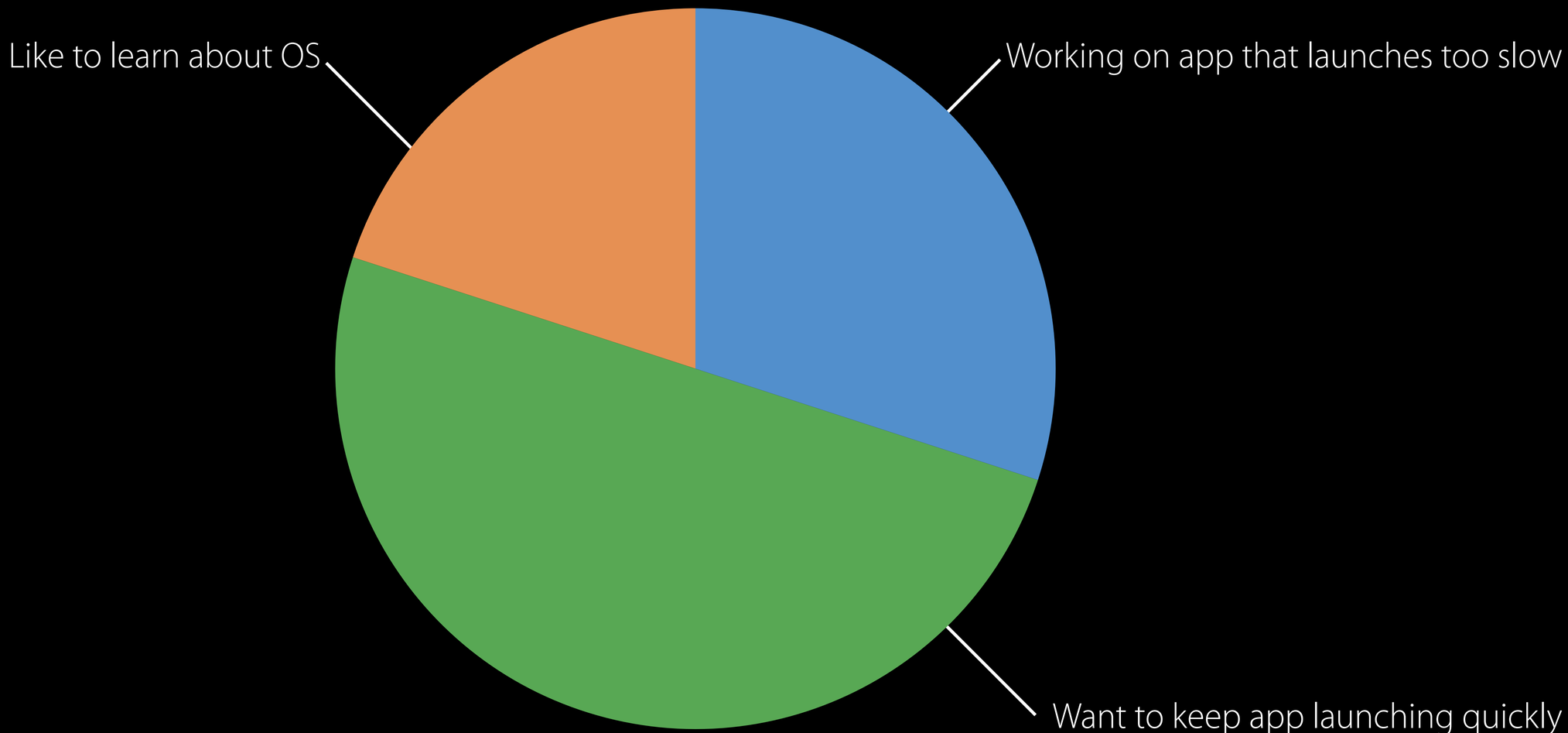
Optimizing App Startup Time

Linkers, loaders, and you

Session 406

Nick Kledzik Dyld Architect
Louis Gerbarg Dyld Visionary

Audience


Like to learn about OS
Working on app that launches too slow
Want to keep app launching quickly

What You Will Learn

Theory

- Everything that happens before main()
- Mach-O format
- Virtual Memory basics
- How Mach-O binaries are loaded and prepared

Practical

- How to measure
- Optimizing start up time

Crash Course:

Mach-O and Virtual Memory

Mach-O Terminology

File Types:

- **Executable**—Main binary for application
- **Dylib**—Dynamic library (aka DSO or DLL)
- **Bundle**—Dylib that cannot be linked, only `dlopen()`, e.g. plug-ins

Image—An executable, dylib, or bundle

Framework—Dylib with directory for resources and headers

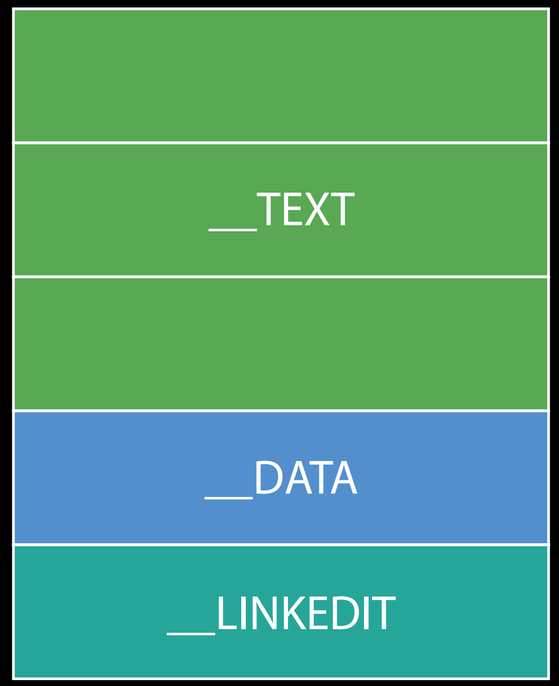
Mach-O Image File

File divided into segments

- Uppercase names

All segments are multiples of page size

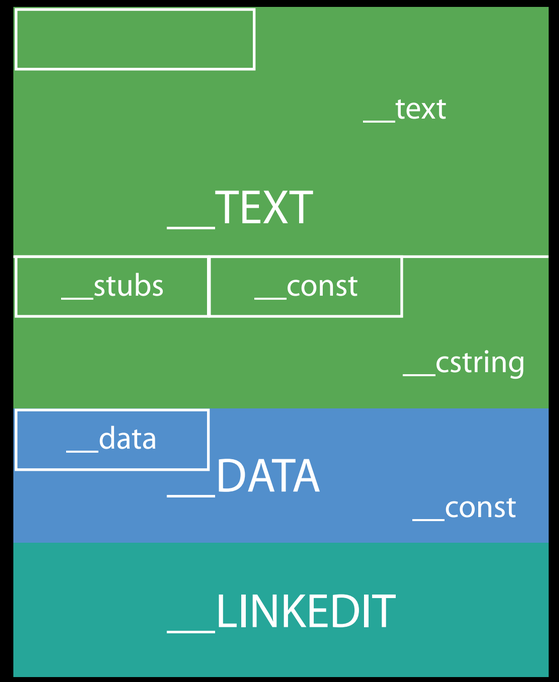
- 16KB on arm64
- 4KB elsewhere



Mach-O Image File

Sections are a subrange of a segment

- Lowercase names



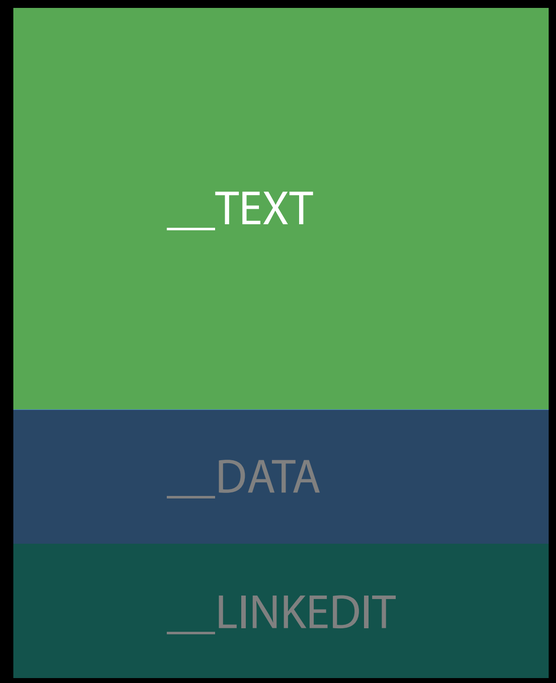
Mach-O Image File

Sections are a subrange of a segment

- Lowercase names

Common segments:

- __TEXT has header, code, and read-only constants



Mach-O Image File

Sections are a subrange of a segment

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Common segments:

- __TEXT has header, code, and read-only constants
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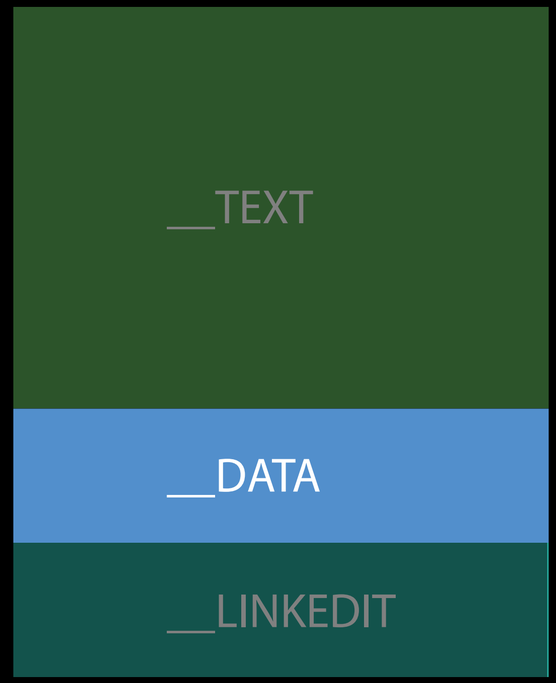


Mach-O Image File

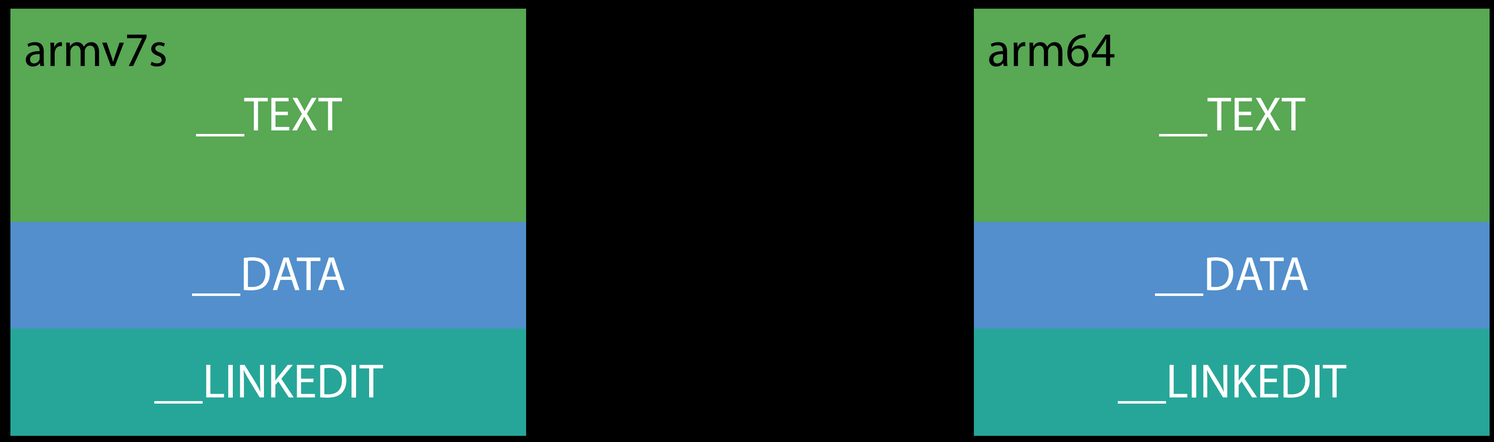
Sections are a subrange of a segment

- Lowercase names

Common segments:

- __TEXT has header, code, and read-only constants
- __DATA has all read-write content: globals, static variables, etc
- __LINKEDIT has "meta data" about how to load the program

Mach-O Universal Files

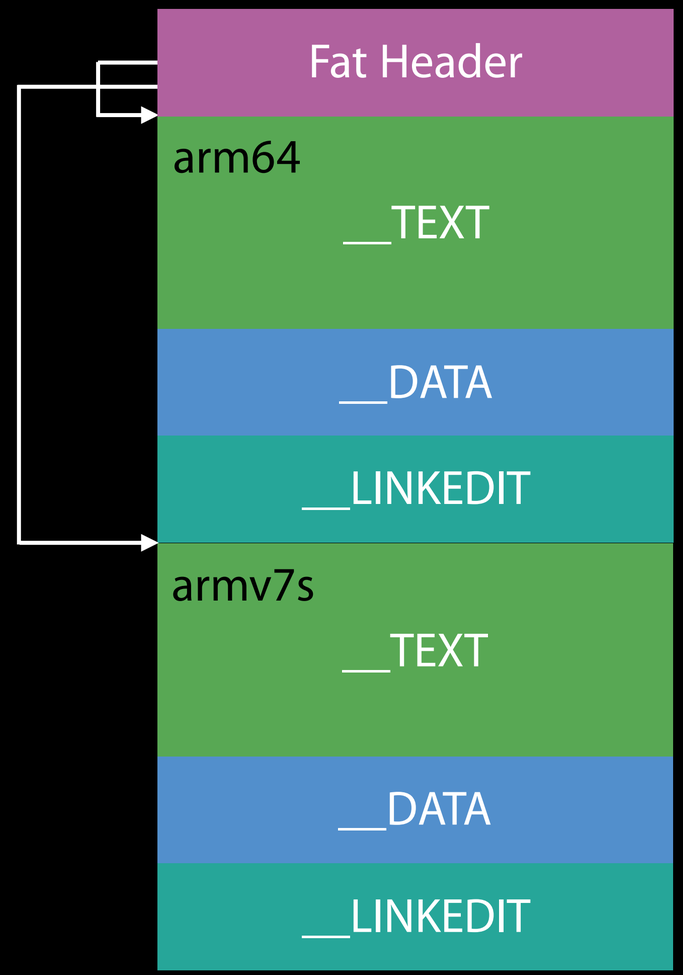


Mach-O Universal Files

Fat Header

- One page in size
- Lists architectures and offsets

Tools and runtimes support fat mach-o files



Virtual Memory

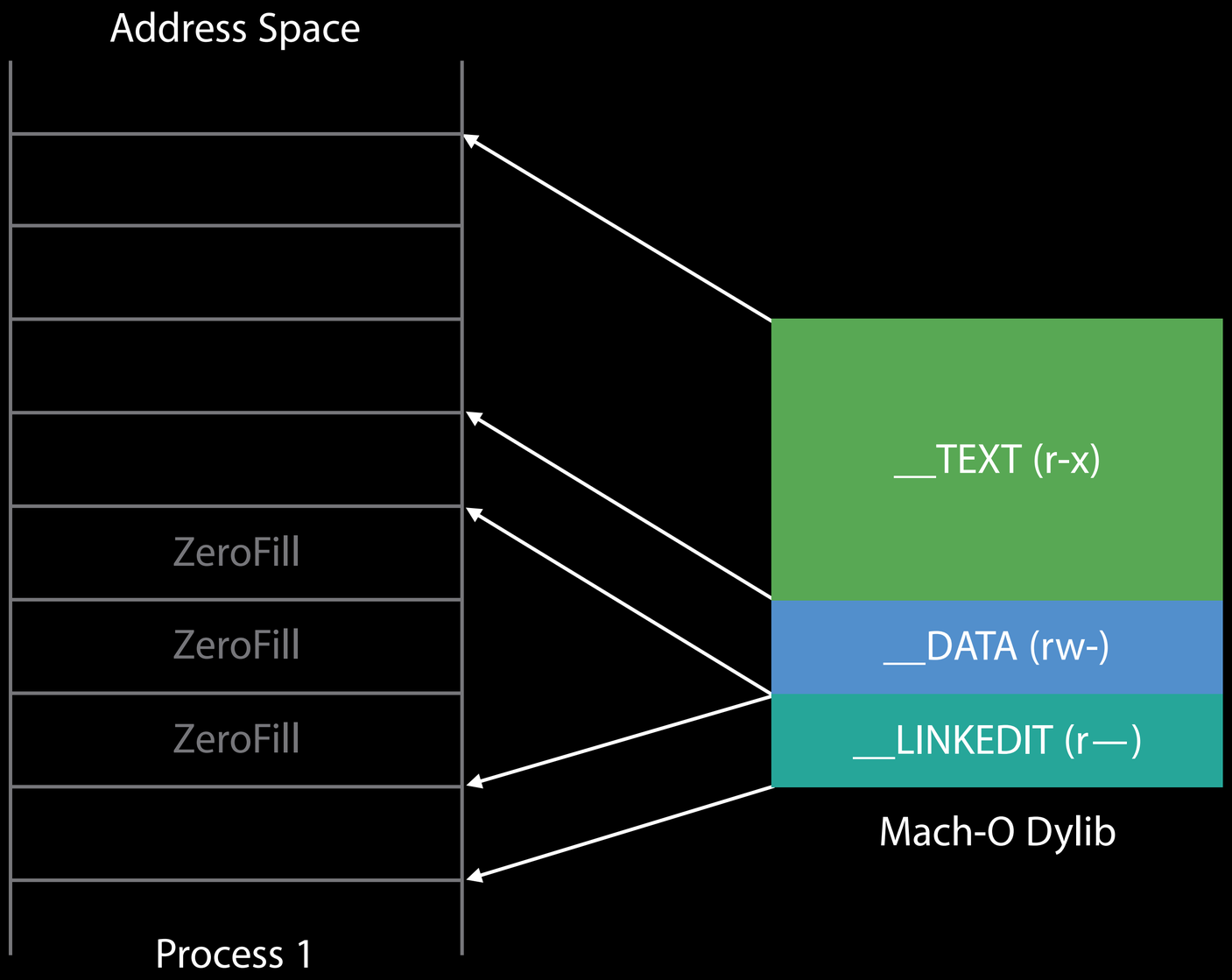
Virtual Memory is a level of indirection

Maps per-process addresses to physical RAM (page granularity)

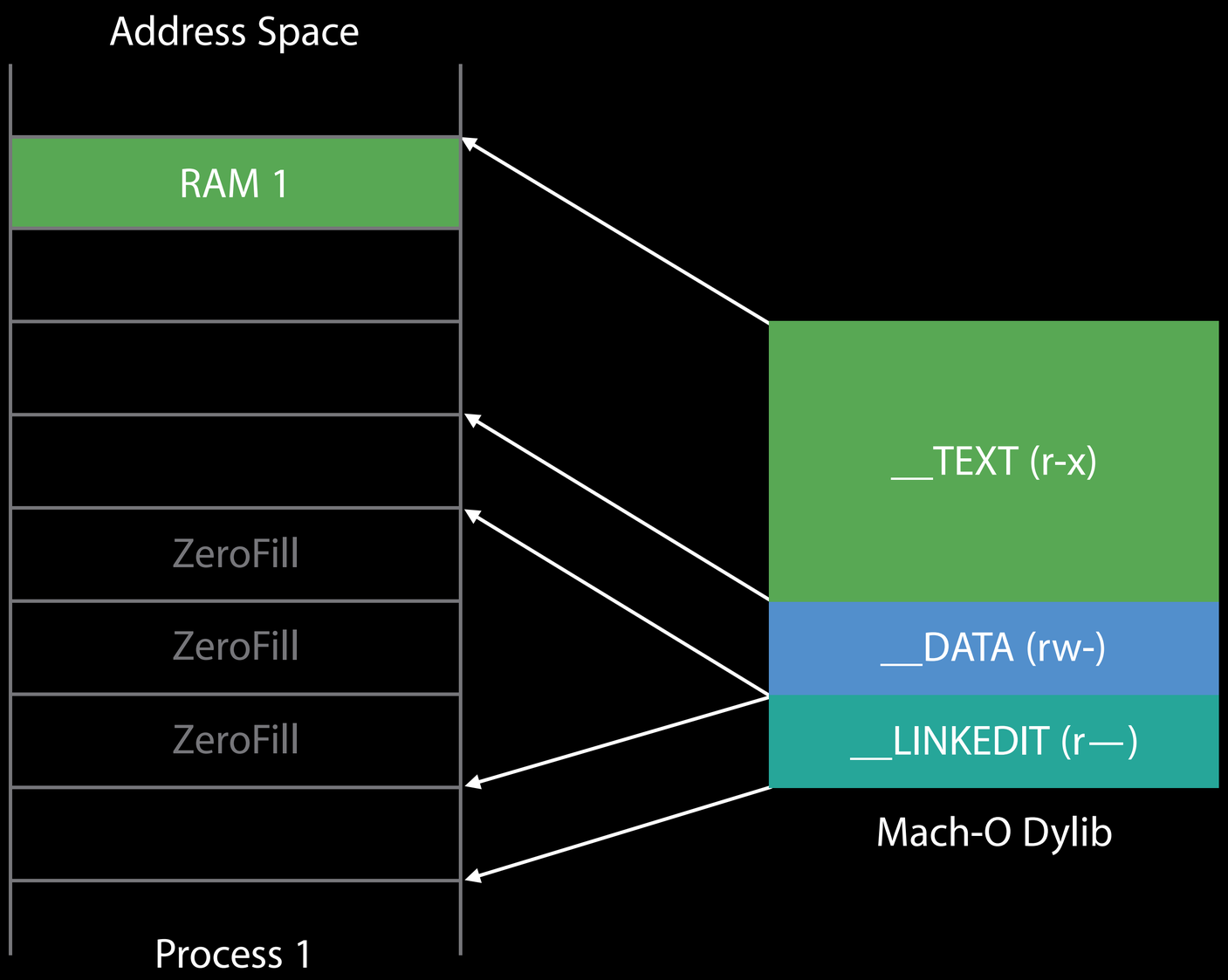
Features:

- Page fault
- Same RAM page appears in multiple processes
- File backed pages
  - `mmap()`
  - lazy reading
- Copy-On-Write (COW)
- Dirty vs. clean pages
- Permissions: rwx

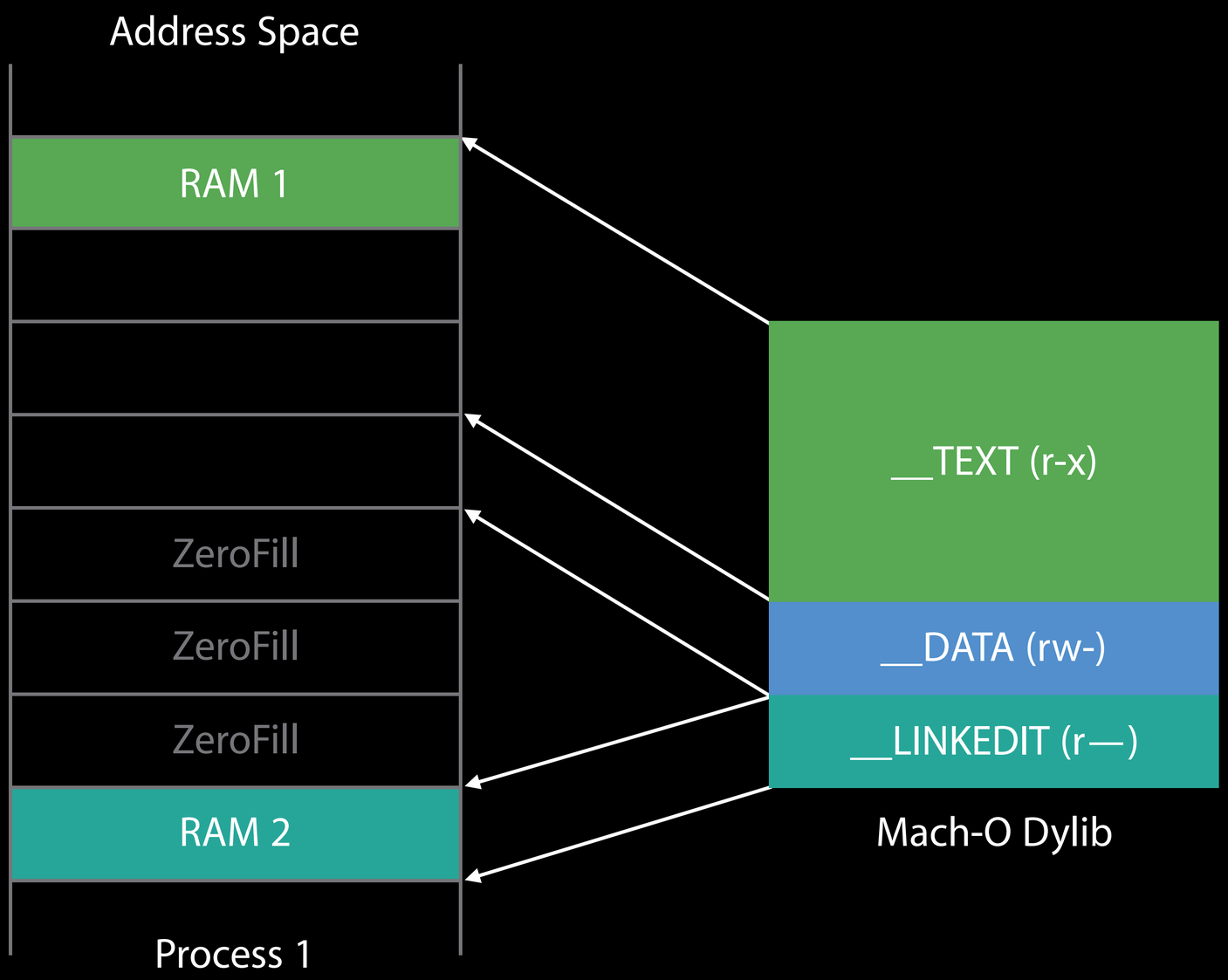
Mach-O Image Loading



Mach-O Image Loading



Mach-O Image Loading



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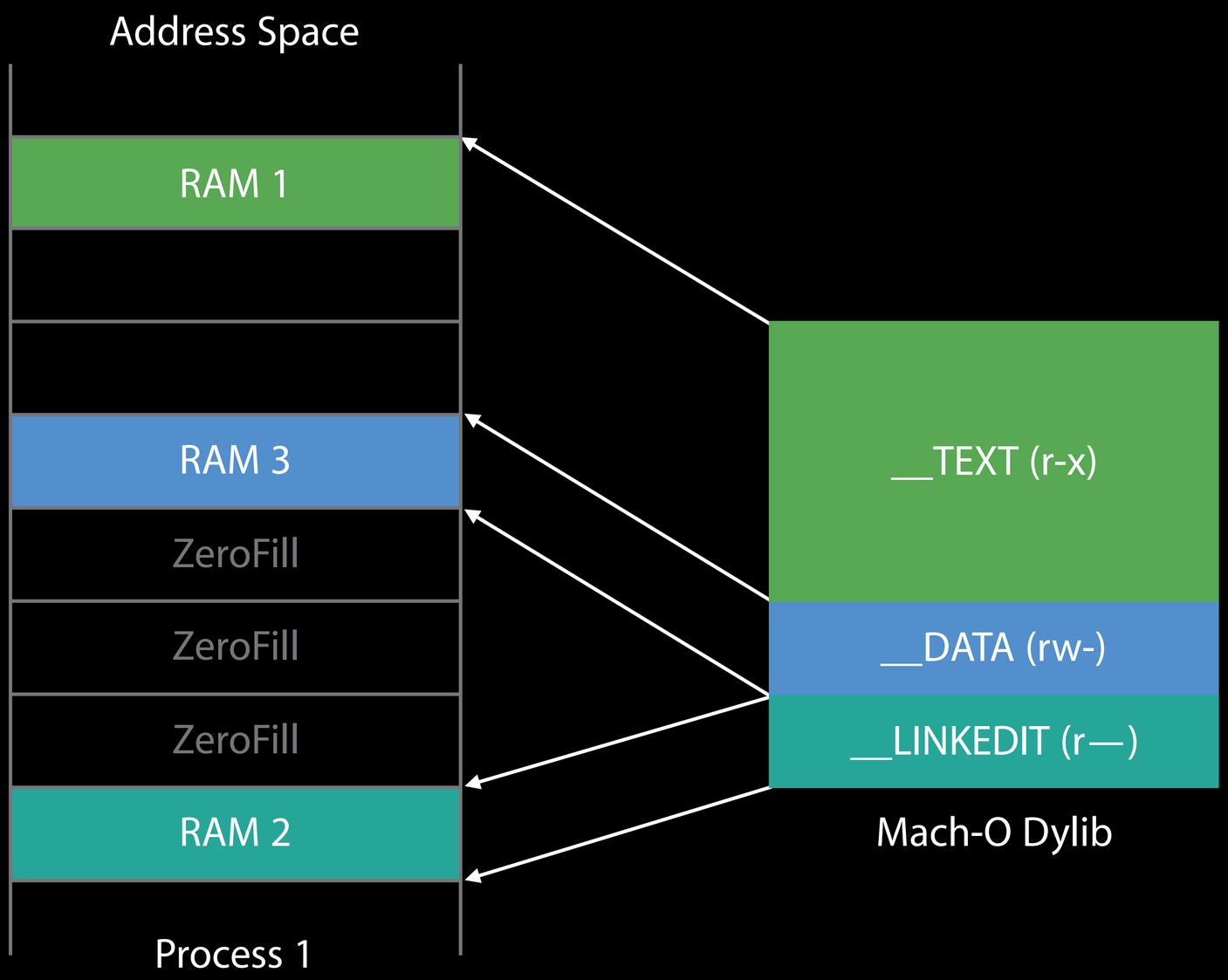

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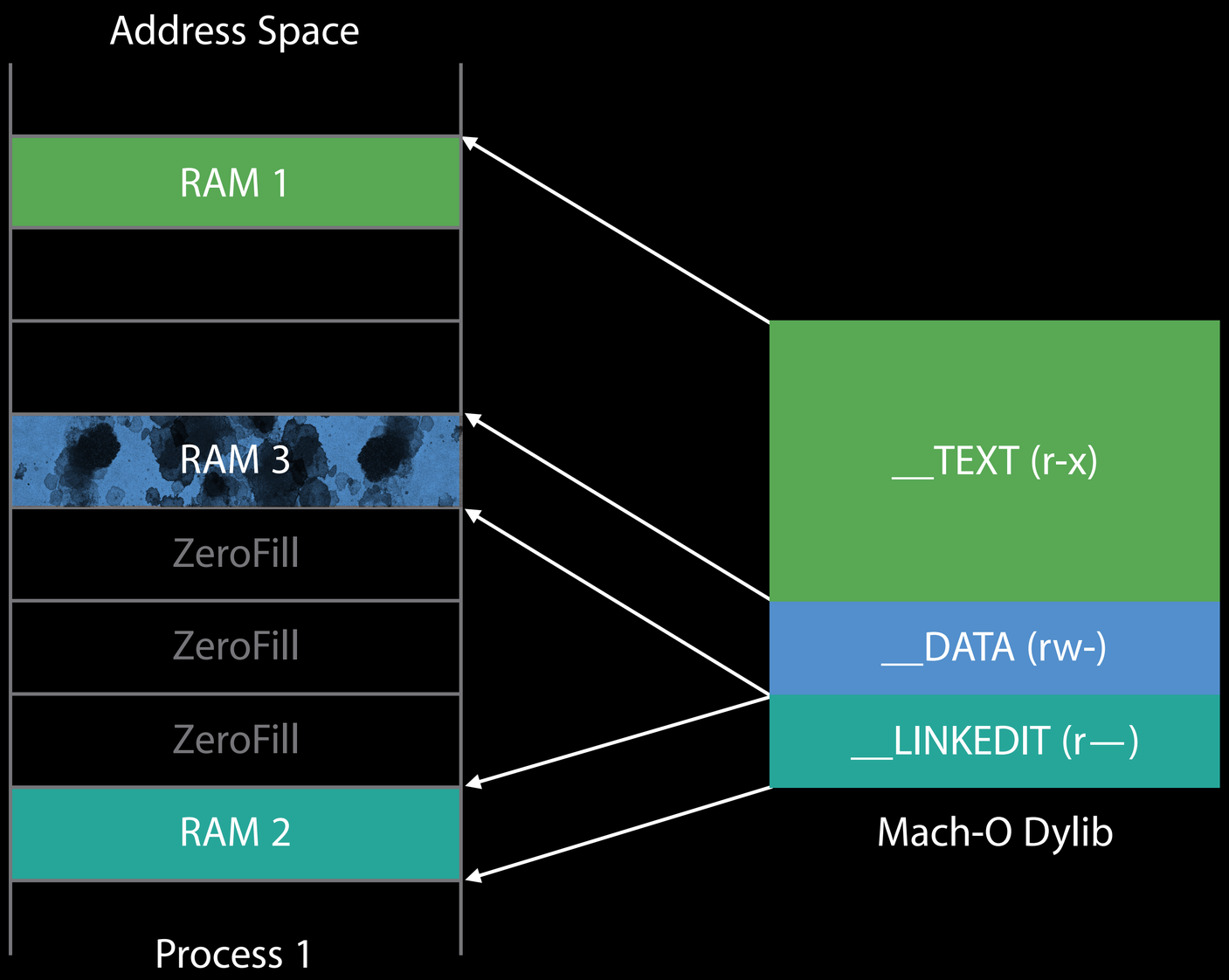

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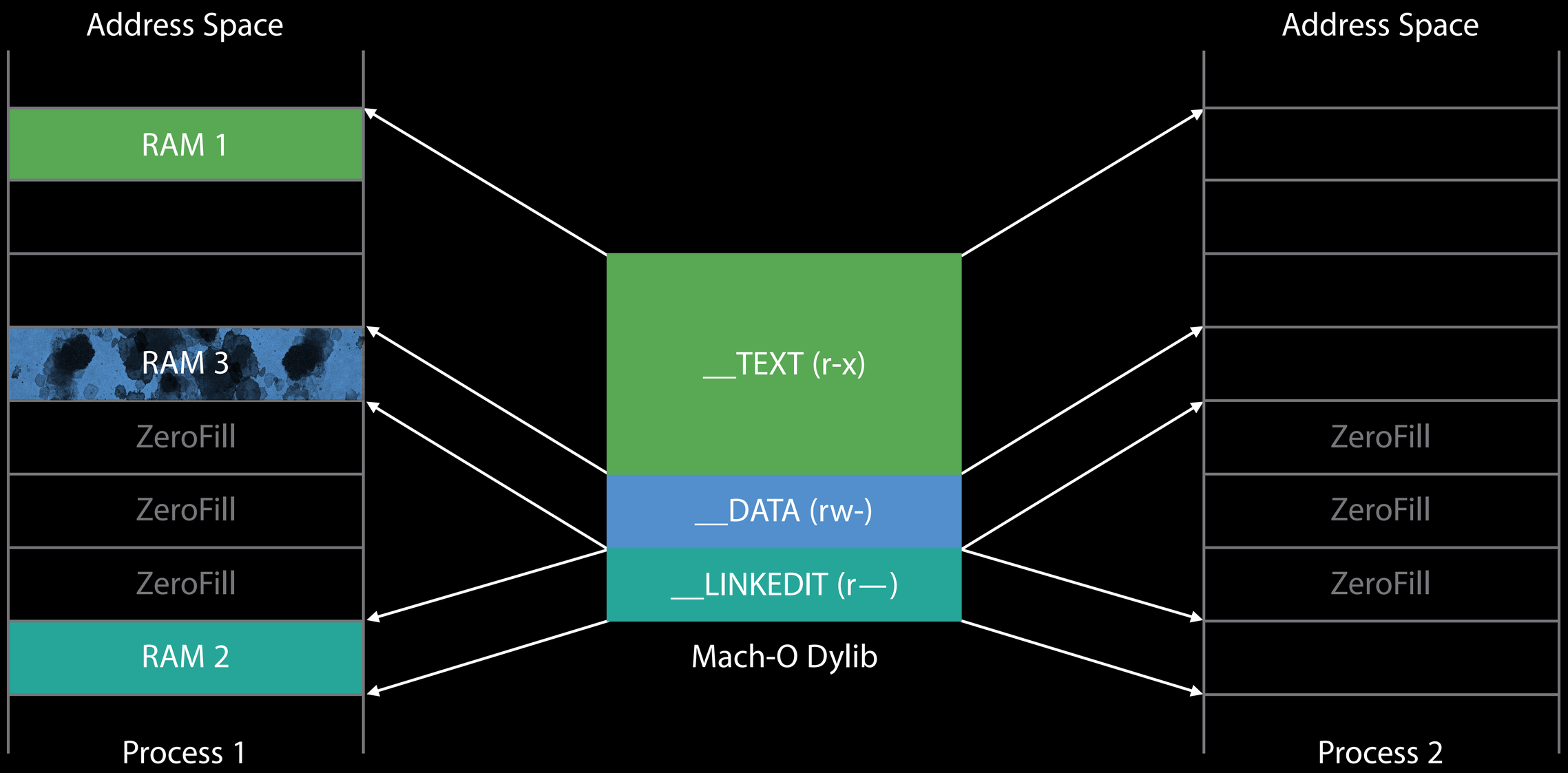

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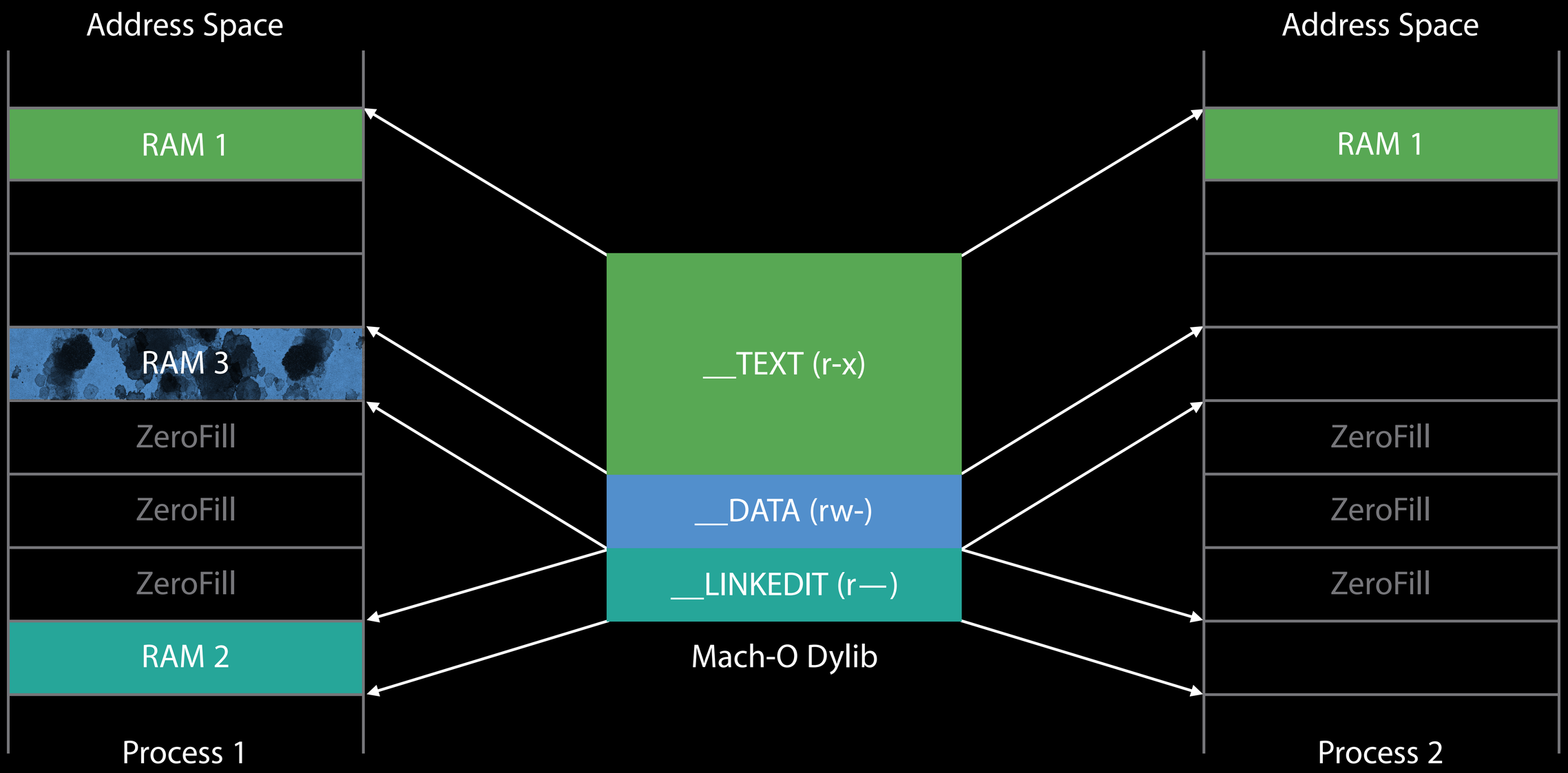
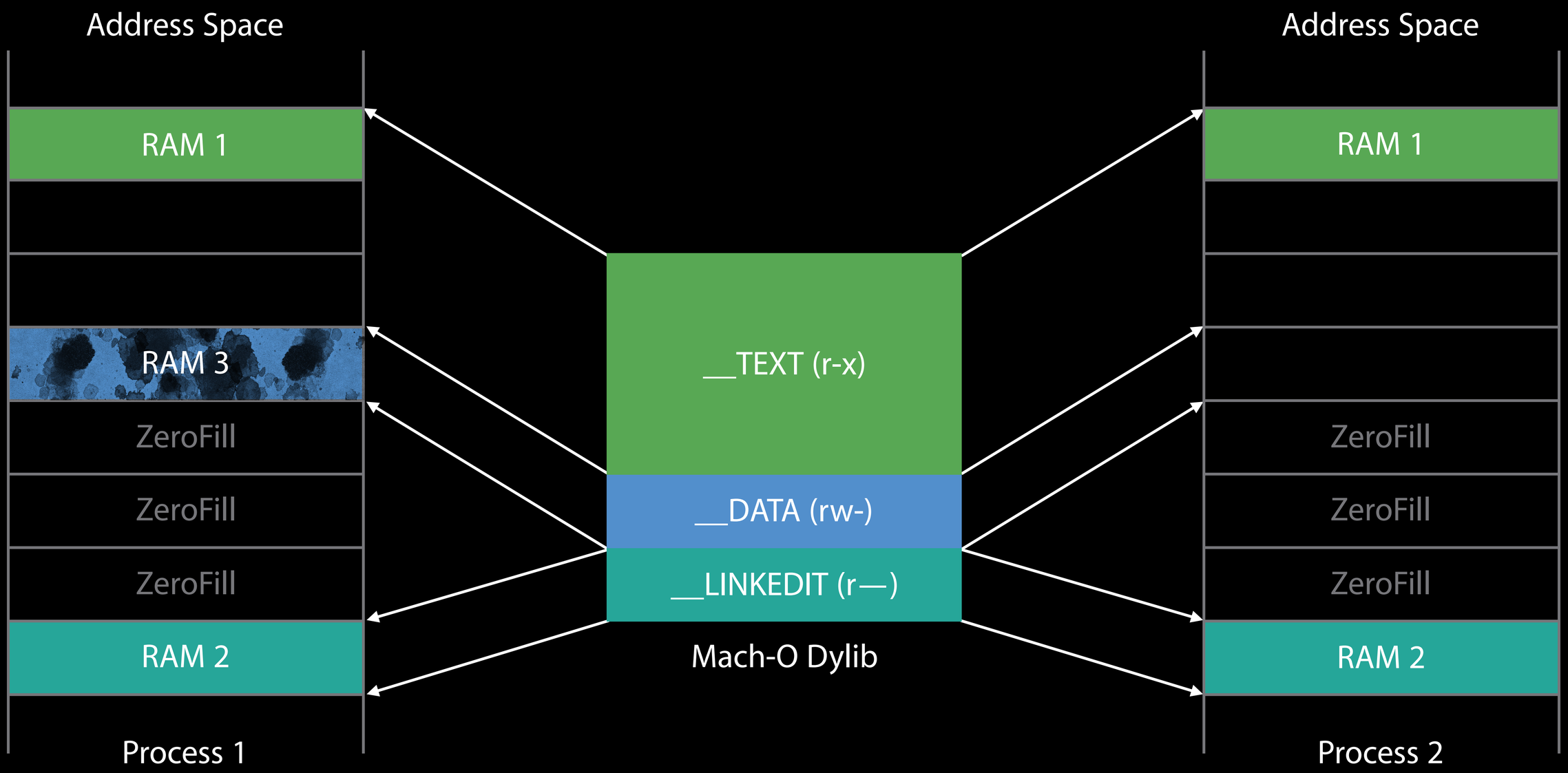
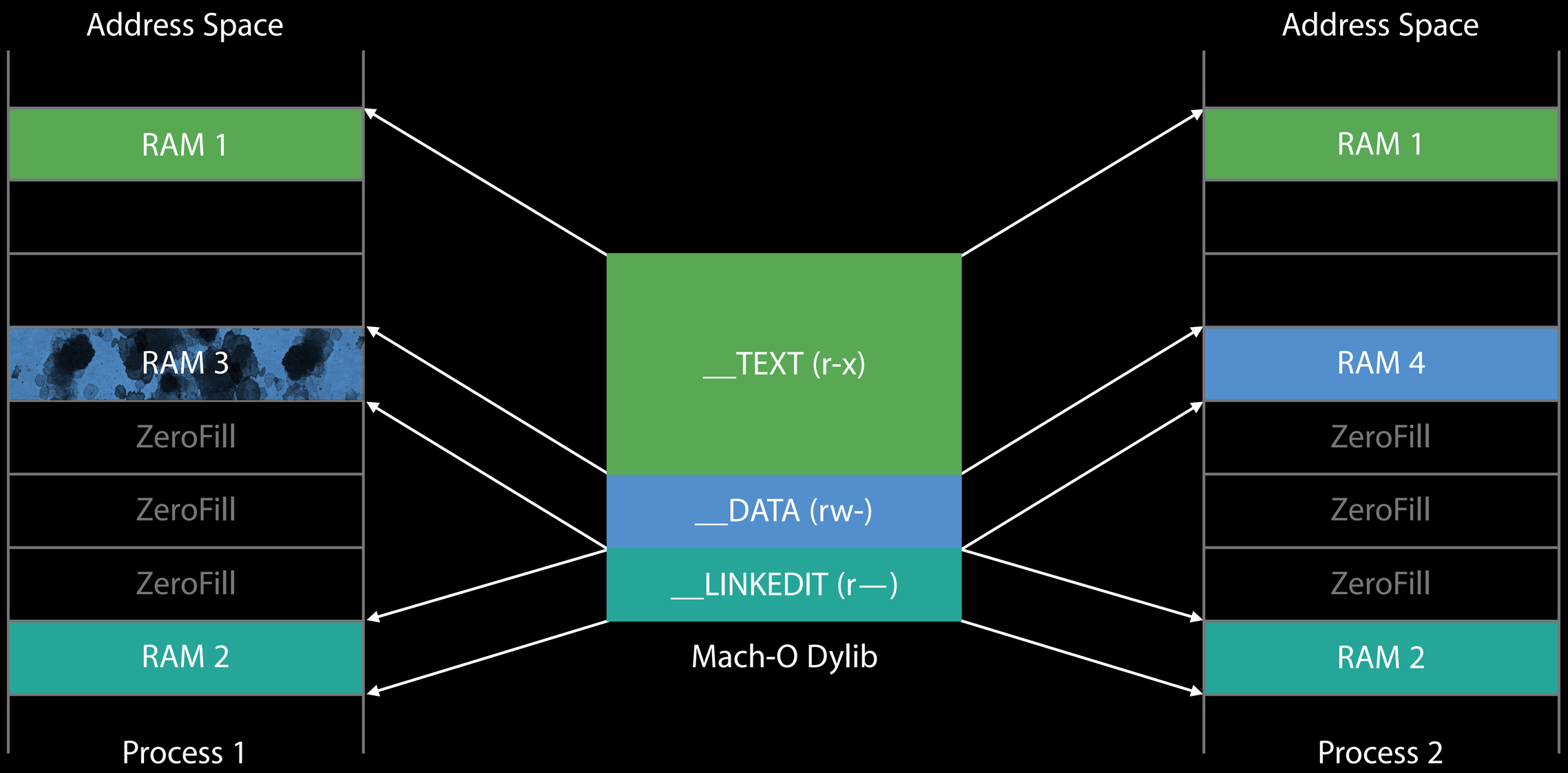


Mach-O Image Loading



Mach-O Image Loading



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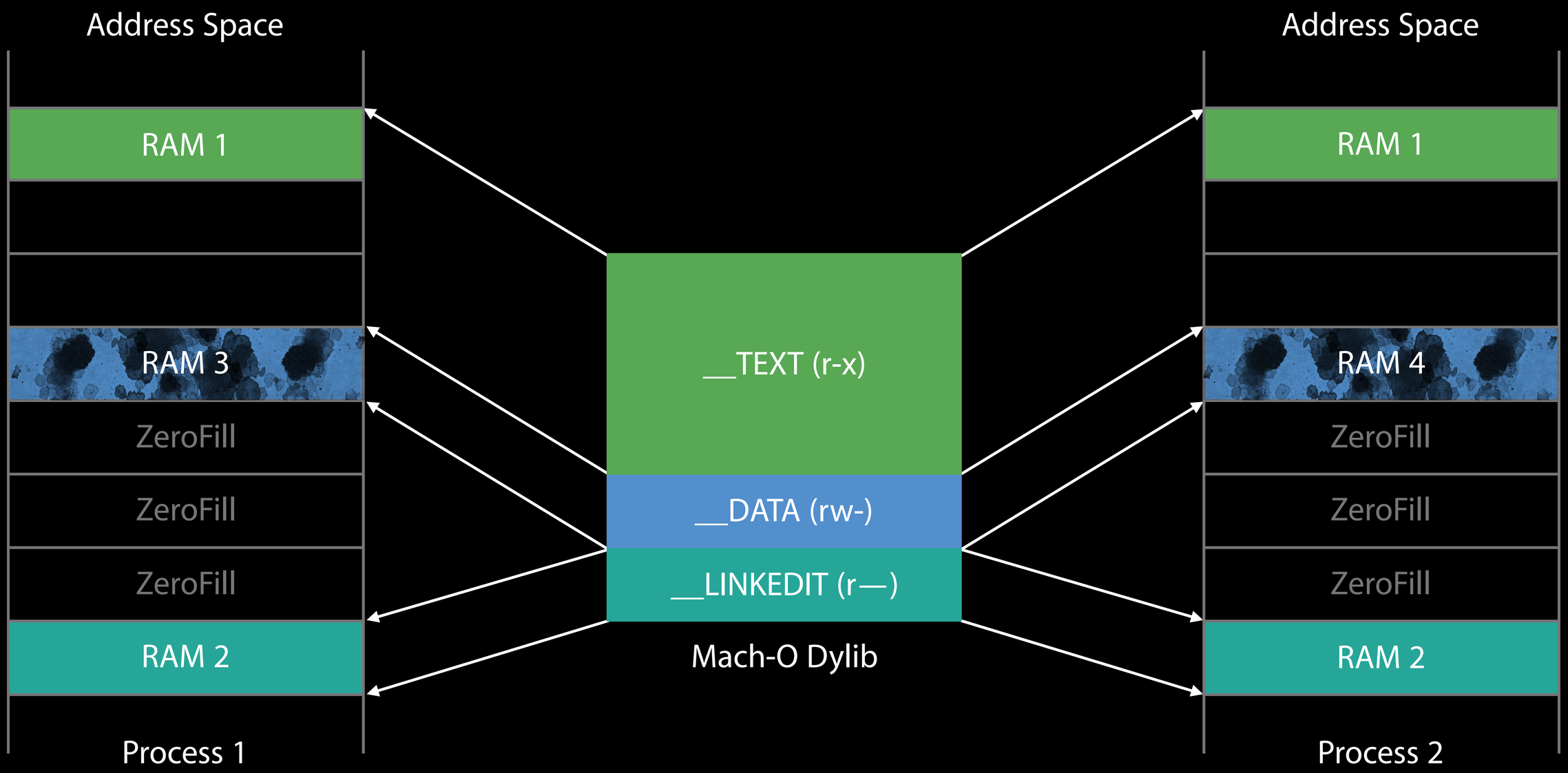
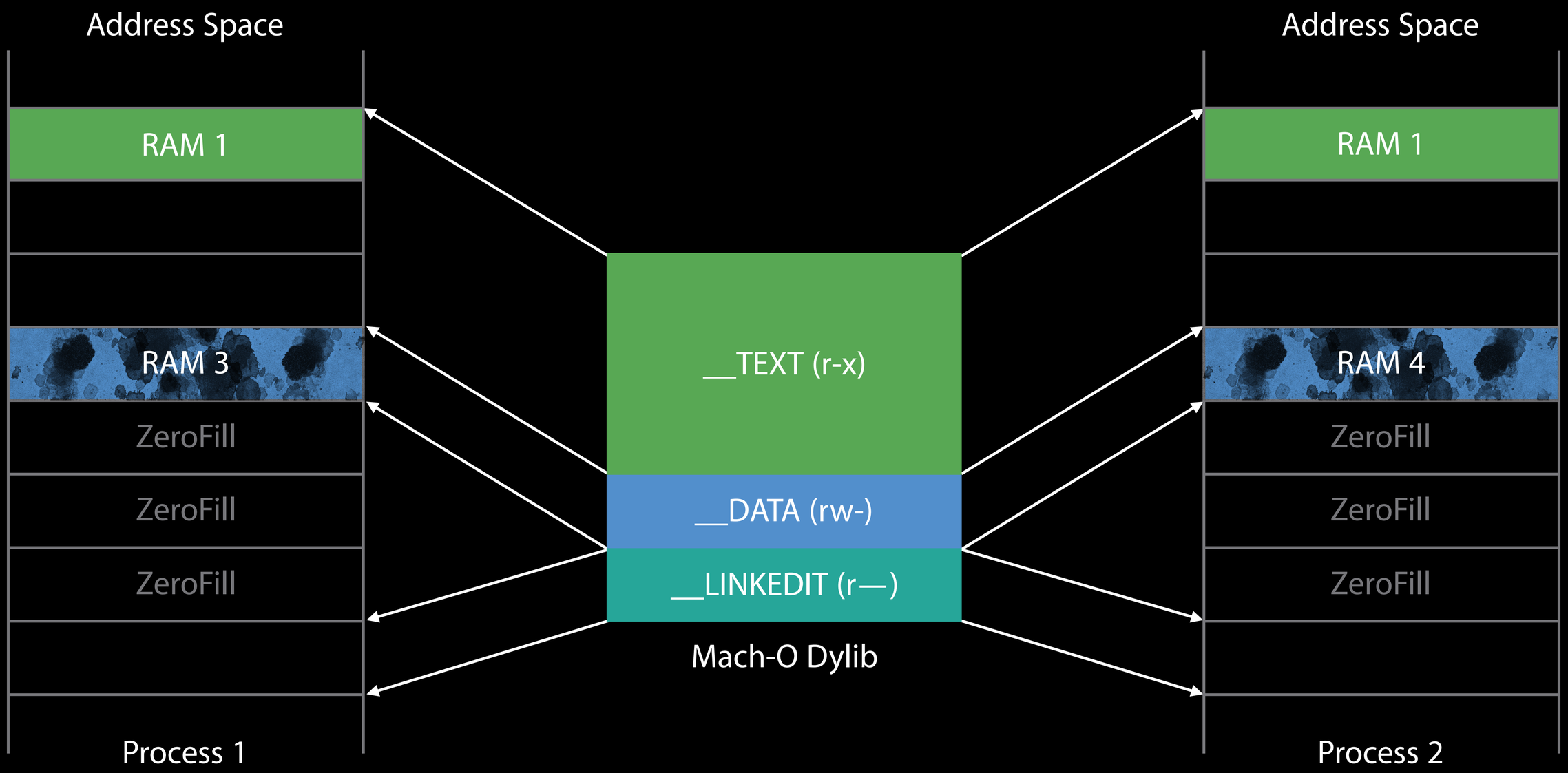


Mach-O Image Loading



Security

ASLR

- Address Space Layout Randomization
- Images load at random address

Code Signing

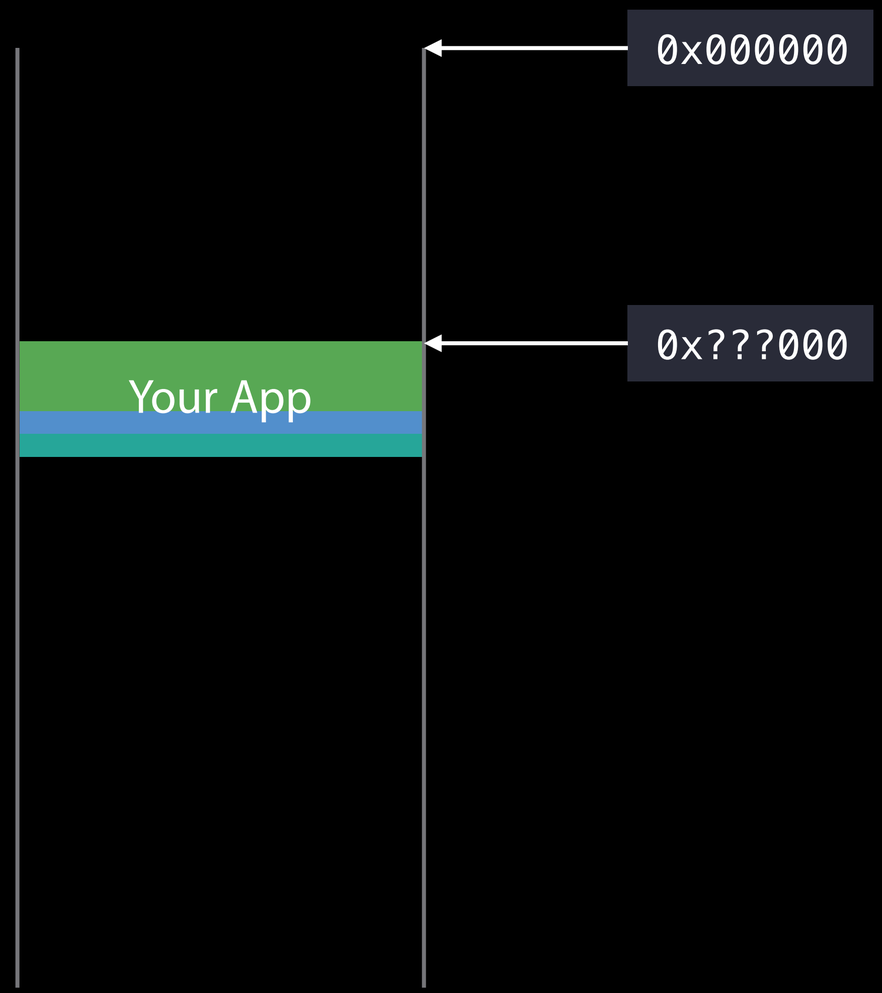
- Content of each page is hashed
- Hash is verified on page-in

exec() to main()

exec()

Kernel maps your application into new address space

Start of your app is random



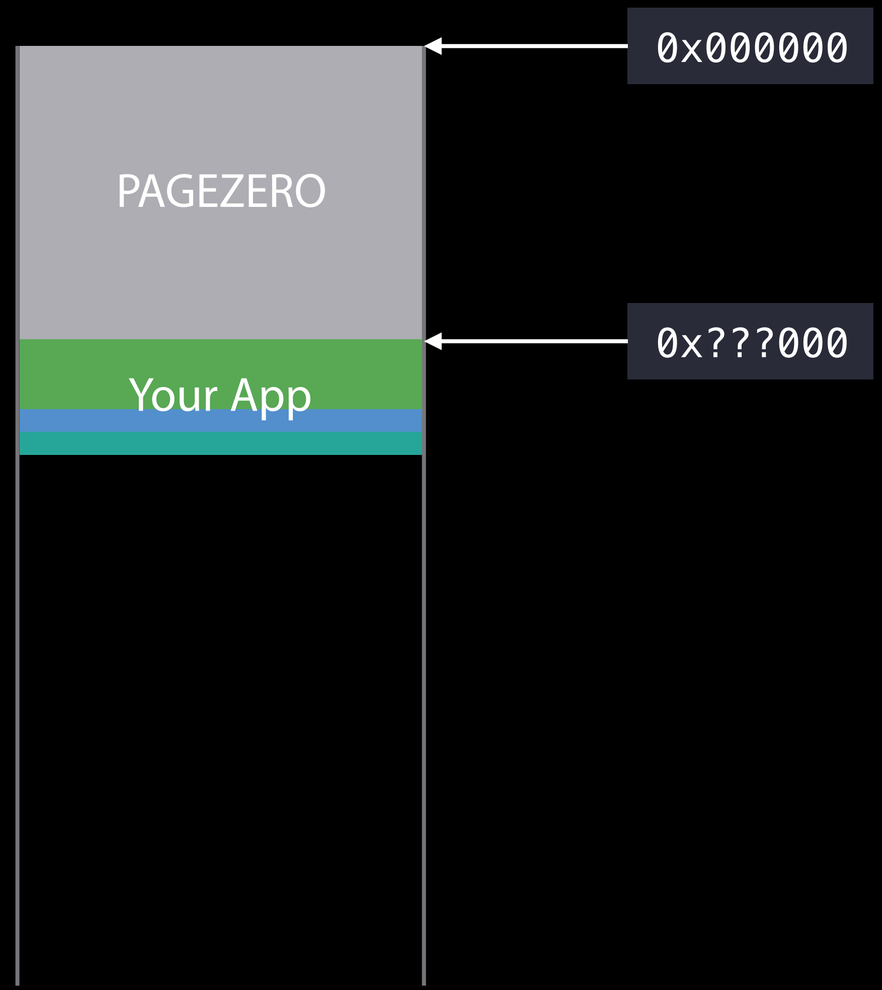
exec()

Kernel maps your application into new address space

Start of your app is random

Low memory is marked inaccessible

- 4KB+ for 32-bit process
- 4GB+ for 64-bit processes
- Catches NULL pointer usage
- Catches pointer truncation errors



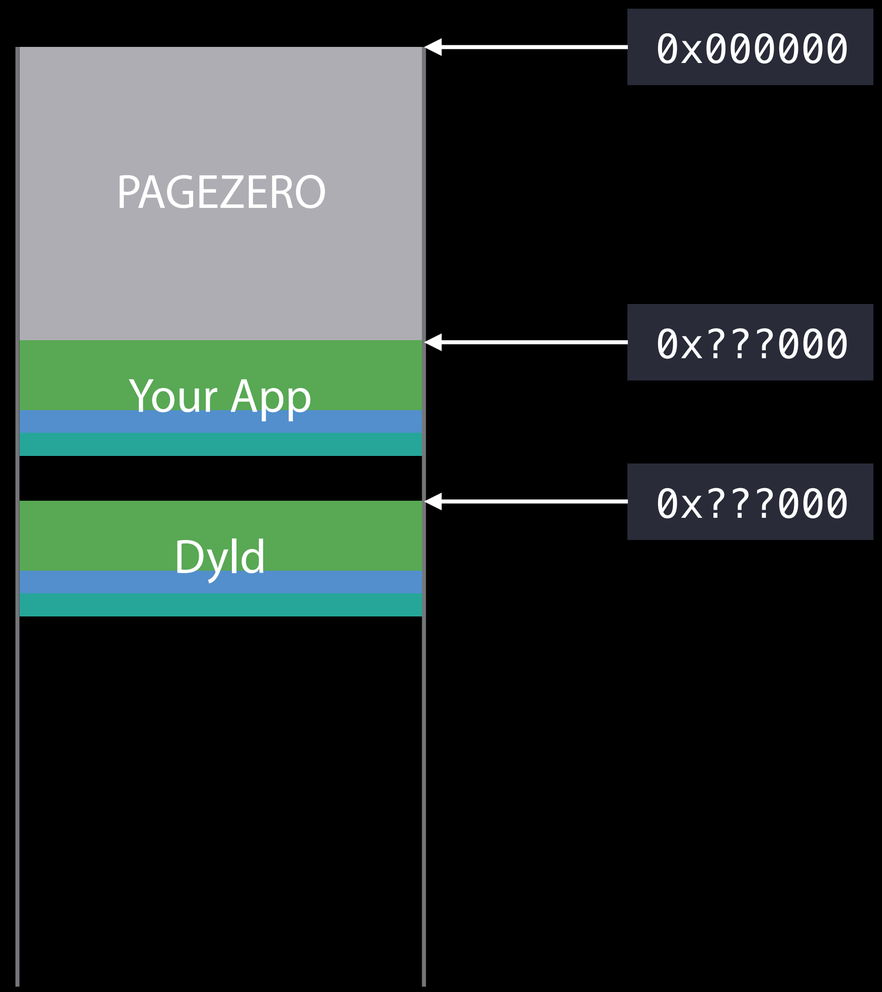
What About Dylibs?

Kernel loads helper program

- Dyld (dynamic loader)
- Executions starts in dyld

Dyld runs in-process

- Loads dependent dylibs
- Has same permissions as app



Dyld Steps

Map all dependent dylibs, recurse

Rebase all images

Bind all images

ObjC prepare images

Run initializers

Loading Dylibs

Parse list of dependent dylibs

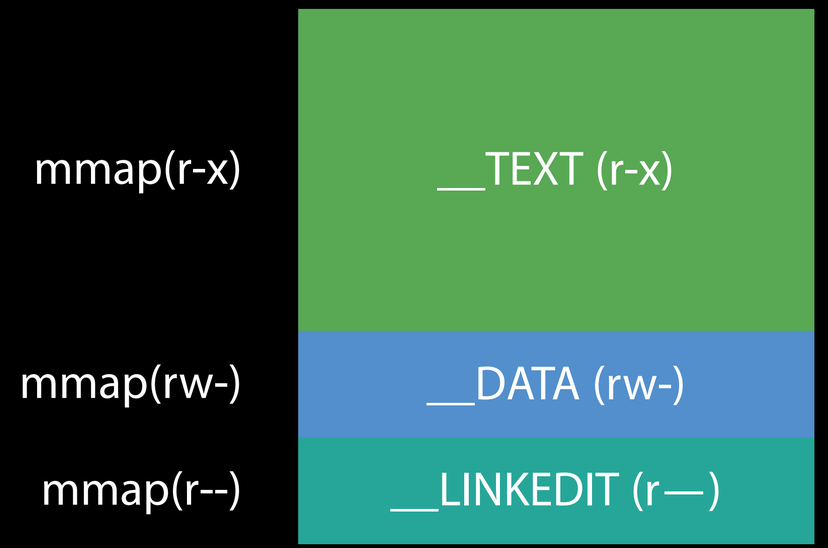
Find requested mach-o file

Open and read start of file

Validate mach-o

Register code signature

Call `mmap()` for each segment



Load dylibs → Rebase → Bind → ObjC → Initializers

Recursive Loading

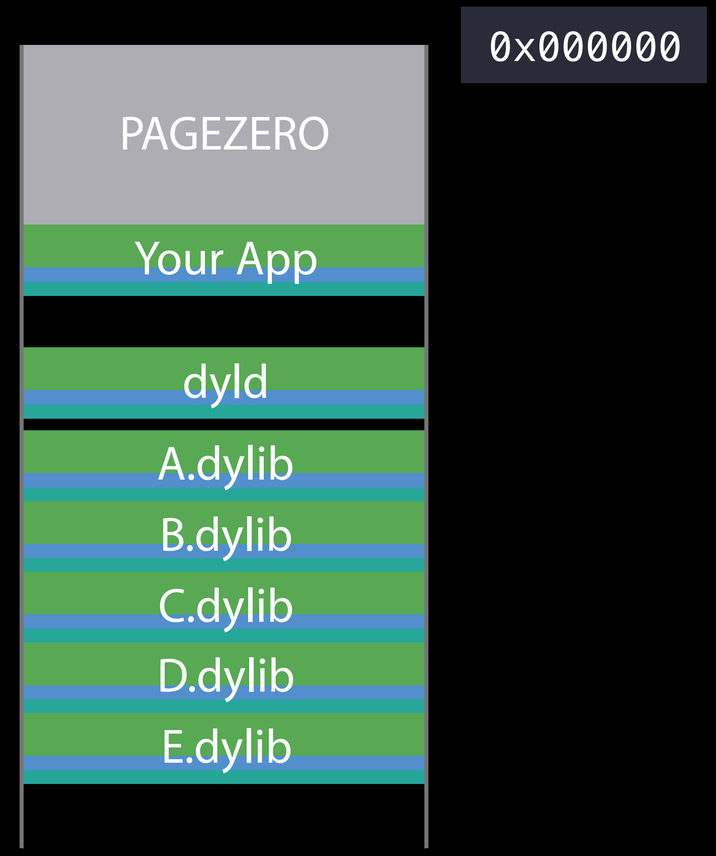
All your app's direct dependents are loaded

Plus any dylib's needed by those dylibs

Rinse and repeat

Apps typically load 100 to 400 dylibs!

- Most are OS dylibs
- We've optimized loading of OS dylibs



Load dylibs | Rebase | Bind | ObjC | Initializers

Fix-ups

Code signing means instructions cannot be altered

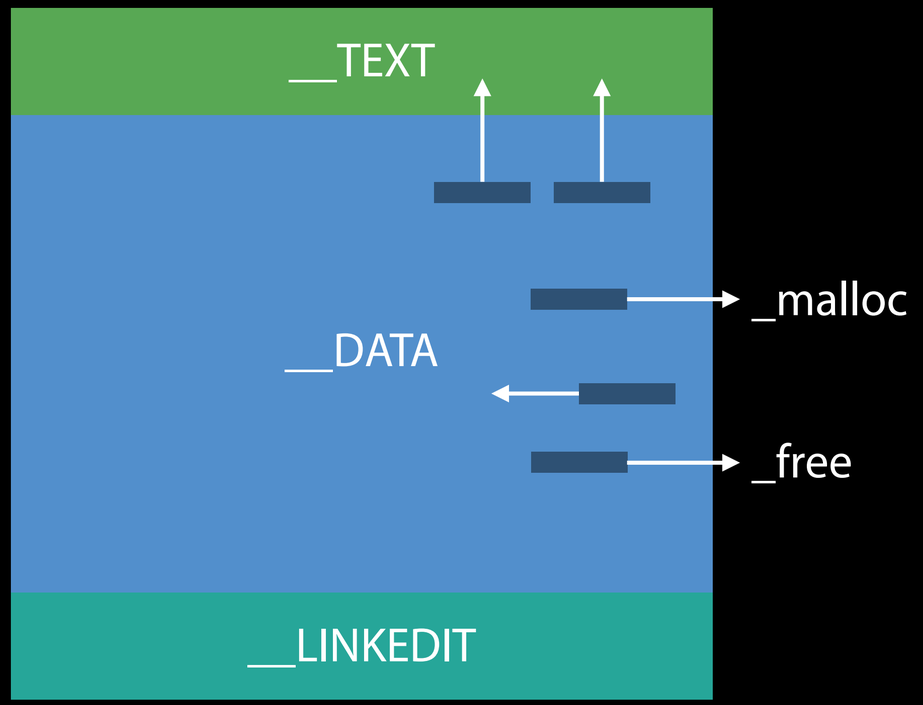
Modern code-gen is dynamic PIC (Position Independent Code)

- Code can run loaded at any address and is never altered
- Instead, all fix ups are in __DATA

Rebasing and Binding

Rebasing: Adjusting pointers to within an image

Binding: Setting pointers to outside image



```
[~]> xcrun dyldinfo -rebase -bind -lazy_bind myapp.app/myapp
rebase information:
segment section          address     type
__DATA  __const          0x10000C1A0  pointer
__DATA  __const          0x10000C1C0  pointer
__DATA  __const          0x10000C1E0  pointer
__DATA  __const          0x10000C210  pointer
…
bind information:
segment section          address      type   add dylib          symbol
__DATA  __objc_classrefs 0x10000D1E8  pointer  0 CoreFoundation  _OBJC_CLASS_$_NSObject
__DATA  __data           0x10000D4D0  pointer  0 CoreFoundation  _OBJC_METACLASS_$_NSObject
__DATA  __data           0x10000D558  pointer  0 CoreFoundation  _OBJC_METACLASS_$_NSObject
__DATA  __got            0x10000C018  pointer  0 libswiftCore    __TMSS
…
lazy binding information:
segment section          address     index  dylib           symbol
__DATA  __la_symbol_ptr  0x10000C0A8 0x0000 libSystem        __Block_copy
__DATA  __la_symbol_ptr  0x10000C0B0 0x0014 libSystem        __Block_release
__DATA  __la_symbol_ptr  0x10000C0B8 0x002B libSystem        _memcpy
…
```

Rebasing

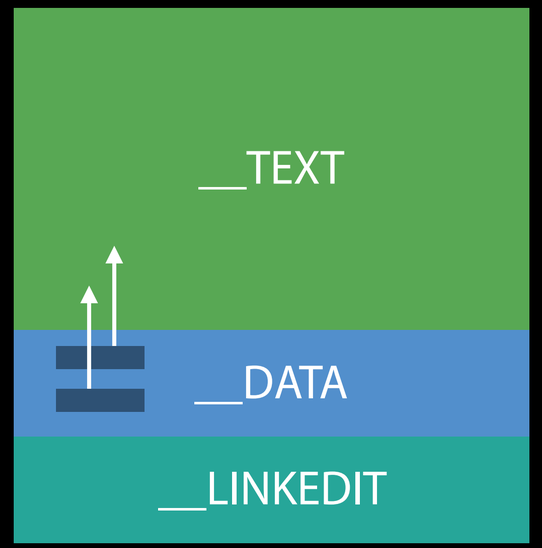
Rebasing is adding a "slide" value to each internal pointer

Slide = actual_address - preferred_address

Location of rebase locations is encoded in LINKEDIT

Pages-in and COW page

Rebasing is done in address order, so kernel starts prefetching



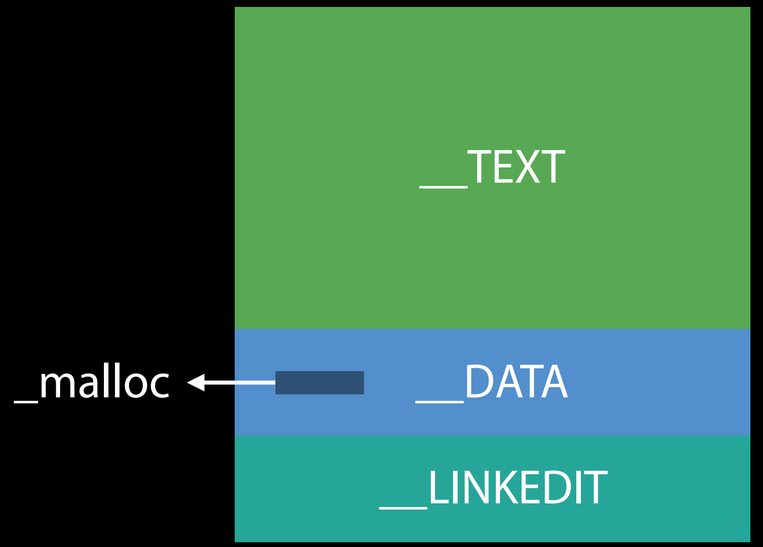
Binding

All references to something in another dylib are symbolic

Dyld needs to find symbol name

More computational than rebasing

Rarely page faults



Notify ObjC Runtime

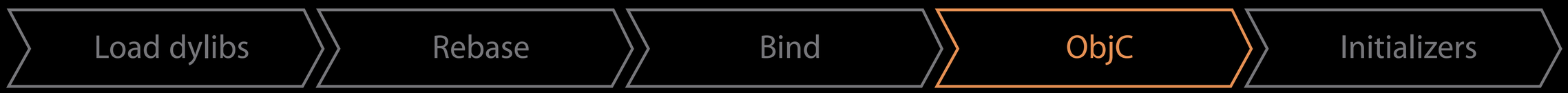
Most ObjC set up done via rebasing and binding

All ObjC class definitions are registered

Non-fragile ivars offsets updated

Categories are inserted into method lists

Selectors are uniqued



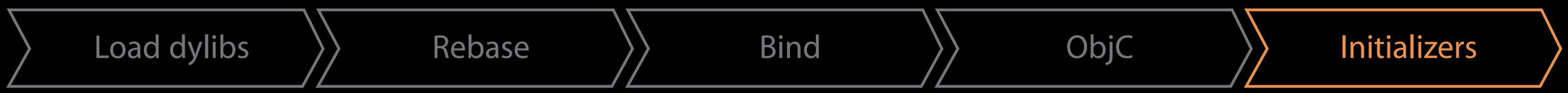
Initializers

C++ generates initializer for statically allocated objects

ObjC +load methods

Run "bottom up" so each initializer can call dylibs below it

Lastly, Dyld calls main() in executable



Pre-main() Summary

Dyld is a helper program

- Loads all dependent dylibs
- Fixes up all pointers in DATA pages
- Runs all initializers

Putting Theory into Practice

Louis Gerbarg

Improving Launch Times

Overview

How fast?

How to measure?

Why is launch slow?

What can you do?

Spoiler

Do Less Stuff

Improving Launch Times

Goals

Launch faster than animation

- Duration varies on devices
- 400ms is a good target

Don’t ever take longer than 20 seconds

- App will be killed

Test on the slowest supported device

Improving Launch Times

Launch recap

Parse images

Map images

Rebase images

Bind images

Run image initializers

Call `main()`

Call `UIApplicationMain()`

Call `applicationWillFinishLaunching`

Improving Launch Times

Warm vs. cold launch

Warm launch

- App and data already in memory

Cold launch

- App is not in kernel buffer cache

Warm and cold launch times will be different

- Cold launch times are important
- Measure cold launch by rebooting

Improving Launch Times

Measurements

NEW

Measuring before `main()` is difficult

Dyld has built in measurements

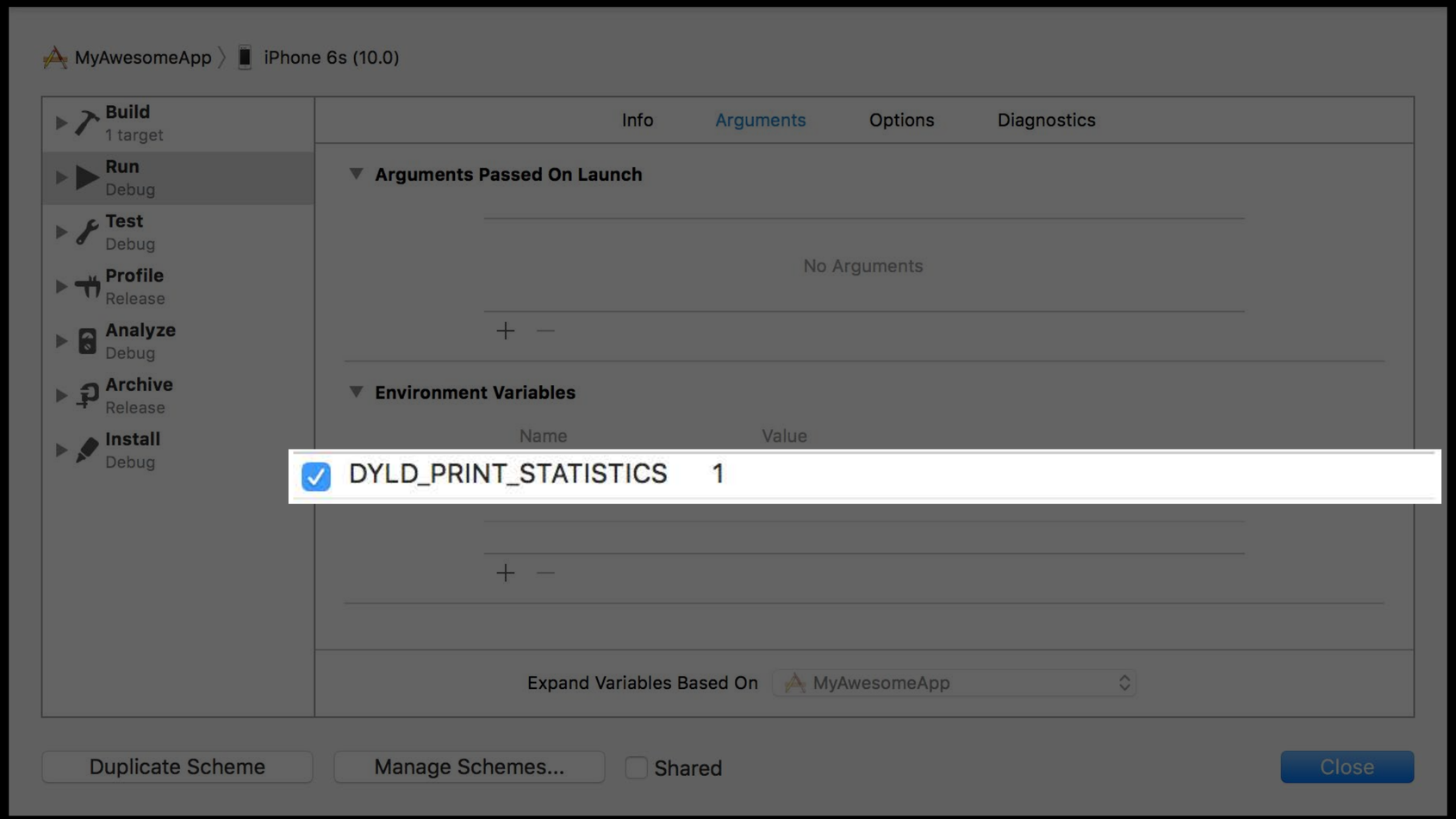
- `DYLD_PRINT_STATISTICS` environment variable
  - Available on shipping OSes
  - Significantly enhanced in new OSes
  - Available in seed 2

Debugger pauses every dylib load

- Dyld subtracts out debugger time
- Console times less than wall clock

Improving Launch Times

DYLD_PRINT_STATISTICS



```
Total pre-main time: 10.6 seconds (100.0%)
         dylib loading time:  240.09 milliseconds (2.2%)
        rebase/binding time:  351.29 milliseconds (3.3%)
            ObjC setup time:  11.83 milliseconds (0.1%)
           initializer time:  10 seconds (94.3%)
          slowest intializers :
                MyAwesomeApp :  10.0 seconds (94.2%)
```

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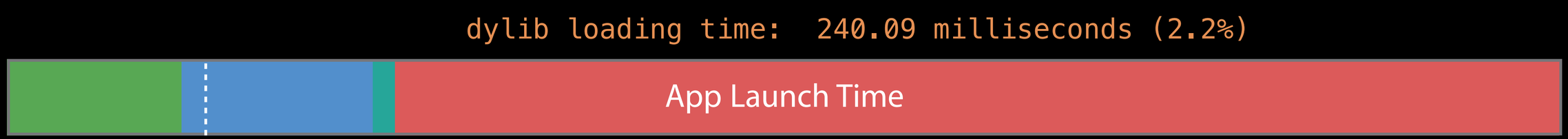
Dylib Loading

Embedded dylibs are expensive



Dylib Loading

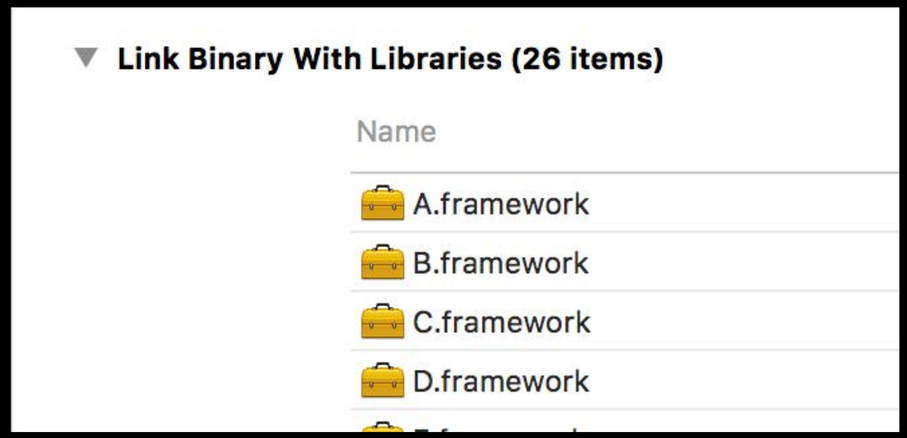
Embedded dylibs are expensive

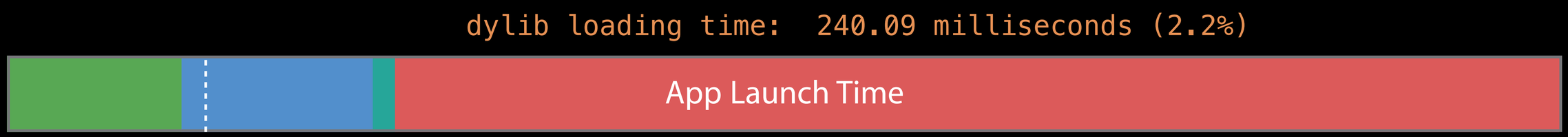
Use fewer dylibs

- Merge existing dylibs
- Use static archives

Lazy load, but…

- `dlopen()` can cause issues
- Actually more work overall





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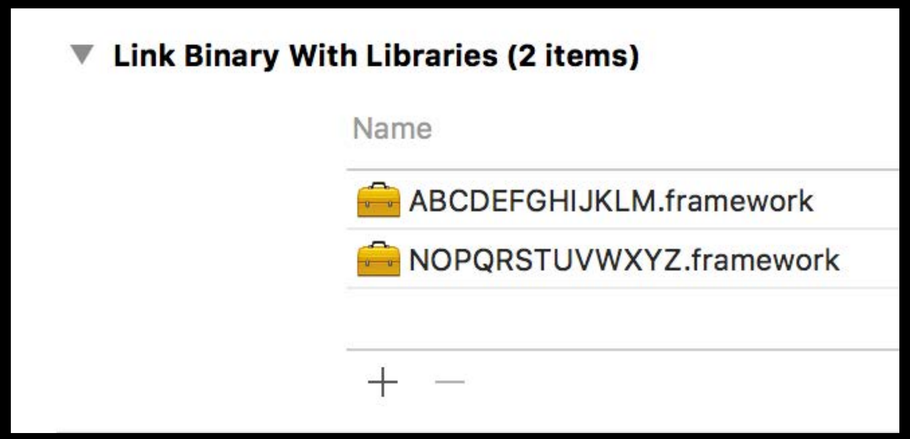


```
dylib loading time:  21.75 milliseconds (0.2%)
```

```
Total pre-main time: 10.4 seconds (100.0%)
         dylib loading time:  21.75 milliseconds (0.2%)
        rebase/binding time:  351.29 milliseconds (3.3%)
           ObjC setup time:  11.83 milliseconds (0.1%)
          initializer time:  10 seconds (94.3%)
     slowest intializers :
               MyAwesomeApp :  10.0 seconds (96.1%)
```

```
Total pre-main time: 10.4 seconds (100.0%)
         dylib loading time:  21.75 milliseconds (0.2%)
        rebase/binding time:  351.29 milliseconds (3.3%)
           ObjC setup time:  11.83 milliseconds (0.1%)
          initializer time:  10 seconds (94.3%)
          slowest intializers :
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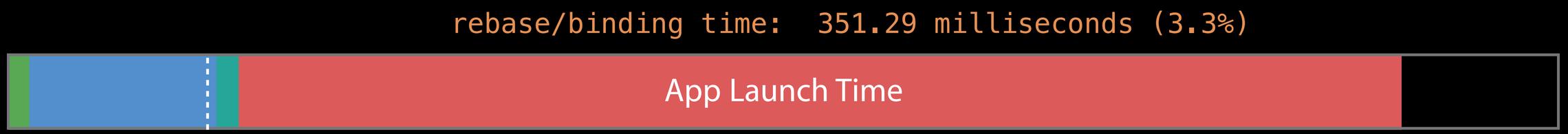
```

Rebase/Binding



Rebase/Binding

Reduce __DATA pointers

Reduce Objective C metadata

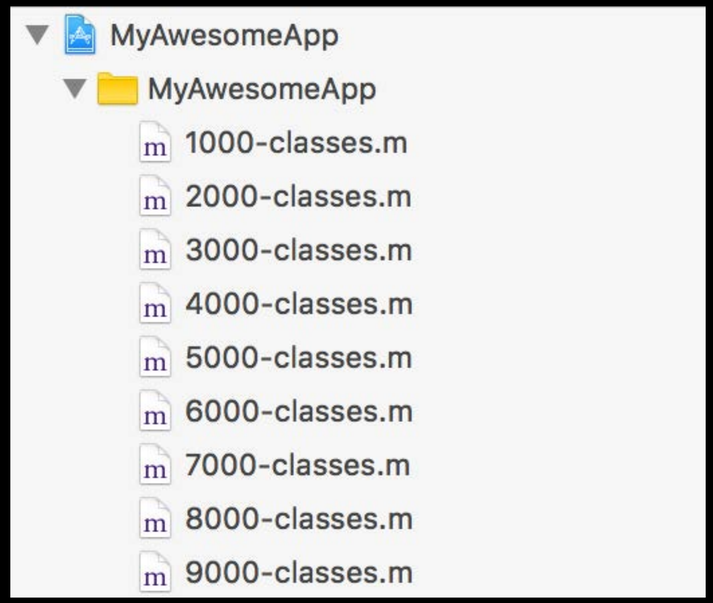
- Classes, selectors, and categories

Reduce C++ virtual

Use Swift structs

Examine machine generated code

- Use offsets instead of pointers
- Mark read only




```
rebase/binding time:  351.29 milliseconds (3.3%)
```

Rebase/Binding

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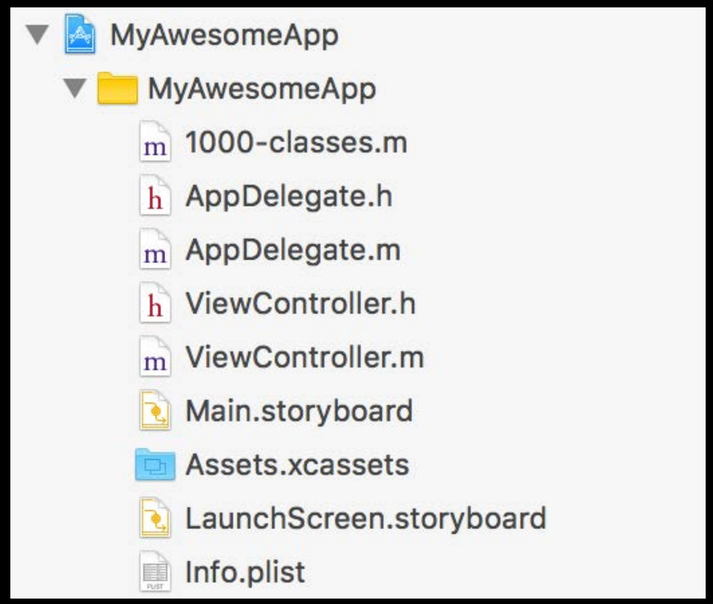



```
rebase/binding time:  19.33 milliseconds (0.2%)
```

```
Total pre-main time: 10.1 seconds (100.0%)
         dylib loading time:  21.75 milliseconds (0.2%)
        rebase/binding time:  19.33 milliseconds (0.2%)
            ObjC setup time:  11.83 milliseconds (0.1%)
           initializer time:  10 seconds (99.4%)
          slowest intializers :
                MyAwesomeApp :  10.0 seconds (99.3%)
```

```
Total pre-main time: 10.1 seconds (100.0%)
         dylib loading time:  21.75 milliseconds (0.2%)
        rebase/binding time:  19.33 milliseconds (0.2%)
            ObjC setup time:  11.83 milliseconds (0.1%)
           initializer time:  10 seconds (99.4%)
          slowest intializers :
                MyAwesomeApp :  10.0 seconds (99.3%)
```

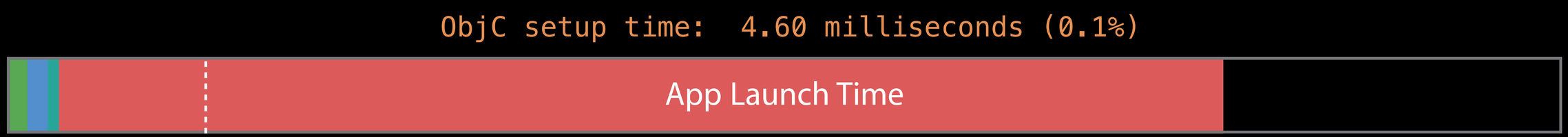
ObjC Setup

Class registration

Non-fragile ivars offsets updated

Category registration

Selector uniquing



```
Total pre-main time: 10.6 seconds (100.0%)
         dylib loading time:  21.75 milliseconds (2.2%)
        rebase/binding time:  19.33 milliseconds (3.3%)
            ObjC setup time:  4.60 milliseconds (0.1%)
           initializer time:  10 seconds (94.3%)
           slowest intializers :
             MyAwesomeApp :  10.0 seconds (99.3%)
```

```
Total pre-main time: 10.6 seconds (100.0%)
         dylib loading time:  21.75 milliseconds (2.2%)
        rebase/binding time:  19.33 milliseconds (3.3%)
            ObjC setup time:  4.60 milliseconds (0.1%)
           initializer time:  10 seconds (99.4%)
           slowest intializers :
             MyAwesomeApp :  10.0 seconds (99.3%)
```

Initializers

Explicit

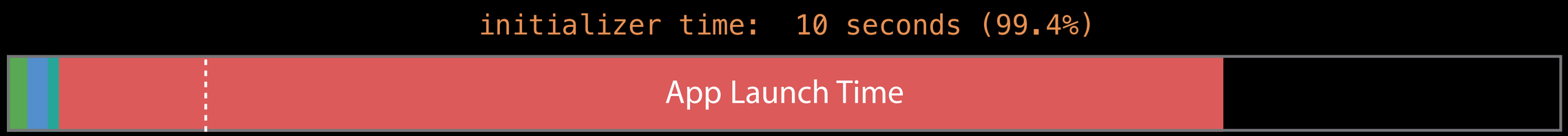
ObjC `+load` methods

- Replace with `+initiailize`

C/C++ __attribute__((constructor))

Replace with call site initializers

- `dispatch_once()`
- `pthread_once()`
- `std::once()`



Initializers

Implicit

C++ statics with non-trivial constructors

- Replace with call site initializers
- Only set simple values (PODs)
- -Wglobal-constructors
- Rewrite in Swift

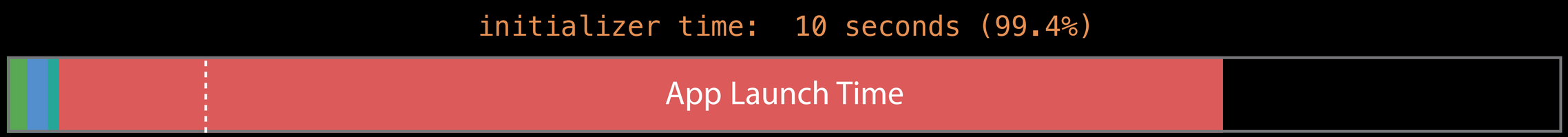
Do not call `dlopen()` in initializers

Do not create threads in initializers

```
#import <UIKit/UIKit.h>
#import "AppDelegate.h"

struct Pause {
    Pause(uint32_t i) {
        sleep(i);
    }
};

Pause onLaunch(10);
```



Initializers

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#import <UIKit/UIKit.h>
#import "AppDelegate.h"

struct Pause {
    Pause(uint32_t i) {
        sleep(i);
    }
};

//Pause onLaunch(10);
```

```
initializer time:  3.96 milliseconds (7.9%)
```

```
Total pre-main time: 49.83 milliseconds (100.0%)
         dylib loading time:  21.75 milliseconds (43.6%)
        rebase/binding time:  19.33 milliseconds (38.7%)
           ObjC setup time:  4.60 milliseconds (9.2%)
          initializer time:  3.96 milliseconds (7.9%)
     slowest intializers :
       libSystem.B.dylib : 2.80 milliseconds (5.6%)
```

```
Total pre-main time: 49.83 milliseconds (100.0%)
         dylib loading time:  21.75 milliseconds (43.6%)
        rebase/binding time:  19.33 milliseconds (38.7%)
            ObjC setup time:  4.60 milliseconds (9.2%)
           initializer time:  3.96 milliseconds (7.9%)
```

```
slowest intializers :
  libSystem.B.dylib : 2.80 milliseconds (5.6%)
```

TL;DR

Measure launch times with `DYLD_PRINT_STATISTICS`

Reduce launch times by

- Embedding fewer dylibs
- Consolidating Objective-C classes
- Eliminating static initializers

Use more Swift

`dlopen()` is discouraged

- Subtle performance and deadlock issues

More Information

https://developer.apple.com/wwdc16/406

Related Sessions

Optimizing I/O for Performance and Battery Life	Nob Hill	Friday 11:00AM
Using Time Profiler in Instruments	Nob Hill	Friday 3:00PM
iOS App Performance Responsiveness	WWDC 2012	

Labs

Compiler, Objective-C, and C++ Lab	Developer Tools Lab B	Wednesday 12:00PM
Compiler, Objective-C, and C++ Lab	Developer Tools Lab B	Wednesday 1:30PM
Compiler, Optimizing App Startup Time Lab	Developer Tools Lab B	Thursday 1:30PM

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