#WWDC19

What's New in Clang and LLVM

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Agenda

Agenda

New platform support

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New platform support

Low-level code size optimizations

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Language-level code size optimizations

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Diagnostics

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Static Analyzer checks

New Platform Support


14:59
11:15AM TRAINING WITH KRISTA
52
68°
89
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UVI
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1:09PM, +3HRS
NYC


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Mon
3

Bitcode

What is LLVM Bitcode?

Source Code

doggo.c

snek.m

birb.swift

pupper.cc

What is LLVM Bitcode?

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What is LLVM Bitcode?

Source Code

Compiler

doggo.c

snek.m

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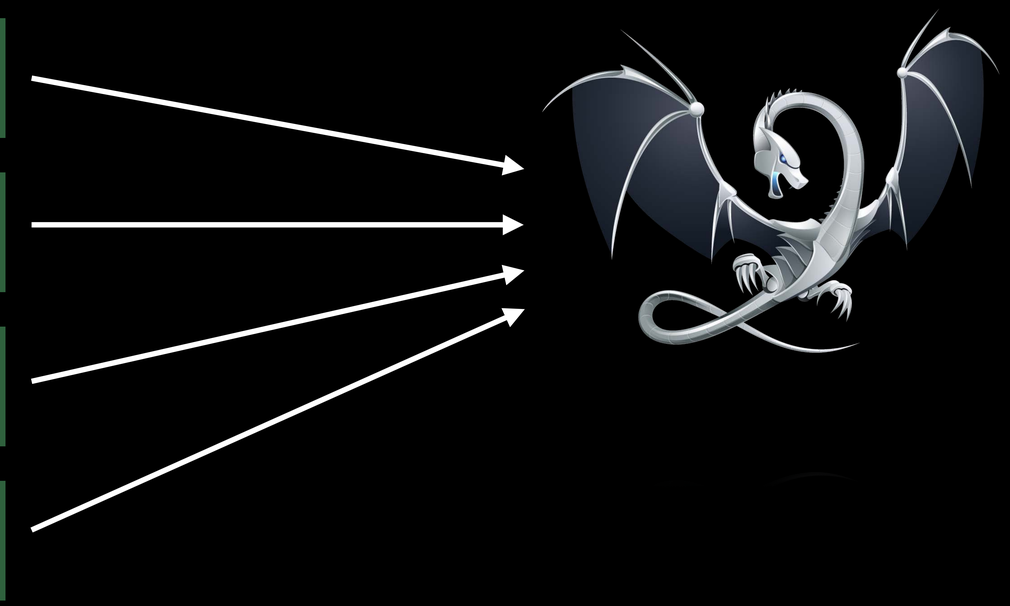
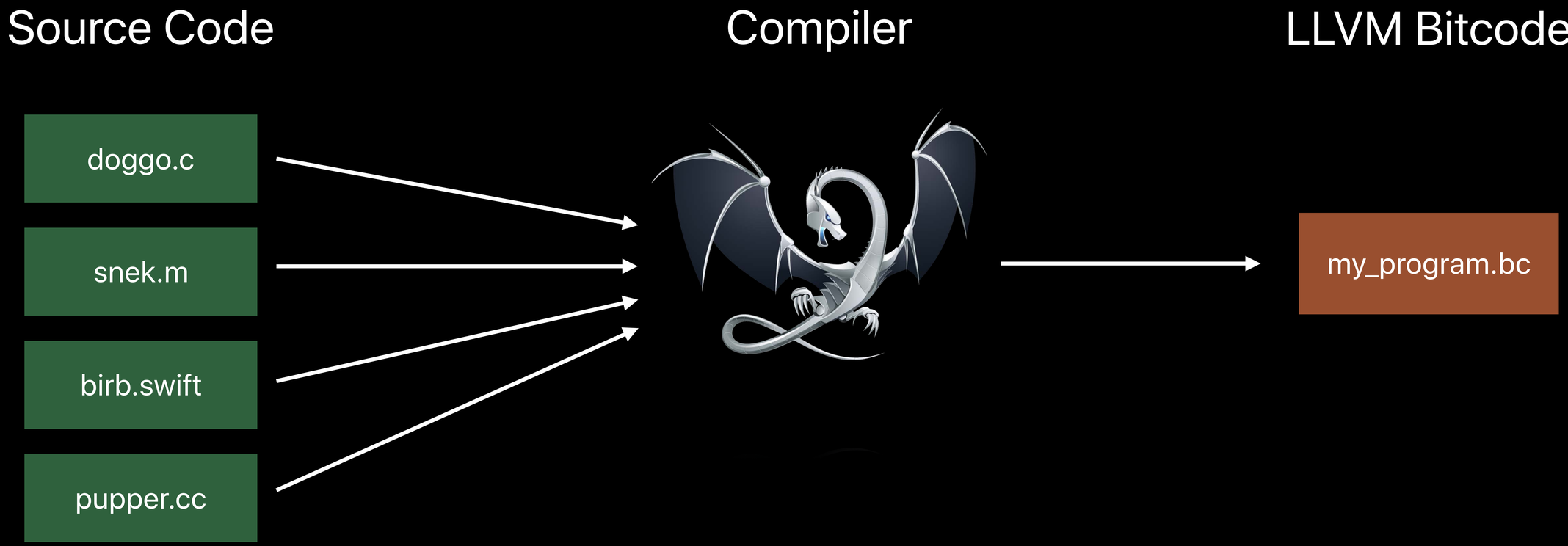
pupper.cc

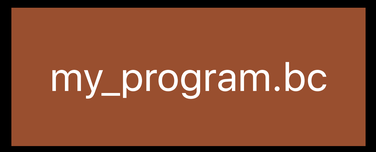


What is LLVM Bitcode?



What is LLVM Bitcode?

LLVM Bitcode



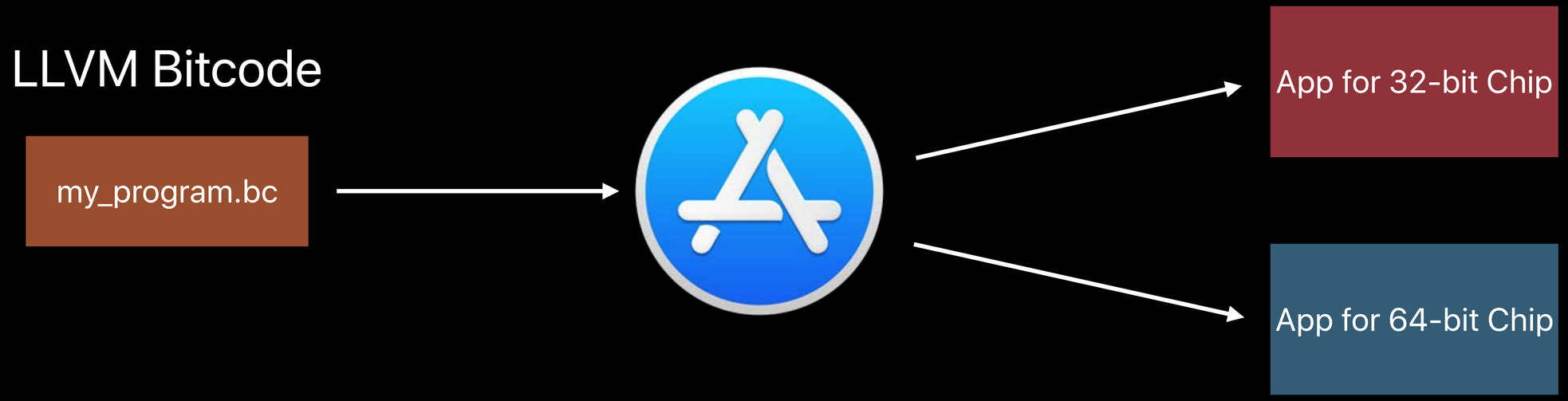
Serialization of internal compiler state

Producing Apps for Two Chips with Bitcode

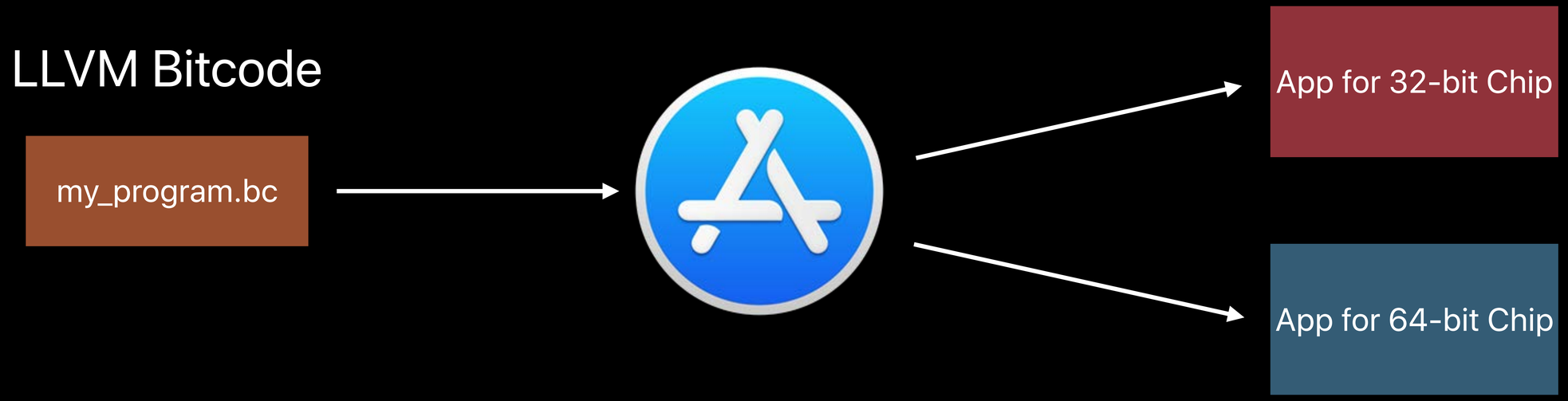
LLVM Bitcode

my_program.bc

Producing Apps for Two Chips with Bitcode



Producing Apps for Two Chips with Bitcode



Target-Tailored Bitcode = More Optimization

Bitcode for 32-bit Chip

Bitcode for 64-bit Chip

Code Size Improvements

Low-level code size optimizations

Why code size?

NEW

-Oz

-Oz

Jessica is Canadian, so she says “zed”

How does a compiler work?

```cpp
int collatz(int Num) {
    if (Num % 2 == 0)
        return Num / 2;
    return Num * 3 + 1;
}
```

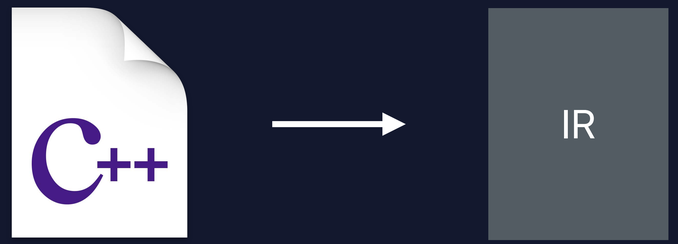
```
define i32 @collatz(i32) {
    if (Num % 2 == 0)
        return Num / 2;
    return Num * 3 + 1;
}
```

```
define i32 @collatz(i32) {
    %2 = and i32 %0, 1
    if (Num % 2 == 0)
        return Num / 2;
    return Num * 3 + 1;
}
```

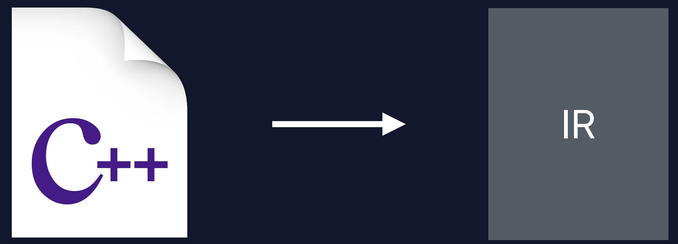
```
define i32 @collatz(i32) {
    %2 = and i32 %0, 1
    %3 = icmp eq i32 %2, 0
    %4 = sdiv i32 %0, 2
    return Num * 3 + 1;
}
```

```
define i32 @collatz(i32) {
    %2 = and i32 %0, 1
    %3 = icmp eq i32 %2, 0
    %4 = sdiv i32 %0, 2
    %5 = mul nsw i32 %0, 3
    %6 = add nsw i32 %5, 1
    %7 = select i1 %3, i32 %4, i32 %6
    ret i32 %7
}
```

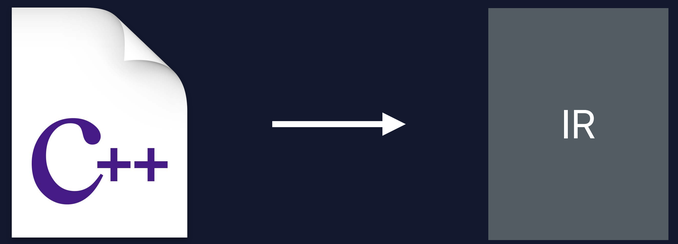
```
define i32 @collatz(i32) {
    %2 = and i32 %0, 1
    %3 = icmp eq i32 %2, 0
    %4 = sdiv i32 %0, 2
    %5 = mul nsw i32 %0, 3
    %6 = add nsw i32 %5, 1
    %7 = select i1 %3, i32 %4, i32 %6
    ret i32 %7
}
```



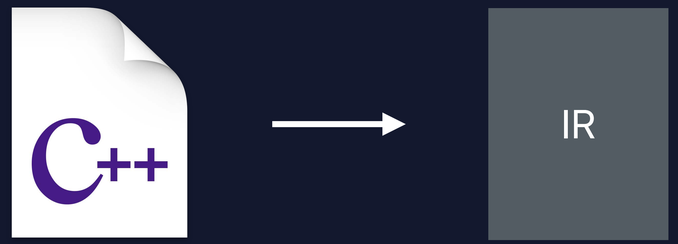
```
name:            collatz
body:             |
  bb.0:
    %2 = and i32 %0, 1
    %3 = icmp eq i32 %2, 0
    %4 = sdiv i32 %0, 2
    %5 = mul nsw i32 %0, 3
    %6 = add nsw i32 %5, 1
    %7 = select i1 %3, i32 %4, i32 %6
    ret i32 %7
}
```



```
name:            collatz
body:             |
  bb.0:
    %0:gpr32 = COPY $w0
    %3 = icmp eq i32 %2, 0
    %4 = sdiv i32 %0, 2
    %5 = mul nsw i32 %0, 3
    %6 = add nsw i32 %5, 1
    %7 = select i1 %3, i32 %4, i32 %6
    ret i32 %7
}
```



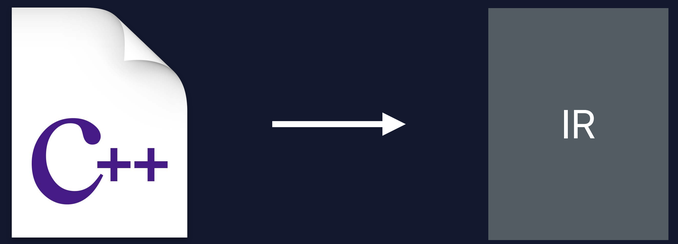
```
name:            collatz
body:             |
  bb.0:
    %0:gpr32 = COPY $w0
    %5:gpr32 = MOVi32imm 2
    %6:gpr32 = SDIVWr %0, %5
    %5 = mul nsw i32 %0, 3
    %6 = add nsw i32 %5, 1
    %7 = select i1 %3, i32 %4, i32 %6
    ret i32 %7
}
```



```
name:            collatz
body:             |
  bb.0:
    %0:gpr32 = COPY $w0
    %5:gpr32 = MOVi32imm 2
    %6:gpr32 = SDIVWr %0, %5
    %7:gpr32 = MOVi32imm 3
    %8:gpr32common = MADDWrrr %0, %7, $wzr
    %7 = select i1 %3, i32 %4, i32 %6
    ret i32 %7
}
```

```
name:            collatz
body:             |
  bb.0:
    %0:gpr32 = COPY $w0
    %5:gpr32 = MOVi32imm 2
    %6:gpr32 = SDIVWr %0, %5
    %7:gpr32 = MOVi32imm 3
    %8:gpr32common = MADDWrrr %0, %7, $wzr
    %10:gpr32 = CSELWr %6, %9, 1, implicit $nzcv
    ret i32 %7
}
```

```
name:            collatz
body:             |
  bb.0:
    %0:gpr32 = COPY $w0
    %5:gpr32 = MOVi32imm 2
    %6:gpr32 = SDIVWr %0, %5
    %7:gpr32 = MOVi32imm 3
    %8:gpr32common = MADDWrrr %0, %7, $wzr
    %10:gpr32 = CSELWr %6, %9, 1, implicit $nzcv
    RET_ReallyLR implicit $w0
```



```
name:            collatz
body:             |
  bb.0:
    %0:gpr32 = COPY $w0
    %5:gpr32 = MOVi32imm 2
    %6:gpr32 = SDIVWr %0, %5
    %7:gpr32 = MOVi32imm 3
    %8:gpr32common = MADDWrrr %0, %7, $wzr
    %10:gpr32 = CSELWr %6, %9, 1, implicit $nzcv
    RET_ReallyLR implicit $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVi32imm 2
    %6:gpr32 = SDIVWr %0, %5
    %7:gpr32 = MOVi32imm 3
    %8:gpr32common = MADDWrrr %0, %7, $wzr
    %10:gpr32 = CSELWr %6, %9, 1, implicit $nzcv
    RET_ReallyLR implicit $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVi32imm 2
    $w9 = MOVi32imm 3
    %6:gpr32 = SDIVWr %0, %5
    %8:gpr32common = MADDWrrr %0, %7, $wzr
    %10:gpr32 = CSELWr %6, %9, 1, implicit $nzcv
    RET_ReallyLR implicit $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVi32imm 2
    $w9 = MOVi32imm 3
    $w8 = SDIVWr $w0, $w8
    %8:gpr32common = MADDWrrr %0, %7, $wzr
    %10:gpr32 = CSELWr %6, %9, 1, implicit $nzcv
    RET_ReallyLR implicit $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVi32imm 2
    $w9 = MOVi32imm 3
    $w8 = SDIVWr $w0, $w8
    $w9 = MADDWrrr $w0, $w9, $wzr
    %10:gpr32 = CSELWr %6, %9, 1, implicit $nzcv
    RET_ReallyLR implicit $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVi32imm 2
    $w9 = MOVi32imm 3
    $w8 = SDIVWr $w0, $w8
    $w9 = MADDWrrr $w0, $w9, $wzr
    $w9 = ADDWri $w9, 1, 0
    $w0 = CSELWr $w8, $w9, 1, $nzcv
    RET_ReallyLR implicit $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVi32imm 2
    $w9 = MOVi32imm 3
    $w8 = SDIVWr $w0, $w8
    $w9 = MADDWrrr $w0, $w9, $wzr
    $w9 = ADDWri $w9, 1, 0
    $w0 = CSELWr $w8, $w9, 1, $nzcv
    RET_ReallyLR $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVZWi 2, 0
    $w9 = MOVi32imm 3
    $w8 = SDIVWr $w0, $w8
    $w9 = MADDWrrr $w0, $w9, $wzr
    $w9 = ADDWri $w9, 1, 0
    $w0 = CSELWr $w8, $w9, 1, $nzcv
    RET_ReallyLR $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVZWi 2, 0
    $w9 = MOVZWi 3, 0
    $w8 = SDIVWr $w0, $w8
    $w9 = MADDWrrr $w0, $w9, $wzr
    $w9 = ADDWri $w9, 1, 0
    $w0 = CSELWr $w8, $w9, 1, $nzcv
    RET_ReallyLR $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVZWi 2, 0
    $w9 = MOVZWi 3, 0
    $w8 = SDIVWr $w0, $w8
    $w9 = MADDWrrr $w0, $w9, $wzr
    $w9 = ADDWri $w9, 1, 0
    $w0 = CSELWr $w8, $w9, 1, $nzcv
    RET $lr, $w0
```

```
name:            collatz
body:             |
  bb.0:
    $w8 = MOVZWi 2, 0
    $w9 = MOVZWi 3, 0
    $w8 = SDIVWr $w0, $w8
    $w9 = MADDWrrr $w0, $w9, $wzr
    $w9 = ADDWri $w9, 1, 0
    $w0 = CSELWr $w8, $w9, 1, $nzcv
    RET $lr, $w0
```

```
collatz:
    mov   w8, #2
    mov   w9, #3
    sdiv  w8, w0, w8
    mul   w9, w0, w9
    add   w9, w9, #1
    csel  w0, w8, w9, ne
    ret
```

Function Outlining

An -Oz code size optimization

```
// These two functions share some instructions

hasse:
  …
  ldr   w0, [sp, #16]
  mul   w0, w1, w2
  add   sp, sp, #16
  ret

kakutani:
  …
  ldr   w0, [sp, #16]
  mul   w0, w1, w2
  add   sp, sp, #16
  ret
```

```
// Create a new function using the shared instructions…

hasse:
  …
  ldr   w0, [sp, #16]
  mul   w0, w1, w2
  add   sp, sp, #16
  ret

kakutani:
  …
  ldr   w0, [sp, #16]
  mul   w0, w1, w2
  add   sp, sp, #16
  ret
```

```
OUTLINED_FUNCTION_0:
  ldr   w0, [sp, #16]
  mul   w0, w1, w2
  add   sp, sp, #16
  ret
```

```
// Replace the repeated sequences with calls to the new function

hasse:
  …
  b OUTLINED_FUNCTION_0

kakutani:
  …
  b OUTLINED_FUNCTION_0
```

```
OUTLINED_FUNCTION_0:
  ldr   w0, [sp, #16]
  mul   w0, w1, w2
  add   sp, sp, #16
  ret
```

25%

Where do the savings come from? 🤔

```
// What does the compiler have to do to represent this function in assembly?

int ulam(int Num, int NumIters) {
    // TODO: Does this always converge?
    while (Num != 1) {
        Num = collatz(Num);
        ++NumIters;
    }
    return NumIters;
}
```

```
// What does the compiler have to do to represent this function in assembly?

int ulam(int Num, int NumIters) {
    // TODO: Does this always converge?
    while (Num != 1) {
        Num = collatz(Num);
        ++NumIters;
    }
    return NumIters;
}
```

```
ulam:
        stp     x20, x19, [sp, #-32]!
        stp     x29, x30, [sp, #16]
        add     x29, sp, #16
        b       LBB1_2
LBB1_1:
        bl      collatz
        add     w19, w19, #1
LBB1_2:
        cmp     w0, #1
        b.ne    LBB1_1
        mov     x0, x19
        ldp     x29, x30, [sp, #16]
        ldp     x20, x19, [sp], #32
        ret
```

```
// What does the compiler have to do to represent this function in assembly?
```

Prologue

Epilogue

```
ulam:
    stp     x20, x19, [sp, #-32]!
    stp     x29, x30, [sp, #16]
    add     x29, sp, #16
    b       LBB1_2
LBB1_1:
    bl      collatz
    add     w19, w19, #1
LBB1_2:
    cmp     w0, #1
    b.ne    LBB1_1
    mov     x0, x19
    ldp     x29, x30, [sp, #16]
    ldp     x20, x19, [sp], #32
    ret
```

```
// Compiler introduces similarity into code
```

```
collatz:
    stp     x20, x19, [sp, #-32]!
    stp     x29, x30, [sp, #16]
    …
    ldp     x29, x30, [sp, #16]
    ldp     x20, x19, [sp], #32
    ret

kakutani:
    stp     x20, x19, [sp, #-32]!
    stp     x29, x30, [sp, #16]
    …
    ldp     x29, x30, [sp, #16]
    ldp     x20, x19, [sp], #32
    ret
```

```
ulam:
    stp     x20, x19, [sp, #-32]!
    stp     x29, x30, [sp, #16]
    add     x29, sp, #16
    b       LBB1_2
LBB1_1:
    bl      collatz
    add     w19, w19, #1
LBB1_2:
    cmp     w0, #1
    b.ne    LBB1_1
    mov     x0, x19
    ldp     x29, x30, [sp, #16]
    ldp     x20, x19, [sp], #32
    ret
```

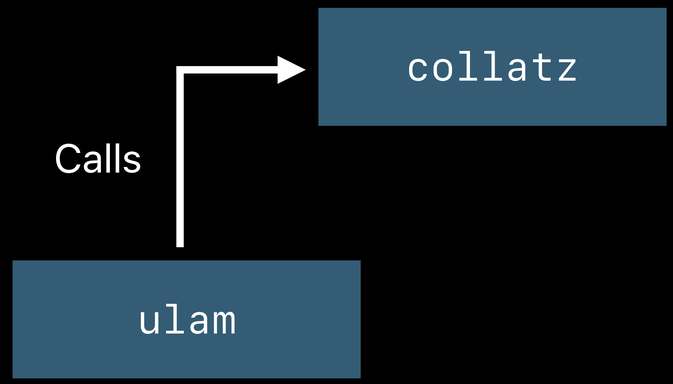
```
// Compiler introduces similarity into code

collatz:
    stp     x20, x19, [sp, #-32]!
    stp     x29, x30, [sp, #16]
    …
    ldp     x29, x30, [sp, #16]
    ldp     x20, x19, [sp], #32
    ret

kakutani:
    stp     x20, x19, [sp, #-32]!
    stp     x29, x30, [sp, #16]
    …
    ldp     x29, x30, [sp, #16]
    ldp     x20, x19, [sp], #32
    ret
```

```
ulam:
    stp     x20, x19, [sp, #-32]!
    stp     x29, x30, [sp, #16]
    add     x29, sp, #16
    b       LBB1_2
LBB1_1:
    bl      collatz
    add     w19, w19, #1
LBB1_2:
    cmp     w0, #1
    b.ne    LBB1_1
    mov     x0, x19
    ldp     x29, x30, [sp, #16]
    ldp     x20, x19, [sp], #32
    ret
```

Gotchas

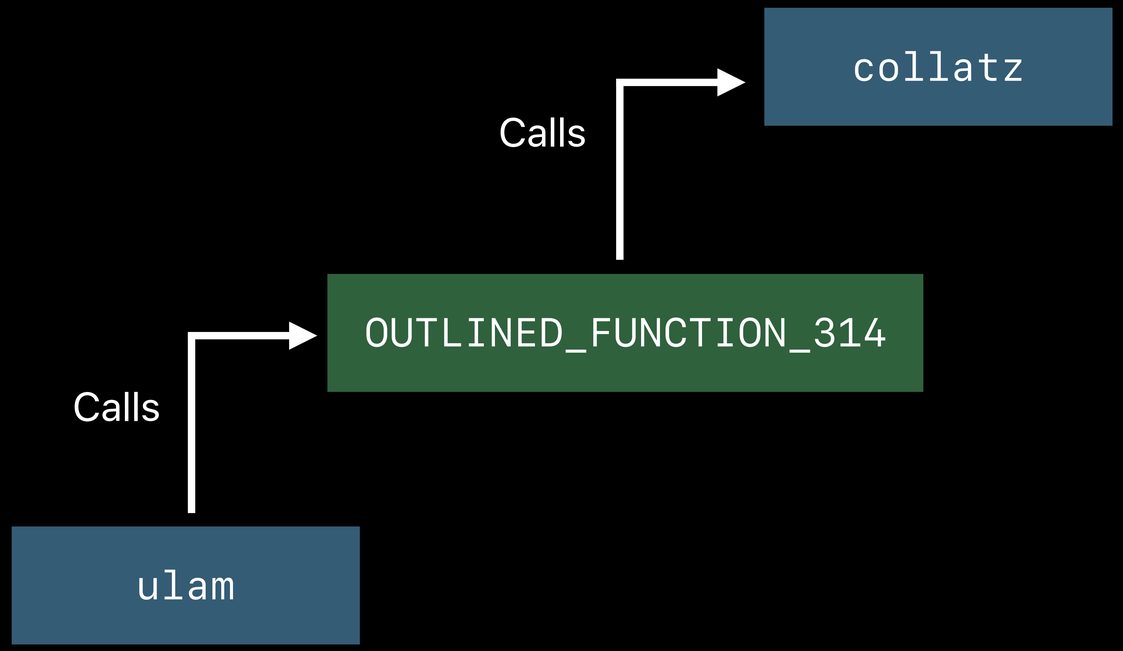
Outlining Changes Control Flow

```
ulam:
    …
    bl      collatz
    add     w19, w19, #1
    …
    ret
```



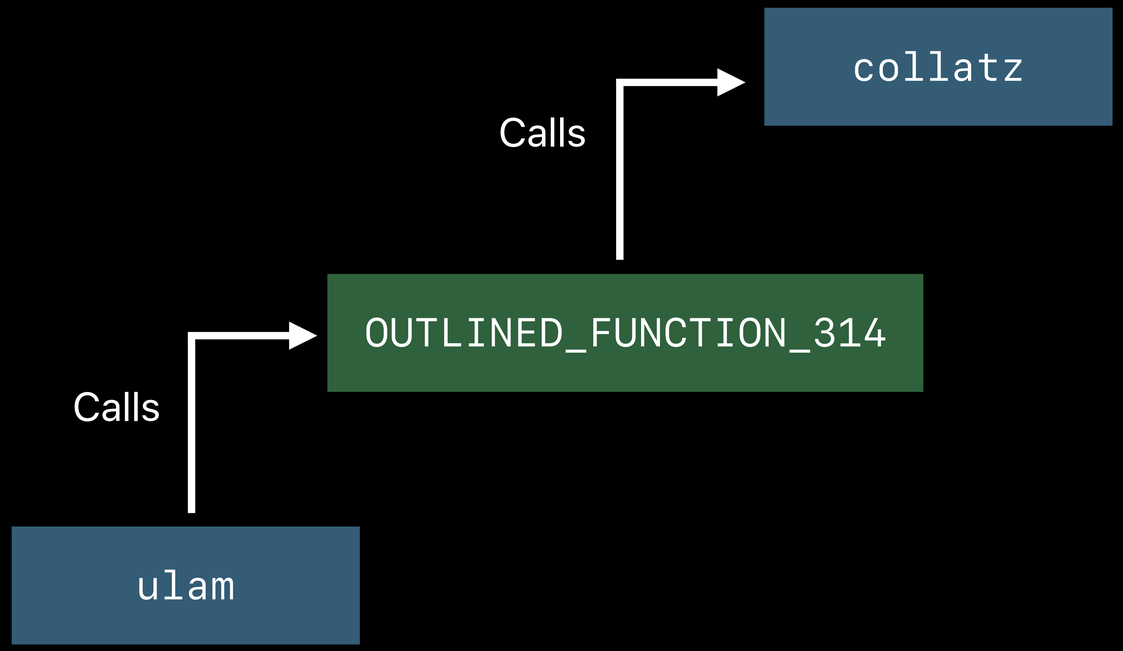
Outlining Changes Control Flow

```
ulam:
    …
    bl      OUTLINED_FUNCTION_314
    …
    ret
```

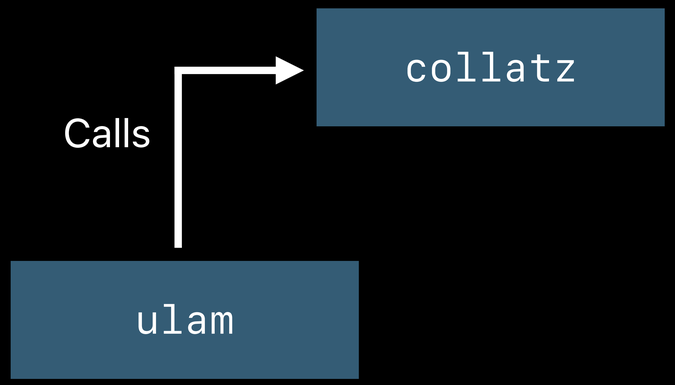


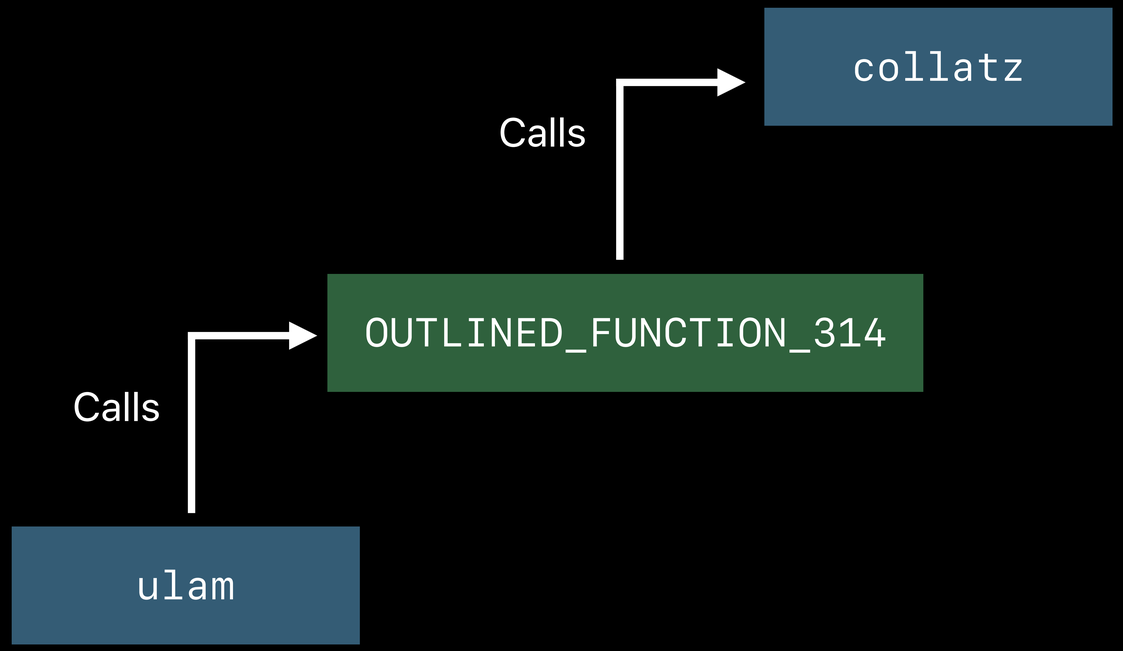
Outlining Changes Control Flow

```
ulam:
        …
        bl      OUTLINED_FUNCTION_314
        …
        ret
```

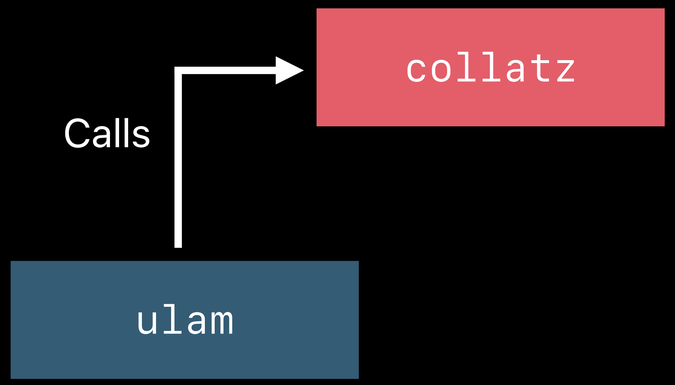


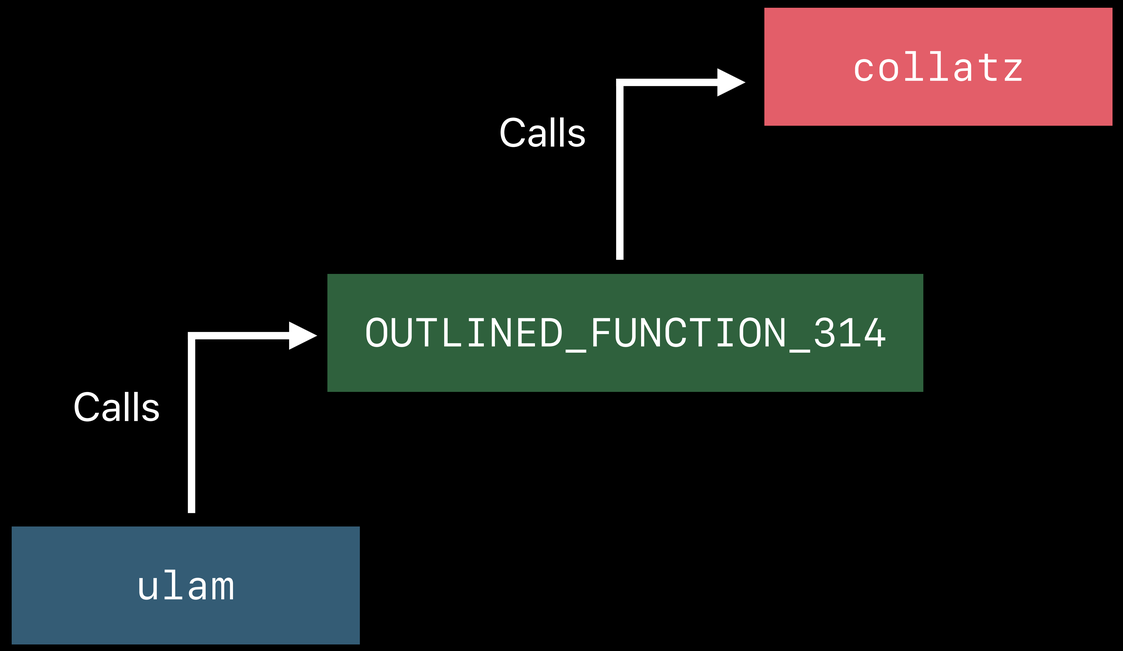
Crashing with Outlined Code





Crashing with Outlined Code





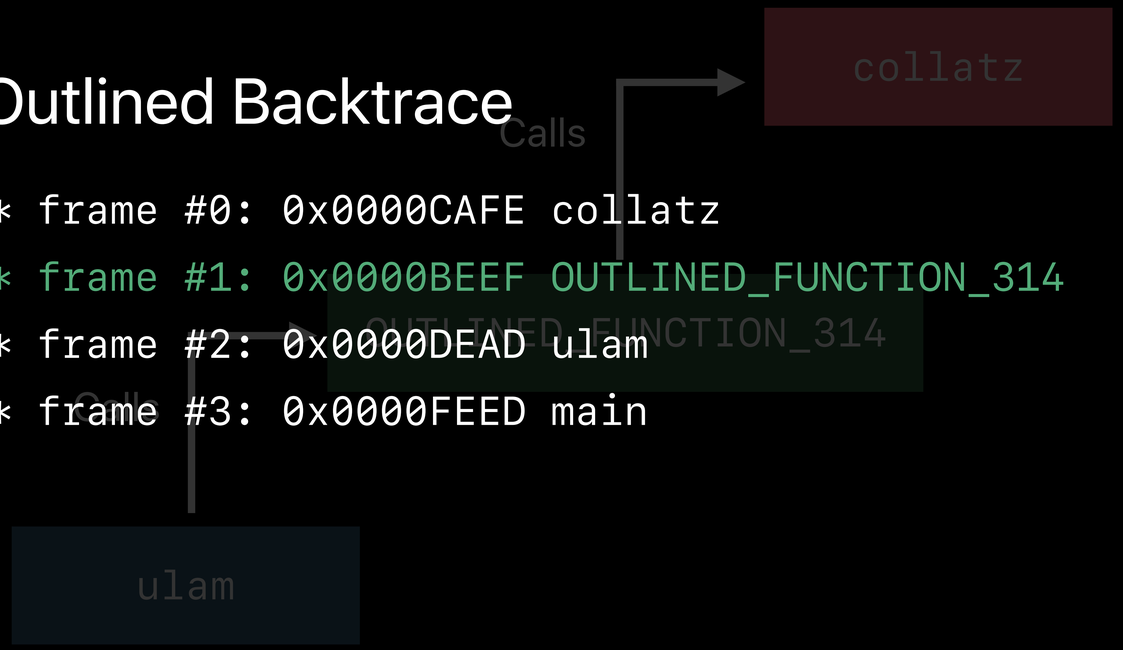
Outlining Can Impact Backtraces

Original Backtrace

```
* frame #0: 0x0000BEEF collatz
* frame #1: 0x0000DEAD ulam
* frame #2: 0x0000FEED main
```

Outlined Backtrace

```
* frame #0: 0x0000CAFE collatz
* frame #1: 0x0000BEEF OUTLINED_FUNCTION_314
* frame #2: 0x0000DEAD ulam
* frame #3: 0x0000FEED main
```



Outlining Can Increase Execution Time

Outlining Can Increase Execution Time

Calls can have execution time overhead

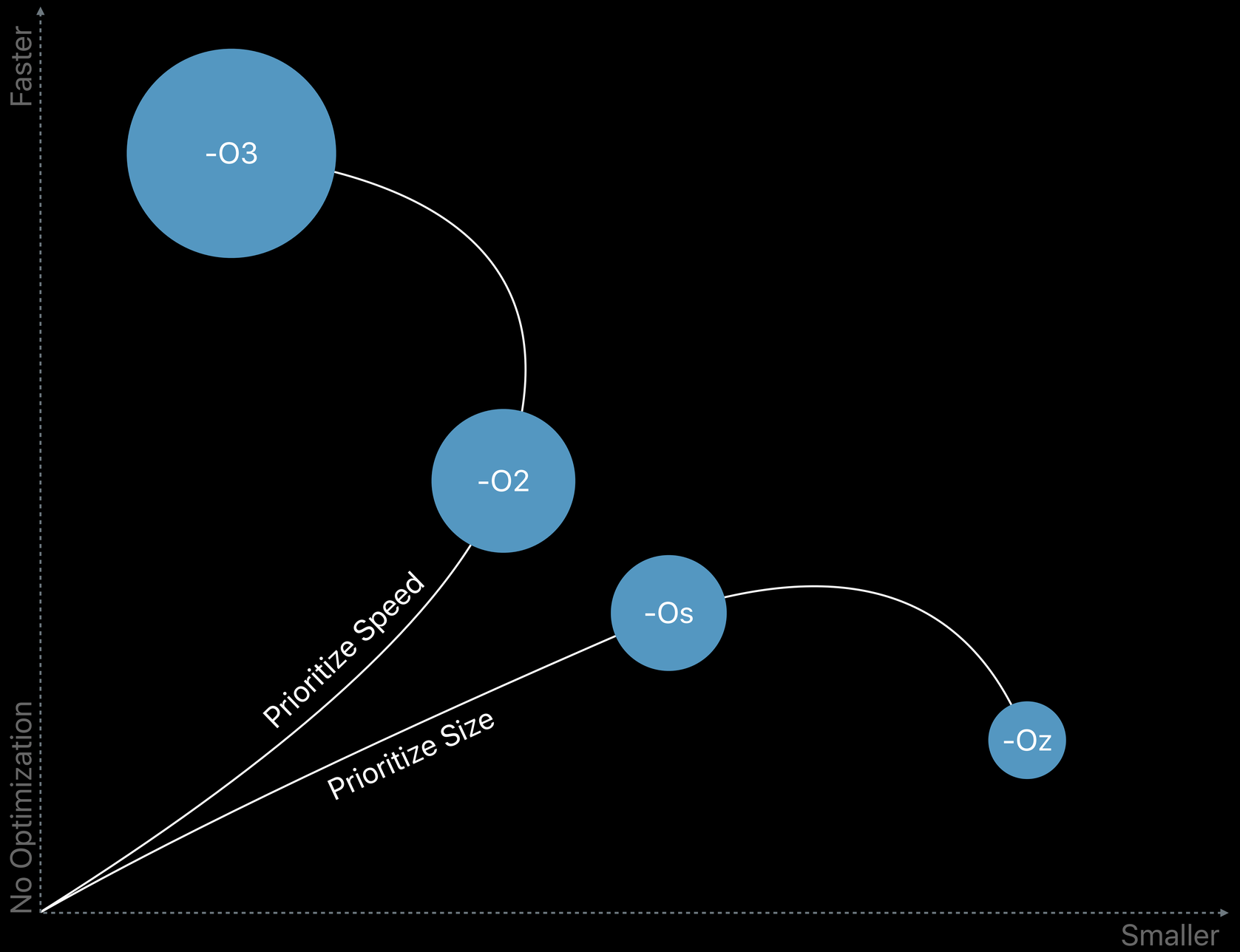
Outlining Can Increase Execution Time

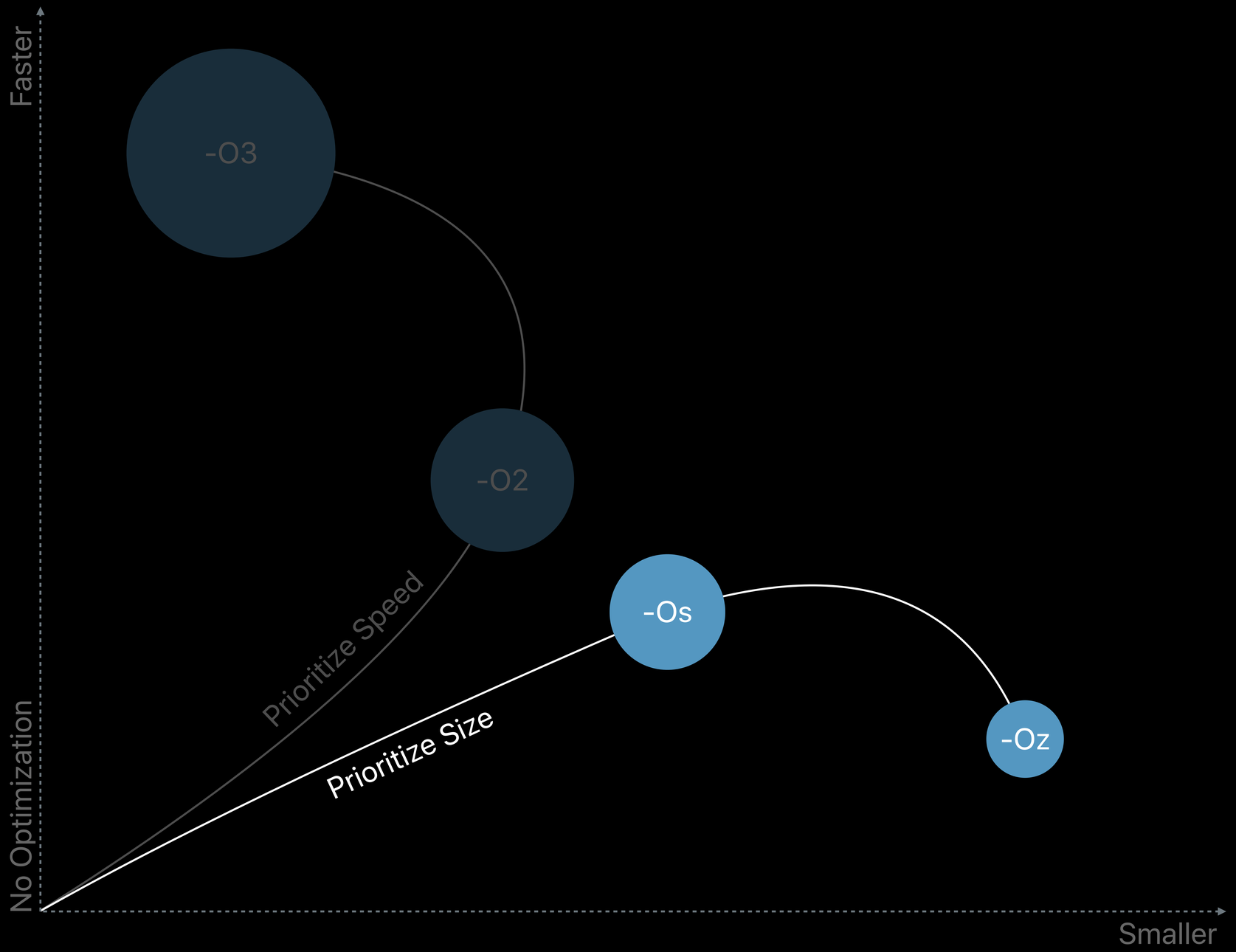
Calls can have execution time overhead

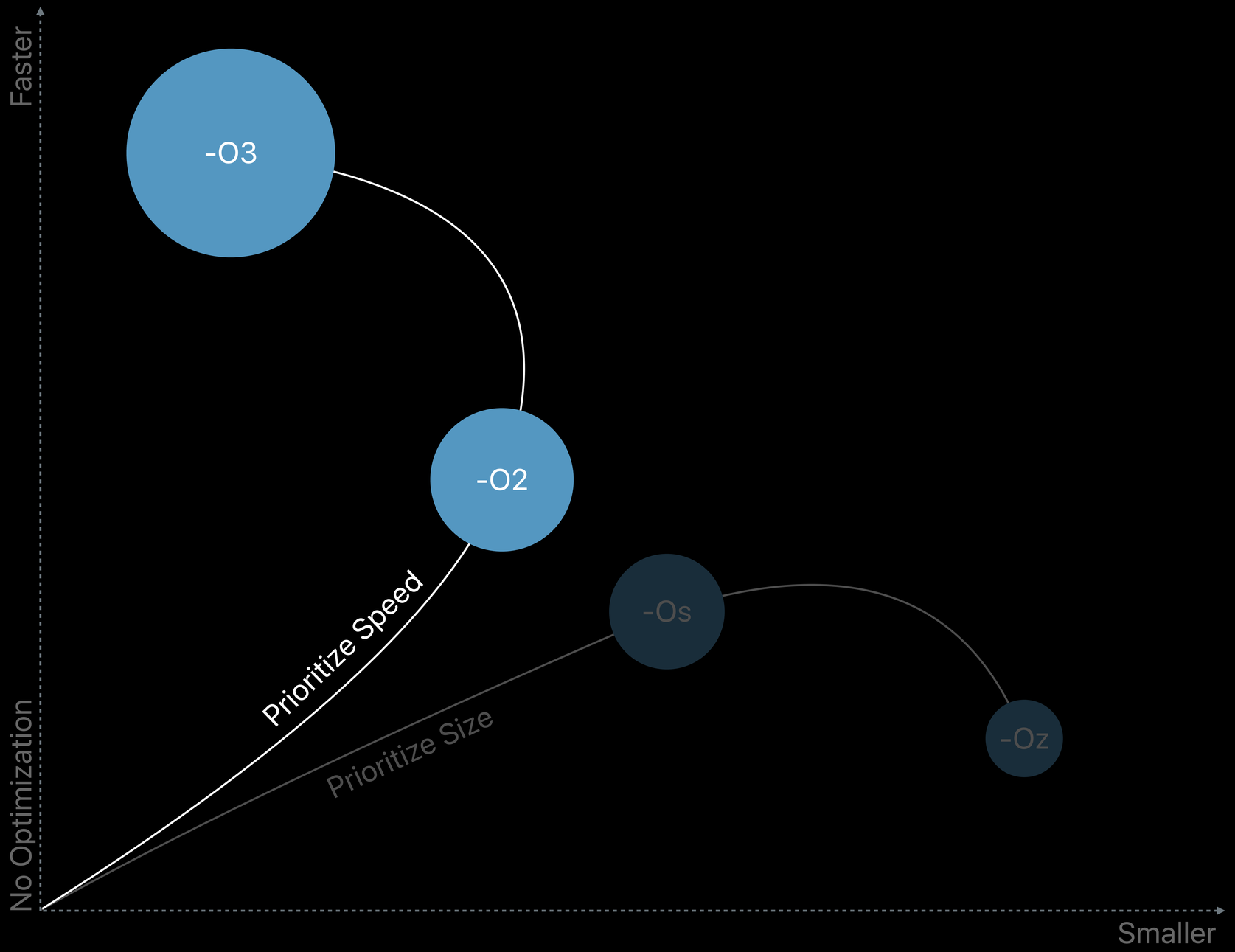
-Oz prioritizes size at all costs

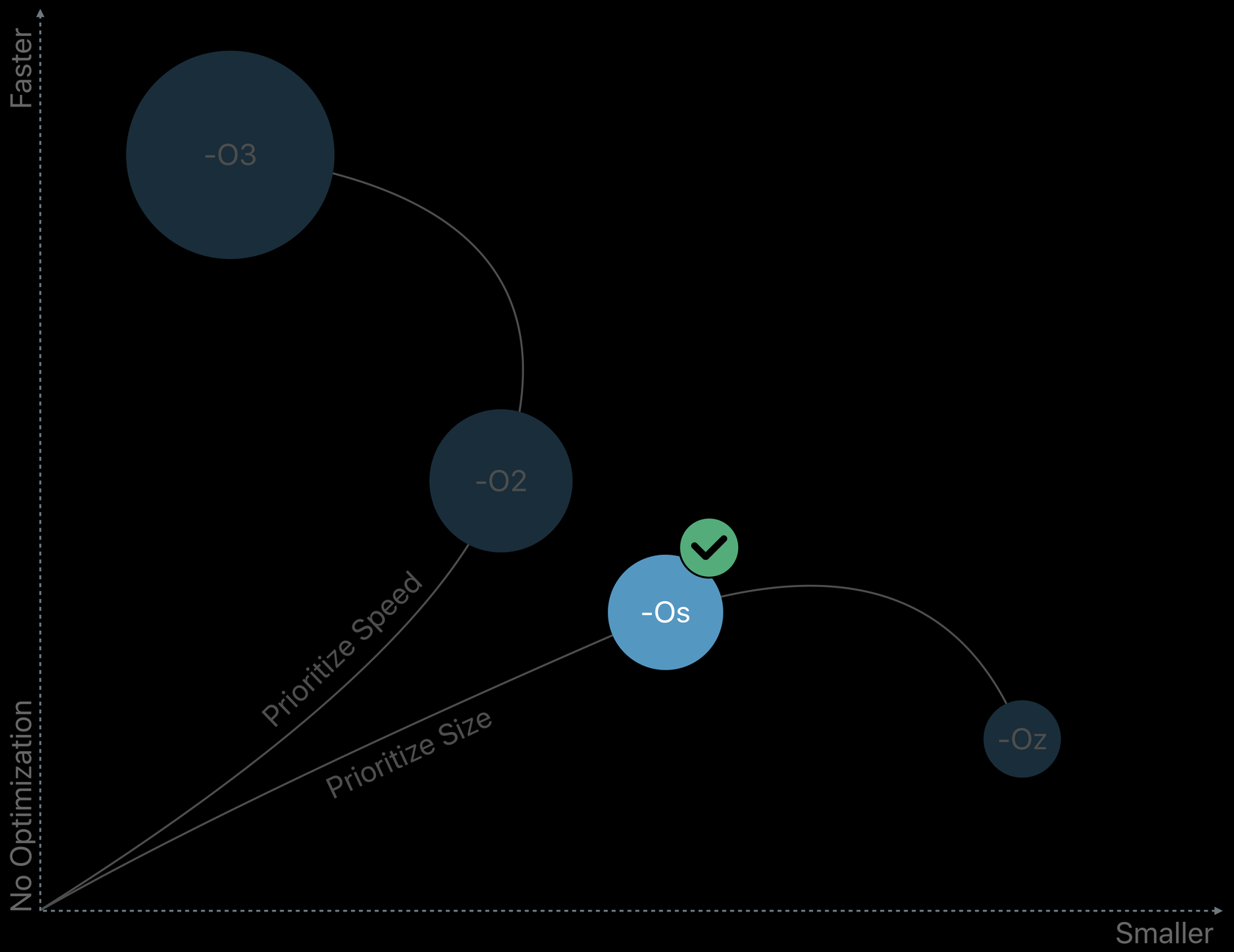
Don’t compile performance-sensitive code with -Oz!

Use Instruments!


Faster
-O3
-O2
-Os
-Oz
Prioritize Speed
Prioritize Size
No Optimization
Smaller


Faster
No Optimization
Smaller
-O3
-O2
-Os
-Oz
Prioritize Speed
Prioritize Size


Faster
-O3
-O2
Prioritize Speed
-Os
-Oz
Prioritize Size
No Optimization
Smaller


Faster
No Optimization
Smaller
-O3
-O2
-Os
-Oz
Prioritize Speed
Prioritize Size

Extra Optimizations

Extra Optimizations

PGO — Profile-guided optimization

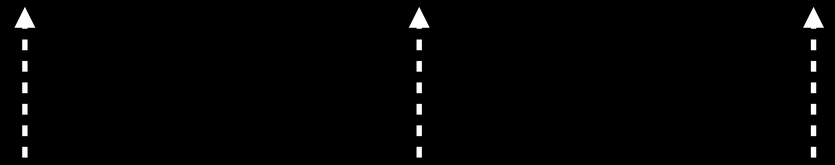
Extra Optimizations

PGO — Profile-guided optimization

LTO — Link-time optimization

Combining Optimizations

LTO + PGO + -O3



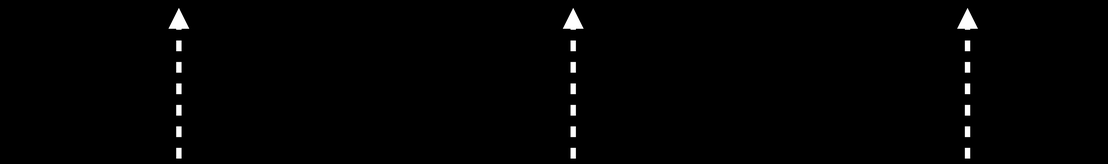
Wait until link-time to optimize

Use profiling information

Prioritize execution time

Combining Optimizations

LTO + PGO + -O3



Wait until link-time to optimize

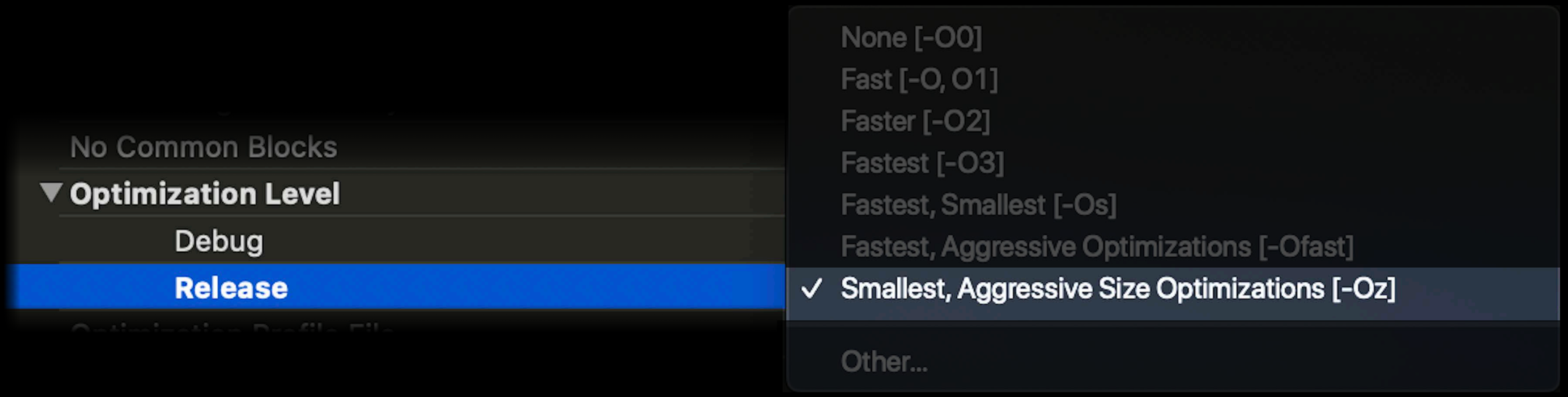
Use profiling information

Prioritize execution time

Enable -Oz in Your Project's Build Settings

C, C++, and Objective-C Projects

NEW



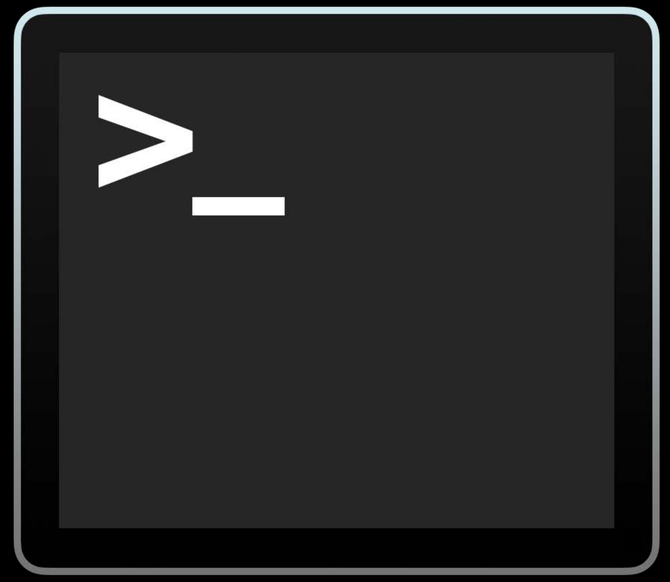
Enable -Oz on Specific Files

C, C++, and Objective-C Files

Build Phases > Compile Sources > Compiler Flags

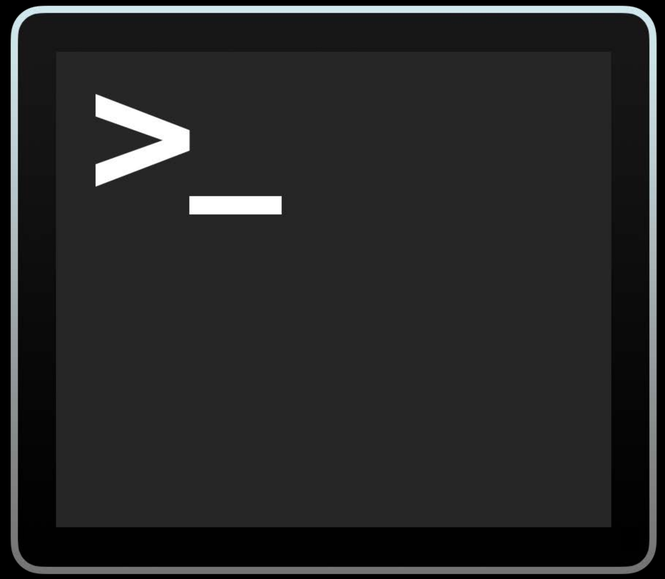
How does this impact app code size?

size



size

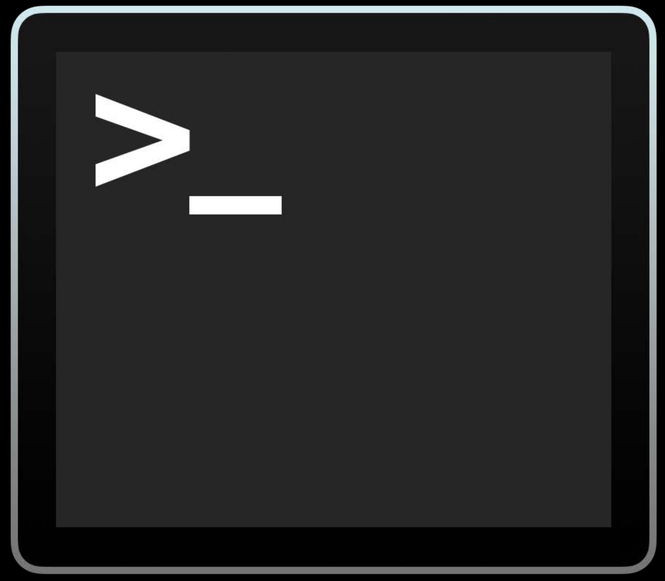
Executable binary code size information



`size`

Executable binary code size information

⚠️ Not the total size of the app



```
# Example: Finding Code Size Info Using size

$ size ~/Library/Developer/Xcode/…/Sniffo.app/Contents/MacOS/Sniffo
```

```
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$ size ~/Library/Developer/Xcode/…/Sniffo.app/Contents/MacOS/Sniffo
```
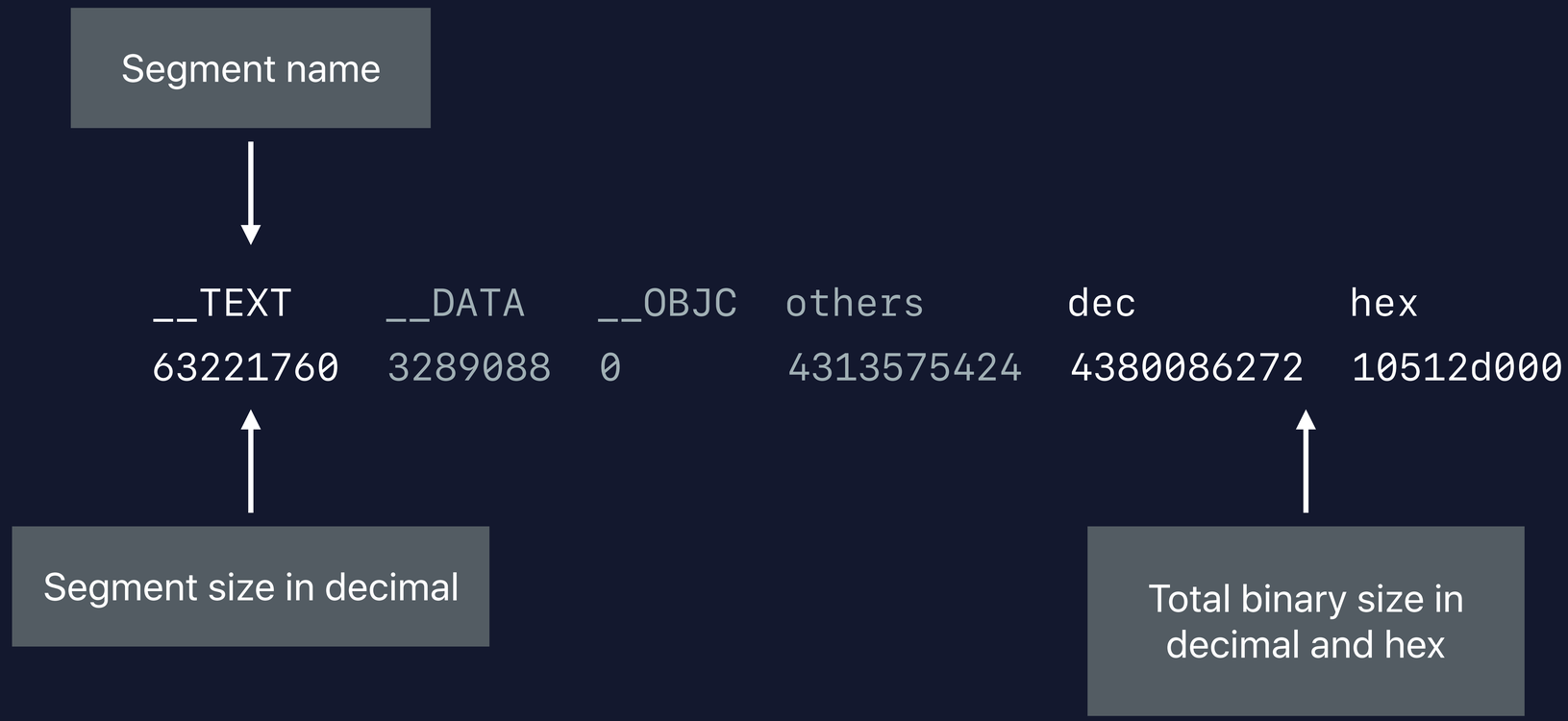
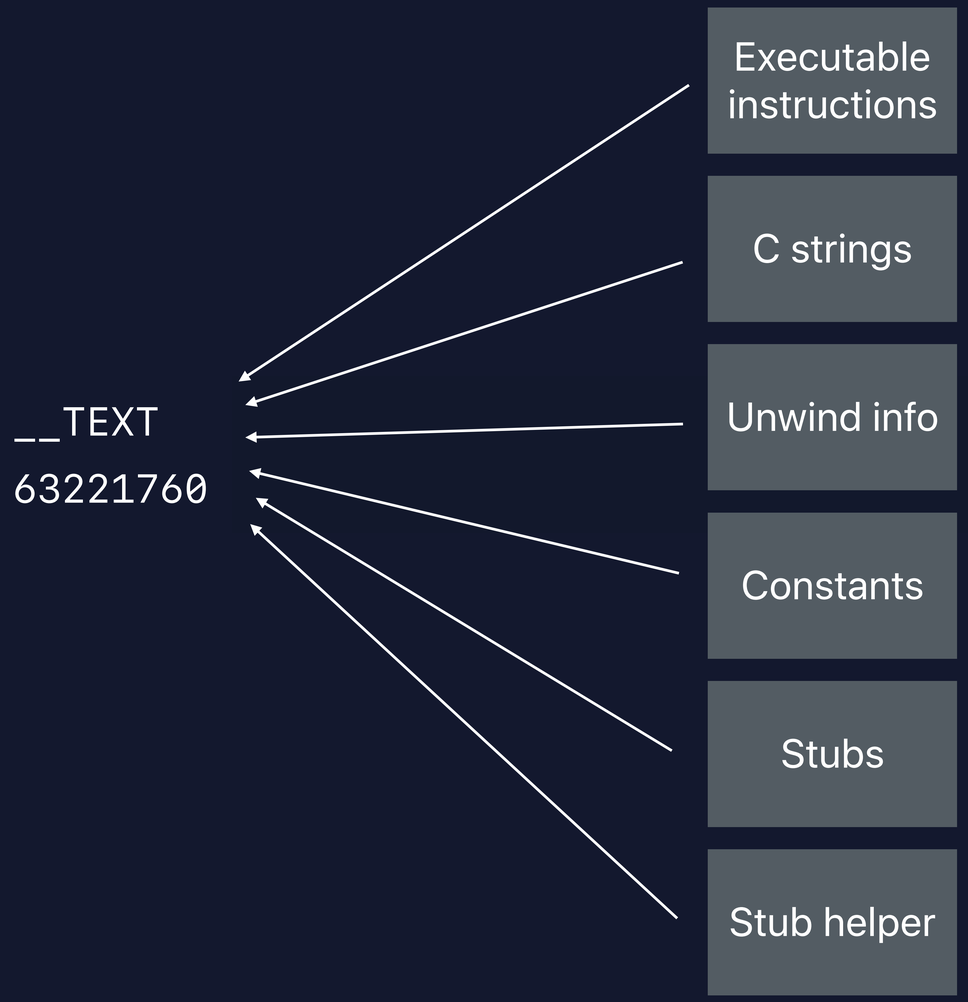



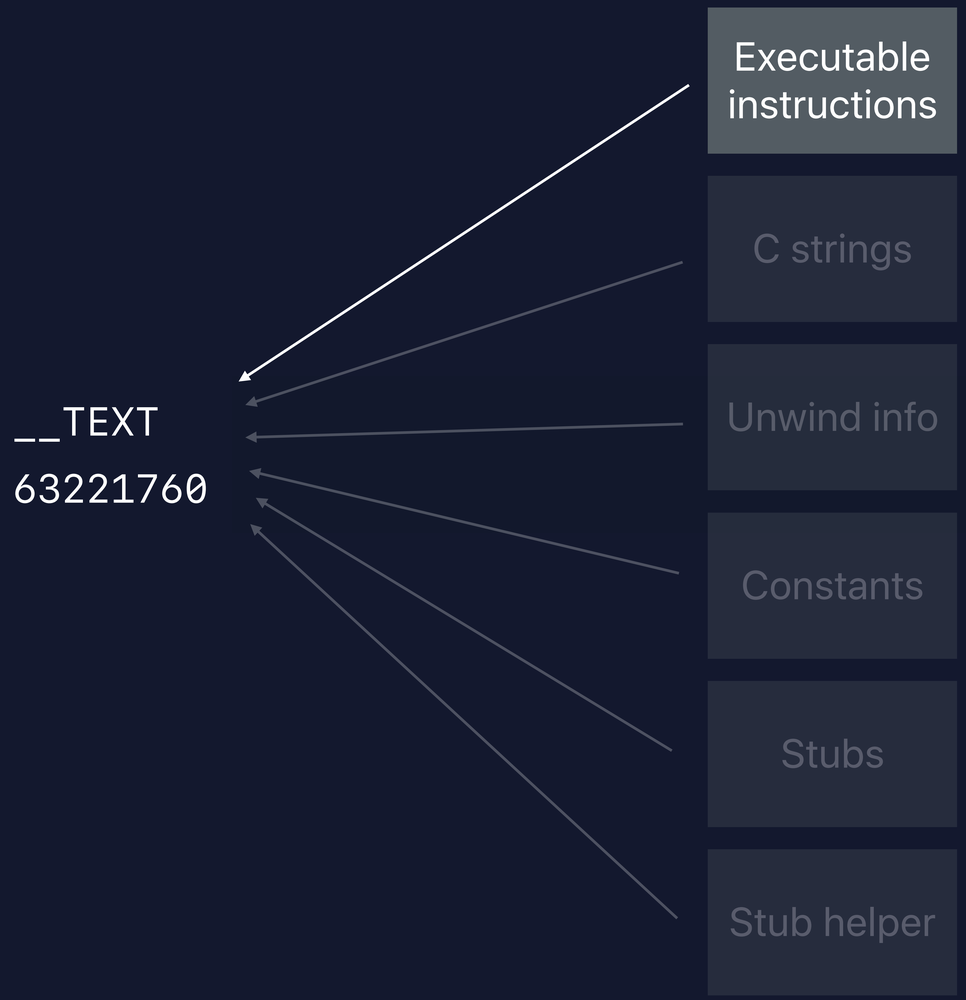
```
# Example: Finding Code Size Info Using size

$ size ~/Library/Developer/Xcode/…/Sniffo.app/Contents/MacOS/Sniffo
```

```
__TEXT
63221760
```

```
# Example: Finding Code Size Info Using size

$ size ~/Library/Developer/Xcode/…/Sniffo.app/Contents/MacOS/Sniffo
```

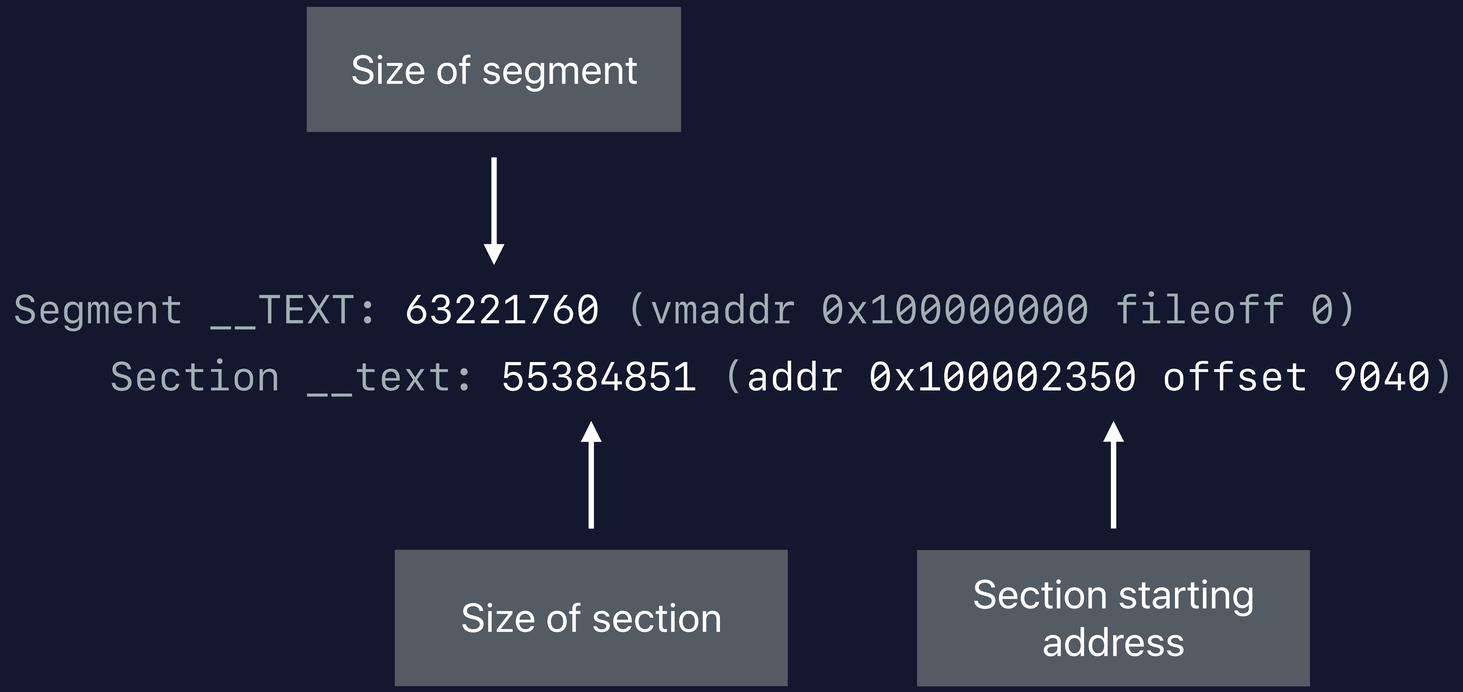


```
# Example: Finding Code Size Info Using size

$ size ~/Library/Developer/Xcode/…/Sniffo.app/Contents/MacOS/Sniffo
```



```
# Example: Detailed Code Size Info Using size

$ size -l -m ~/Library/Developer/Xcode/…/Sniffo.app/Contents/MacOS/Sniffo
```

```
# Example: Detailed Code Size Info Using size

$ size -l -m ~/Library/Developer/Xcode/…/Sniffo.app/Contents/MacOS/Sniffo
```



Code Size Improvements

Language-level optimizations

JF Bastien, Compiler Engineer

Merge redundant block helpers and metadata

```
// Merge redundant block helpers and metadata
```

```objc
// Merge redundant block helpers and metadata


- (void)neutron:(id)particle {
  [self fuseWithCallbackBlock:^ (id nuclei) {
    [nuclei collide:particle];
    [self upDownDown];
  }];
}

- (void)proton:(id)particle chargeQuantity:(double)charge {
  [self fuseWithCallbackBlock:^ (id nuclei) {
    [self checkCoulombForce:charge];
    [particle collide:nuclei];
  }];
}
```

```
// Merge redundant block helpers and metadata
```

```
struct Metadata {
  unsigned long reserved, block_size;
  void          *copy_helper;
  void          *destroy_helper;
  const char    *block_method_signature;
  uintptr_t      block_layout_info;
};
```

```
- (void)neutron:(id)particle {
  [self fuseWithCallbackBlock:^ (id nuclei) {
    [nuclei collide:particle];
    [self upDownDown];
  }];
}

- (void)proton:(id)particle chargeQuantity:(double)charge {
  [self fuseWithCallbackBlock:^ (id nuclei) {
    [self checkCoulombForce:charge];
    [particle collide:nuclei];
  }];
}
```

```
// Generated block metadata — as of Xcode 11

static const char  *__block_method_signature_v16_0_8 = "v16@?0@8";
static const struct { // neutron block metadata
  unsigned long reserved = 0, block_size = 48;
  void         *copy_helper            = ___copy_helper_block_ea8_32s40s;
  void         *destroy_helper         = ___destroy_helper_block_ea8_32s40s;
  const char   *block_method_signature = __block_method_signature_v16_0_8;
  uintptr_t     block_layout_info      = 512;
} ___block_descriptor_48_ea8_32s40s_e8_v16?08l;
static const struct { // proton block metadata
  unsigned long reserved = 0, block_size = 52;
  void         *copy_helper            = ___copy_helper_block_ea8_32s40s;
  void         *destroy_helper         = ___destroy_helper_block_ea8_32s40s;
  const char   *block_method_signature = __block_method_signature_v16_0_8;
  uintptr_t     block_layout_info      = 512;
} ___block_descriptor_52_ea8_32s40s_e8_v16?08l;
```

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// Generated block metadata — as of Xcode 11

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  void          *destroy_helper          = ___destroy_helper_block_ea8_32s40s;
  const char    *block_method_signature = __block_method_signature_v16_0_8;
  uintptr_t      block_layout_info       = 512;
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  void          *destroy_helper          = ___destroy_helper_block_ea8_32s40s;
  const char    *block_method_signature = __block_method_signature_v16_0_8;
  uintptr_t      block_layout_info       = 512;
} ___block_descriptor_52_ea8_32s40s_e8_v16?08l;
```

🗣️ **48 ≠ 52 ∴ can't merge**

```
// Generated block metadata — as of Xcode 11

static const char  *__block_method_signature_v16_0_8 = "v16@?0@8";
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  uintptr_t     block_layout_info      = 512;
} ___block_descriptor_52_ea8_32s40s_e8_v16?08l;
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  void          *copy_helper            = ___copy_helper_block_ea8_32s40s;
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  uintptr_t      block_layout_info      = 512;
} ___block_descriptor_52_ea8_32s40s_e8_v16?08l;
```

```
___copy_helper_block_ea8_32s40s
```

```
___destroy_helper_block_ea8_32s40s
```

```
// Generated block helpers — as of Xcode 11

static void ___copy_helper_block_ea8_32s40s(void *block) {


}

static void ___destroy_helper_block_ea8_32s40s(void *block) {


}
```

```
// Generated block helpers — as of Xcode 11

static void ___copy_helper_block_ea8_32s40s(void *block) {
  objc_retain(*(id*)(((char*)block) + 32));
  objc_retain(*(id*)(((char*)block) + 40));
}

static void ___destroy_helper_block_ea8_32s40s(void *block) {
  objc_release(*(id*)(((char*)block) + 32));
  objc_release(*(id*)(((char*)block) + 40));
}
```

2–7%

Typical code size reduction

Instance Variables of Direct Subclasses of NSObject

Offsets can be constant in the implementation

```
// Card.h — a direct subclass of NSObject

@interface Card : NSObject

@property (copy) NSString *name;
@property (copy) NSString *type;
@property (copy) NSDictionary *manaCost;
@property (copy) NSString *abilitiesText;
@property (copy) NSString *flavourText;
@property (copy) NSString *expansion;
@property int power;
@property int toughness;
@property UIImage *art;
@property (copy) NSString *artist;
- (instancetype)initWithName:(NSString *)name;

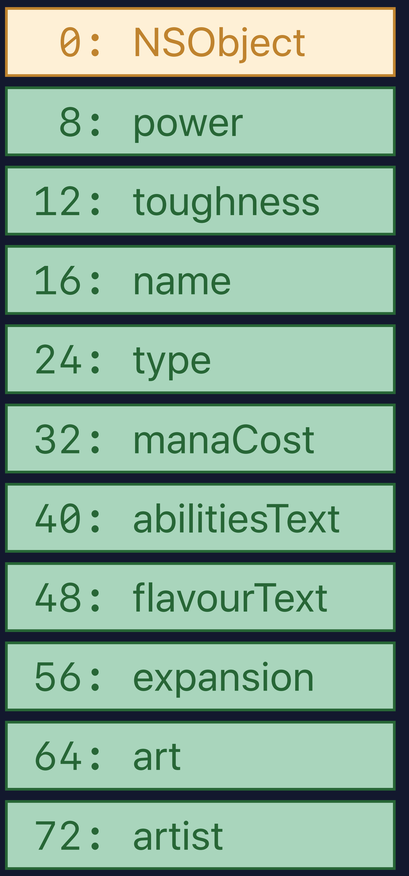
@end
```

```objc
// Card.h — a direct subclass of NSObject

@interface Card : NSObject

@property (copy) NSString *name;
@property (copy) NSString *type;
@property (copy) NSDictionary *manaCost;
@property (copy) NSString *abilitiesText;
@property (copy) NSString *flavourText;
@property (copy) NSString *expansion;
@property int power;
@property int toughness;
@property UIImage *art;
@property (copy) NSString *artist;
- (instancetype)initWithName:(NSString *)name;

@end
```




0: NSObject
8: power
12: toughness
16: name
24: type
32: manaCost
40: abilitiesText
48: flavourText
56: expansion
64: art
72: artist


0: NSObject
8: power
12: toughness
16: name
24: type
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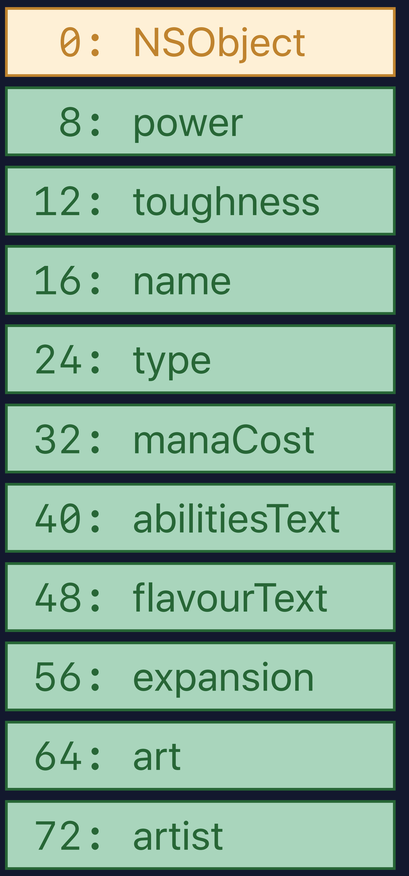
40: abilitiesText
48: flavourText
56: expansion
64: art
72: artist

```objc
// Card.mm — @implementation knows all offsets

#import "Card.h"

@implementation Card
- (instancetype)initWithName:(NSString *)name {
  if ((self = [super init])) {
    self.name = name;
    //   ...
    // ☀️💧💀🔥🌳
    //   ...
  }
  return self;
}
@end
```



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  if ((self = [super init])) {
    self.name = name;
    //    ...
    // ☀️💧💀🔥🌳
    //    ...
  }
  return self;
}
@end
```

```
"-[Card setName:]":                     ; Before Xcode 11
  adrp    x8, _OBJC_IVAR_$_Card._name@PAGE
  ldrsw   x3, [x8, _OBJC_IVAR_$_Card._name@PAGEOFF]
  b       _objc_setProperty_atomic
```

```objc
// Card.mm — @implementation knows all offsets

#import "Card.h"

@implementation Card
- (instancetype)initWithName:(NSString *)name {
  if ((self = [super init])) {
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    //    ...
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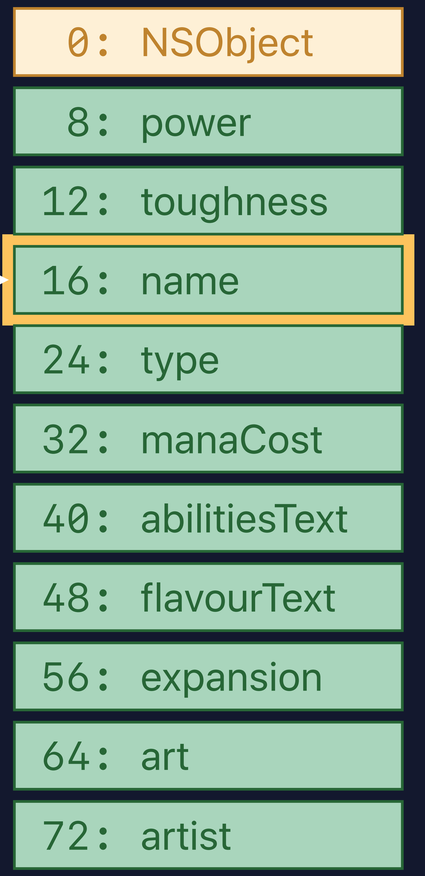

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  b       _objc_setProperty_atomic

"-[Card setName:]":                    ; Xcode 11
  orr     w3, wzr, #0x10
  b       _objc_setProperty_atomic
```

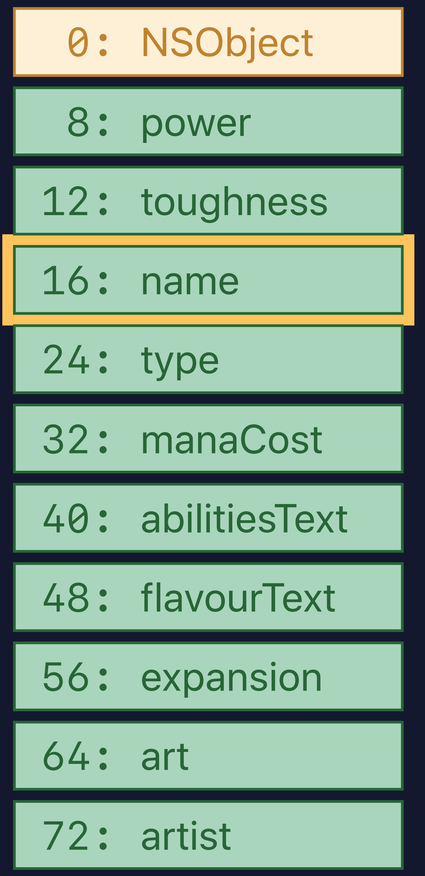

2%

Typical code size reduction

Improved Debuggability of C++ Types

And associated code size wins

```
// Debugging around standard library code — print.cc

#include <cstdlib>
#include <iostream>
#include <string>
#include <vector>

int main(int argc, char** argv) {
    std::vector<std::string> args(argv + 1, argv + argc);
    std::vector<int> numbers;
    numbers.reserve(args.size());
    for (std::string const& arg : args) {
        int n = std::atoi(arg.c_str());
        numbers.push_back(n);
    }
    for (int i : numbers)
       std::cout << i << '\n';
}
```

```cpp
// Debugging around standard library code — print.cc

#include <cstdlib>
#include <iostream>
#include <string>
#include <vector>

int main(int argc, char** argv) {
    std::vector<std::string> args(argv + 1, argv + argc);
    std::vector<int> numbers;
    numbers.reserve(args.size());
    for (std::string const& arg : args) {
        int n = std::atoi(arg.c_str());
        numbers.push_back(n);                    // Let's set a breakpoint at line 12.
    }
    for (int i : numbers)
       std::cout << i << '\n';
}
```

$

```
$ lldb -- ./print 1 1 2 3 5
(lldb)
```

```
$ lldb -- ./print 1 1 2 3 5
(lldb)
```

```
$ lldb -- ./print 1 1 2 3 5
(lldb) b 12
Breakpoint 1: where = print`main + 420 at print.cc:12:17, address = 0x0000000000c0ffee
(lldb)
```

```
$ lldb -- ./print 1 1 2 3 5
(lldb) b 12
Breakpoint 1: where = print`main + 420 at print.cc:12:17, address = 0x0000000000c0ffee
(lldb) r
```

```
$ lldb -- ./print 1 1 2 3 5
(lldb) b 12
Breakpoint 1: where = print`main + 420 at print.cc:12:17, address = 0x0000000000c0ffee
(lldb) r
Process 1337 launched: '/Users/j_appleseed/print' (x86_64)
Process 1337 stopped
* thread #1, queue = 'com.apple.main-thread', stop reason = breakpoint 1.1
    frame #0: 0x0000000000c0ffee print`main(argc=6, argv=0x0000c0defefe0000) at print.cc:12:17
   9        numbers.reserve(args.size());
   10       for (std::string const& arg : args) {
   11           int n = std::atoi(arg.c_str());
-> 12           numbers.push_back(n);
   13       }
   14       for (int i : numbers)
   15           std::cout << i << '\n';
Target 0: (print) stopped.
```

```
$ lldb -- ./print 1 1 2 3 5
(lldb) b 12
Breakpoint 1: where = print`main + 420 at print.cc:12:17, address = 0x0000000000c0ffee
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Process 1337 launched: '/Users/j_appleseed/print' (x86_64)
Process 1337 stopped
* thread #1, queue = 'com.apple.main-thread', stop reason = breakpoint 1.1
    frame #0: 0x0000000000c0ffee print`main(argc=6, argv=0x0000c0defefe0000) at print.cc:12:17
   9        numbers.reserve(args.size());
   10       for (std::string const& arg : args) {
   11           int n = std::atoi(arg.c_str());
-> 12           numbers.push_back(n);
   13       }
   14       for (int i : numbers)
   15           std::cout << i << '\n';
Target 0: (print) stopped.
```

† in release configuration of codebases that heavily use the C++ Standard Library

7%

Code size reduction† and better debugging!

† in release configuration of codebases that heavily use the C++ Standard Library

C++ Static Destructor Suppression

```
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc


Logger logger;
```

```cpp
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc


Logger logger;
```

```cpp
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc


Logger logger;
```

```cpp
// Another file — Game.cc
#include "logger.h"

class Game {
public:
  Game();
  ~Game();
  // ...
  //  🚀
  // ...
};
Game game;

Game::~Game() {



}
```

```cpp
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc


Logger logger;
```

```cpp
// Another file — Game.cc
#include "logger.h"

class Game {
public:
  Game();
  ~Game();
  // ...
  //  🚀
  // ...
};
Game game;

Game::~Game() {



}
```

```cpp
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc


Logger logger;
```

```cpp
// Another file — Game.cc
#include "logger.h"

class Game {
public:
  Game();
  ~Game();
  // ...
  //  🚀
  // ...
};
Game game;

Game::~Game() {
  logger.log("Thank you for playing ",
    game_name, "!");
}
```

```cpp
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc


Logger logger;
```

```cpp
// Another file — Game.cc
#include "logger.h"

class Game {
public:
  Game();
  ~Game();
  // ...
  //  🚀
  // ...
};
Game game;

Game::~Game() {
  logger.log("Thank you for playing ",
    game_name, "!");
}
```

```cpp
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc


Logger logger;
```

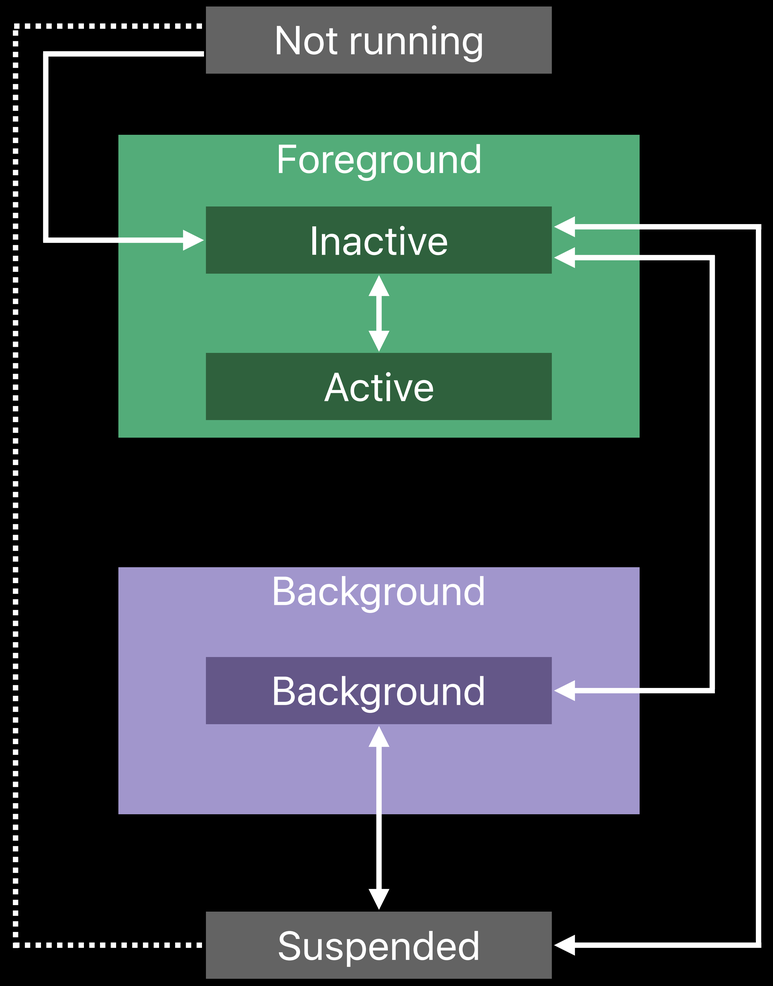
```cpp
// Another file — Game.cc
#include "logger.h"

class Game {
public:
  Game();
  ~Game();
  // ...
  //  🚀
  // ...
};
Game game;

Game::~Game() {



}
```

C++ Static Destructor Suppression

Application lifecycle

C++ Static Destructor Suppression

Application lifecycle

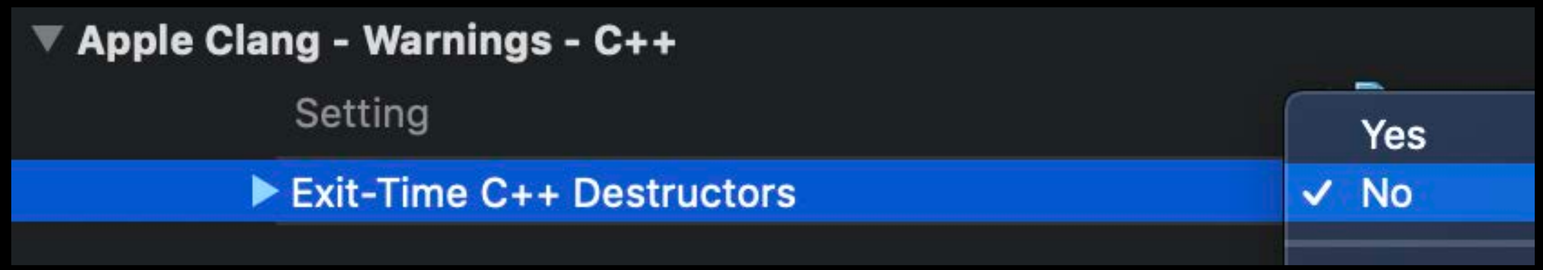


```
// Handling an application's lifecycle


@interface CowClicker : NSObject <UIApplicationDelegate>

- (void)applicationWillResignActive:(UIApplication *)application;
- (void)applicationDidBecomeActive:(UIApplication *)application;
- (void)applicationWillEnterForeground:(UIApplication *)application;
- (void)applicationDidEnterBackground:(UIApplication *)application;
- (void)applicationWillTerminate:(UIApplication *)application;

@end
```

```
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc


Logger logger;
```

```cpp
// Global with a destructor — logger.h

class Logger {
public:
  template <typename... Ts>
    void log(Ts&&... message);
  void flush();

private:
  std::vector<std::string> mBuffer;
};
extern Logger logger;

// Implementation file — logger.cc

[[clang::no_destroy]]
Logger logger;
```

C++ static Destructor Suppression



1%

Typical code size reduction

Diagnostics

```
// -Wcall-to-pure-virtual-from-ctor-dtor
```

```
// -Wcall-to-pure-virtual-from-ctor-dtor




class Table {


};
```

```
// -Wcall-to-pure-virtual-from-ctor-dtor



Grail* find(Knight*);
Shrubbery* find(Knight*);

class Table {
  virtual Knight* galahad() = 0;
  virtual ~Table() { find(galahad()); }
};
```

```
// -Wcall-to-pure-virtual-from-ctor-dtor



Grail* find(Knight*);
Shrubbery* find(Knight*);

class Table {
  virtual Knight* galahad() = 0;
  virtual ~Table() { find(galahad()); }
};

 warning: call to pure virtual member function 'galahad' has undefined behaviour;
          overrides of 'galahad' in subclasses are not available in the destructor of 'Table'
```

```
// -Wcall-to-pure-virtual-from-ctor-dtor



Grail* find(Knight*);
Shrubbery* find(Knight*);

class Table {
  virtual Knight* galahad() = 0;
  virtual ~Table() {                    }
};
```

```
// -Wcall-to-pure-virtual-from-ctor-dtor



Grail* find(Knight*);
Shrubbery* find(Knight*);

class Table {
  virtual Knight* galahad() = 0;
  virtual ~Table() { /* nothing! */   }
};
```

```
class RoundTable : public Table {
  Knight* galahad() final { /* 🐴 */ }
  ~RoundTable() override { find(galahad()); }
};
```

```
// -Wmemset-transposed-args
```

```
// -Wmemset-transposed-args

struct Inbox { int emails[1024]; };
```

```
// -Wmemset-transposed-args

struct Inbox { int emails[1024]; };
void me_after_vacation(struct Inbox* inbox) {

}
```

```
// -Wmemset-transposed-args

struct Inbox { int emails[1024]; };
void me_after_vacation(struct Inbox* inbox) {
  memset(inbox, sizeof(struct Inbox), 0);
}
```

```
warning: 'size' argument to memset is '0';
         did you mean to transpose the last two arguments?
```

```
// -Wmemset-transposed-args

struct Inbox { int emails[1024]; };
void me_after_vacation(struct Inbox* inbox) {
  memset(inbox, 0, sizeof(struct Inbox));
}
```

```
// -Wmemset-transposed-args

struct Inbox { int emails[1024]; };
void me_after_vacation(struct Inbox* inbox) {
  memset(inbox, 0, sizeof(struct Inbox));
}
```

Avoid

memset

```
// -Wmemset-transposed-args

struct Inbox { int emails[1024]; };
void me_after_vacation(struct Inbox* inbox) {
  memset(inbox, 0, sizeof(struct Inbox));
}
```

Avoid

`memset`

Recommended

`<algorithm>` → `std::fill` or `std::fill_n`

```
// -Wmemset-transposed-args

struct Inbox {            int  1024  emails; };
void me_after_vacation(struct Inbox* inbox) {

}
```

Avoid

`memset`

Recommended

`<algorithm>` → `std::fill` or `std::fill_n`

```cpp
// -Wmemset-transposed-args

struct Inbox { std::array<int, 1024> emails; };
void me_after_vacation(struct Inbox* inbox) {
  std::fill(inbox->emails.begin(), inbox->emails.end(), 0);
}
```

Avoid

`memset`

Recommended

`<algorithm>` → `std::fill` or `std::fill_n`

```
// -Wreturn-std-move
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };

struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };

struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };

template <typename Creature> void slay(Creature&);

Goat bellerophon(Chimæra chimæra) {
  slay(chimæra);
  return chimæra;
}
```

```
warning: local variable 'chimæra' will be copied despite being returned by name
note:    call 'std::move' explicitly to avoid copying
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };

struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };

template <typename Creature> void slay(Creature&);

Goat bellerophon(Chimæra chimæra) {
  slay(chimæra);
  return chimæra;
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```
warning: local variable 'chimæra' will be copied despite being returned by name
note:    call 'std::move' explicitly to avoid copying
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```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };

struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };

template <typename Creature> void slay(Creature&);

Goat bellerophon(Chimæra chimæra) {
  slay(chimæra);
  return           chimæra ;
}
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };

struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };

template <typename Creature> void slay(Creature&);

Goat bellerophon(Chimæra chimæra) {
  slay(chimæra);
  return std::move(chimæra);
}
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };

struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };

template <typename Creature> void slay(Creature&);

       bellerophon(Chimæra chimæra) {
  slay(chimæra);
  return chimæra;
}
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };

struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };

template <typename Creature> void slay(Creature&);

Chimæra bellerophon(Chimæra chimæra) {
  slay(chimæra);
  return chimæra;
}
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
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struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };

template <typename Creature> void slay(Creature&);

                     bellerophon(Chimæra chimæra) {
  slay(chimæra);
  return chimæra;
}
```

```
// -Wreturn-std-move

struct Lion  {       /* 🦁 */      };
struct Goat  { std::vector<int> v; };
struct Snake {       /* 🐍 */      };

struct Chimæra : Lion, Goat, Snake { /* 🔥 🦁 🐐 🐍 */ };

template <typename Creature> void slay(Creature&);

std::optional<Chimæra> bellerophon(Chimæra chimæra) {
  slay(chimæra);
  return chimæra;
}
```

```
// -Wsizeof-pointer-div
```

```
// -Wsizeof-pointer-div

void all_work() {
  int no_play[10];
  size_t array_elts = sizeof(no_play) / sizeof(no_play[0]);
  // ... 💻 ...
}
```

```
// -Wsizeof-pointer-div

void        (int       [10]) {
  size_t array_elts = sizeof(      ) / sizeof(      [0]);
  // ...    ...

}
```

```
// -Wsizeof-pointer-div

void pigeon(int array[10]) {
  size_t array_elts = sizeof(array) / sizeof(array[0]);  // Is this a 10? 🦋
  // ... 💁 ...
  // ...
}
```

```
      warning: 'sizeof(array)' will return the size of the pointer, not the array itself
```

```c
// -Wsizeof-pointer-div

void pigeon(int array[10]) {
  size_t array_elts = sizeof(array) / sizeof(array[0]);  // Is this a 10? 🦋
  // ... 🤦 ...
  // ...
}
```

```
      warning: 'sizeof(array)' will return the size of the pointer, not the array itself
```

Avoid

```c
sizeof(array) / sizeof(array[0])
```

```
// -Wsizeof-pointer-div

void pigeon(int array[10]) {
  size_t array_elts = sizeof(array) / sizeof(array[0]);  // Is this a 10? 🦋
  // ... 💁 ...
  // ...
}
```

```
      warning: 'sizeof(array)' will return the size of the pointer, not the array itself
```

Avoid

```
sizeof(array) / sizeof(array[0])
```

Recommended

C++17 `<iterator>` → `std::size`

```
// -Wsizeof-pointer-div

void          () {
  int         [10]
  size_t array_elts =
  // ...    ...
}
```

```
// -Wsizeof-pointer-div

void dull_boi() {
  int no_play[10];
  size_t array_elts = std::size(no_play);
  // ... 💻 ...
}
```

```
// -Wdefaulted-function-deleted
```

```
// -Wdefaulted-function-deleted

struct Aberration {
  float& eyestalks;
  int eye;
  int mouth;
  Aberration() = default;
};
```

```
warning: explicitly defaulted default constructor is implicitly deleted
note:    default constructor of 'Aberration' is implicitly deleted because
         field 'eyestalks' of reference type 'float &' would not be initialized
```

```
// -Wdefaulted-function-deleted

struct Aberration {
  float& eyestalks;
  int eye;
  int mouth;
  Aberration(               )
};
```

```
// -Wdefaulted-function-deleted

struct Aberration {
  float& eyestalks;
  int eye;
  int mouth;
  Aberration(float& eyestalks) : eyestalks(eyestalks) { }
};
```

```
// -Wdefaulted-function-deleted

struct Aberration {
  float eyestalks;
  int eye;
  int mouth;
  Aberration()
};
```

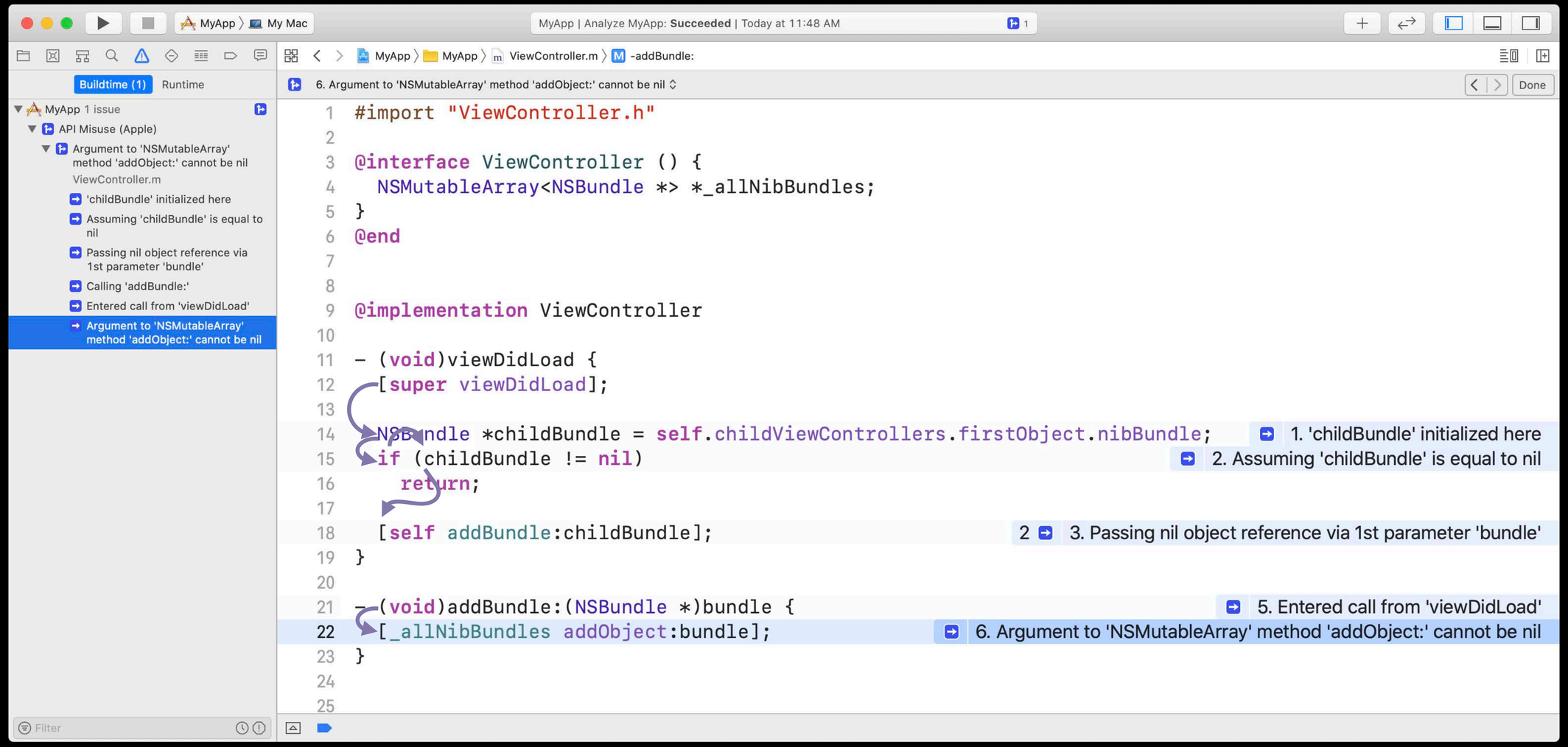
```
// -Wdefaulted-function-deleted

struct Aberration {
  float eyestalks;
  int eye;
  int mouth;
  Aberration() = default;
};
```

New Static Analyzer Checks

Devin Coughlin, Program Analysis Engineer

Finds Deep Bugs

Great at catching hard-to-produce, edge-case bugs



Three New C++ Checks

NEW

Use after move bugs

Dangling C string pointers with `std::string`

Reference-counting bugs in DriverKit and IOKit

NEW

Use After Move in C++

C++ Moves Avoid Unwanted Copies

```
Book myNovel("It was the best of times...");

publish(std::move(myNovel));
```

C++ Moves Avoid Unwanted Copies

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Moves from source variable rather than copying

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Moves from source variable rather than copying

Can enforce unique ownership semantics

C++ Moves Avoid Unwanted Copies

```
Book myNovel("It was the best of times...");

publish(std::move(myNovel));
```

Moves from source variable rather than copying

Can enforce unique ownership semantics

Leaves source in unspecified state

Do Not Use Variable after Moving

```
Book myNovel("It was the best of times...");

publish(std::move(myNovel));
```

Do Not Use Variable after Moving

```
Book myNovel("It was the best of times...");

publish(std::move(myNovel));

myNovel.spellCheck();
```

Do Not Use Variable after Moving

```
Book myNovel("It was the best of times...");

publish(std::move(myNovel));

myNovel.spellCheck();
```

May have unexpected results or even crash!

Do Not Use Variable after Moving

```
Book myNovel("It was the best of times...");

publish(std::move(myNovel));

myNovel.spellCheck();
```

Method called on moved-from object

May have unexpected results or even crash!

Do Not Use Variable after Moving

```
Book myNovel("It was the best of times...");

publish(std::move(myNovel));

myNovel.spellCheck();
```

Method called on moved-from object

May have unexpected results or even crash!

Common fix is to reorder code

Do Not Use Variable after Moving

```
Book myNovel("It was the best of times...");

myNovel.spellCheck();


publish(std::move(myNovel));
```

May have unexpected results or even crash!

Common fix is to reorder code

NEW

Dangling Pointers from `std::string`

Mixing C++ and C Strings Can Be Tricky!

```
const char *generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

Mixing C++ and C Strings Can Be Tricky!

```
const char *generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

Mixing C++ and C Strings Can Be Tricky!

```
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  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

Mixing C++ and C Strings Can Be Tricky!

```
const char *generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

Mixing C++ and C Strings Can Be Tricky!

```
const char *generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

`c_str()` returns inner pointer to buffer inside `std::string`

Mixing C++ and C Strings Can Be Tricky!

```
const char *generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

`c_str()` returns inner pointer to buffer inside `std::string`

Buffer deallocated when `std::string` goes out of scope

Mixing C++ and C Strings Can Be Tricky!

```
const char *generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

Returning memory that will be deallocated

`c_str()` returns inner pointer to buffer inside `std::string`

Buffer deallocated when `std::string` goes out of scope

Mixing C++ and C Strings Can Be Tricky!

```
const char *generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

Returning memory that will be deallocated

`c_str()` returns inner pointer to buffer inside `std::string`

Buffer deallocated when `std::string` goes out of scope

Using deallocated memory may crash!

Mixing C++ and C Strings Can Be Tricky!

```
const char *generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting.c_str();
}

printf("%s from WWDC!", generateGreeting("World"));
```

Returning memory that will be deallocated

Inner string pointer used after deallocation

`c_str()` returns inner pointer to buffer inside `std::string`

Buffer deallocated when `std::string` goes out of scope

Using deallocated memory may crash!

Match Lifetimes of C++ and C Strings

```
std::string generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting;
}
std::string greeting = generateGreeting("World");
printf("%s from WWDC!", greeting.c_str());
```

Match Lifetimes of C++ and C Strings

```
std::string generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting;
}
std::string greeting = generateGreeting("World");
printf("%s from WWDC!", greeting.c_str());
```

Match Lifetimes of C++ and C Strings

```
std::string generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting;
}
std::string greeting = generateGreeting("World");
printf("%s from WWDC!", greeting.c_str());
```

Match Lifetimes of C++ and C Strings

```
std::string generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting;
}
std::string greeting = generateGreeting("World");
printf("%s from WWDC!", greeting.c_str());
```

Match Lifetimes of C++ and C Strings

```
std::string generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting;
}
std::string greeting = generateGreeting("World");
printf("%s from WWDC!", greeting.c_str());
```

Change scope of `std::string` to last as long as C string is used

Match Lifetimes of C++ and C Strings

```
std::string generateGreeting(const char *name) {
  std::string greeting = "Hello ";
  greeting.append(name);
  return greeting;
}
std::string greeting = generateGreeting("World");
printf("%s from WWDC!", greeting.c_str());
```

Change scope of `std::string` to last as long as C string is used

Often easier to stay within C++ world

NEW

Reference Counting in DriverKit and IOKit

System Extensions and DriverKit

WWDC 2019

Drivers Use Manual Retain/Release

Drivers Use Manual Retain/Release

`OSObject` uses retain/release for memory management

- Similar to CoreFoundation or Objective-C without ARC

Drivers Use Manual Retain/Release

`OSObject` uses retain/release for memory management

- Similar to CoreFoundation or Objective-C without ARC

Easy to over-release

- Memory used after deallocated

Drivers Use Manual Retain/Release

`OSObject` uses retain/release for memory management

- Similar to CoreFoundation or Objective-C without ARC

Easy to over-release

- Memory used after deallocated

Easy to under-release

- Memory leaked

Allocated Objects Must Be Released

```
OSArray *devices = OSArray::withCapacity(2);
fillInDevices(devices);
setUpDevices(devices);

return true;
```

Allocated Objects Must Be Released

```
OSArray *devices = OSArray::withCapacity(2);
fillInDevices(devices);
setUpDevices(devices);

return true;
```

Allocated Objects Must Be Released

```
OSArray *devices = OSArray::withCapacity(2);
fillInDevices(devices);
setUpDevices(devices);

return true;
```

Array allocated and returned retained

`OSArray::withCapacity()` returns retained

Allocated Objects Must Be Released

```
OSArray *devices = OSArray::withCapacity(2);
fillInDevices(devices);
setUpDevices(devices);

return true;
```

Array allocated and returned retained

`OSArray::withCapacity()` returns retained

Array will leak if not released

Allocated Objects Must Be Released

```
OSArray *devices = OSArray::withCapacity(2);
fillInDevices(devices);
setUpDevices(devices);

return true;
```

Array allocated and returned retained

Leak of object stored into ‘devices’

`OSArray::withCapacity()` returns retained

Array will leak if not released

Allocated Objects Must Be Released

```
OSArray *devices = OSArray::withCapacity(2);
fillInDevices(devices);
setUpDevices(devices);
OSObjectRelease(devices);
return true;
```

Array allocated and returned retained

`OSArray::withCapacity()` returns retained

Array will leak if not released

Convention for Memory Management

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Similar in spirit to rules for CoreFoundation and ObjC Manual Retain/Release

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Default convention is to return retained (+1)

- Clients must call `OSObjectRelease()`

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Similar in spirit to rules for CoreFoundation and ObjC Manual Retain/Release

Default convention is to return retained (+1)

- Clients must call `OSObjectRelease()`

Except getters return unretained (+0)

- Clients must not call `OSObjectRelease()`

Differing from Convention

```
OSObject *findFirstDevice()  {
   OSObject *result = devices->getObject(0);

   return result;
}
```

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Differing from Convention

```
OSObject *findFirstDevice()  {
   OSObject *result = devices->getObject(0);

   return result;
}
```

Object with +0 retain count returned where +1 is expected

Differing from Convention

```
OSObject *findFirstDevice()  {
   OSObject *result = devices->getObject(0);

   return result;
}
```

Change behavior to follow convention

Differing from Convention

```
OSObject *findFirstDevice()  {
   OSObject *result = devices->getObject(0);
   OSObjectRetain(result);
   return result;
}
```

Change behavior to follow convention

Differing from Convention

```
OSObject *findFirstDevice()  {
   OSObject *result = devices->getObject(0);

   return result;
}
```

Change behavior to follow convention

Rename method to follow convention

Differing from Convention

```
OSObject *getFirstDevice()   {
   OSObject *result = devices->getObject(0);

   return result;
}
```

Change behavior to follow convention

Rename method to follow convention

Differing from Convention

```
OSObject *findFirstDevice()  {
   OSObject *result = devices->getObject(0);

   return result;
}
```

Change behavior to follow convention

Rename method to follow convention

Add annotation to tell readers and analyzer convention not followed

Differing from Convention

```
OSObject *findFirstDevice() DRIVERKIT_RETURNS_NOT_RETAINED;

OSObject *findFirstDevice()  {
  OSObject *result = devices->getObject(0);

  return result;
}
```

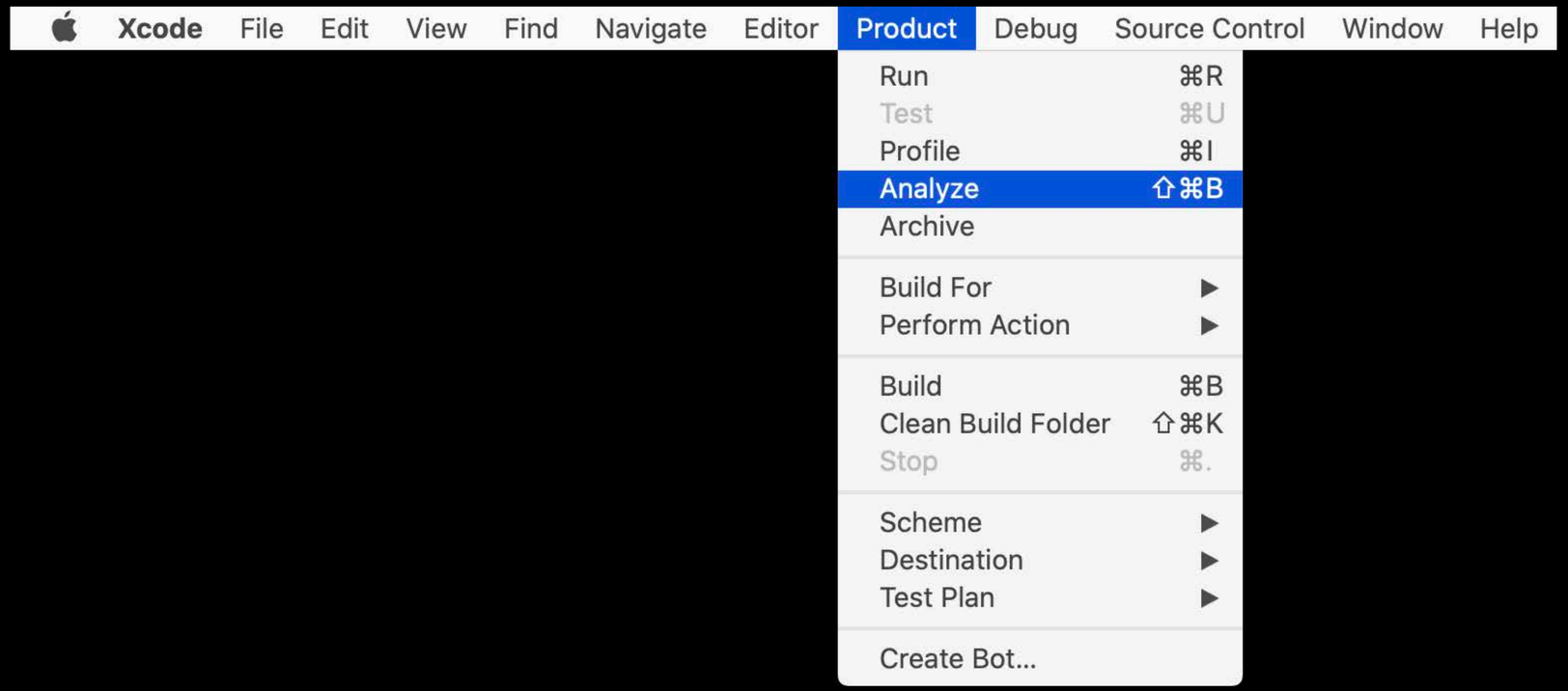
Change behavior to follow convention

Rename method to follow convention

Add annotation to tell readers and analyzer convention not followed

Run Analyzer on Your Code!

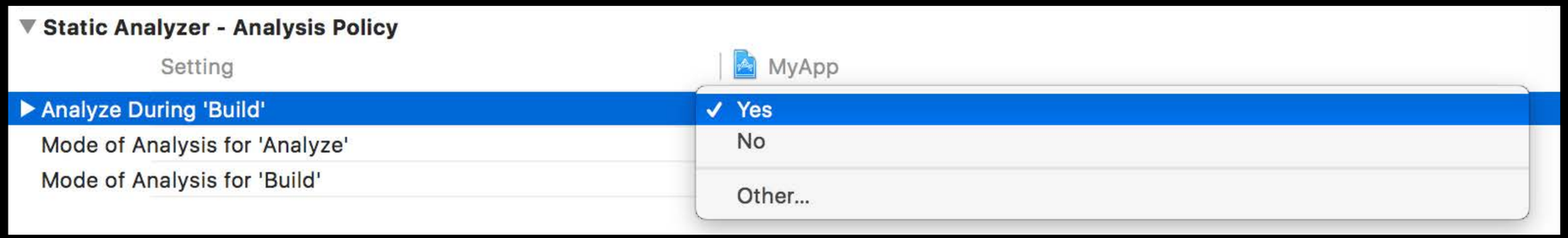
Supports Objective-C, C, C++



Run Analyzer on Your Code!

Supports Objective-C, C, C++

Analyze During Build



Summary

LLVM bitcode enabled seamless 64-bit transition for watchOS

Reduce code size with new compiler optimizations

Run the static analyzer on your code

More Information

developer.apple.com/wwdc19/409

LLVM Compiler, Objective-C, C++, and Linking Lab	Thursday, 9:00
Performance, Power, Crashes, and Debugging Lab	Thursday, 12:00


WWDC19