Reducing Code Size with Speculative Inlining

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Meta

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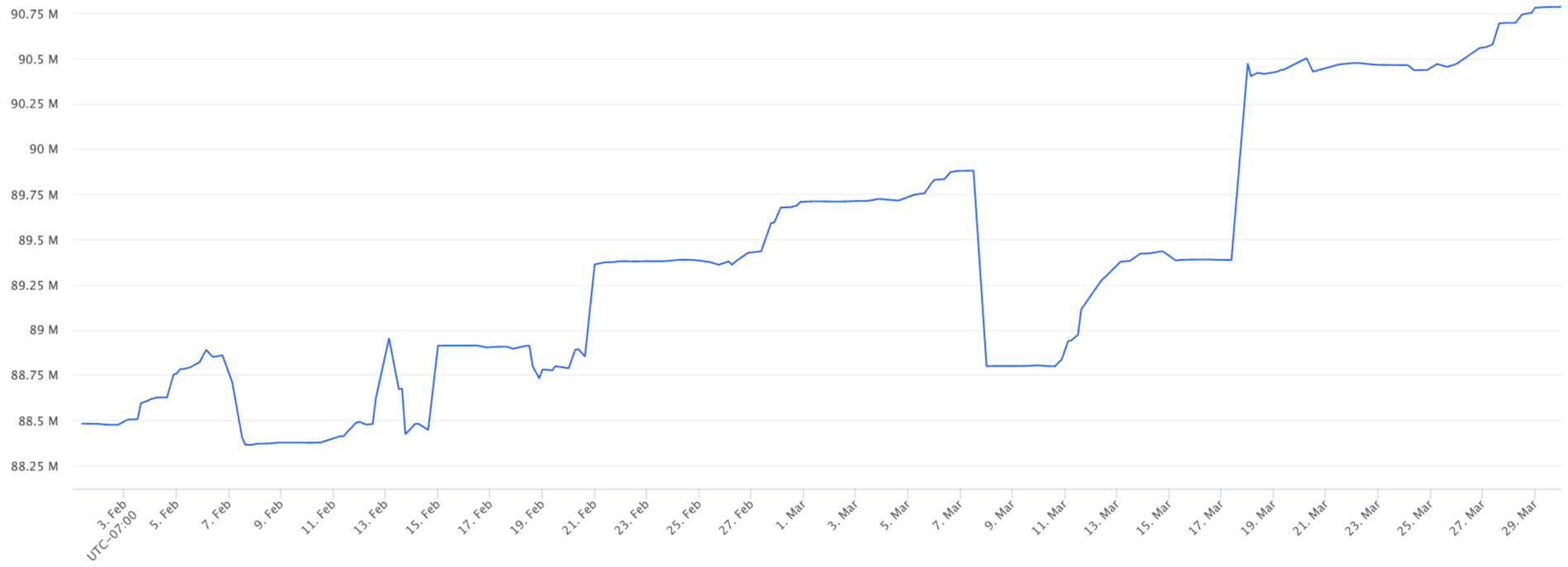
Growth in App Size

- Reducing app size is important for mobile applications
- Large apps impact user experience and user retention
- Employ optimizations (e.g. inliner) to reduce code size



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Inlining for Code Size

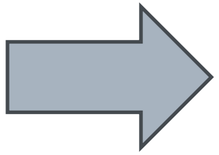
- LLVM generally tuned for performance and not code size
- Performance often viewed at the expense of increased code size
- Inlining is critical for compiler optimizations
- Leverage inlining to reduce code size may help with performance
  - Potential to speed up programs by maximizing amount of hot code in instruction cache

Example

```c
int f2(int *ptr, int a, int b, int n, int scale) {
    int valid = ptr ? 1 : 0;
    int s = 0;
    for (int i = 0; i < a; i++)
        for (int j = 0; j < b; j++)
            if (n * valid)
                s += scale * ptr[i];
    return s;
}

void f1(int *arr, int a, int b, int n, int t) {
    for (int i = 0; i < n; i++) {
        arr[i] = f2(0, a, b, n, t);
    }
}

void f1_optimized(int *arr, int a, int b, int n, int t) {
    for (int i = 0; i < n; i++) {
        arr[i] = 0;
    }
}
```



Under -Oz

```
define dso_local void @f1(...)
  %6 = tail call i32 @llvm.smax.i32(i32 %3, i32 0)
  %7 = zext nneg i32 %6 to i64
  br label %8

8:
  %9 = phi i64 [ %15, %12 ], [ 0, %5 ]
  %10 = icmp eq i64 %9, %7
  br i1 %10, label %11, label %12

11:
  ret void

12:
  %13 = tail call noundef i32 @f2(...)
  %14 = getelementptr inbounds nuw i32, ptr %0, i64 %9
  store i32 %13, ptr %14, align 4
  %15 = add nuw nsw i64 %9, 1
  br label %8
}
```

Under -O3

```
define dso_local void @f1_optimized(...)
  %6 = tail call i32 @llvm.smax.i32(i32 %3, i32 0)
  %7 = zext nneg i32 %6 to i64
  br label %8

8:
  %9 = phi i64 [ %14, %12 ], [ 0, %5 ]
  %10 = icmp eq i64 %9, %7
  br i1 %10, label %11, label %12

11:
  ret void

12:
  %13 = getelementptr inbounds nuw i32, ptr %0, i64 %9
  store i32 0, ptr %13, align 4
  %14 = add nuw nsw i64 %9, 1
  br label %8
}
```

https://godbolt.org/z/E71E9xqjK

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Speculative Inliner

- Inliner pass that measures the cost of inlining based on the material outcome of the post-inliner optimizations on the inlined code
  - Consider all inline viable call sites for speculation and ignoring LLVM’s standard inline thresholds
- Post-inline optimizations (i.e. simplification) determines whether an inline is profitable or not

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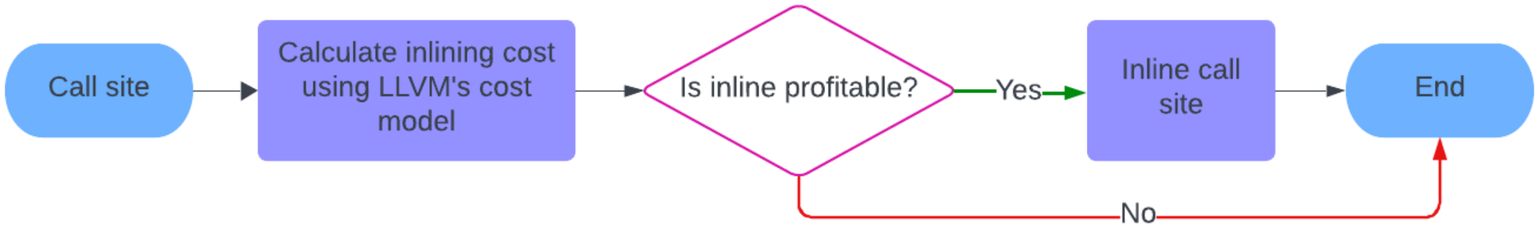
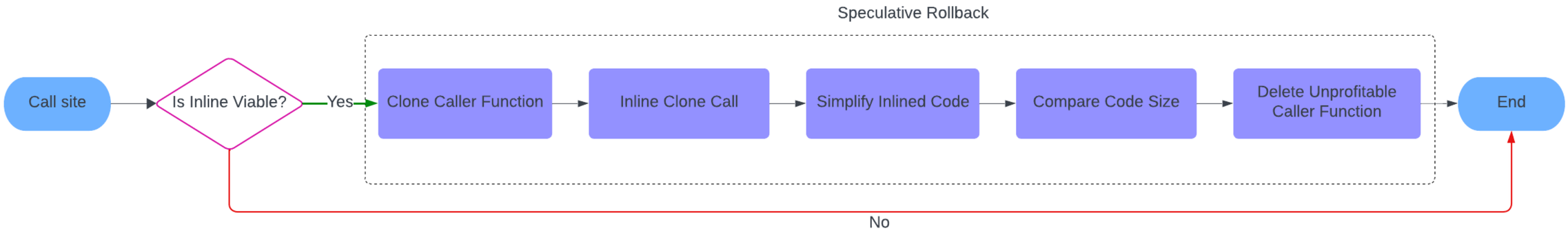
LLVM Inliner



Speculative Inliner



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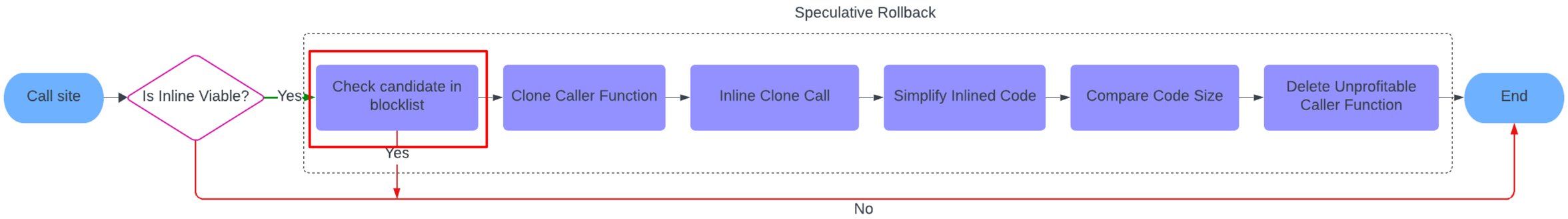
Problem #1: Uninlineable callsites

- Inline assembly
- Known mis-optimizations deeper in the pipeline
- Added a blocklist
  - Prevent inlining callee into caller
  - Prevent inlining **all** callees into caller



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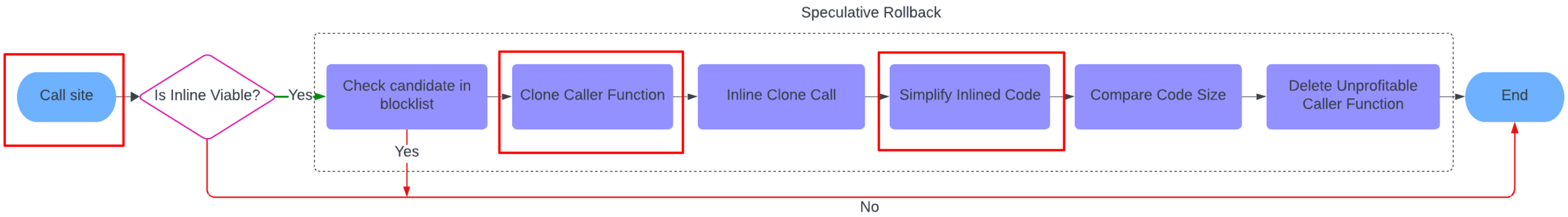
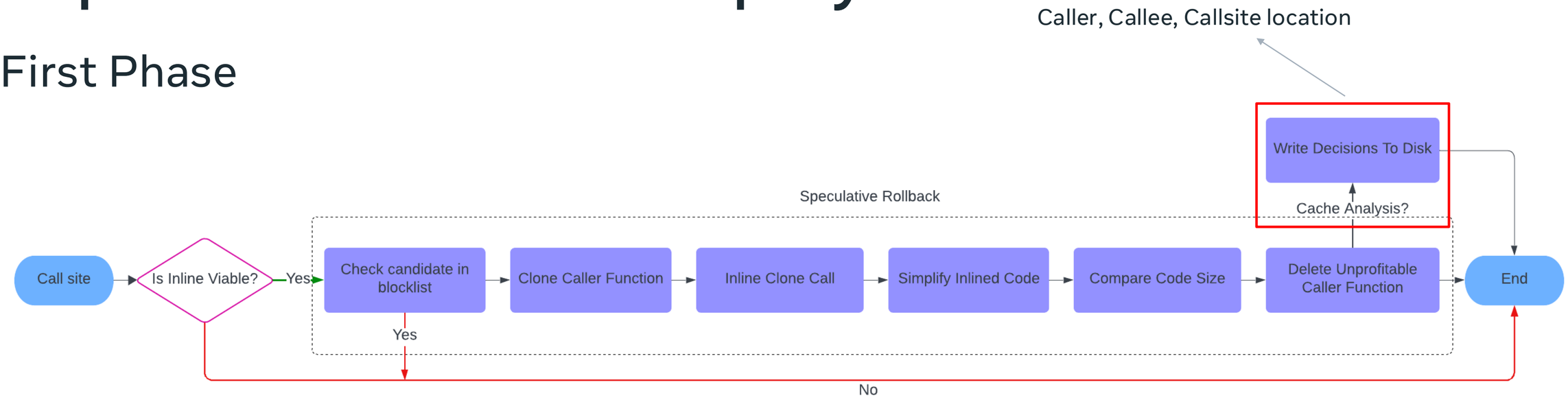
Problem #2: Searching

- Build time is very expensive
  - Large amount of callsites
  - Cloning operation can be costly
  - Simplifying large functions do not scale linearly

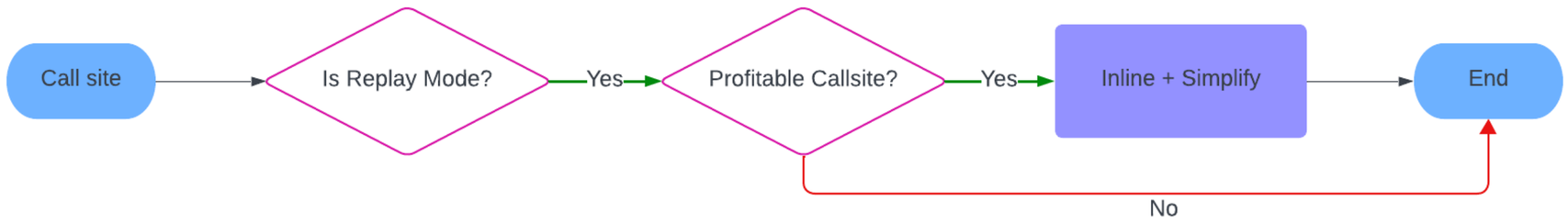


Speculative Inliner Replay

First Phase



Second Phase



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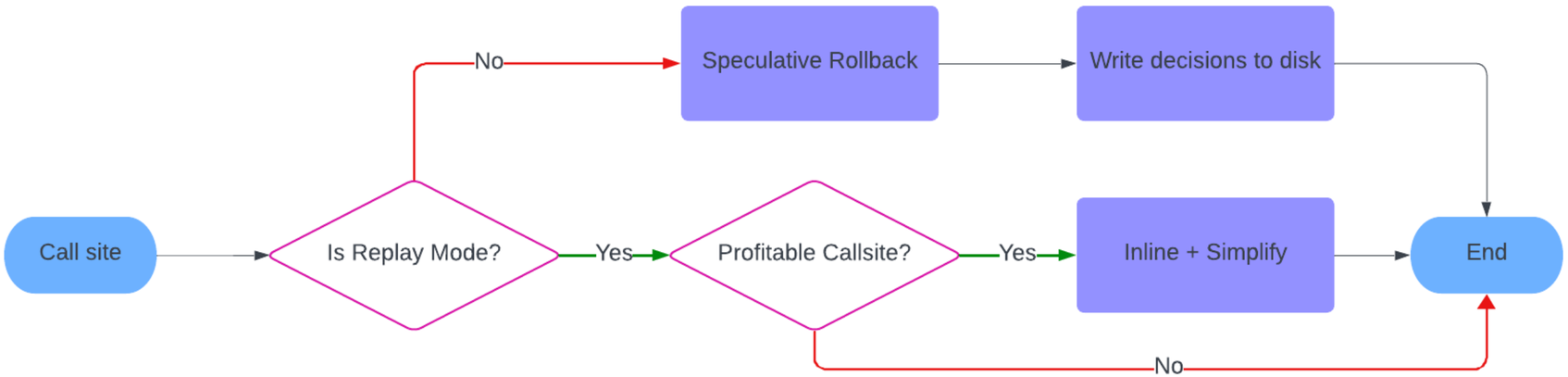
Speculative Inliner Replay



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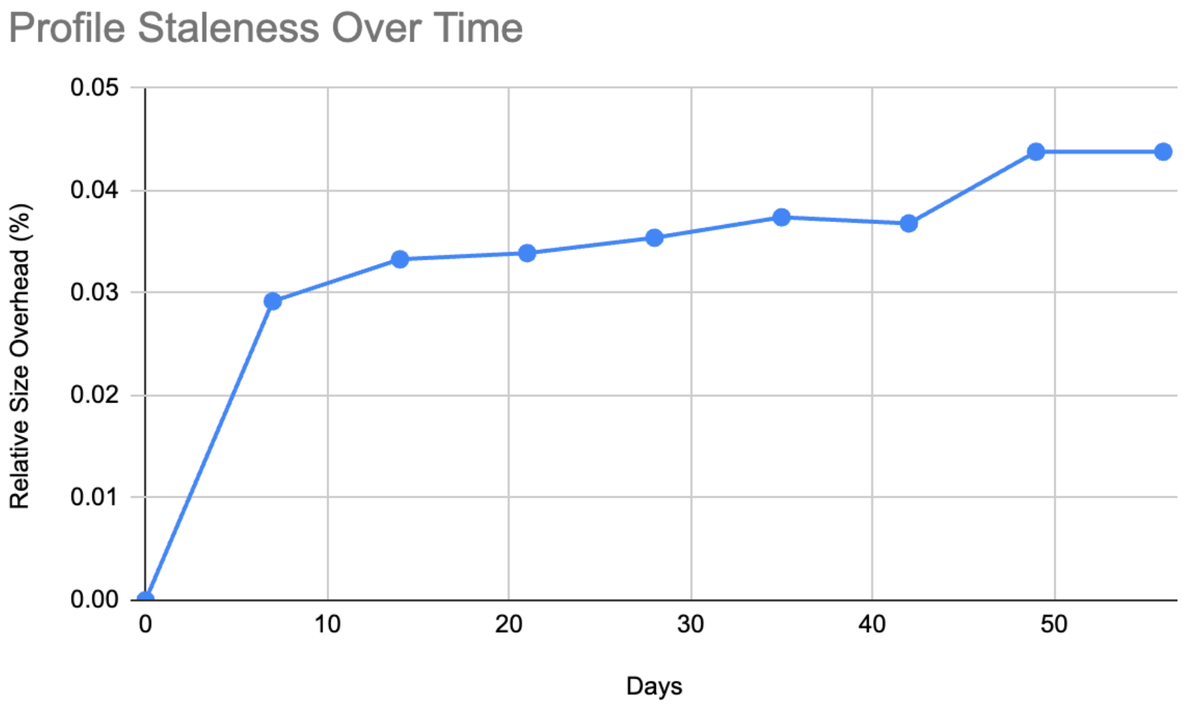
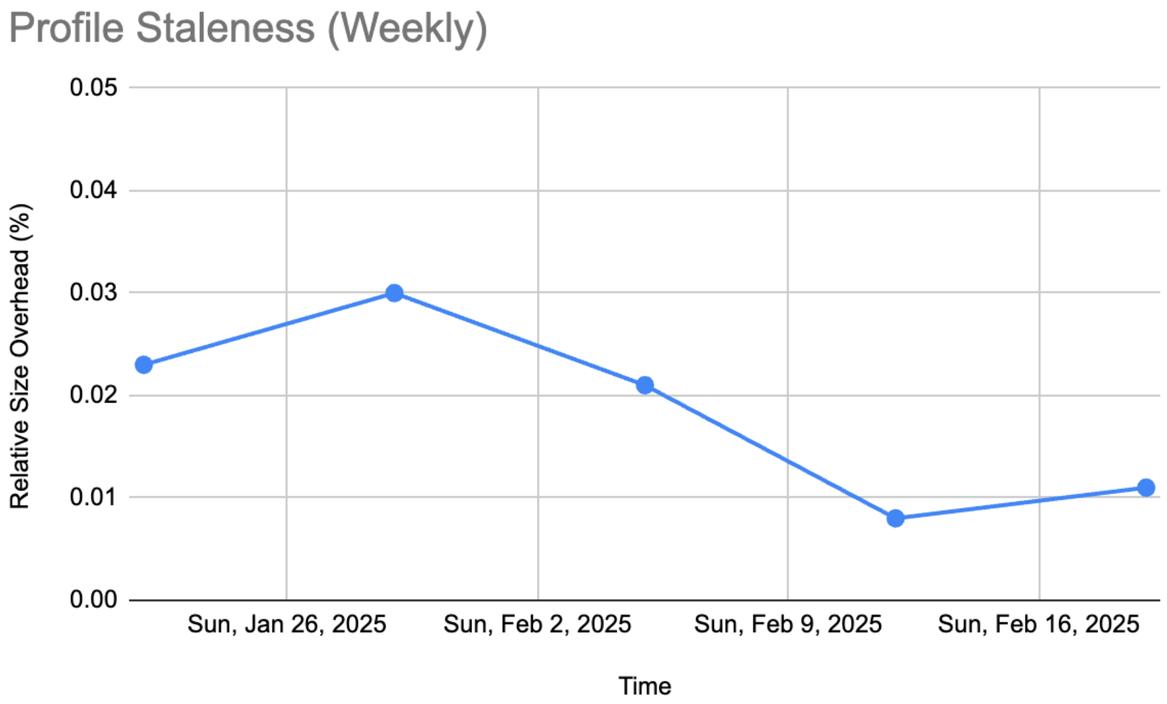
Profile Staleness





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Size Beneficial Inlining

- Obtained when the callee can be removed from the program after inlining
  - Dropping its use count to zero
  - Internal linkage function

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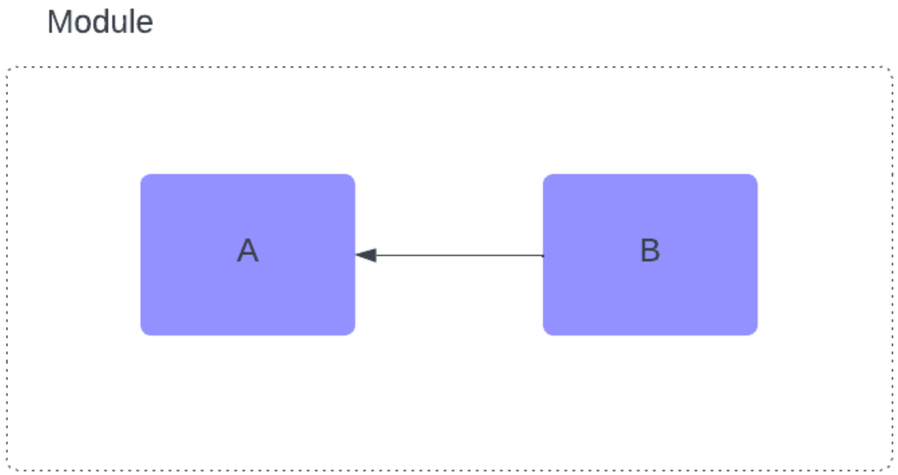
N = 1 callsite



- Guaranteed code size win once B is inlined into A

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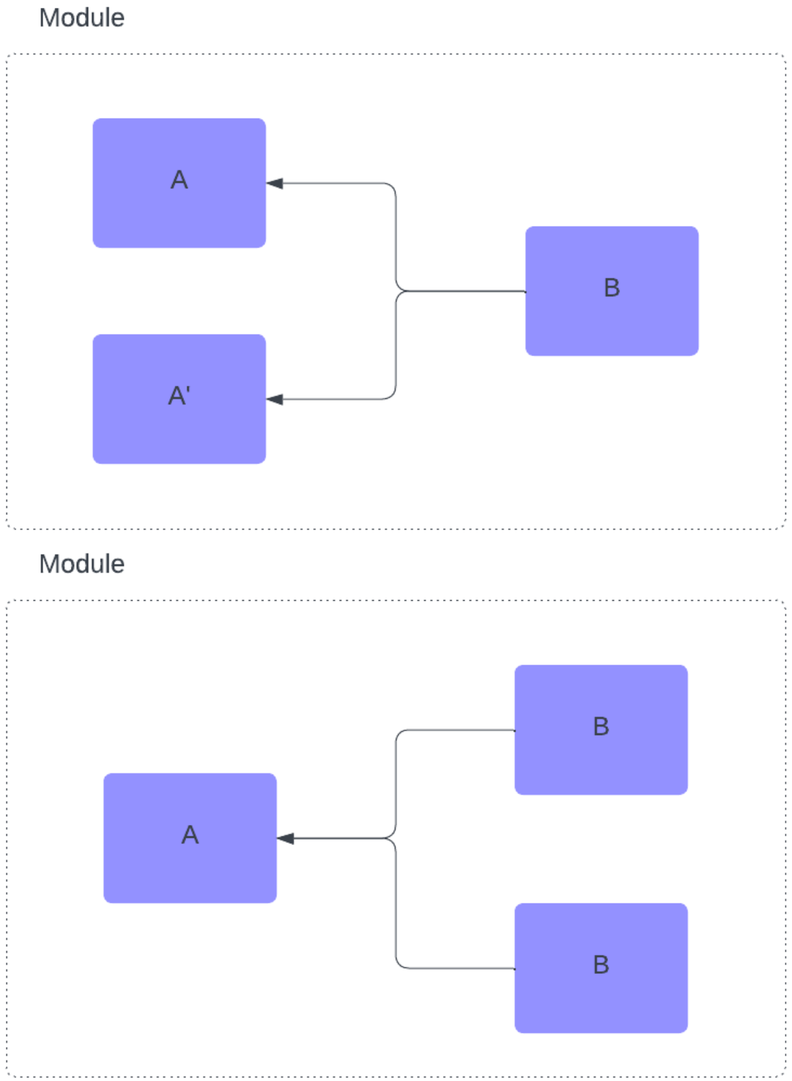
N = 2 callsites



- Not always guaranteed a win, but has been mostly true for small functions
  - Register pressure on larger functions
- Gated behind an arbitrary threshold
  - ~15 LLVM IR instructions through empirical testing

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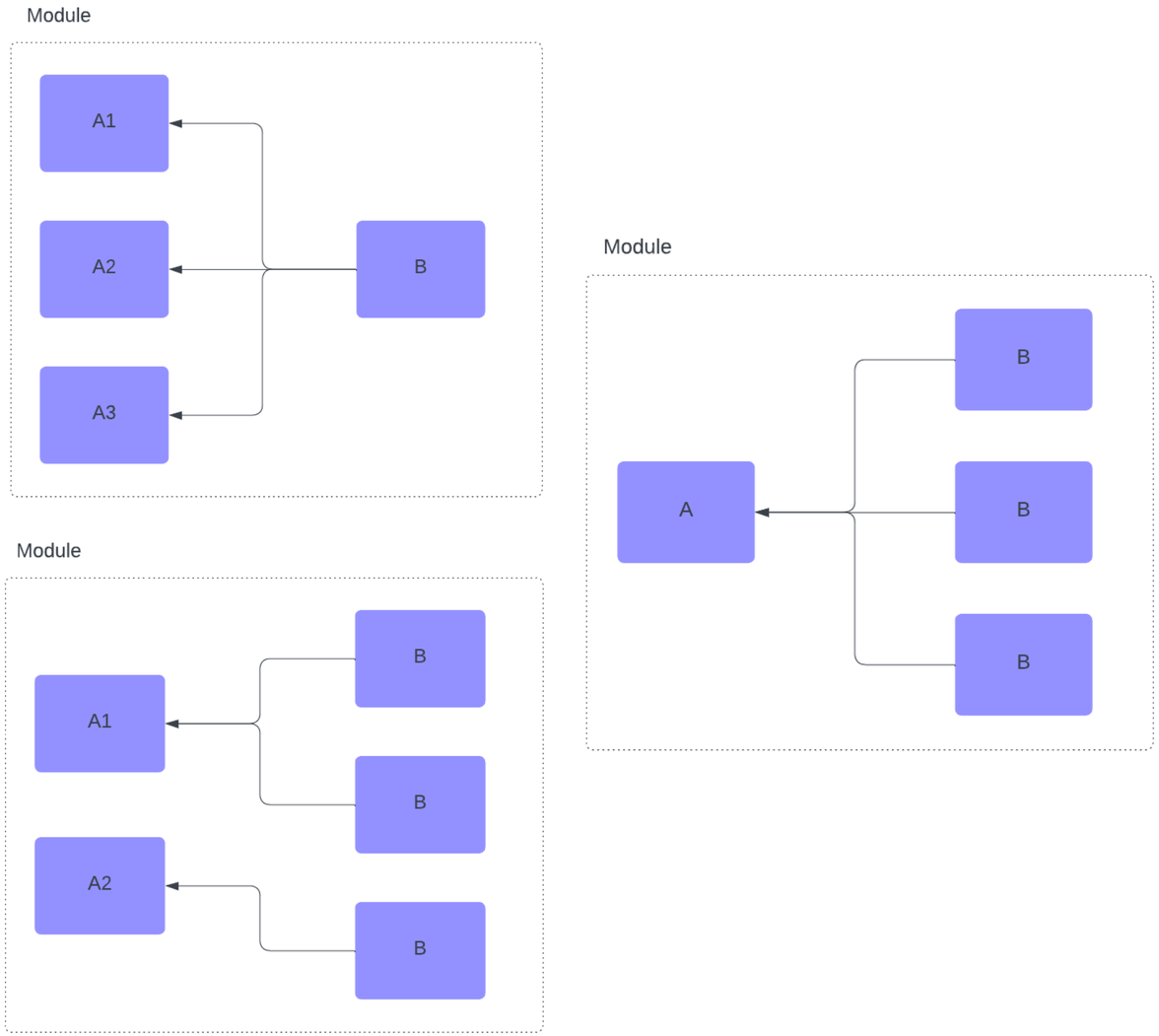
N = 3+ callsites



- Largely a size regression due to duplication
- Non-trivial heuristic

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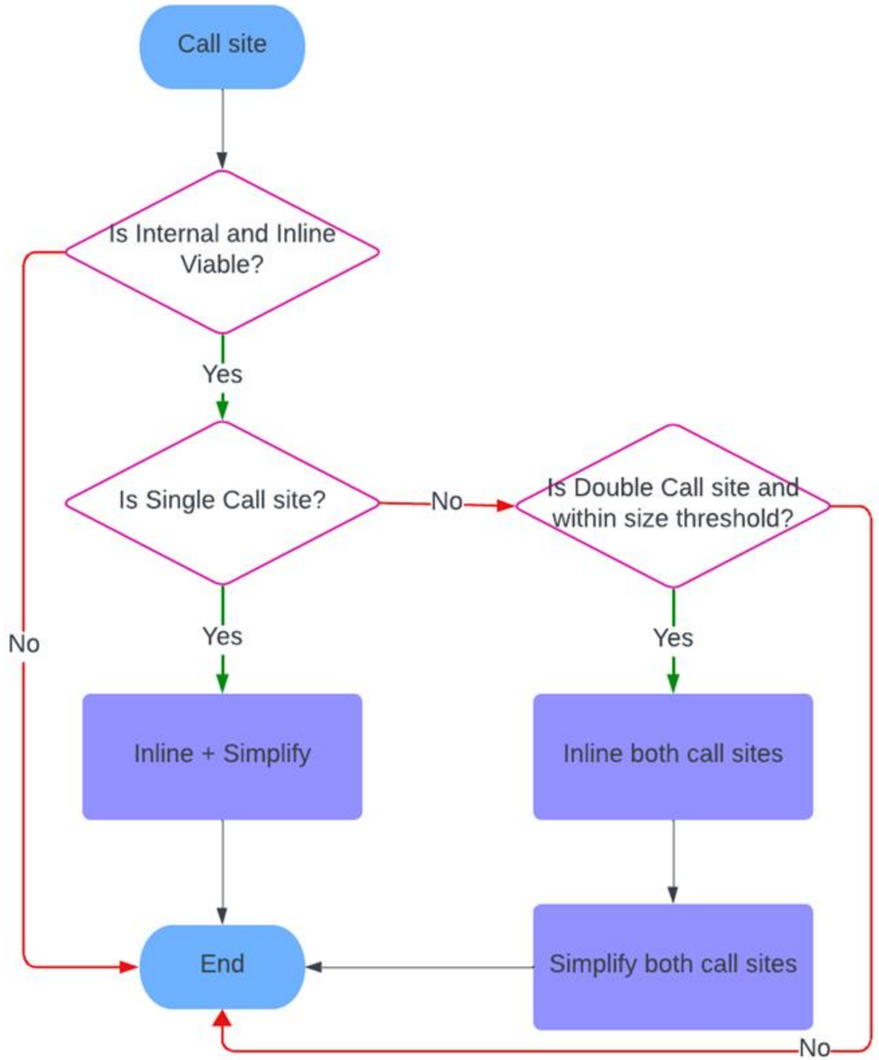
Internal Simplification Inliner

- Inliner pass that optimistically inlines and simplifies internal linkage functions based on the number of uses from a given call site
  - Similar to the speculative inliner - all inline viable call sites and ignores LLVM's standard inline thresholds



- No rollback mechanism
- Pass runs significantly faster!

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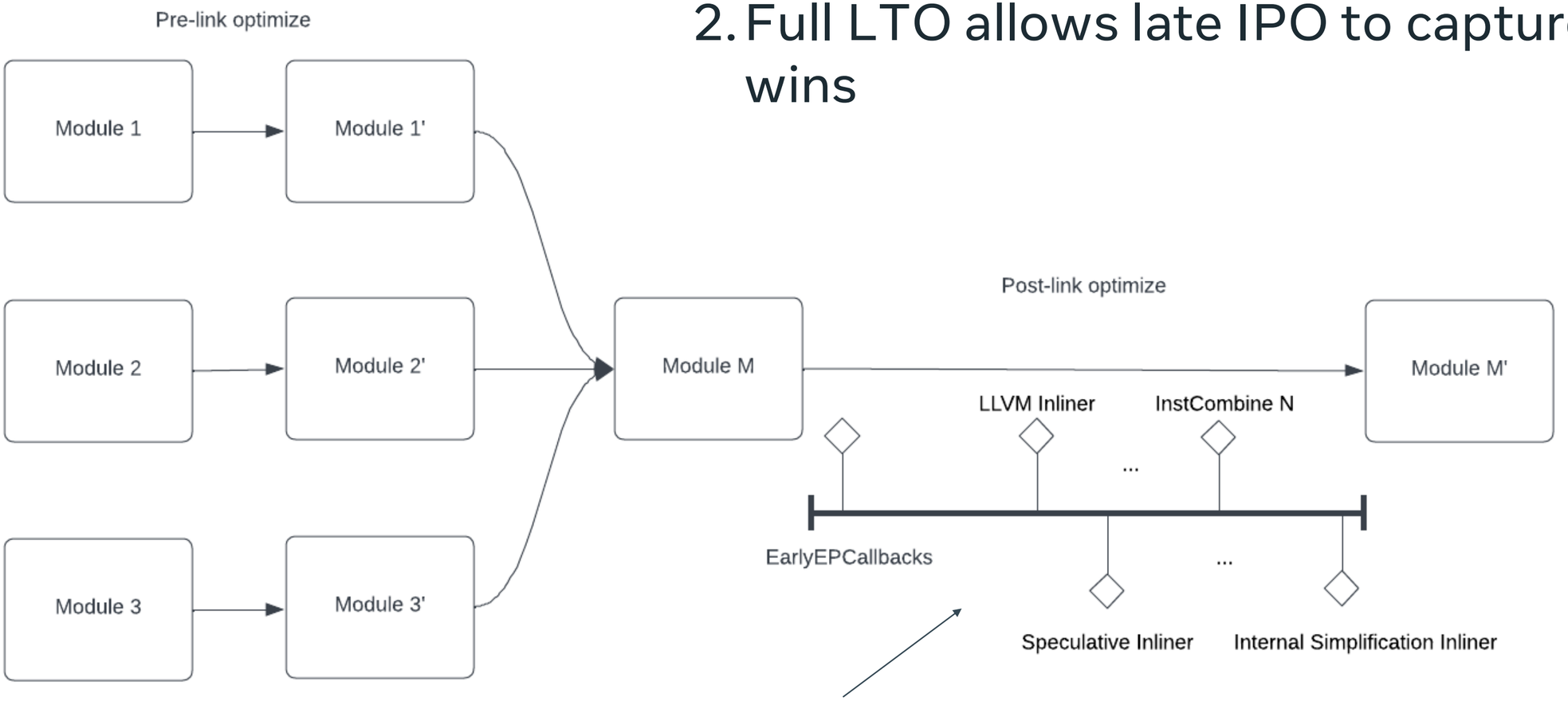
FullLTO

1. Inlining compounds with other passes
2. Full LTO allows late IPO to capture more wins



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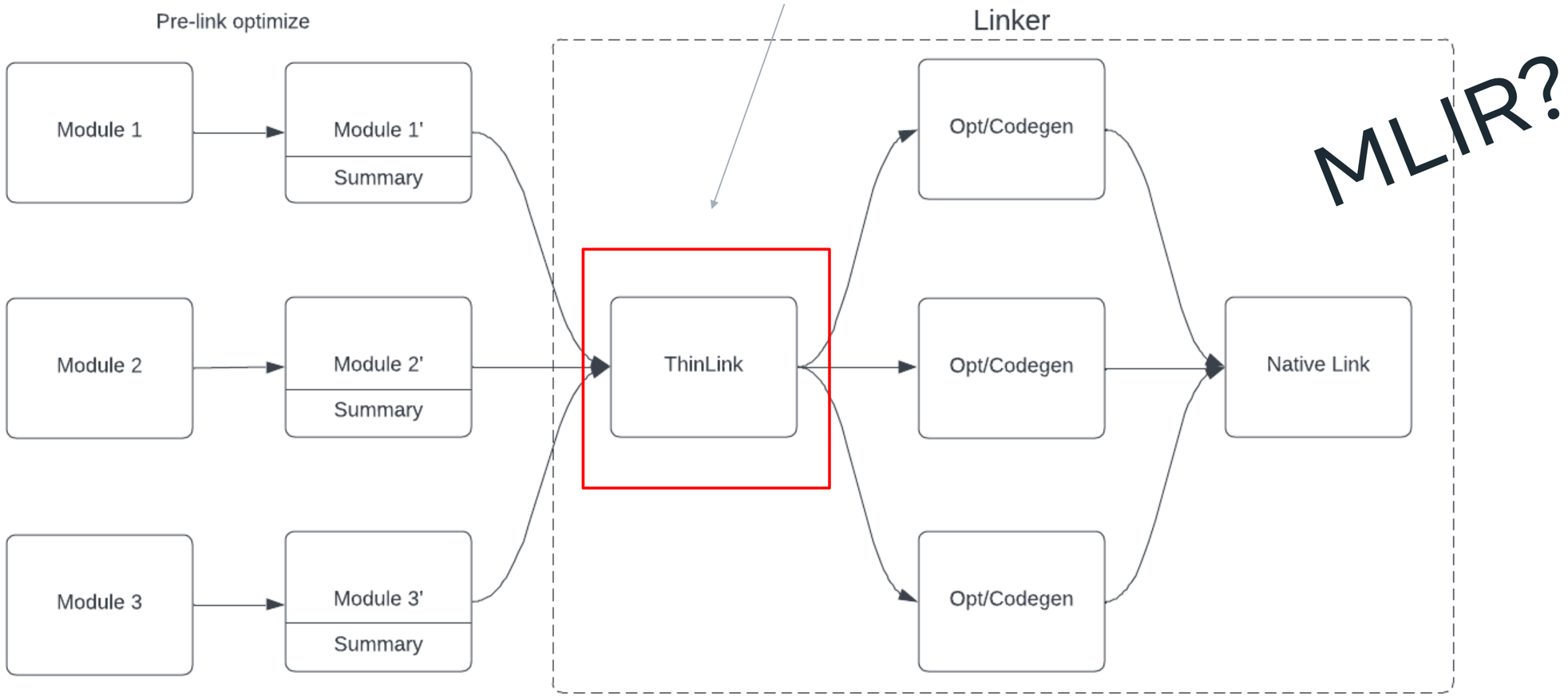
ThinLTO

Cross module import happens in the beginning



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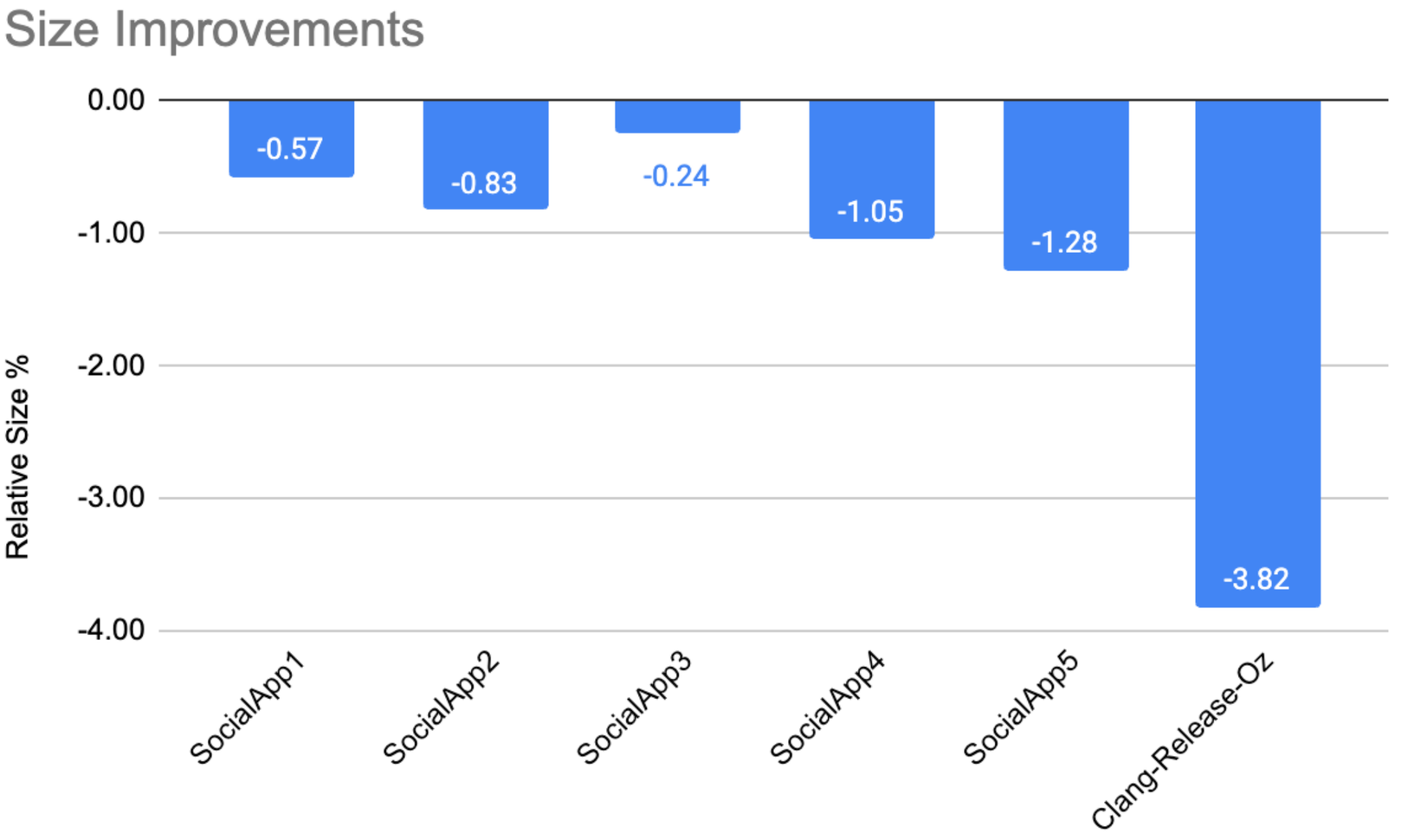
Size Improvements
0.00
-1.00
-2.00
-3.00
-4.00
Relative Size %
-0.57
-0.83
-0.24
-1.05
-1.28
-3.82
SocialApp1
SocialApp2
SocialApp3
SocialApp4
SocialApp5
Clang-Release-Oz

Meta

Conclusions

- Current LLVM paradigm has limitations in modeling the benefits of downstream simplifications for size
- Speculative inlining addresses this limitation, which can provide up to ~4% in code size reduction*
  - Size tradeoff with build time costs solved by replaying
- More wins to be captured when running IPO at different points of the pass pipeline
  - Experiments show running it early results in size regression, and running it late is more profitable


Meta