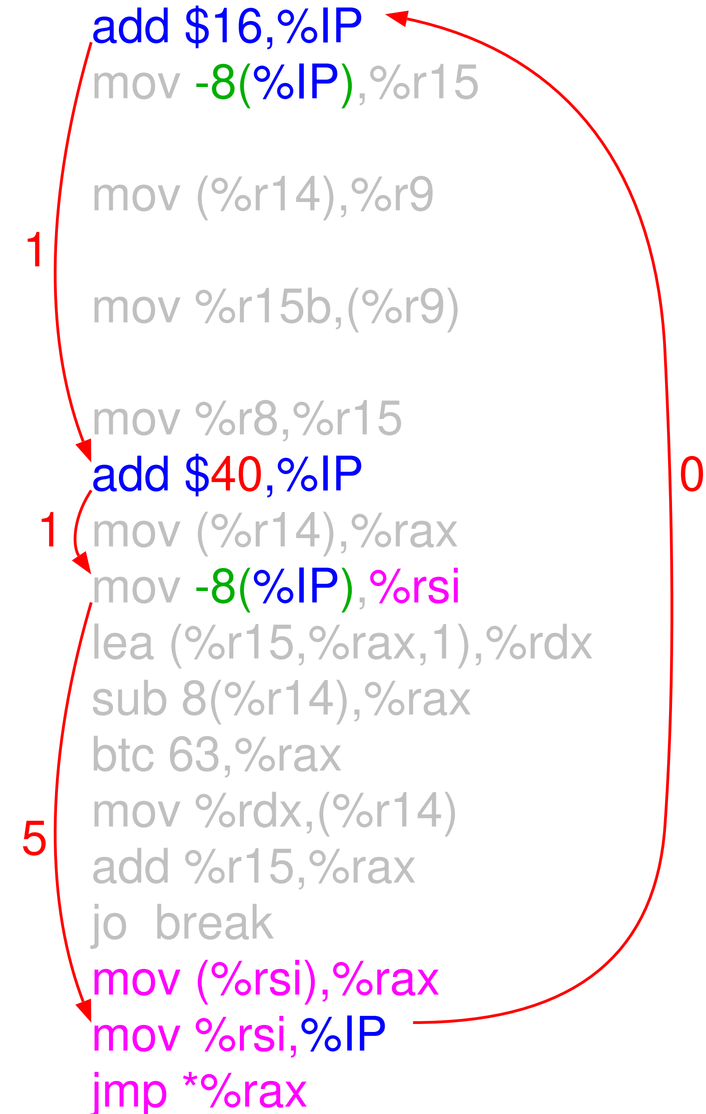
Instruction pointer updates limit execution rate



C: combine instruction pointer updates

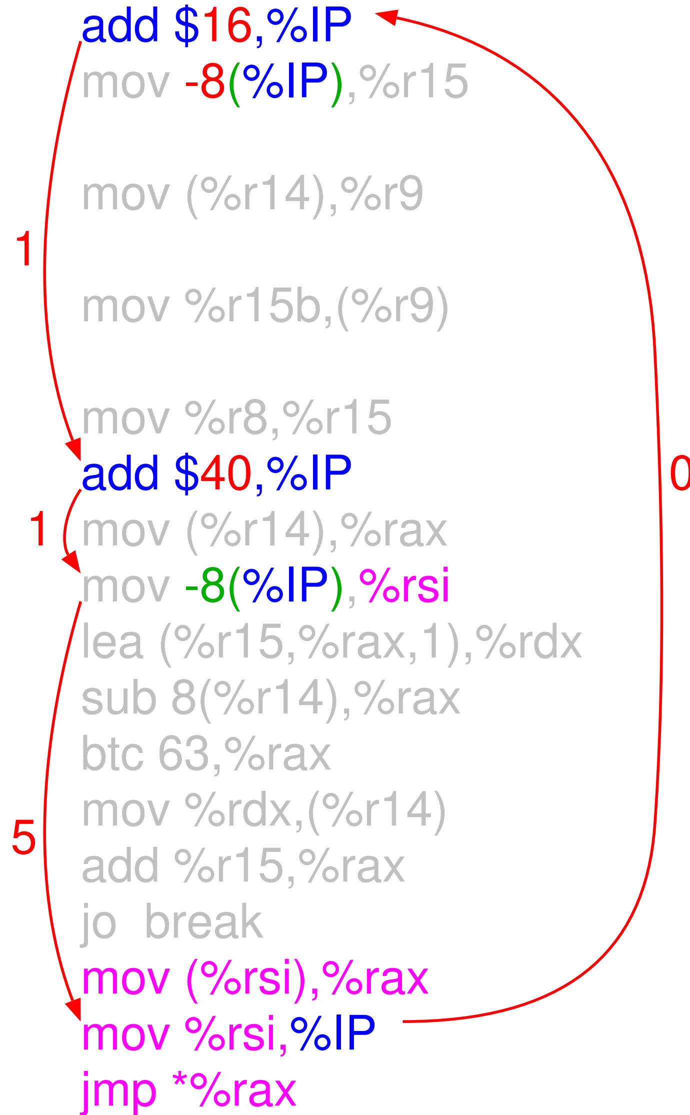
lit
#0
i
c!
dup
(+loop)
#start

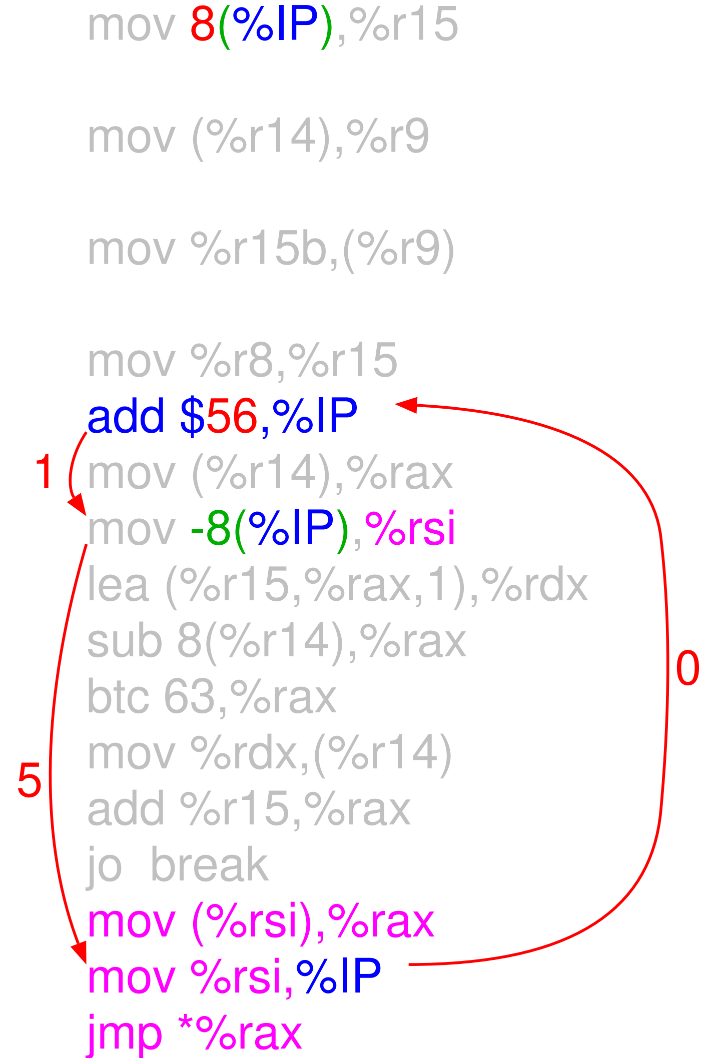




ci: ... and optimize immediate VM instructions

lit
#0
i
c!
dup
(+loop)
#start



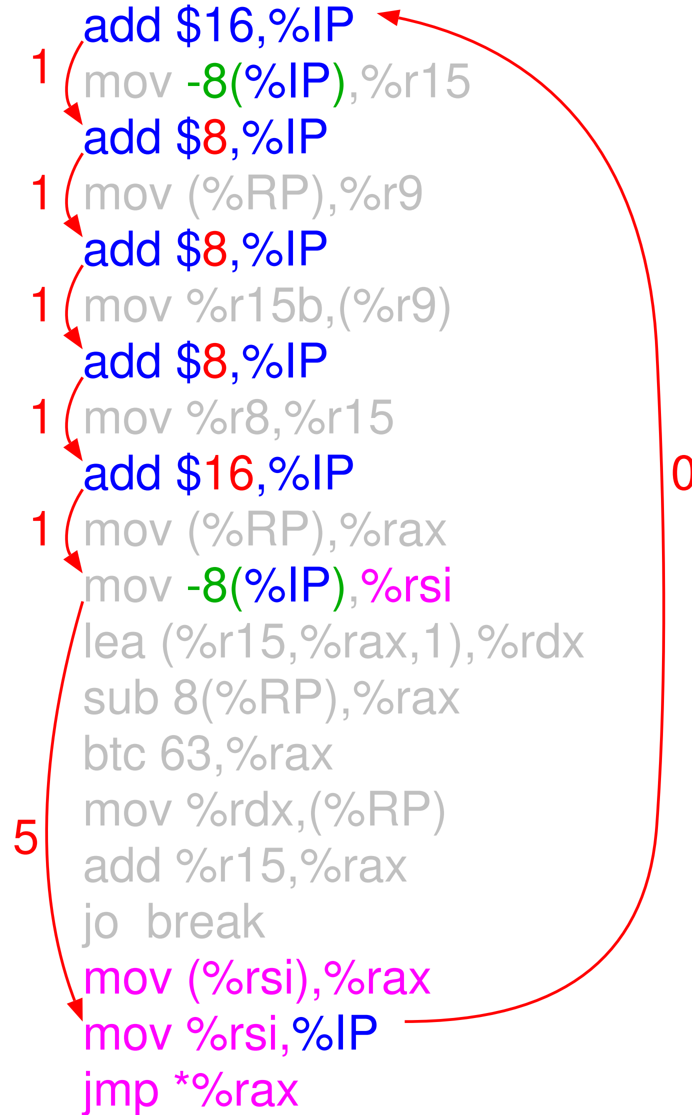


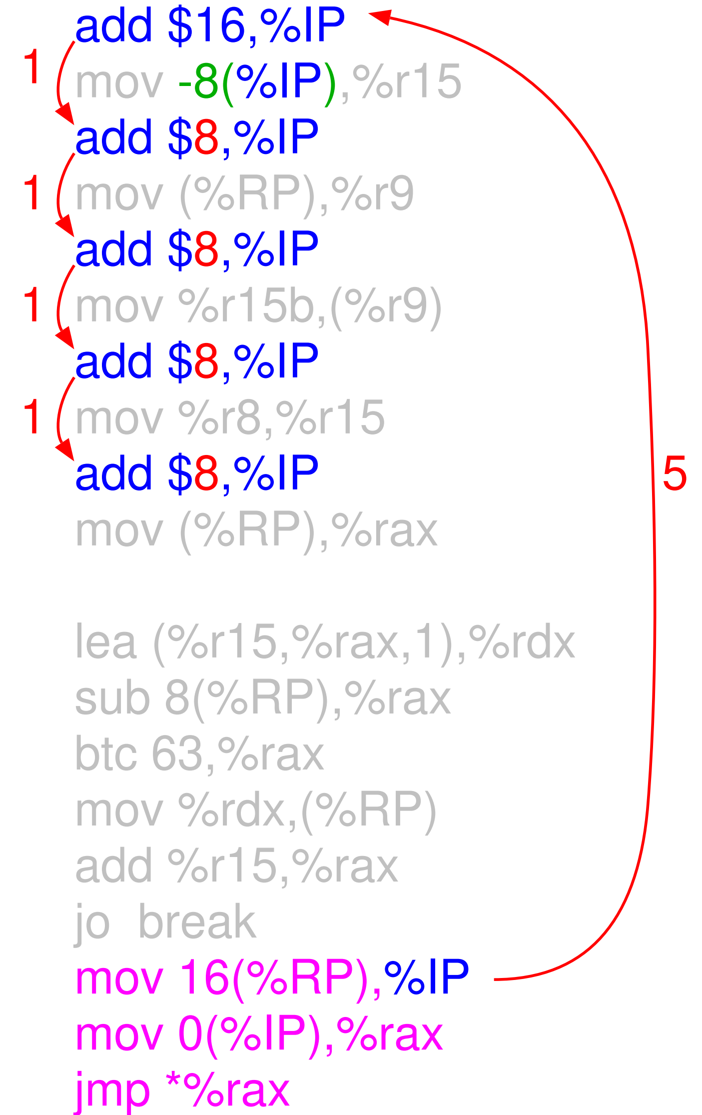
cib: ... and optimize VM branch instructions

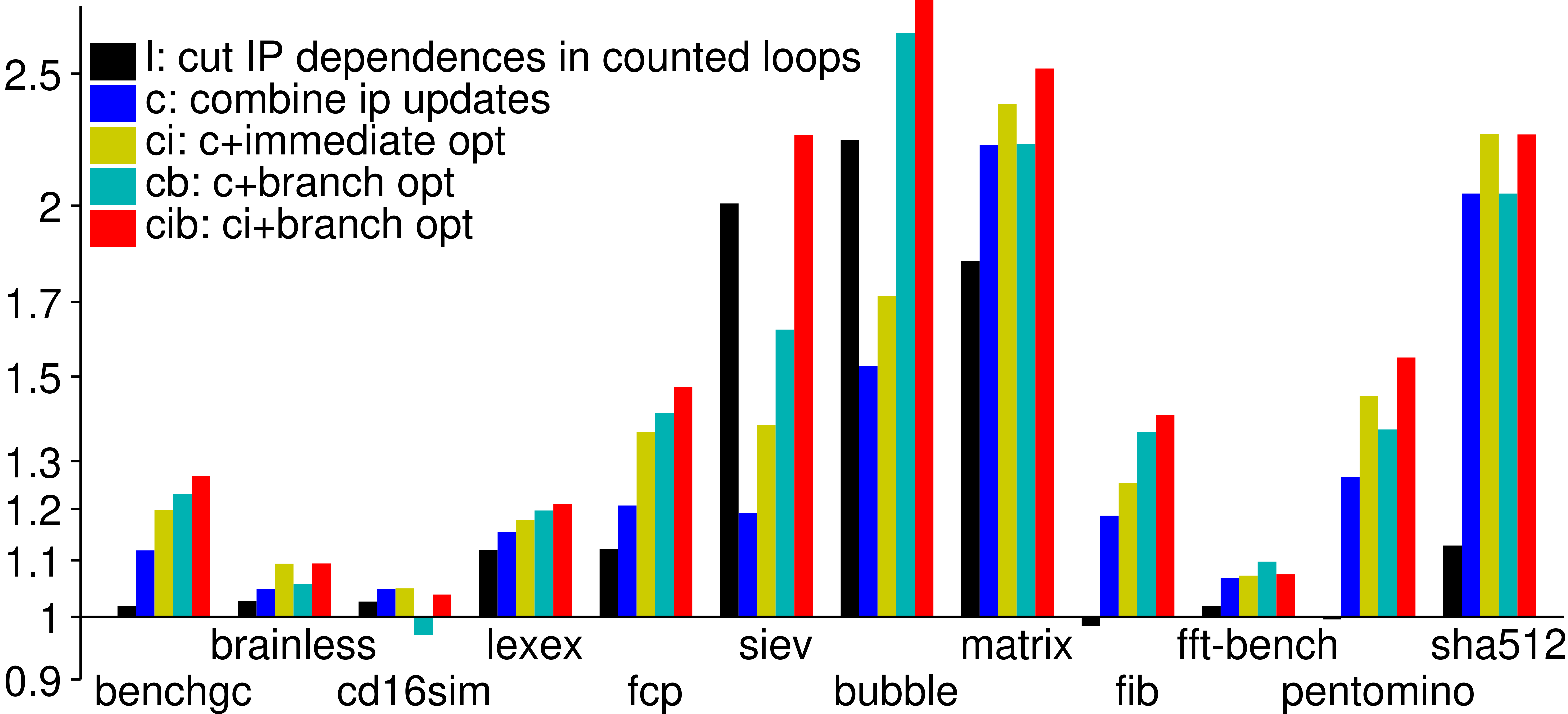
```
lit
#0        mov 8(%IP),%r15              mov 8(%IP),%r15
i
c!        mov (%r14),%r9               mov (%r14),%r9
dup
(+loop)   mov %r15b,(%r9)              mov %r15b,(%r9)
#start
          mov %r8,%r15                 mov %r8,%r15
          add $56,%IP
        1 mov (%r14),%rax              mov    (%r14),%rax
          mov -8(%IP),%rsi
          lea (%r15,%rax,1),%rdx       lea    (%r15,%rax,1),%rdx
          sub 8(%r14),%rax             sub    8(%r14),%rax
          btc 63,%rax             0    btc    $63,%rax
          mov %rdx,(%r14)              mov    %rdx,(%r14)
        5 add %r15,%rax                add    %r15,%rax
          jo  break                    jo     break
          mov (%rsi),%rax              mov    (%IP),%rax
          mov %rsi,%IP
          jmp *%rax                    jmp    *%rax
```

I: break loop dependencies

lit
#0
i
c!
dup
(+loop)
#start





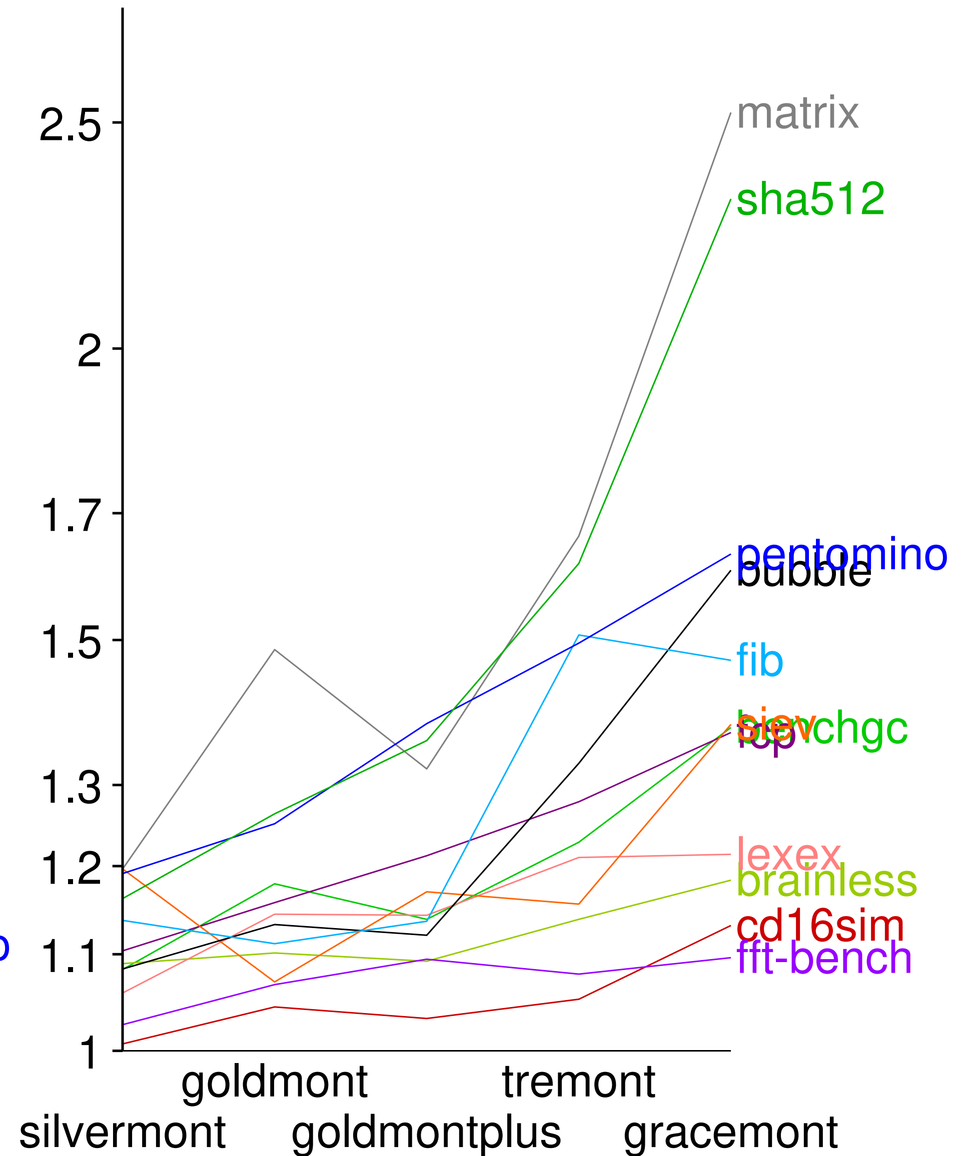

Speedup over baseline, log scale, Tiger Lake
l: cut IP dependences in counted loops
c: combine ip updates
ci: c+immediate opt
cb: c+branch opt
cib: ci+branch opt
2.5
2
1.7
1.5
1.3
1.2
1.1
1
0.9
benchgc
brainless
cd16sim
lexex
fcp
siev
bubble
matrix
fib
fft-bench
pentomino
sha512

speedup of cib over baseline, log scale
Intel P-core evolution

2.5
2
1.7
1.5
1.3
1.2
1.1
1

bubble
siev
sha512
matrix
lexex
fcp
pentomino
cd16sim
fft-bench

nehalem
haswell
rocketlake
goldencove
penryn
sandybridge
skylake
tigerlake



Conclusion

- Problem: VM instruction-pointer updates can be a performance bottleneck
- Solution: Optimize instruction-pointer updates
  combine them
  immediate operand variants
  branch to (adjusted) instruction pointer
  load **l**oop start address without using the instruction pointer
- Results
  speedup factors > 2 on loop-dominated benchmarks: critical path
  speedup factors 1.1–1.3 on call-dominated benchmarks
- Paper: DOI: 10.4230/LIPIcs.ECOOP.2024.14
  `https://drops.dagstuhl.de/entities/document/10.4230/LIPIcs.ECOOP.2024.14`

Gforth (interpreter) vs. SwiftForth (JIT)

Gforth VM	Gforth machine code	source	SwiftForth

lit
#0
	mov 0x8(%rbx),%r15	0	lea -0x8(%rbp),%rbp
			mov %rbx,0x0(%rbp)
			mov $0x0,%ebx

i	mov (%r14),%r9	i	lea -0x8(%rbp),%rbp
			mov %rbx,0x0(%rbp)
			mov %r14,%rbx
			add %r15,%rbx

c!	mov %r15b,(%r9)	c!	mov 0x0(%rbp),%eax
			mov %al,(%rbx)
			mov 0x8(%rbp),%rbx
			lea 0x10(%rbp),%rbp

dup	mov %r8,%r15	dup	lea -0x8(%rbp),%rbp mov %rbx,0x0(%rbp)

(+loop)
#start
	mov (%r14),%rax
	lea (%r15,%rax,1),%rdx
	sub 0x8(%r14),%rax
	btc $0x3f,%rax
	mov %rdx,(%r14)
	add %r15,%rax
	jo end
	mov (%rbx),%rax
	jmp *%rax
		+loop	add %rbx,%r14
			mov 0x0(%rbp),%rbx
			lea 0x8(%rbp),%rbp
			jno start

Why is gcc -O3 so slow for *bubble*?

```
gcc -O1

1c: add     $0x4,%rax
    cmp     %rsi,%rax
    je      35
25: mov     (%rax),%edx
    mov     0x4(%rax),%ecx
    cmp     %ecx,%edx
    jle     1c
    mov     %ecx,(%rax)
    mov     %edx,0x4(%rax)
    jmp     1c
35:
```

```
gcc -O3

c0: movq    (%rax),%xmm0
    add     $0x1,%edx
    pshufd  $0xe5,%xmm0,%xmm1
    movd    %xmm0,%edi
    movd    %xmm1,%ecx
    cmp     %ecx,%edi
    jle     e1
    pshufd  $0xe1,%xmm0,%xmm0
    movq    %xmm0,(%rax)
e1: add     $0x4,%rax
    cmp     %r8d,%edx
    jl      c0
```