Optimizing App Startup Time

Linkers, loaders, and you

Session 406

Nick Kledzik Dyld Architect
Louis Gerbarg Dyld Visionary

Audience

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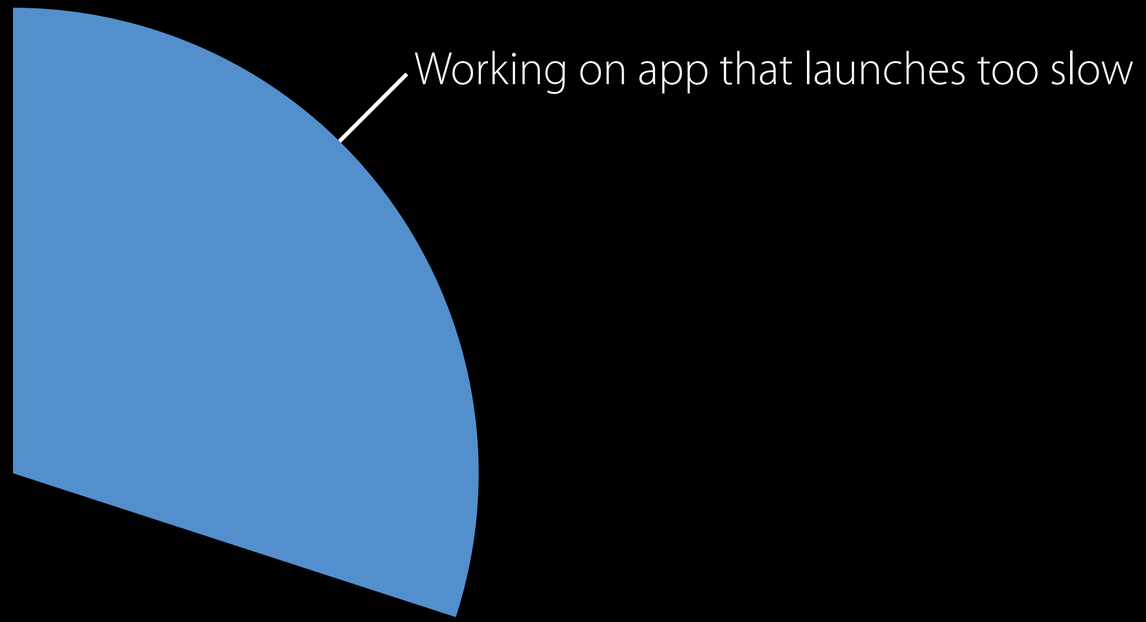

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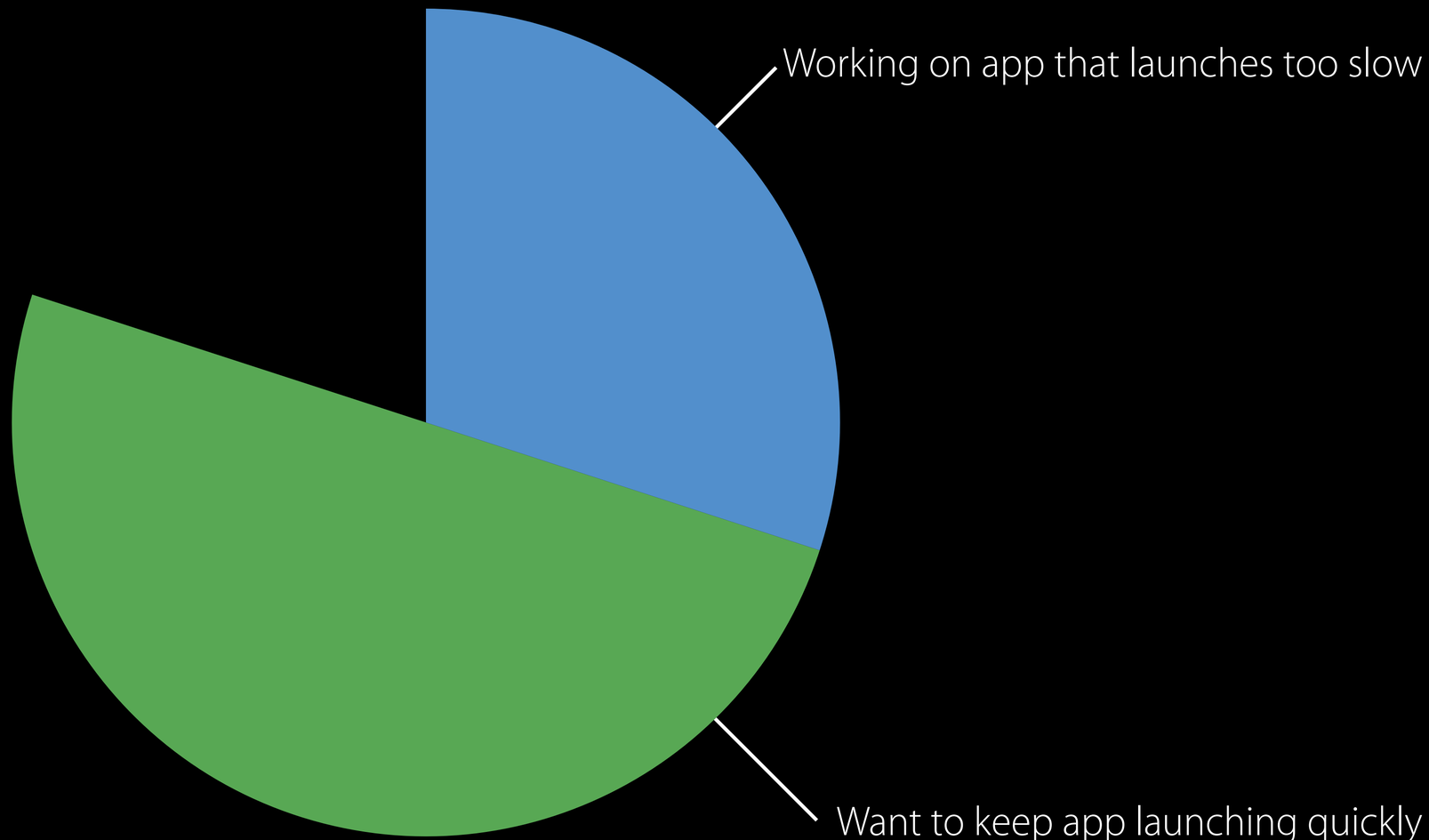
Working on app that launches too slow
Want to keep app launching quickly

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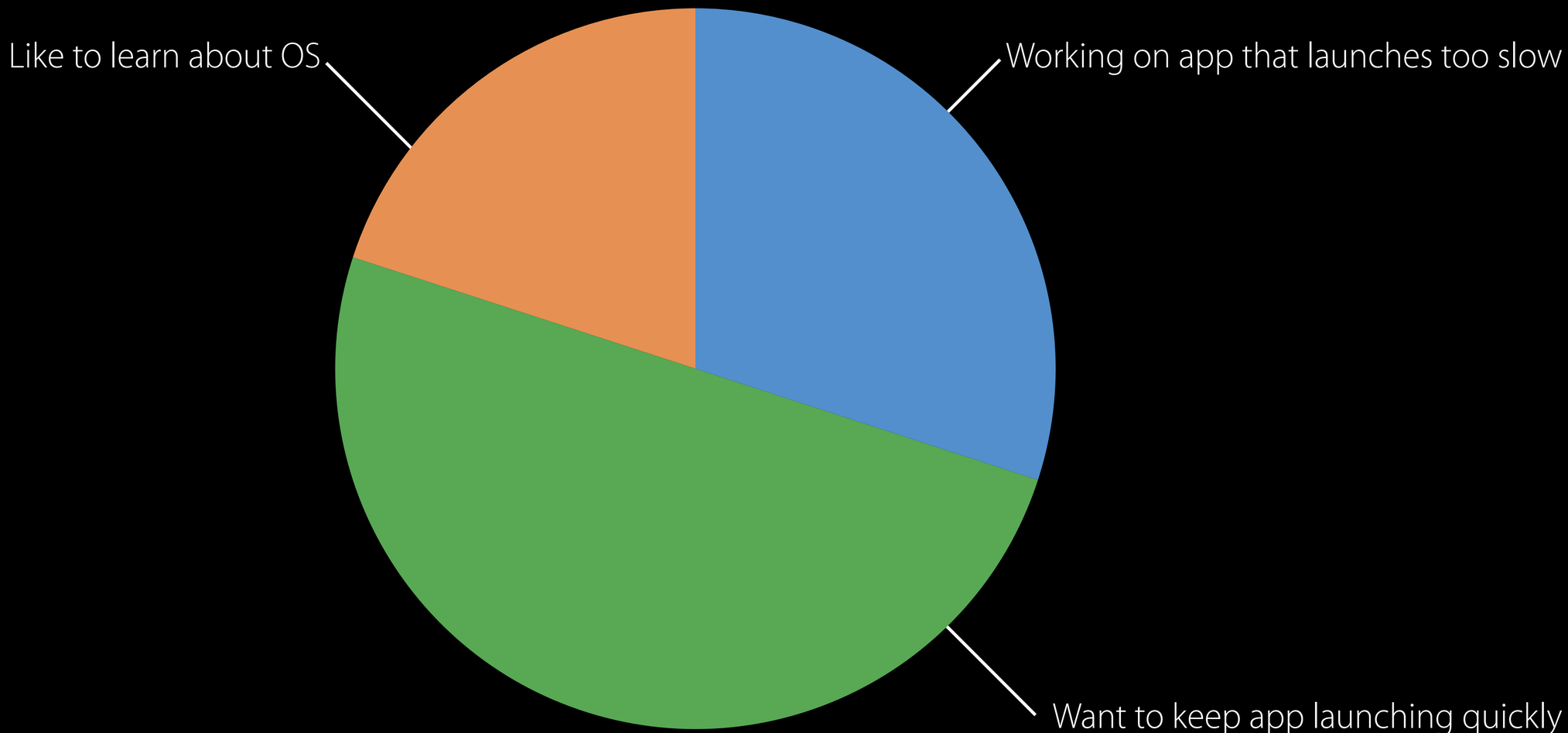
Like to learn about OS
Working on app that launches too slow
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What You Will Learn

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Theory

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

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Practical

- How to measure
- Optimizing start up time

Crash Course:

Mach-O and Virtual Memory

Mach-O Terminology

File Types:

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Image—An executable, dylib, or bundle

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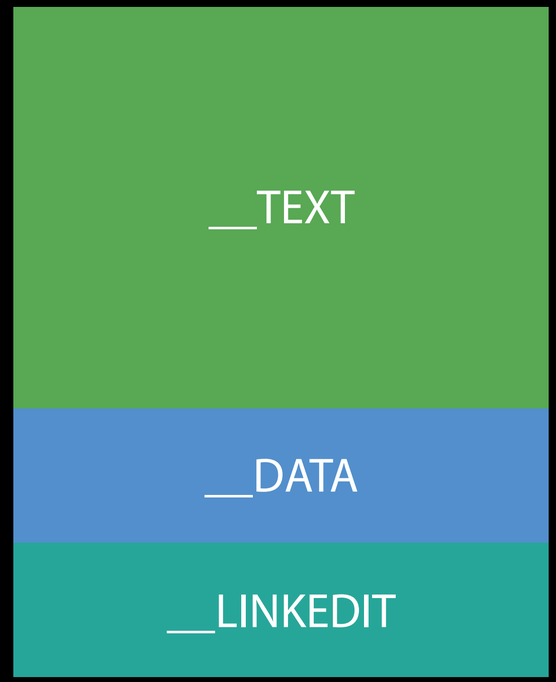
Image—An executable, dylib, or bundle

Framework—Dylib with directory for resources and headers

Mach-O Image File

File divided into segments

- Uppercase names



Mach-O Image File

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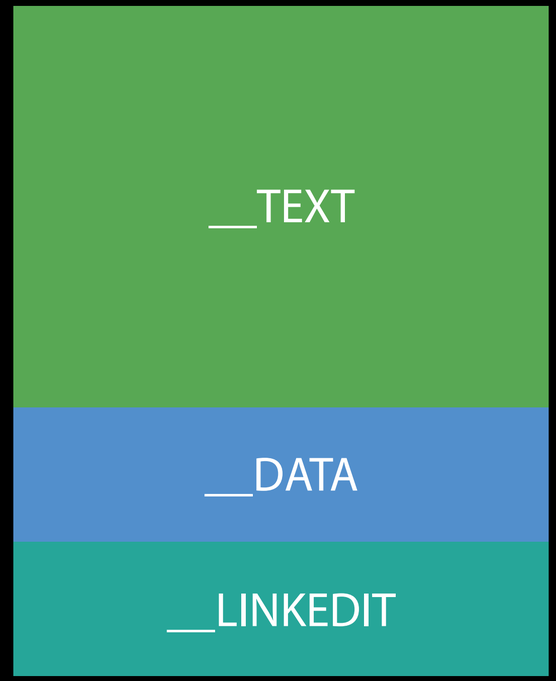
All segments are multiples of page size

- 16KB on arm64
- 4KB elsewhere



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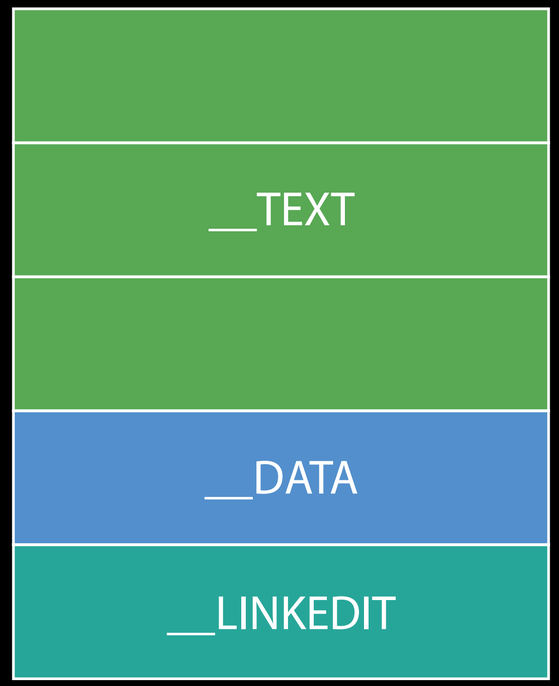

Mach-O Image File

Sections are a subrange of a segment

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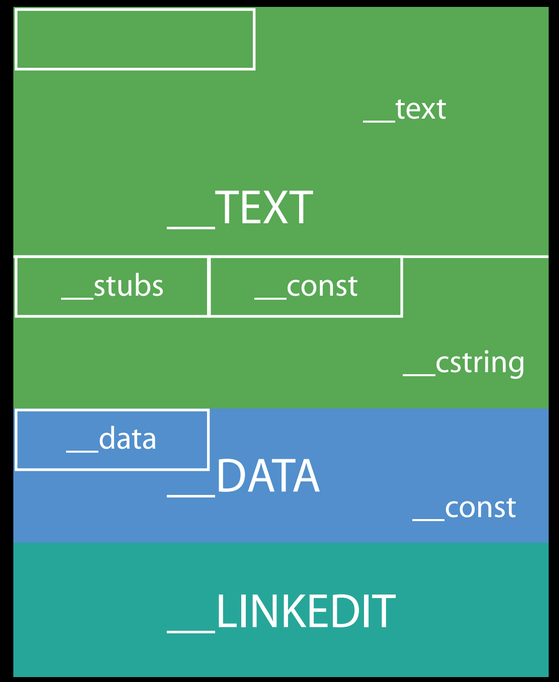

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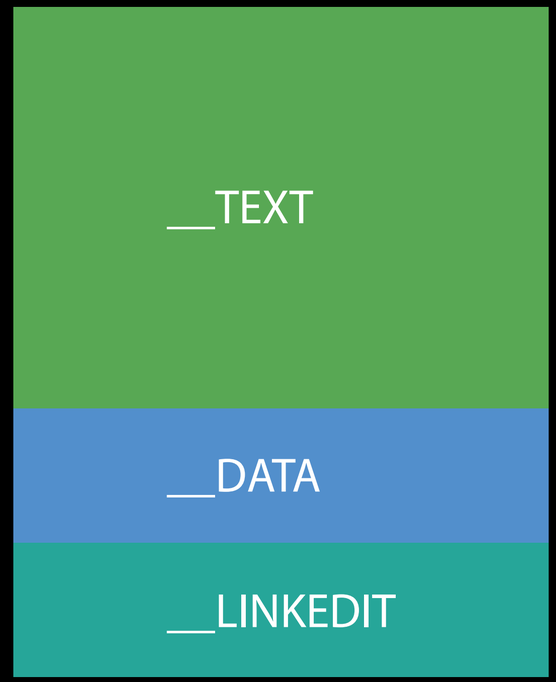

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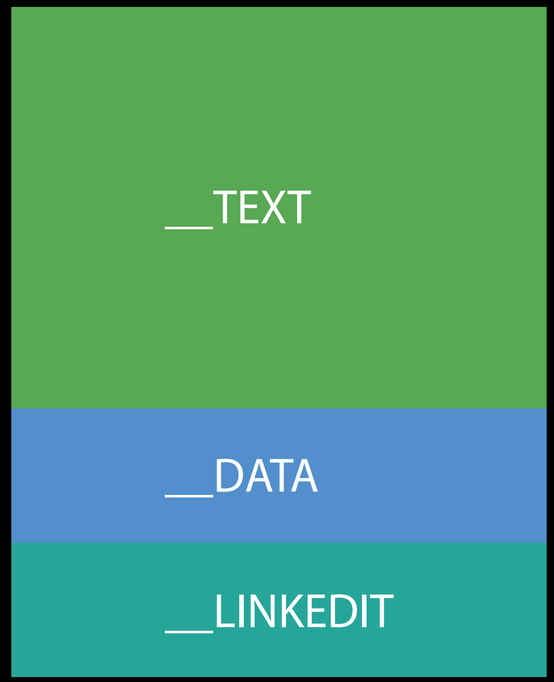
Common segments:



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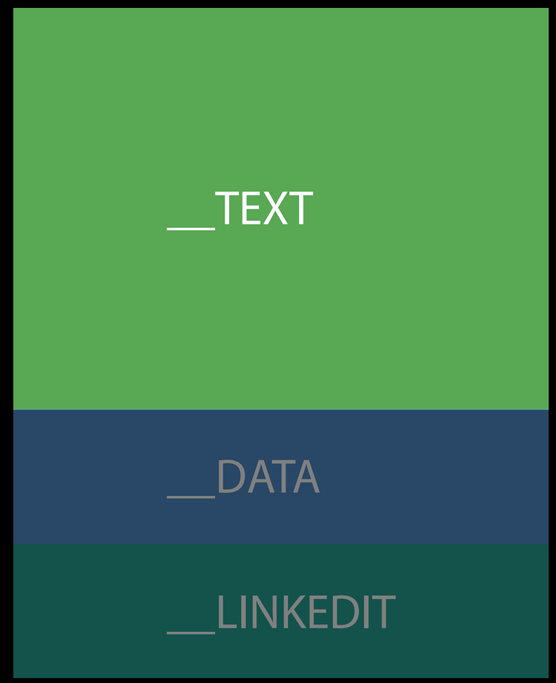

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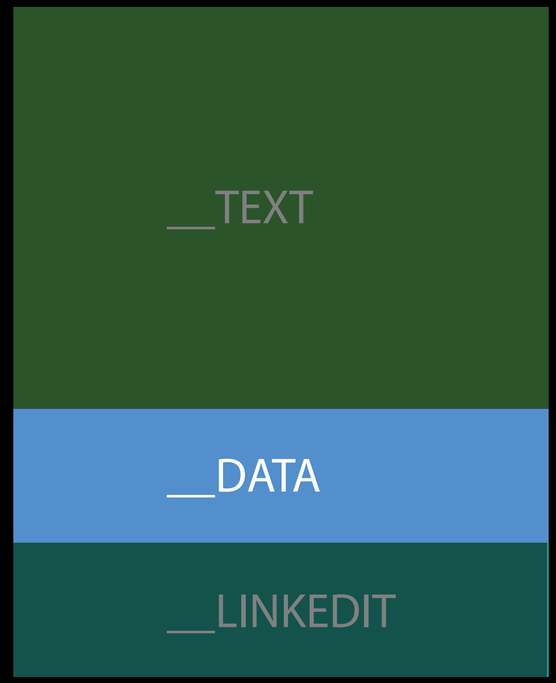

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Common segments:

- __TEXT has header, code, and read-only constants
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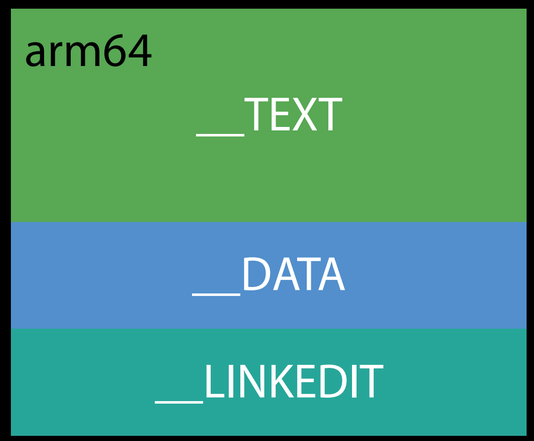
- __LINKEDIT has "meta data" about how to load the program

Mach-O Universal Files



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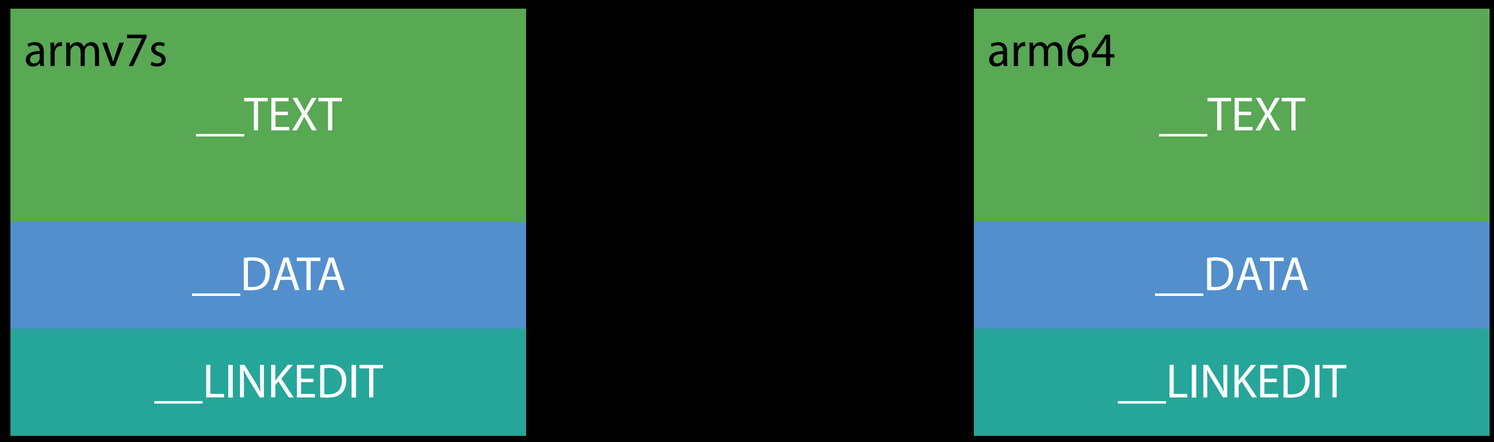
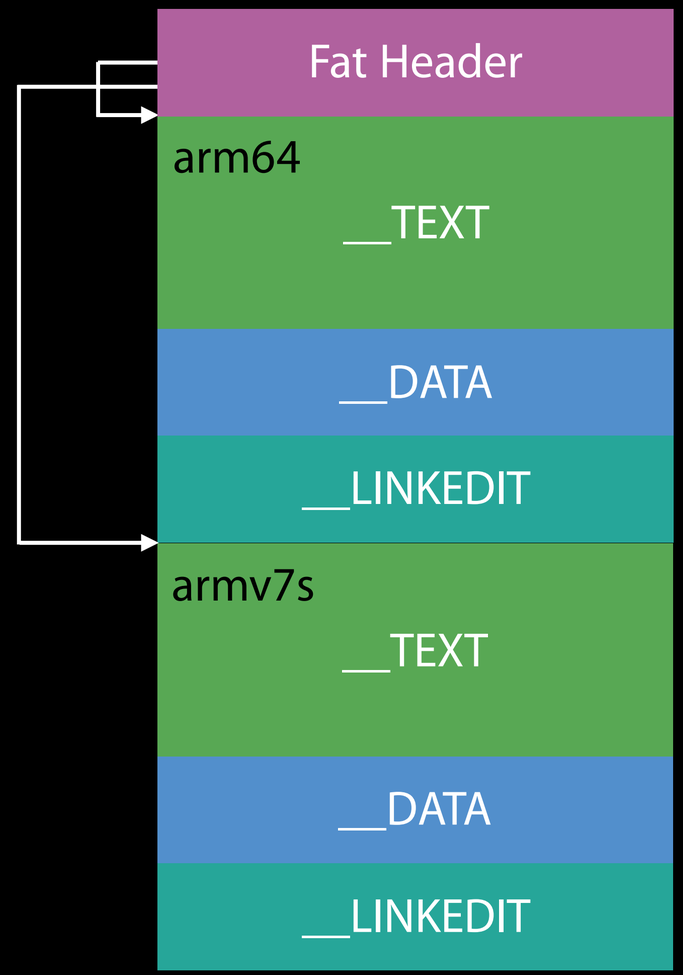


Mach-O Universal Files

Fat Header

- One page in size
- Lists architectures and offsets

Tools and runtimes support fat mach-o files



Virtual Memory

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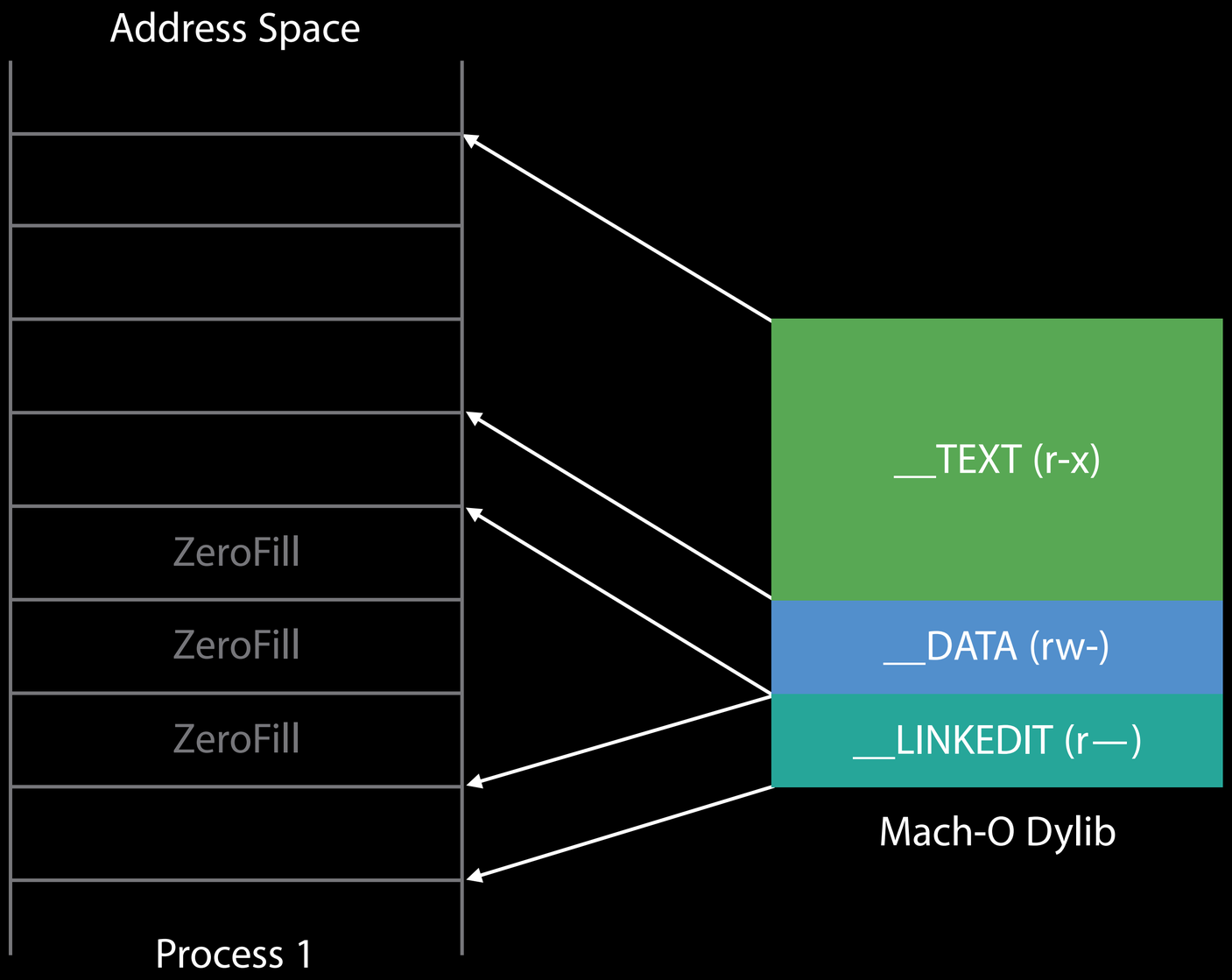
- Permissions: rwx

Mach-O Image Loading



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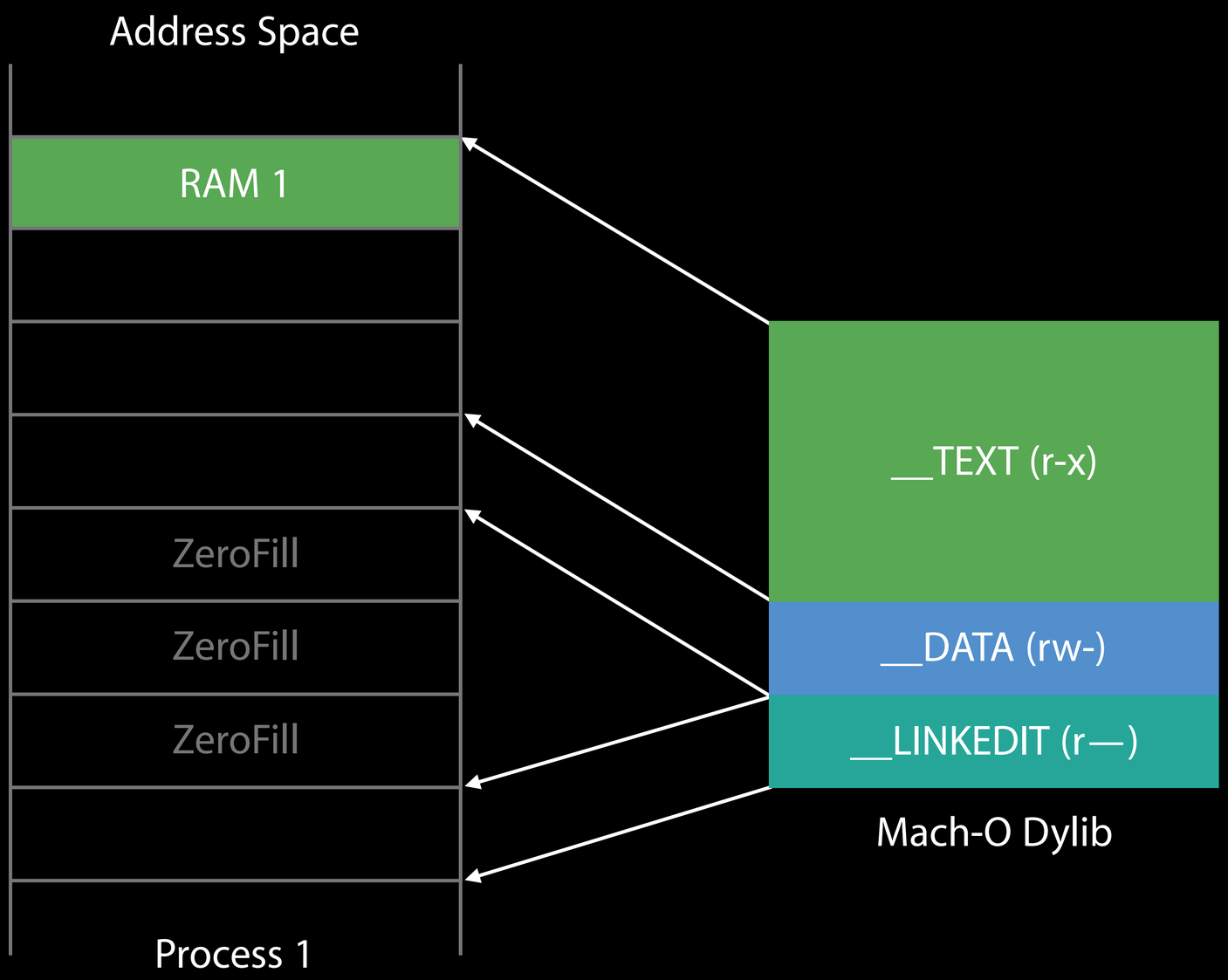

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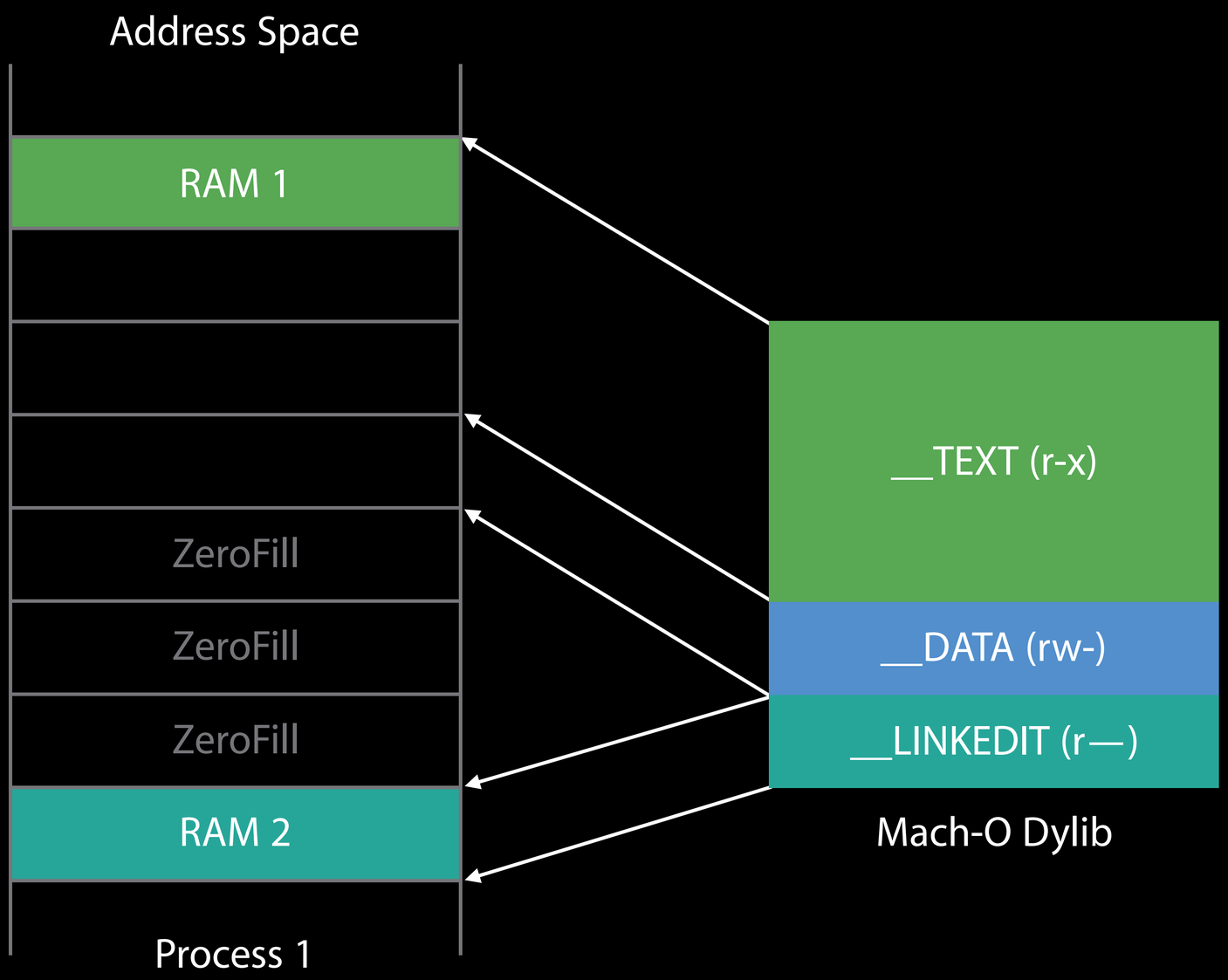

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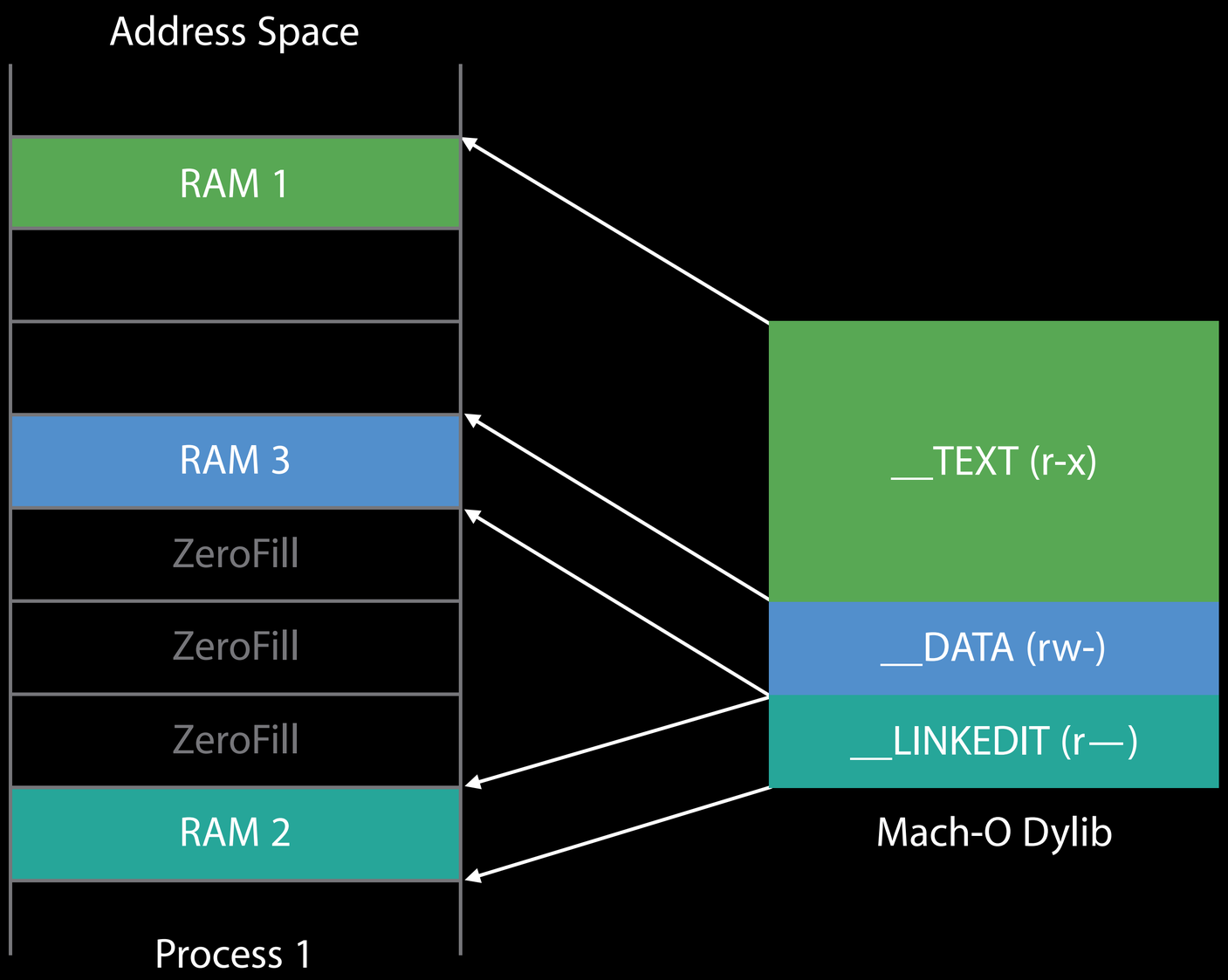

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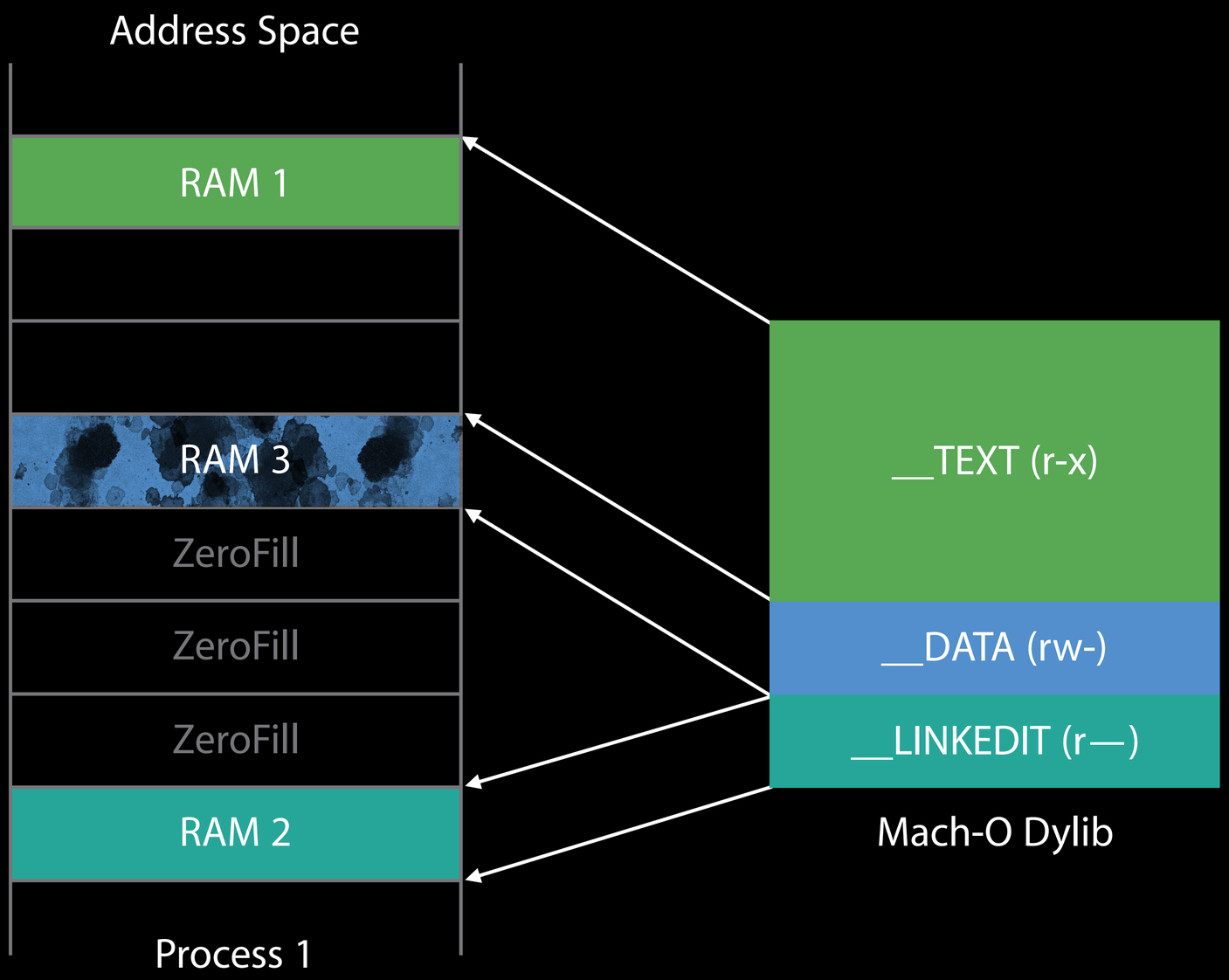

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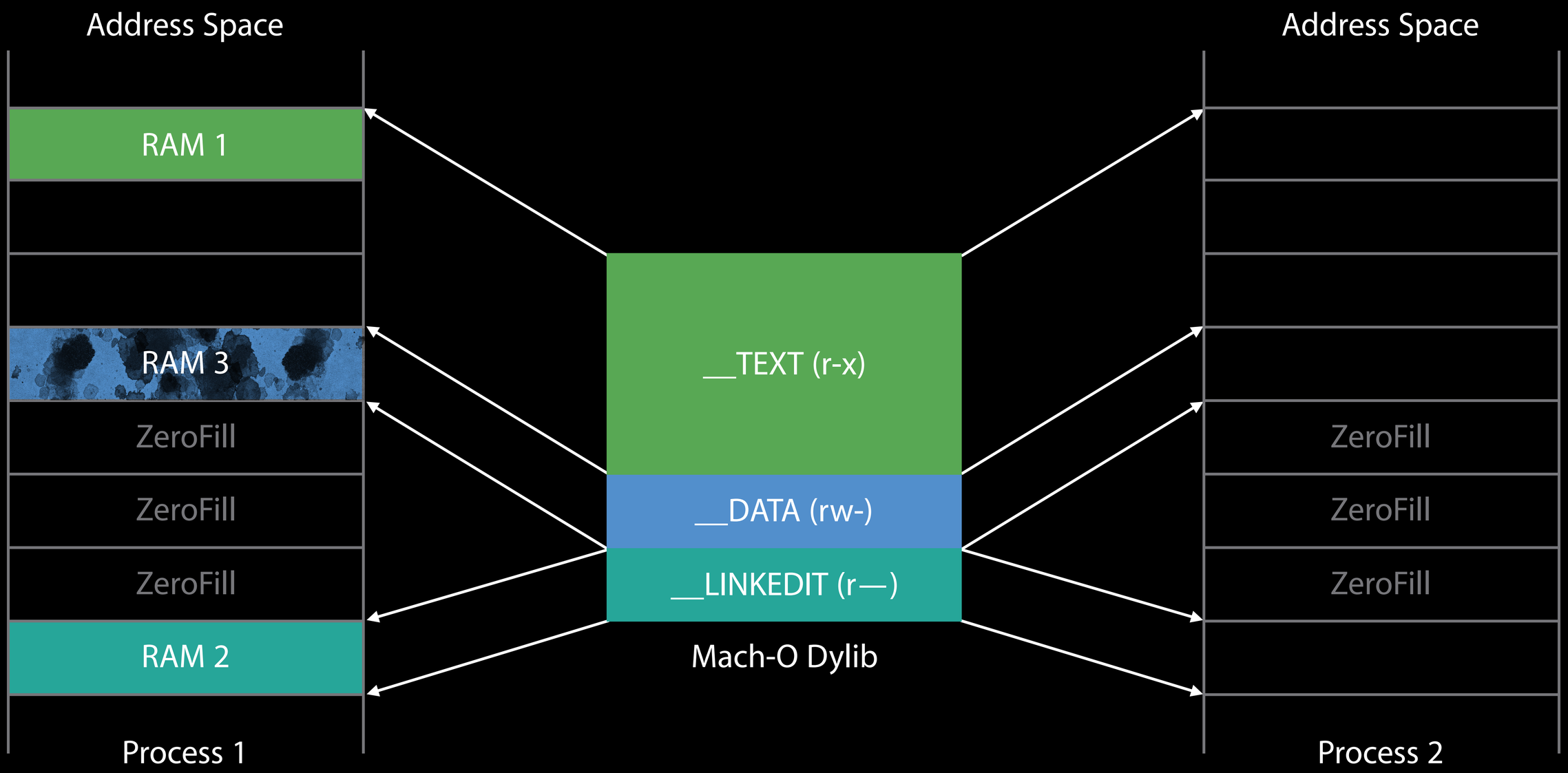

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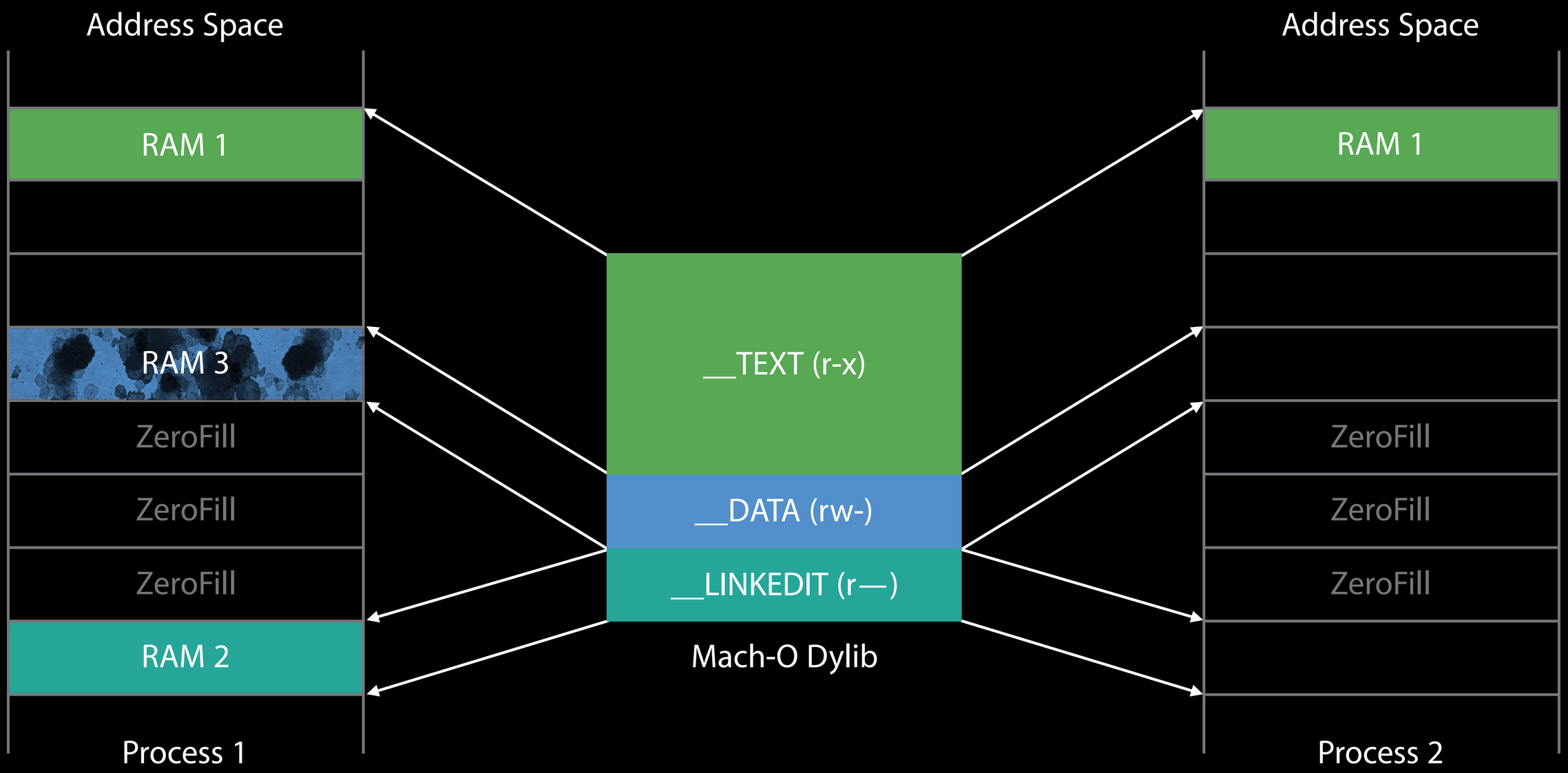

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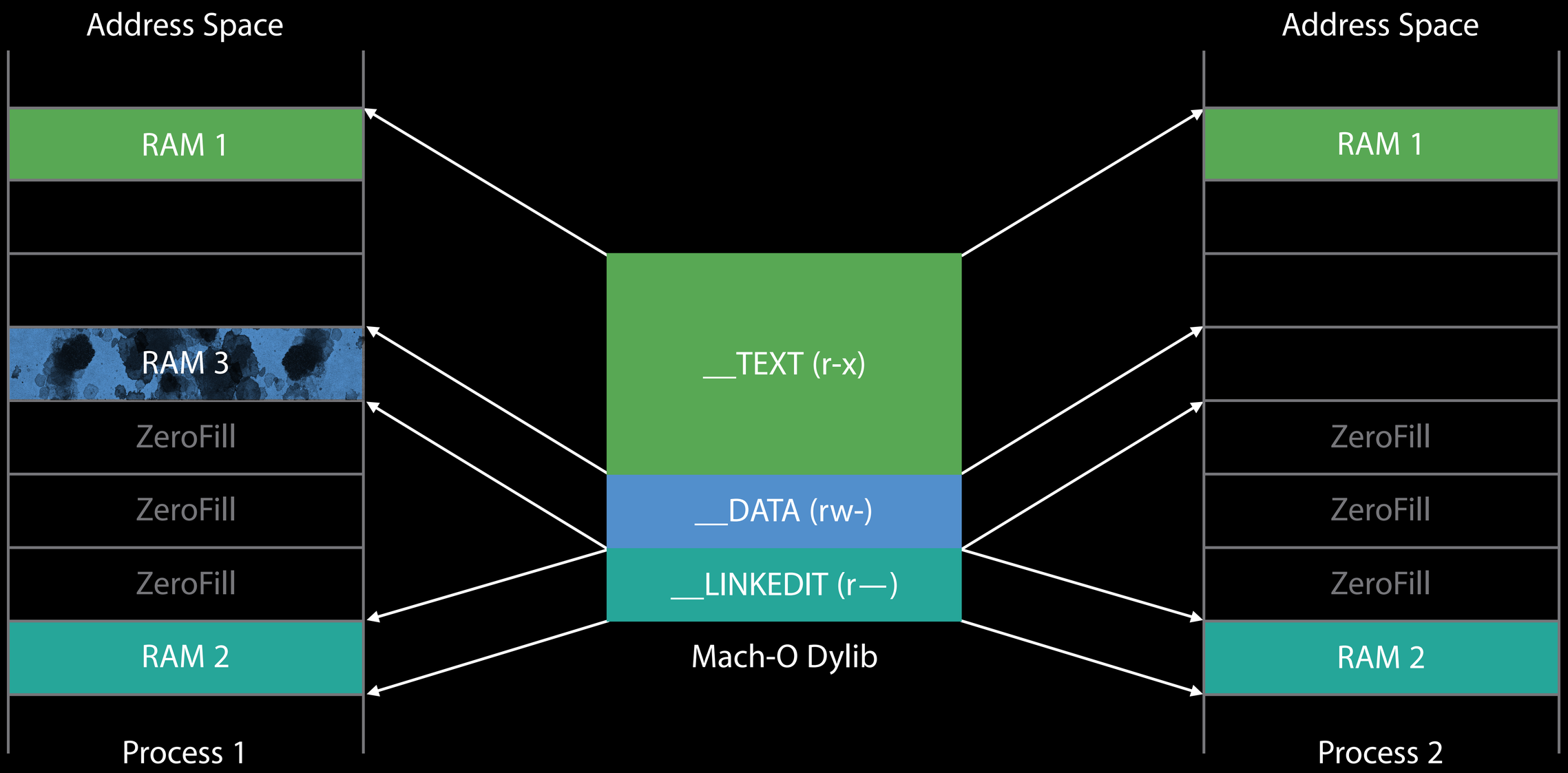

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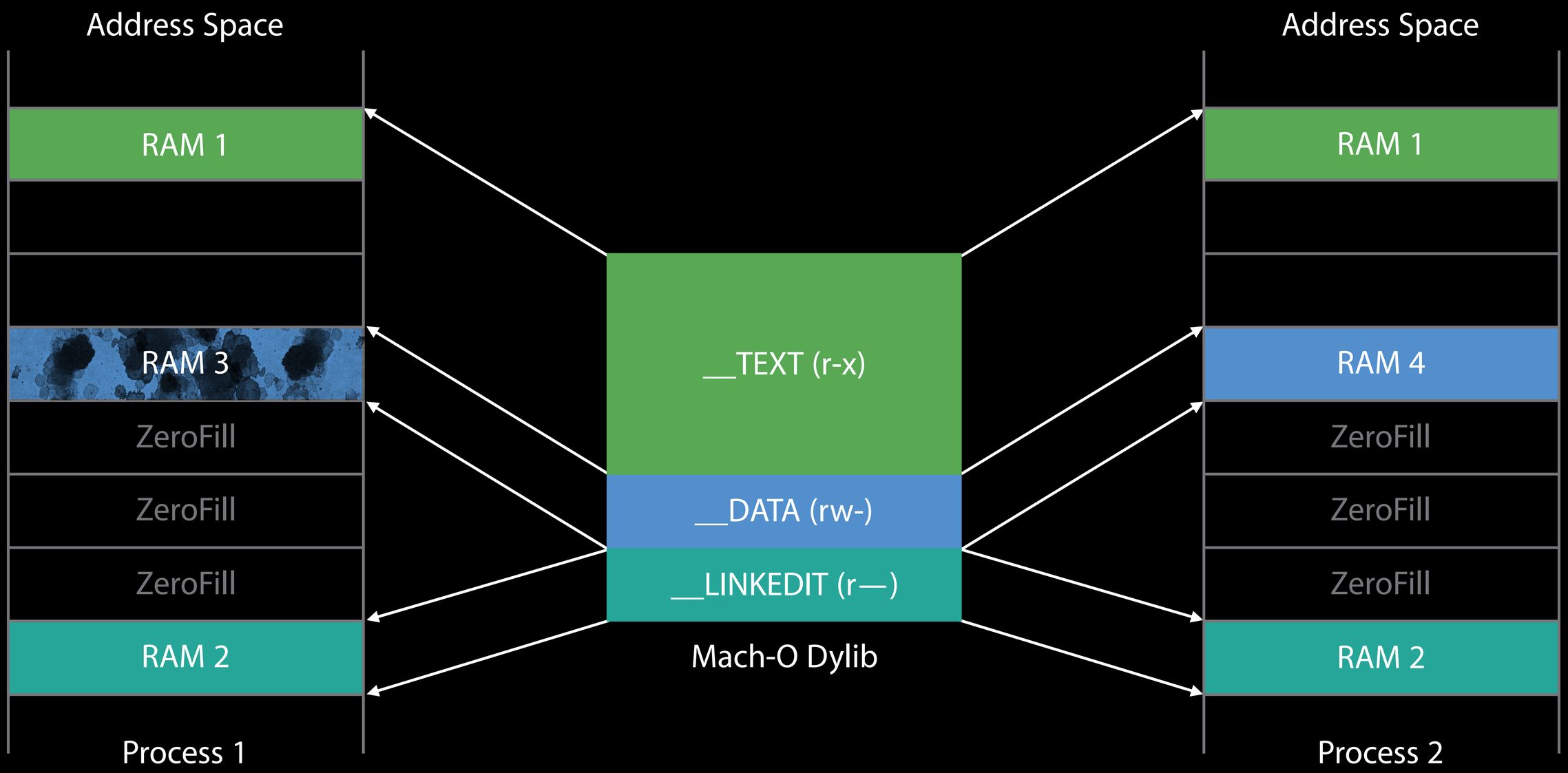

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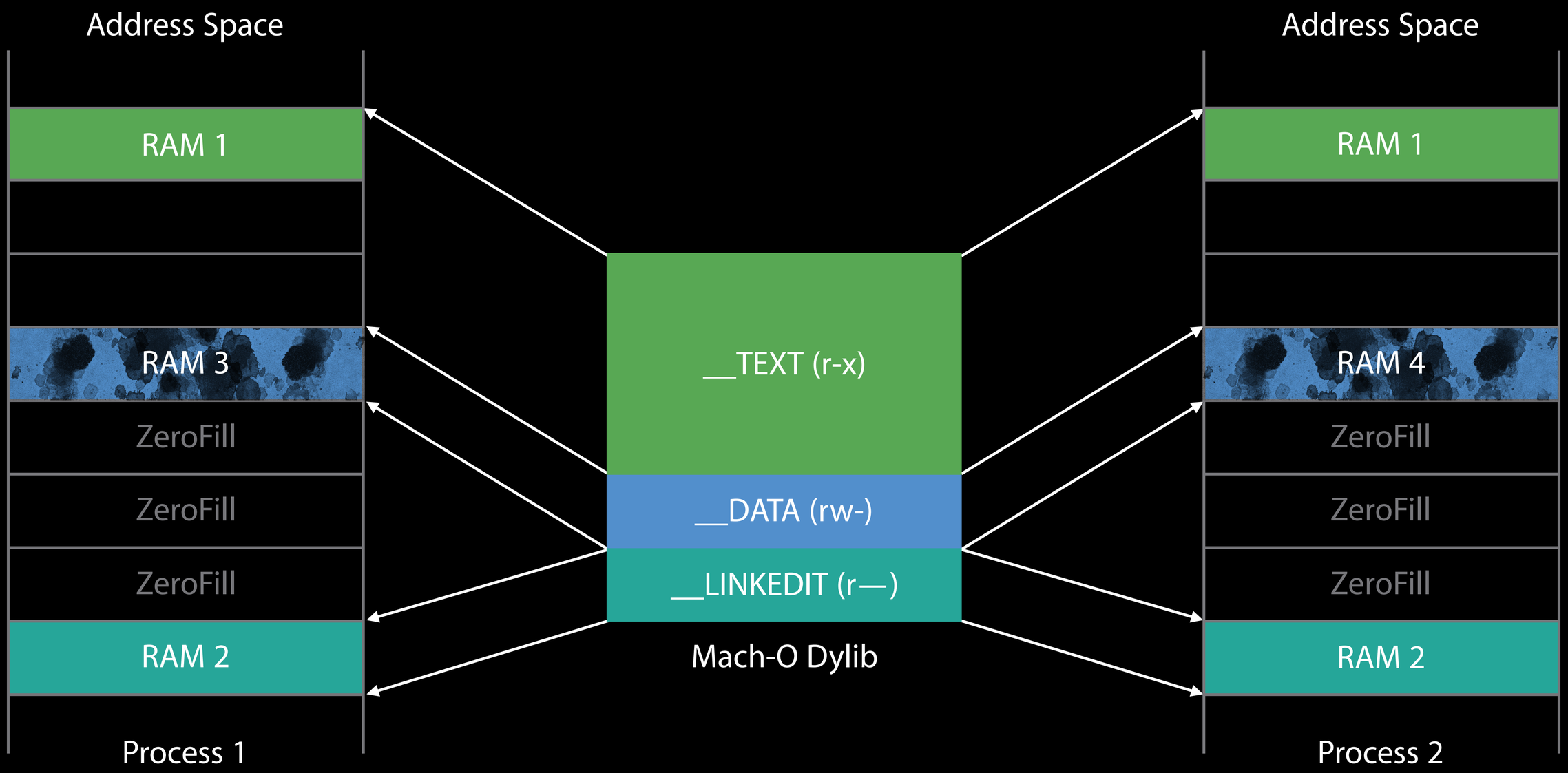

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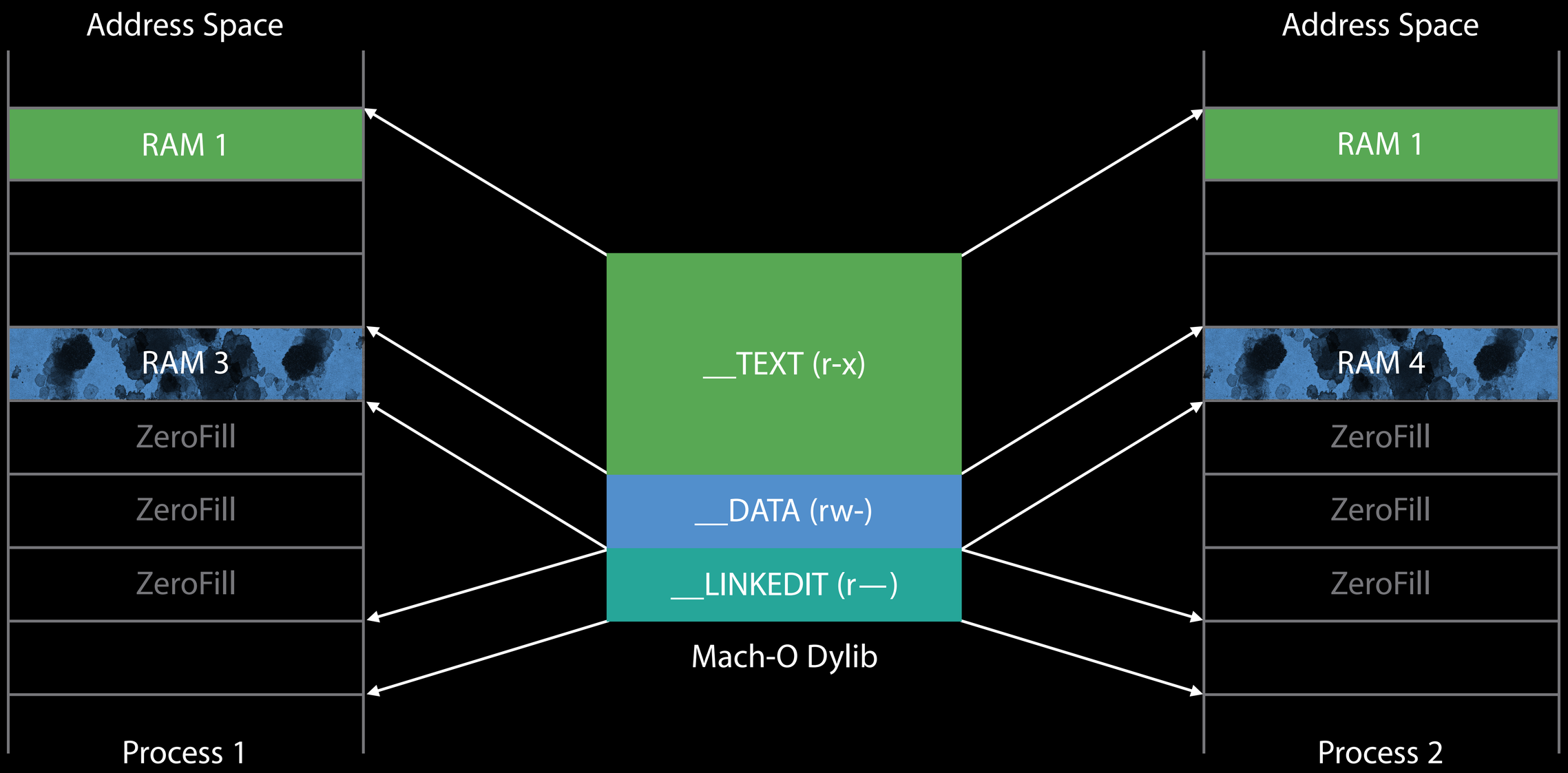

Security

ASLR

- Address Space Layout Randomization
- Images load at random address

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Code Signing

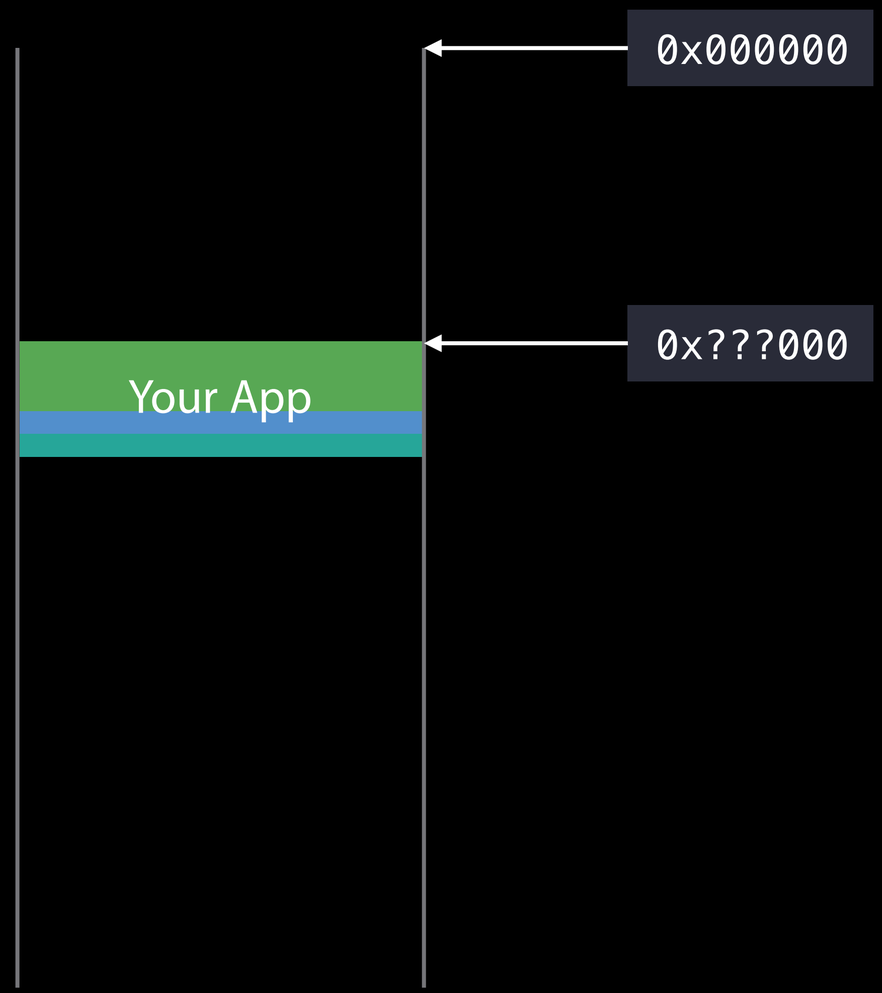
- Content of each page is hashed
- Hash is verified on page-in

exec() to main()

exec()

Kernel maps your application into new address space

Start of your app is random



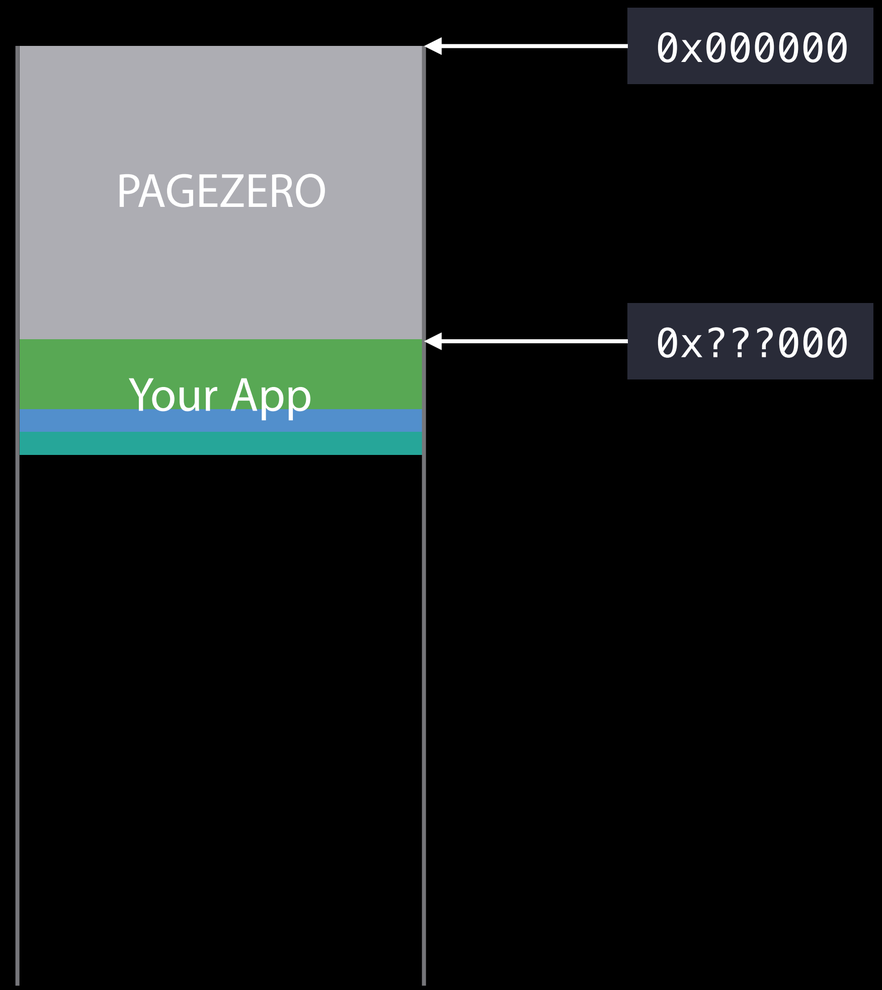
exec()

Kernel maps your application into new address space

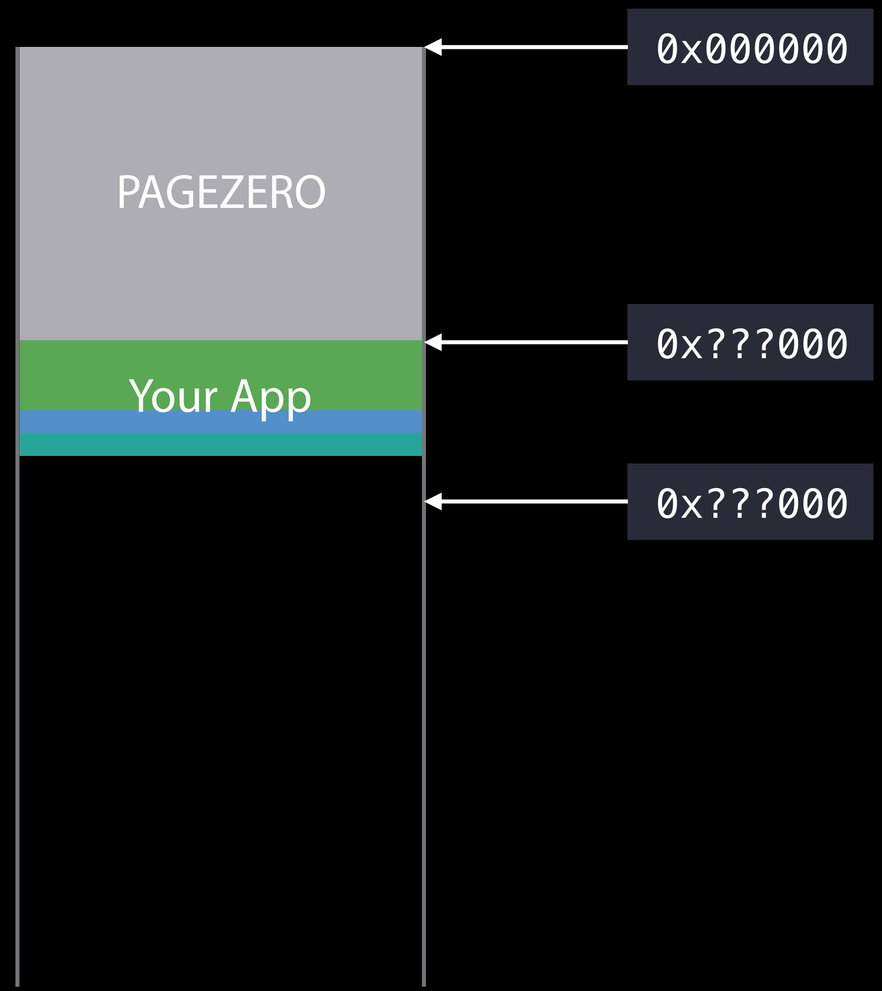
Start of your app is random

Low memory is marked inaccessible

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



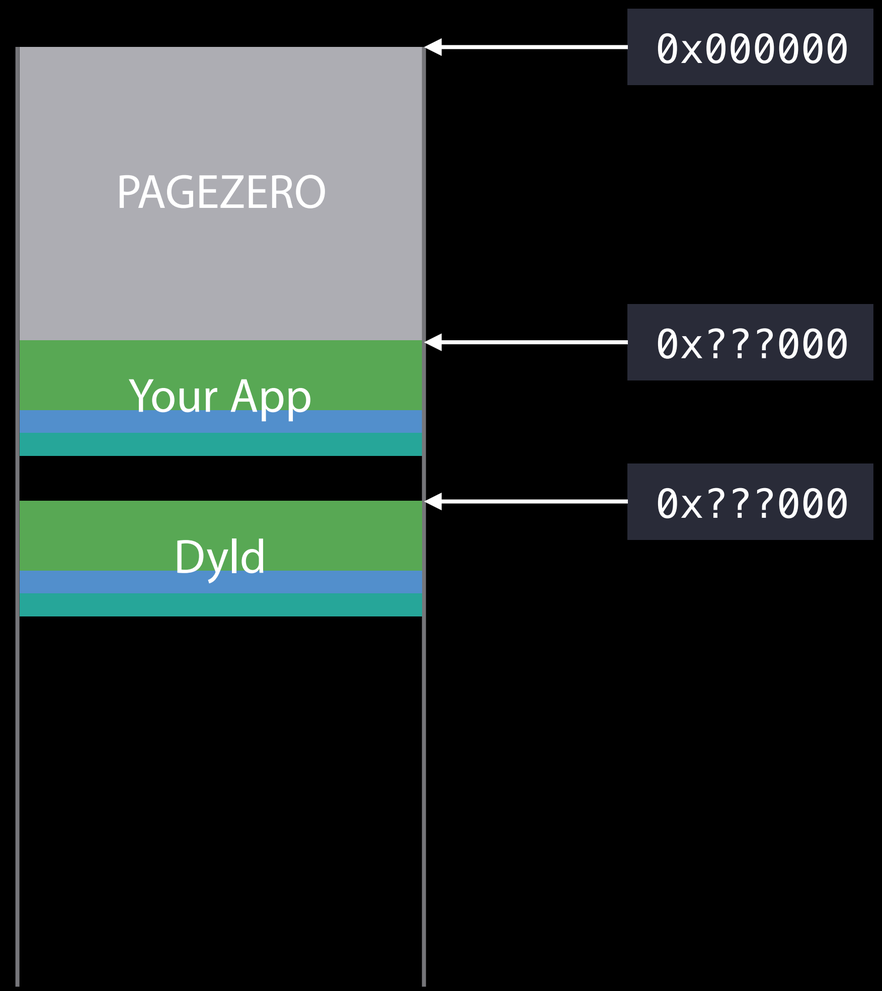
What About Dylibs?



What About Dylibs?

Kernel loads helper program

- Dyld (dynamic loader)
- Executions starts in dyld



What About Dylibs?

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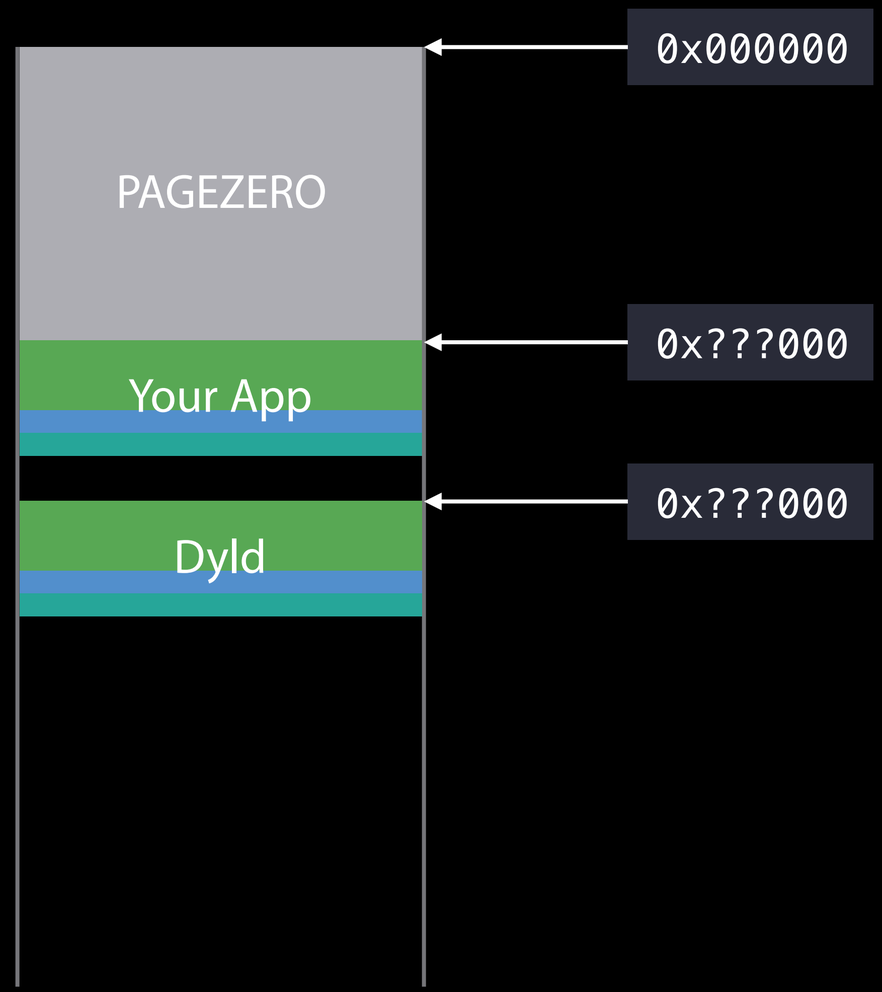
Dyld runs in-process

- Loads dependent dylibs
- Has same permissions as app



Dyld Steps

Dyld Steps

Map all dependent dylibs, recurse

Rebase all images

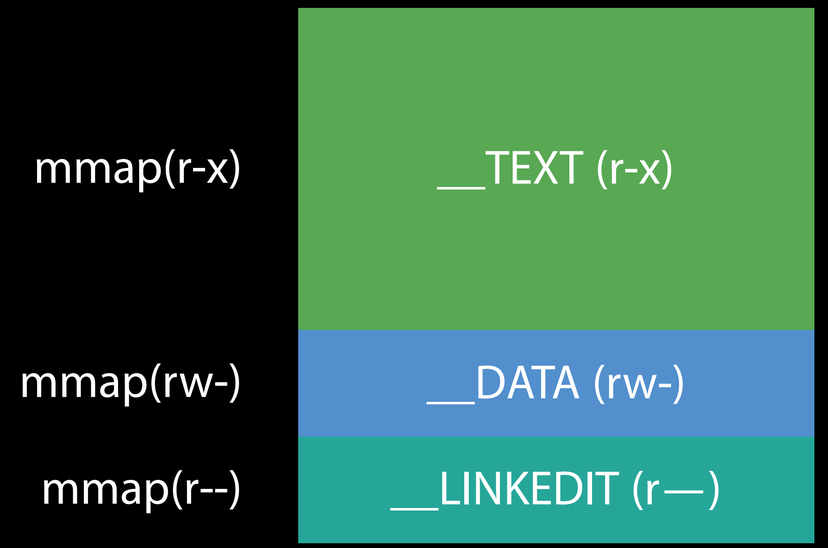
Bind all images

ObjC prepare images

Run initializers

Loading Dylibs

Parse list of dependent dylibs

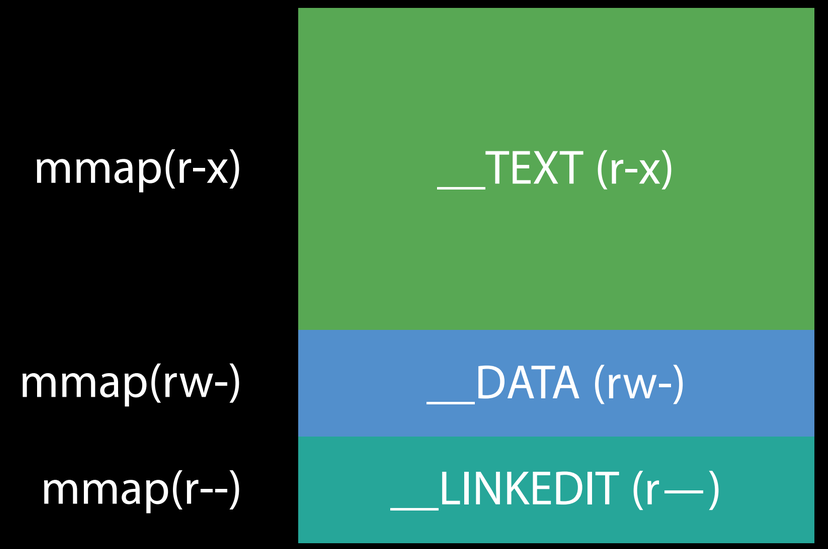


Load dylibs → Rebase → Bind → ObjC → Initializers

Loading Dylibs

Parse list of dependent dylibs

Find requested mach-o file



Loading Dylibs

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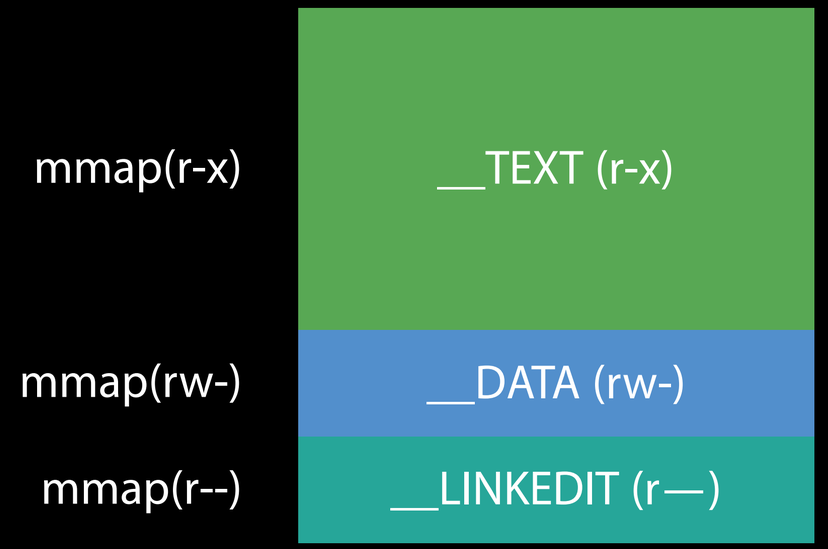
Find requested mach-o file

Open and read start of file



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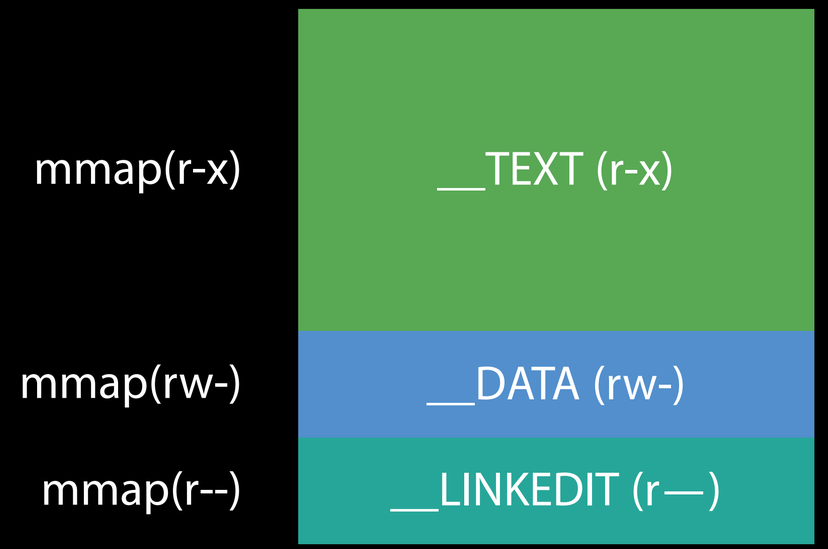
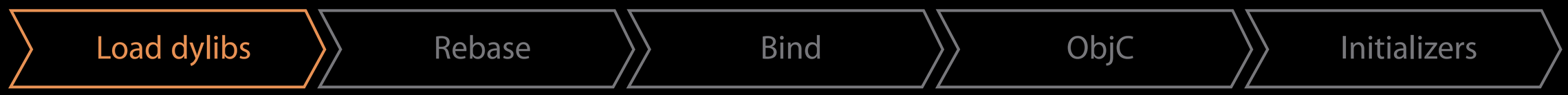
Validate mach-o





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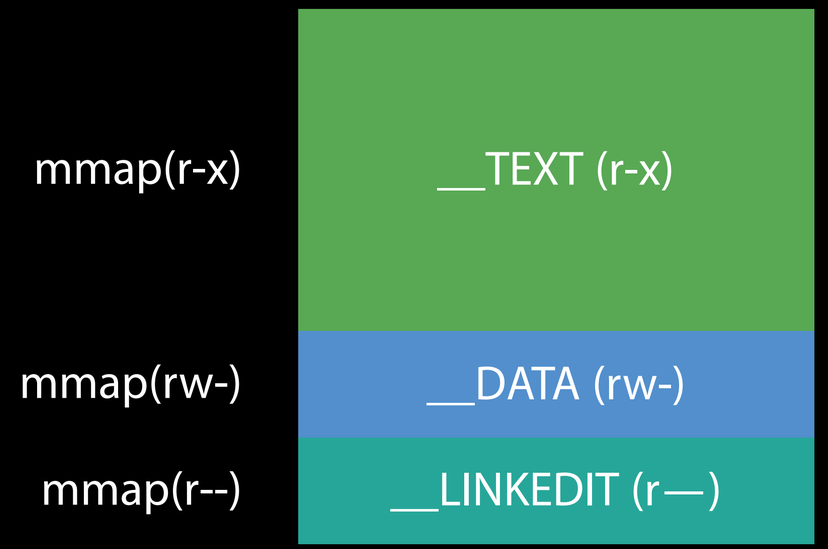
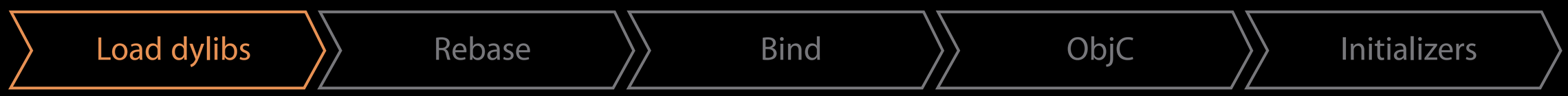
Validate mach-o

Register code signature





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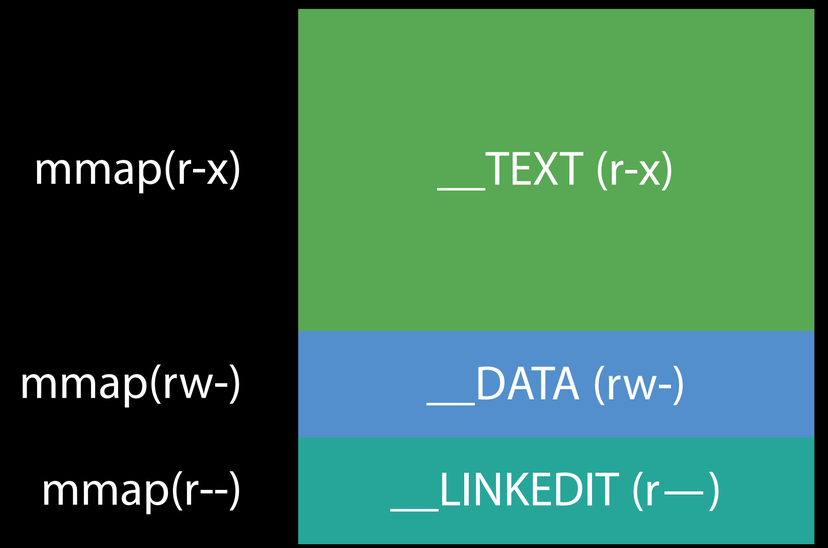
Call `mmap()` for each segment



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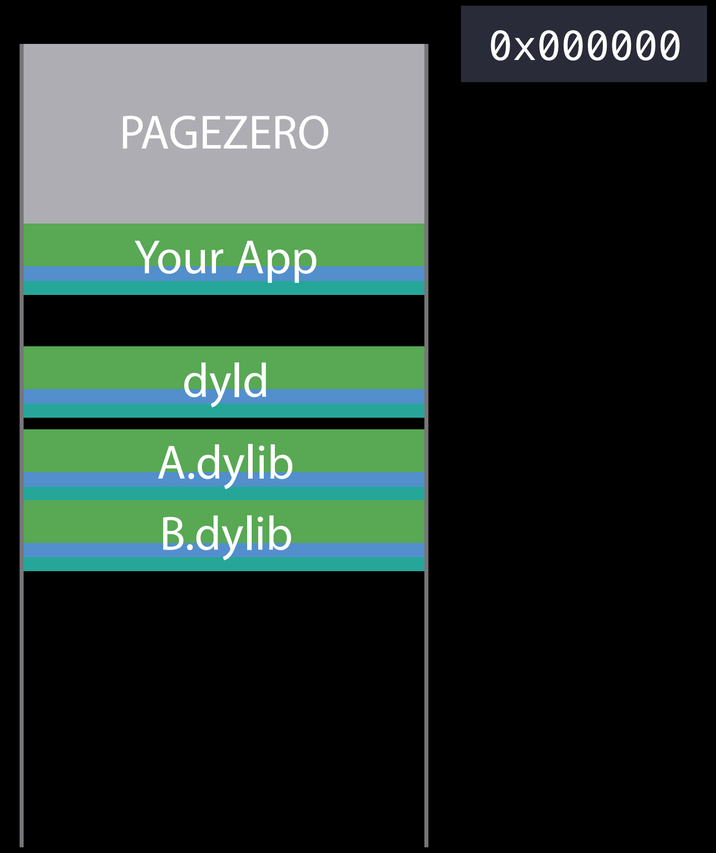
Recursive Loading

All your app's direct dependents are loaded



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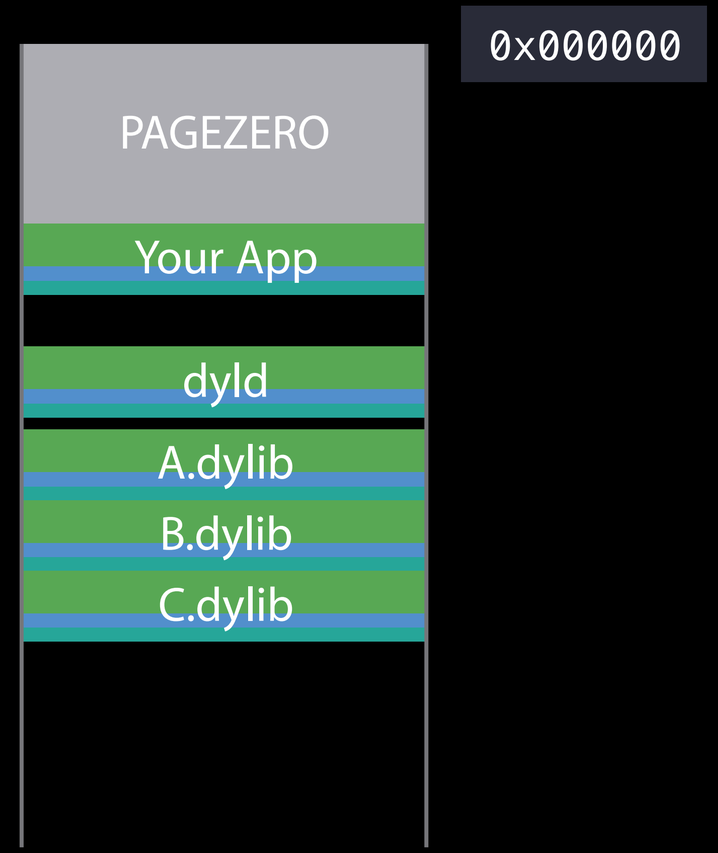

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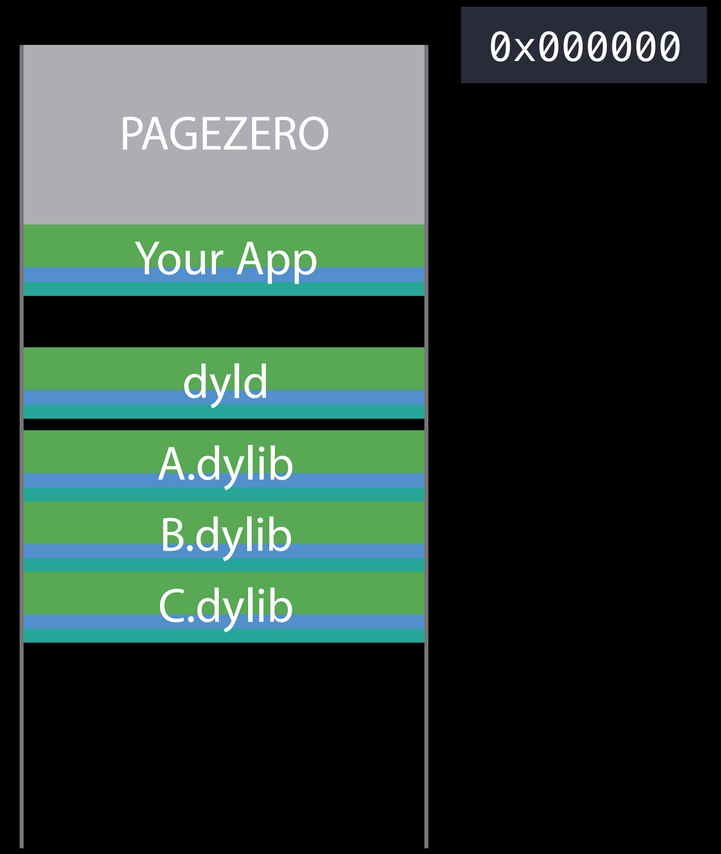

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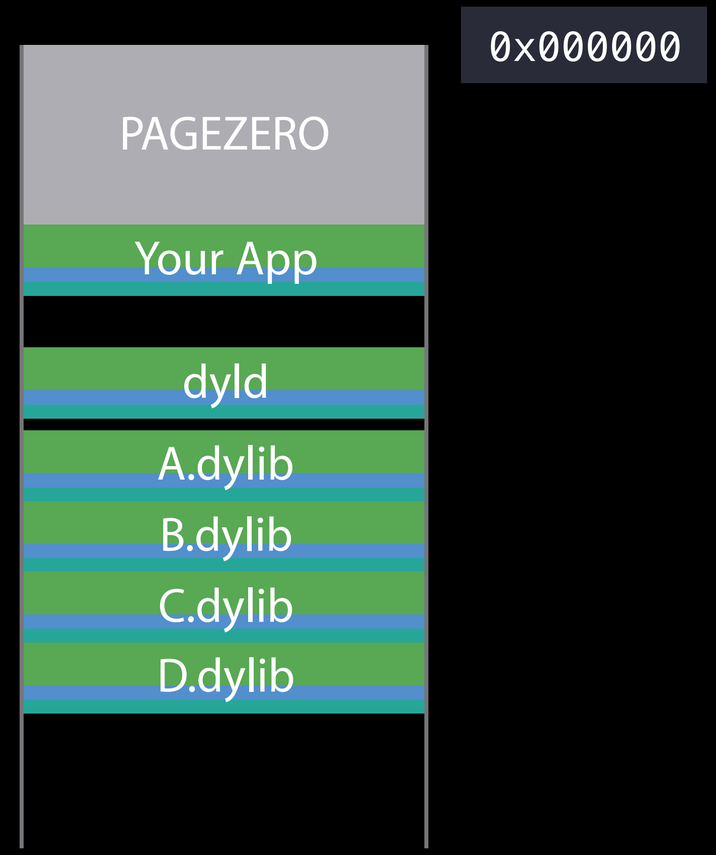

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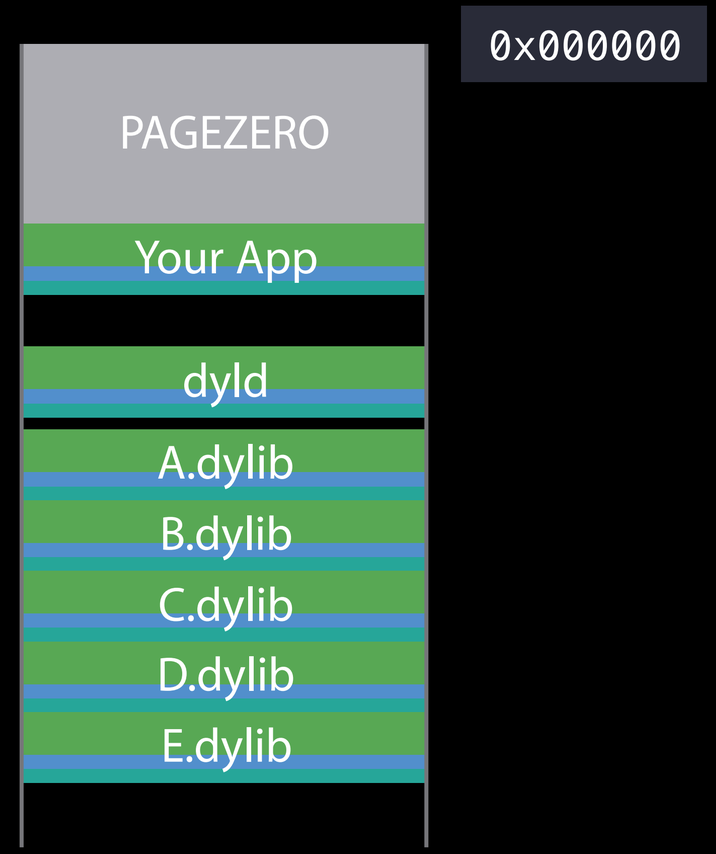

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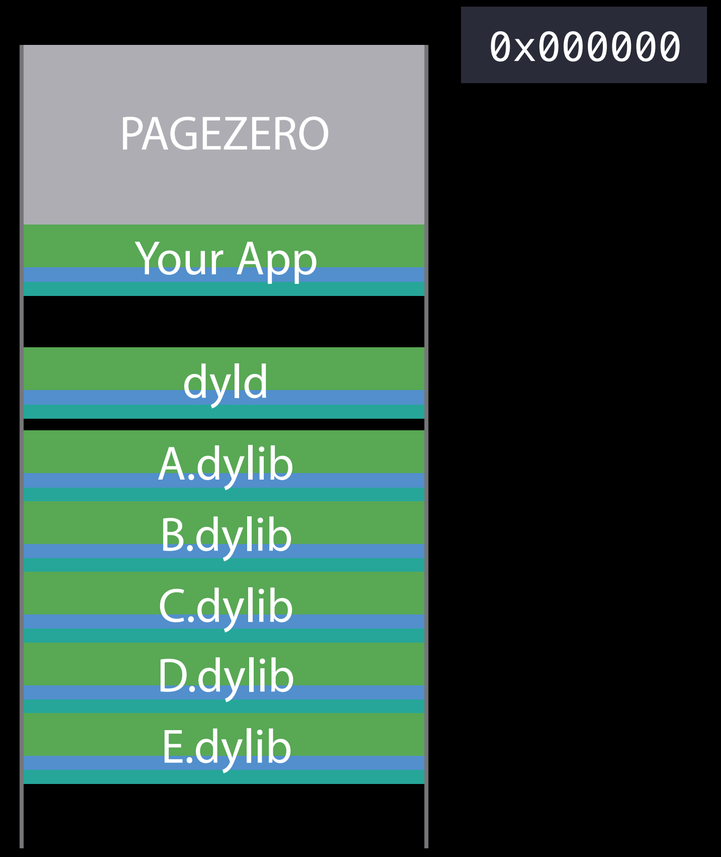
Rinse and repeat

Apps typically load 100 to 400 dylibs!



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!

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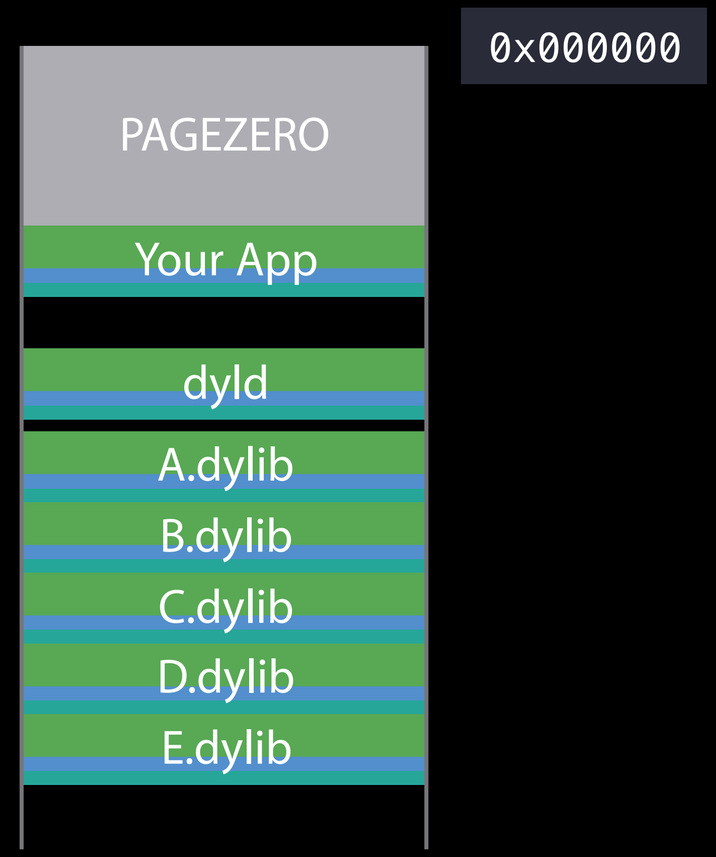

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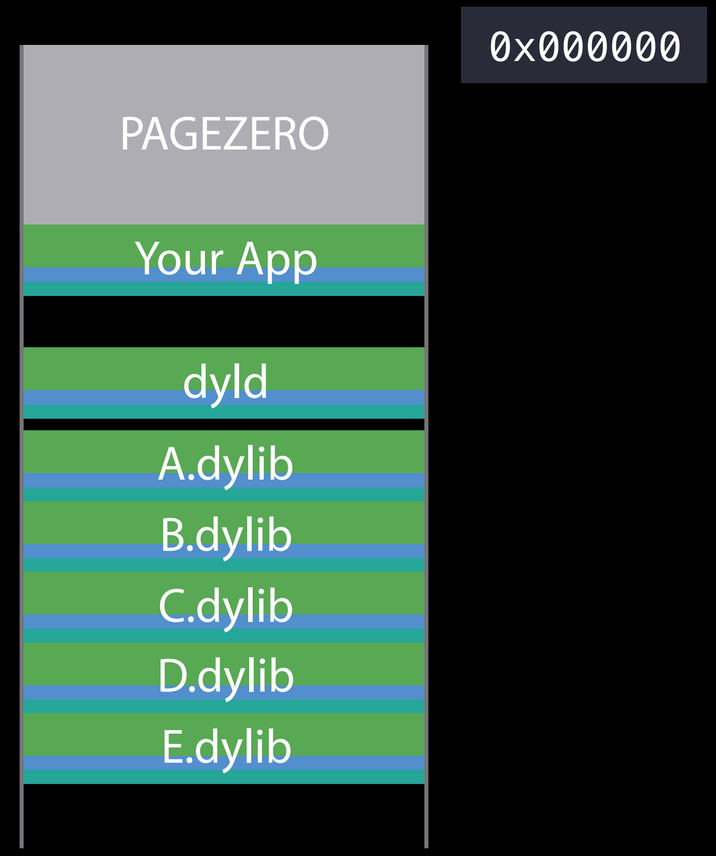
- We've optimized loading of OS dylibs



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Fix-ups

Code signing means instructions cannot be altered

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

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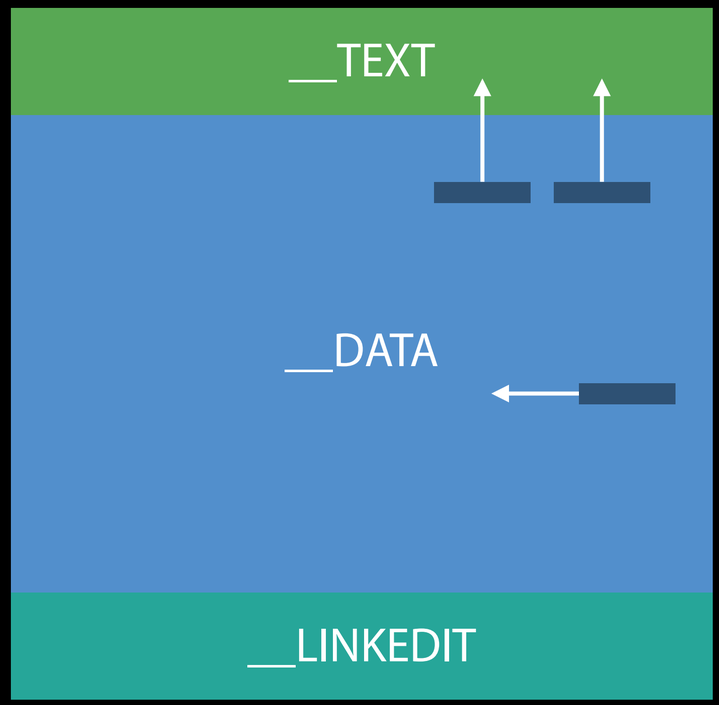
- Instead, all fix ups are in __DATA

Rebasing and Binding

Rebasing: Adjusting pointers to within an image

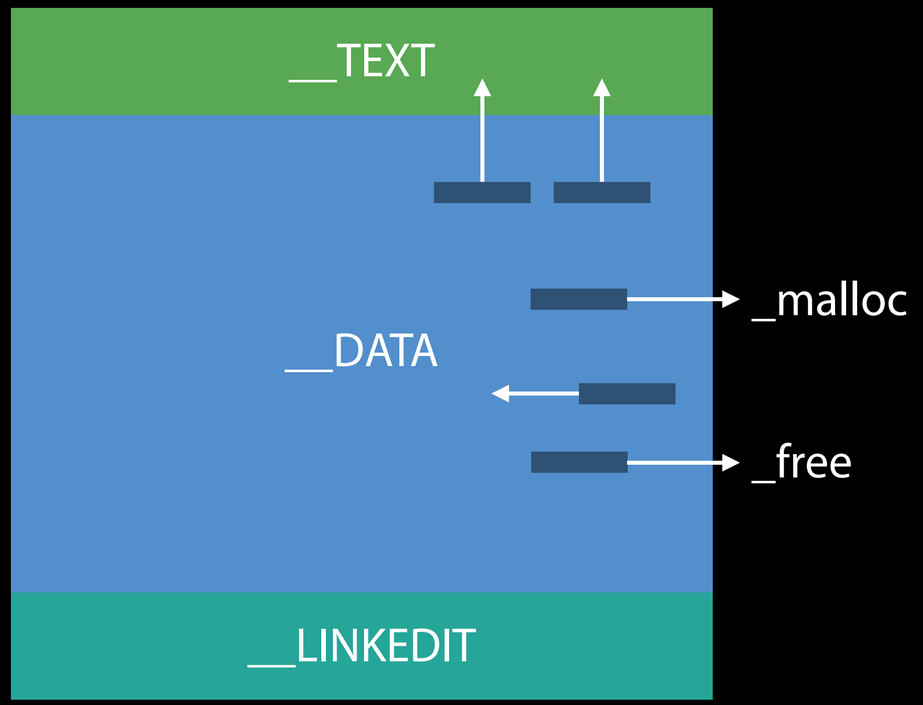


Load dylibs → Rebase → Bind → ObjC → Initializers

Rebasing and Binding

Rebasing: Adjusting pointers to within an image

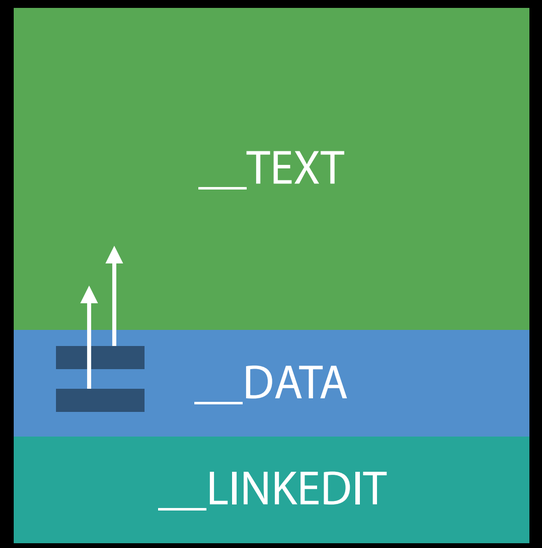
Binding: Setting pointers to outside image



```
[~]> 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



Load dylibs → **Rebase** → Bind → ObjC → Initializers

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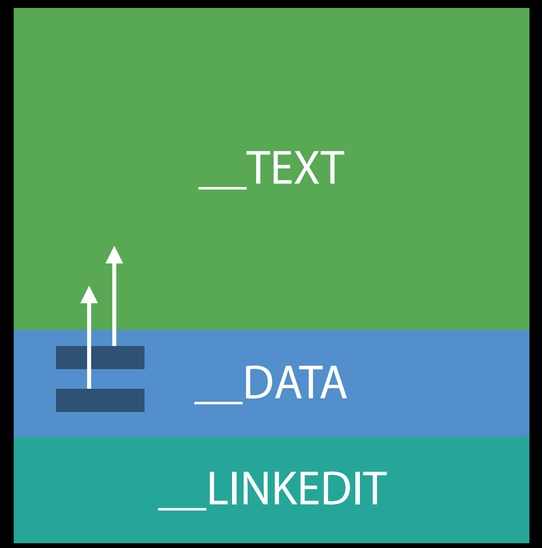
Slide = actual_address - preferred_address



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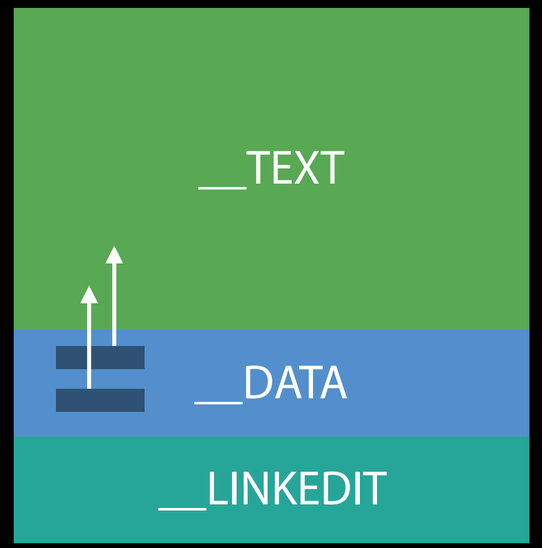

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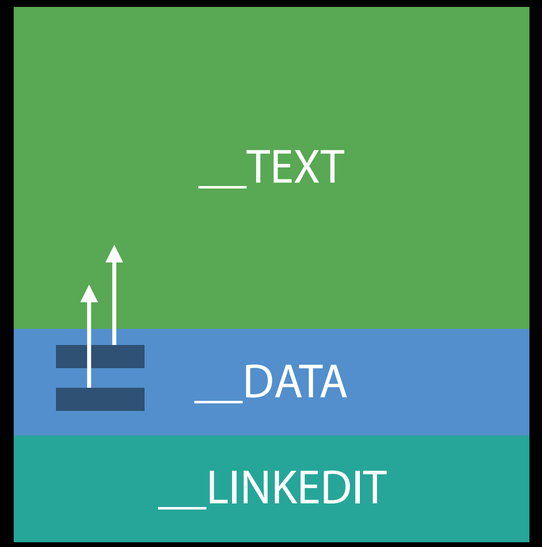

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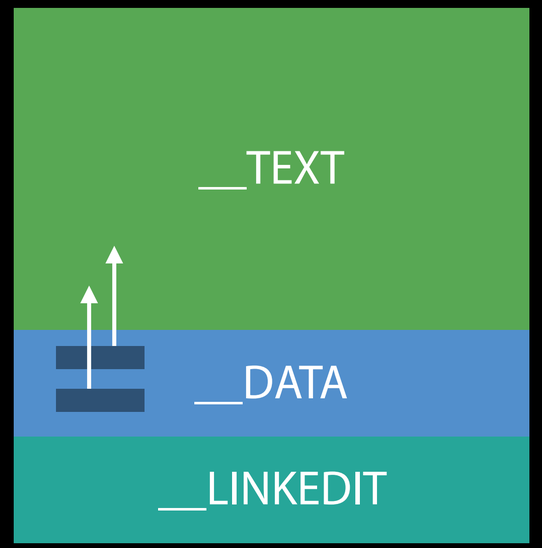
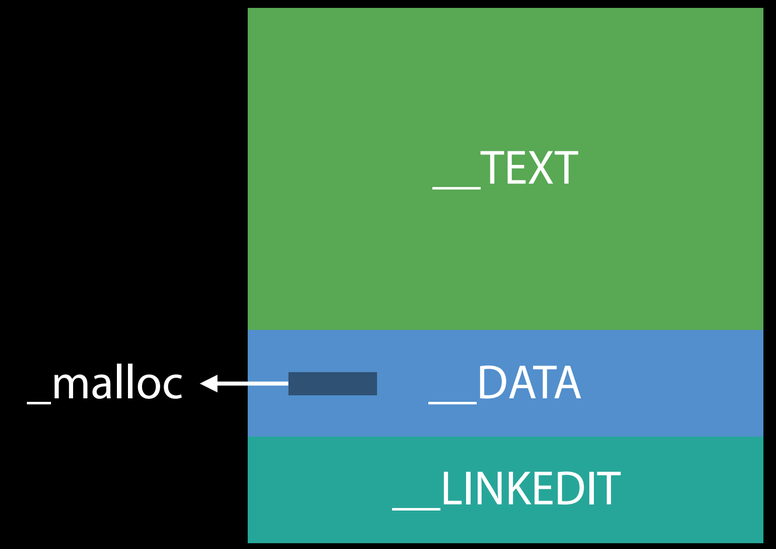
Pages-in and COW page

Rebasing is done in address order, so kernel starts prefetching



Binding

All references to something in another dylib are symbolic



Load dylibs | Rebase | **Bind** | ObjC | Initializers

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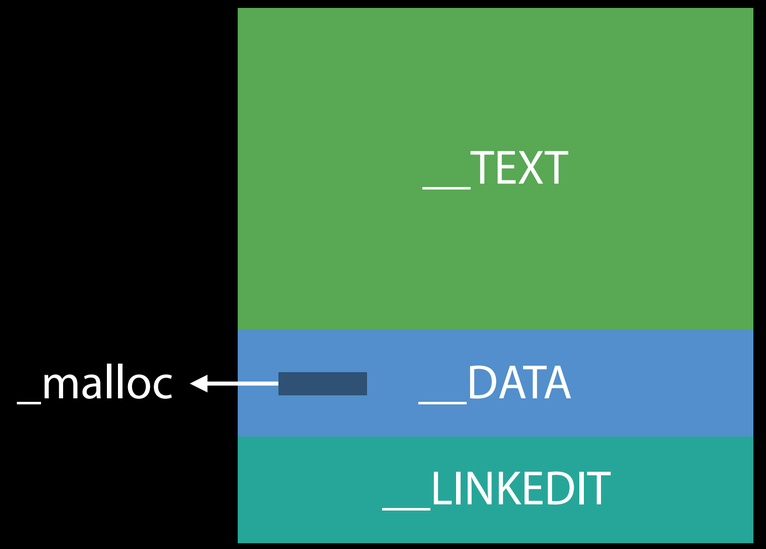
Dyld needs to find symbol name



Load dylibs → Rebase → **Bind** → ObjC → Initializers

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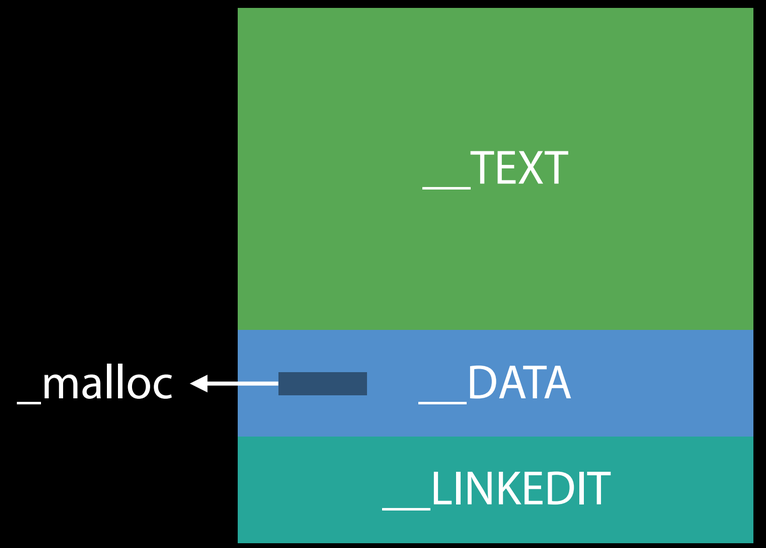
More computational than rebasing



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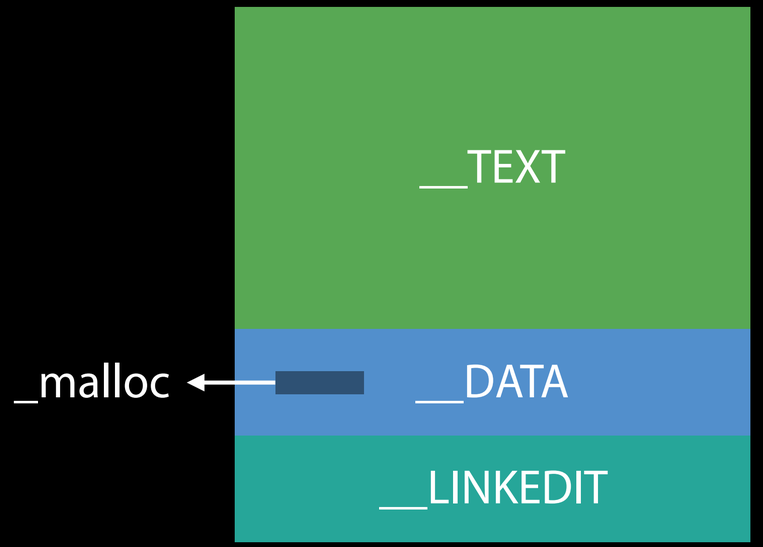
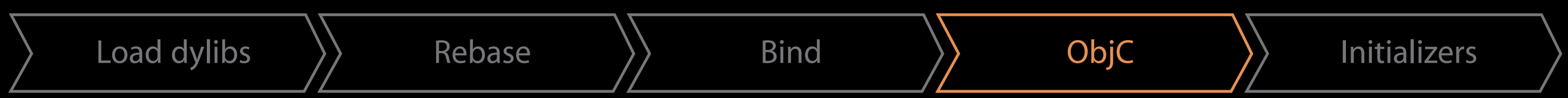
More computational than rebasing

Rarely page faults



Notify ObjC Runtime

Most ObjC set up done via rebasing and binding



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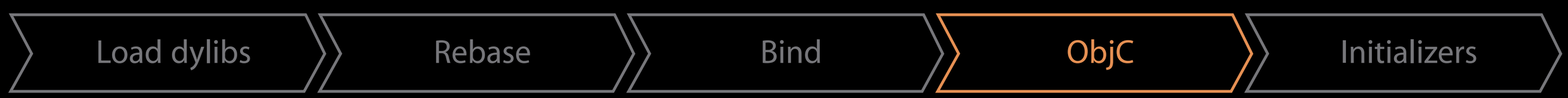

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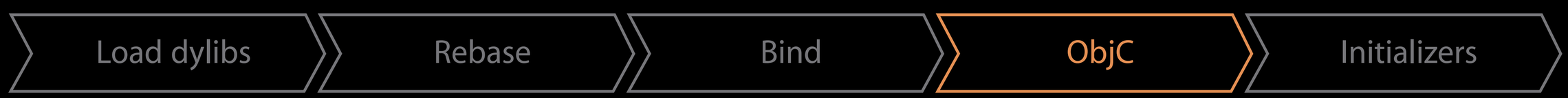

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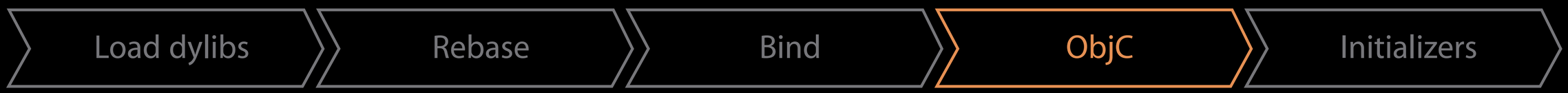
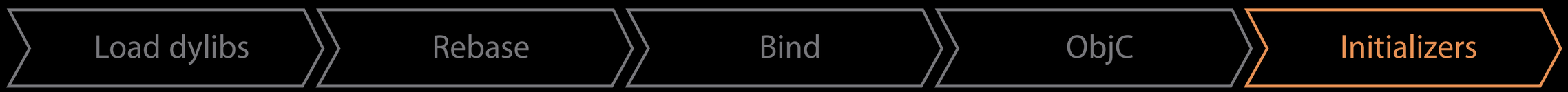


Initializers

C++ generates initializer for statically allocated objects



Initializers

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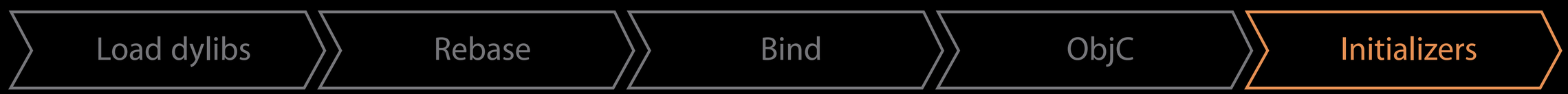
ObjC +load methods



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C++ generates initializer for statically allocated objects

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

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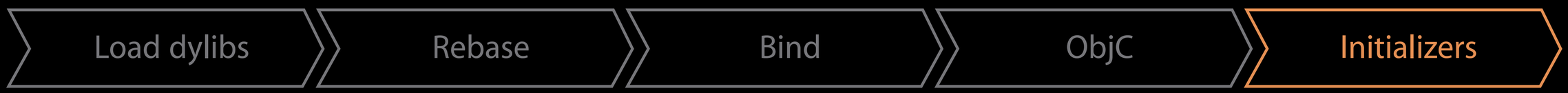
ObjC +load methods

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

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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?

Improving Launch Times

Overview

How fast?

How to measure?

Improving Launch Times

Overview

How fast?

How to measure?

Why is launch slow?

Improving Launch Times

Overview

How fast?

How to measure?

Why is launch slow?

What can you do?

Spoiler

Spoiler

Do Less Stuff

Improving Launch Times

Goals

Launch faster than animation

Improving Launch Times

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- Duration varies on devices

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Test on the slowest supported device

Improving Launch Times

Launch recap

Improving Launch Times

Launch recap

Parse images

Map images

Rebase images

Bind images

Run image initializers

Call `main()`

Improving Launch Times

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Improving Launch Times

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Call `main()`

Call `UIApplicationMain()`

Call `applicationWillFinishLaunching`

Improving Launch Times

Warm vs. cold launch

Warm launch

Improving Launch Times

Warm vs. cold launch

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- App and data already in memory

Improving Launch Times

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Improving Launch Times

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Improving Launch Times

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Warm and cold launch times will be different

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- Measure cold launch by rebooting

Improving Launch Times

Measurements

Measuring before `main()` is difficult

Improving Launch Times

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Dyld has built in measurements

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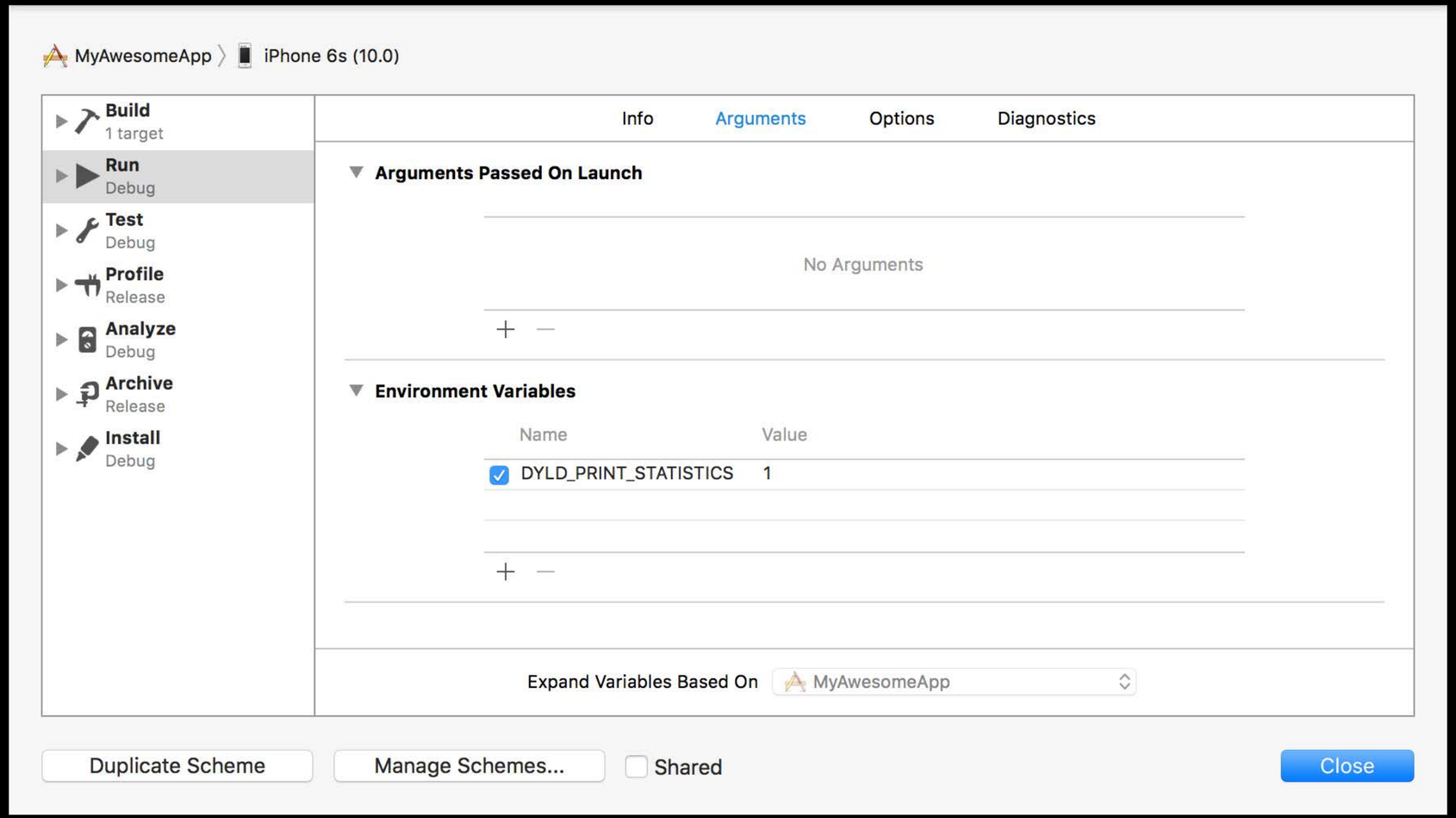
Improving Launch Times

DYLD_PRINT_STATISTICS



Improving Launch Times

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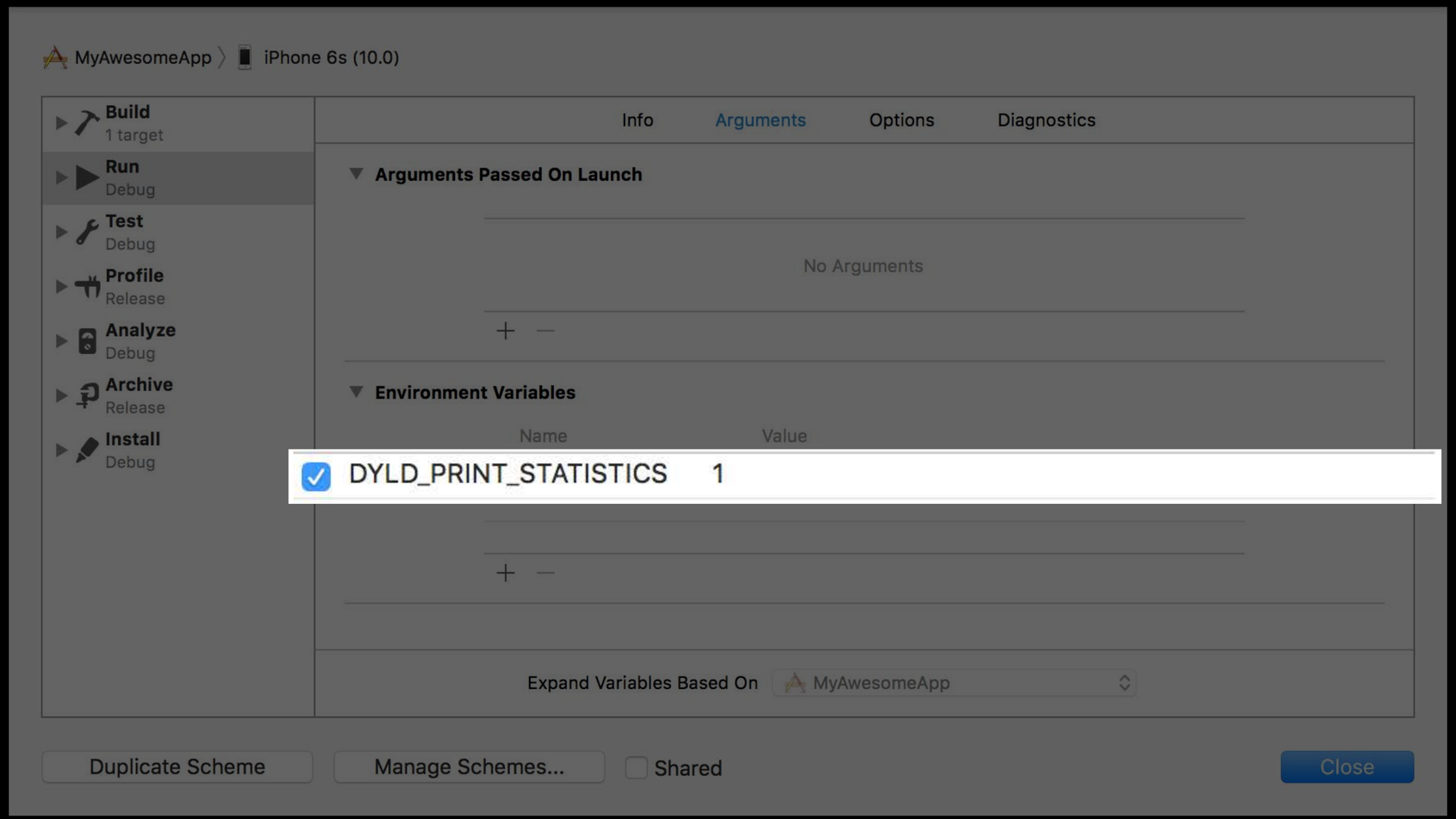

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Total pre-main time: 10.6 seconds (100.0%)
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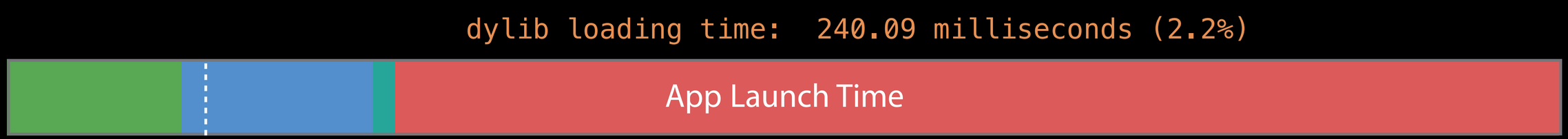
Embedded dylibs are expensive



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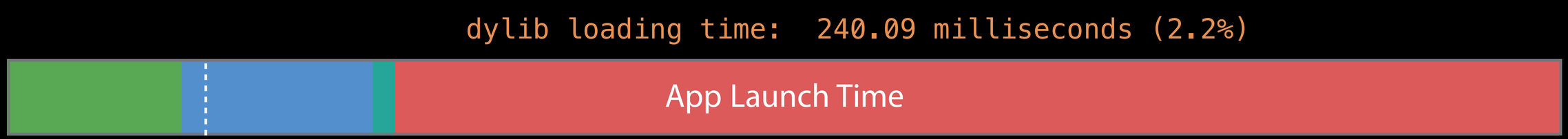

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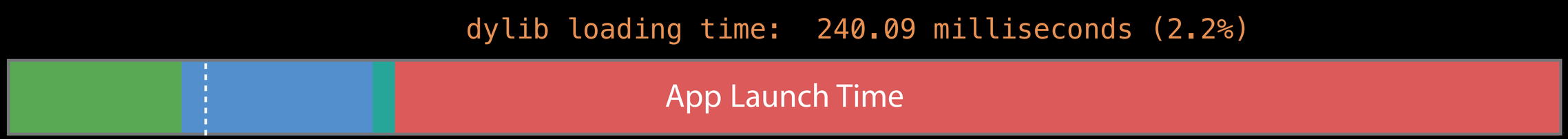

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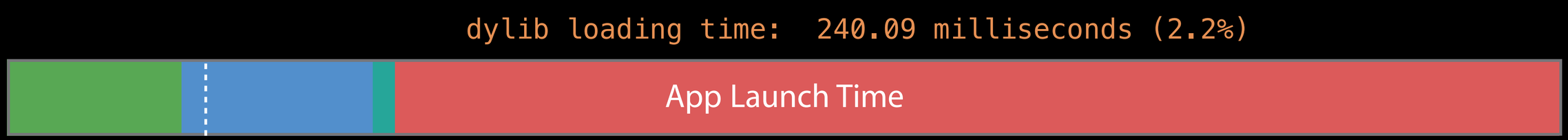

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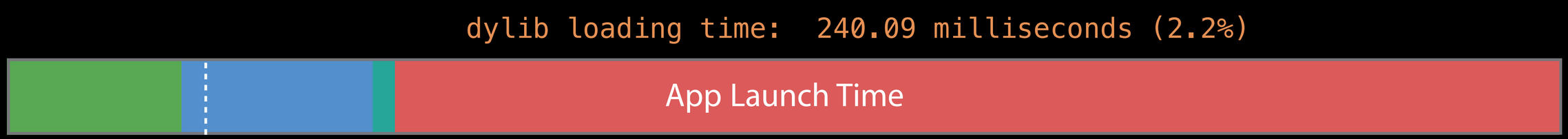

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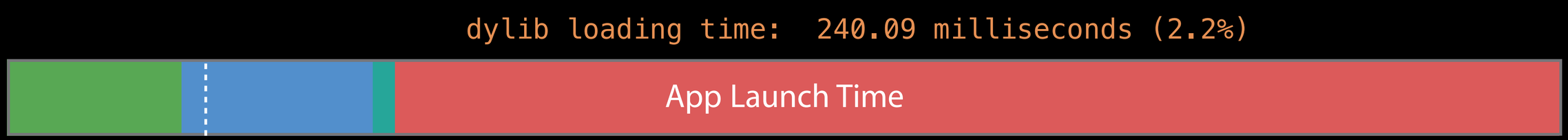
- Actually more work overall



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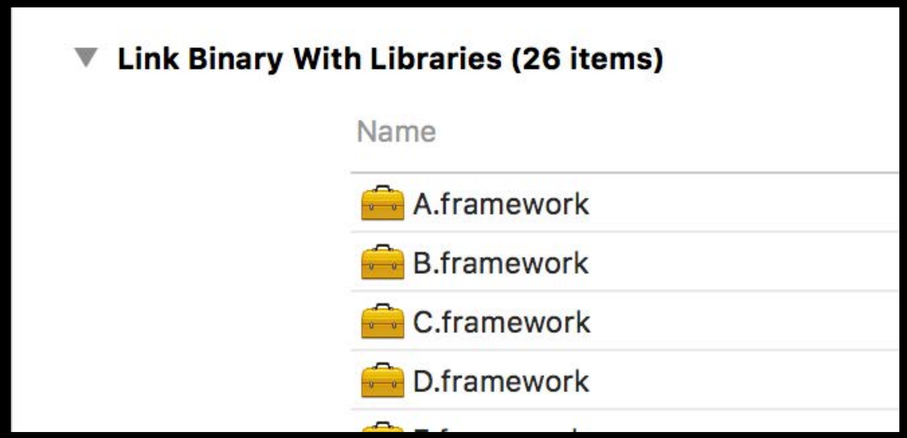

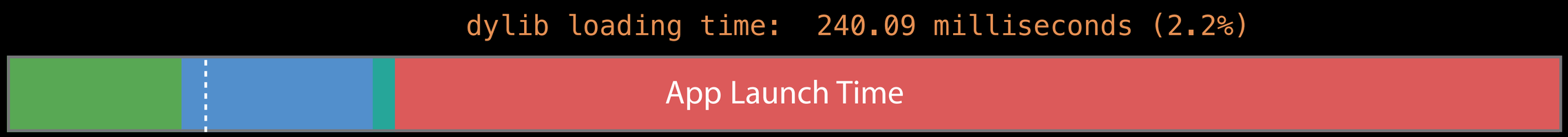

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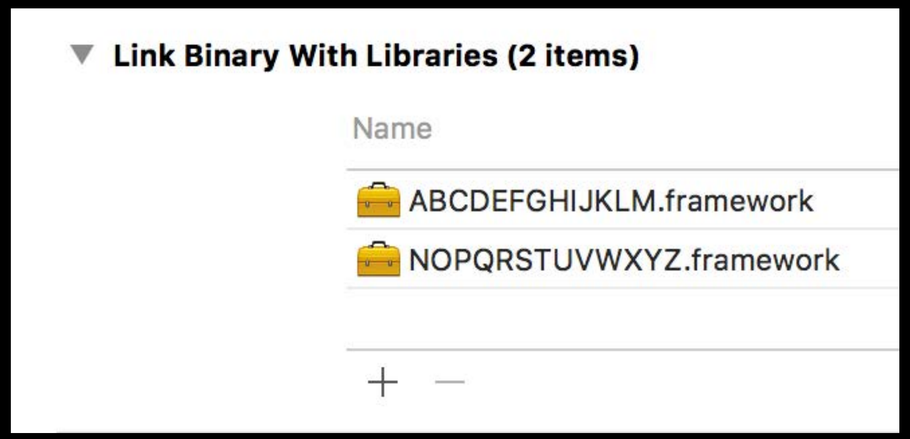


```
dylib loading time:  21.75 milliseconds (0.2%)
```

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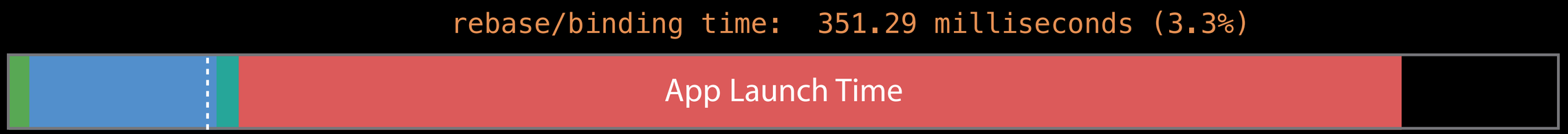
            ObjC setup time:  11.83 milliseconds (0.1%)
           initializer time:  10 seconds (94.3%)
           slowest intializers :
             MyAwesomeApp :  10.0 seconds (96.1%)
```

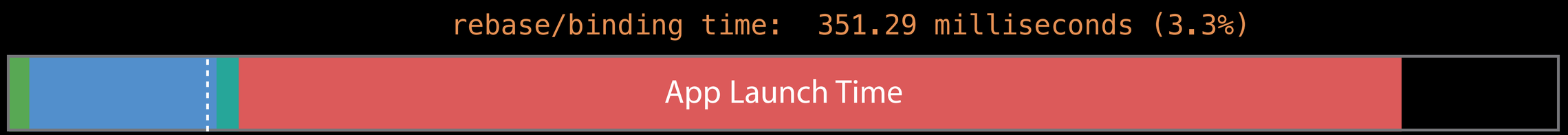
```
Total pre-main time: 10.4 seconds (100.0%)
         dylib loading time:  21.75 milliseconds (0.2%)
        rebase/binding time:  351.29 milliseconds (3.3%)
           ObjC setup time:  11.83 milliseconds (0.1%)
          initializer time:  10 seconds (94.3%)
          slowest intializers :
     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

Rebase/Binding



Rebase/Binding

Reduce __DATA pointers



Rebase/Binding

Reduce __DATA pointers

Reduce Objective C metadata

- Classes, selectors, and categories

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

Rebase/Binding

Reduce __DATA pointers

Reduce Objective C metadata

- Classes, selectors, and categories
- Reduce C++ virtual

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

Rebase/Binding

Reduce __DATA pointers

Reduce Objective C metadata

- Classes, selectors, and categories

Reduce C++ virtual

Use Swift structs

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

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

Reduce __DATA pointers

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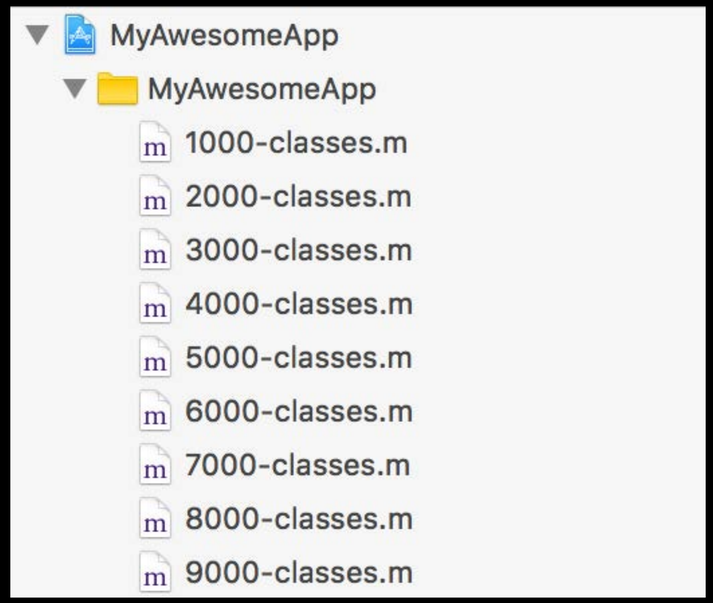


```
rebase/binding time:  351.29 milliseconds (3.3%)
```

Rebase/Binding

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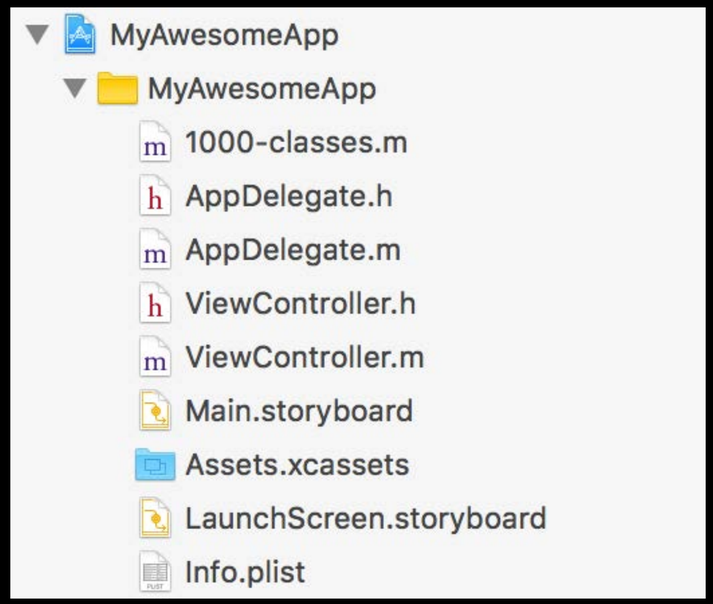


```
rebase/binding time:  19.33 milliseconds (0.2%)
```

```
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%)
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Total pre-main time: 10.1 seconds (100.0%)
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            ObjC setup time:  11.83 milliseconds (0.1%)
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Total pre-main time: 10.1 seconds (100.0%)
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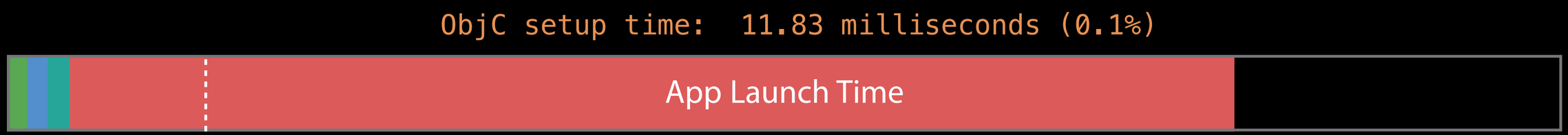
```

ObjC Setup

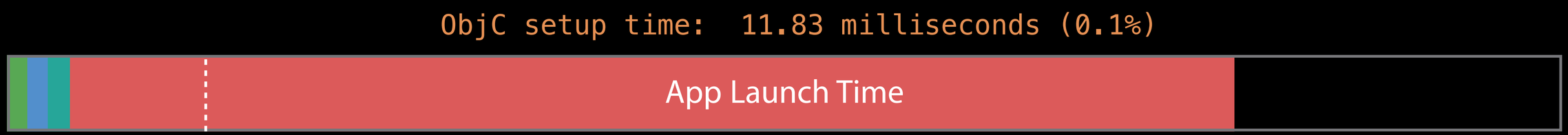
Class registration



ObjC Setup

Class registration

Non-fragile ivars offsets updated

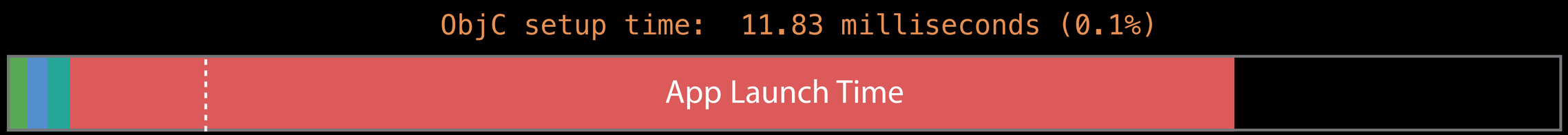


ObjC Setup

Class registration

Non-fragile ivars offsets updated

Category registration



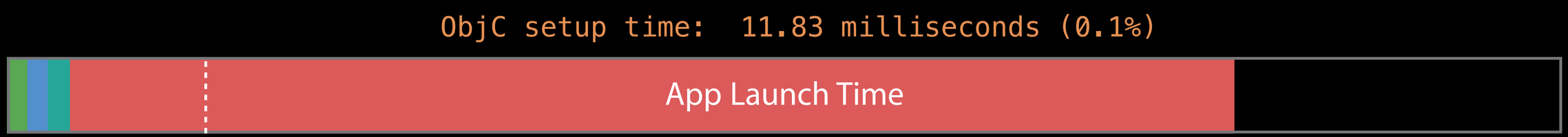
ObjC Setup

Class registration

Non-fragile ivars offsets updated

Category registration

Selector uniquing



ObjC Setup

Class registration

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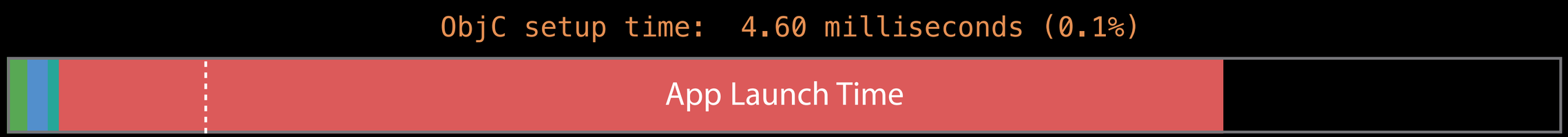
Selector uniquing

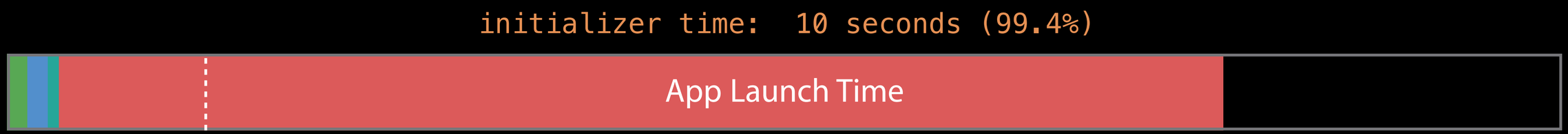


```
Total pre-main time: 10.6 seconds (100.0%)
         dylib loading time:  21.75 milliseconds (2.2%)
        rebase/binding time:  19.33 milliseconds (3.3%)
            ObjC setup time:  4.60 milliseconds (0.1%)
           initializer time:  10 seconds (94.3%)
           slowest intializers :
    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

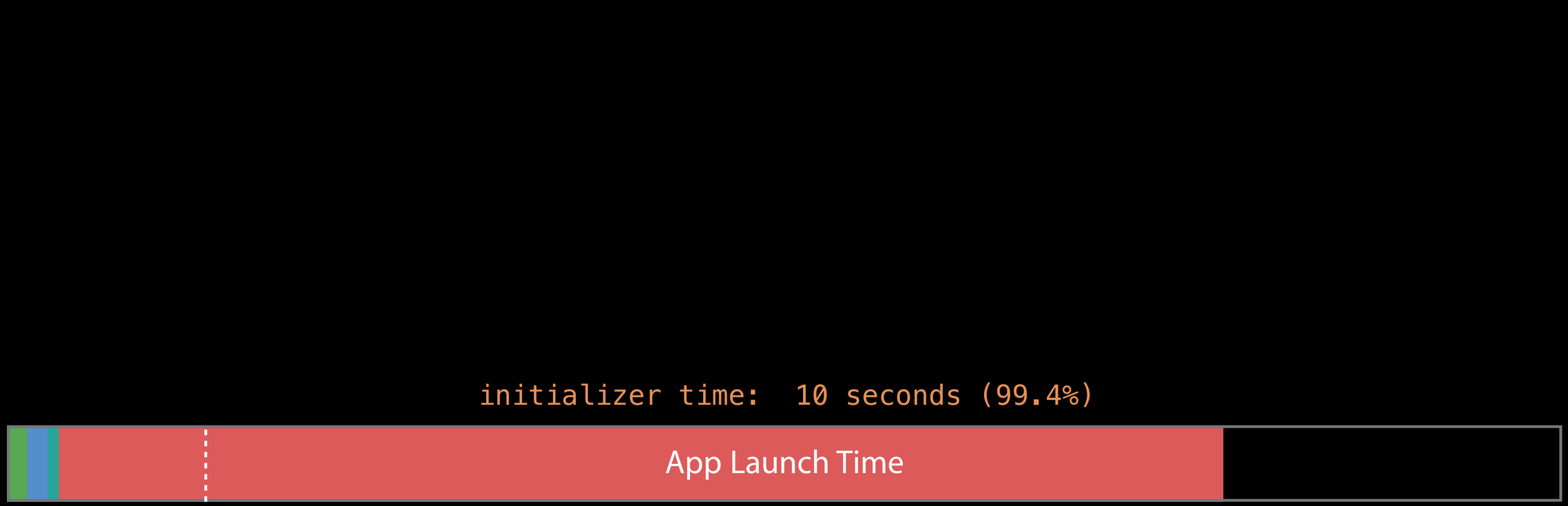
Explicit



Initializers

Explicit

ObjC `+load` methods



Initializers

Explicit

ObjC `+load` methods

- Replace with `+initiailize`

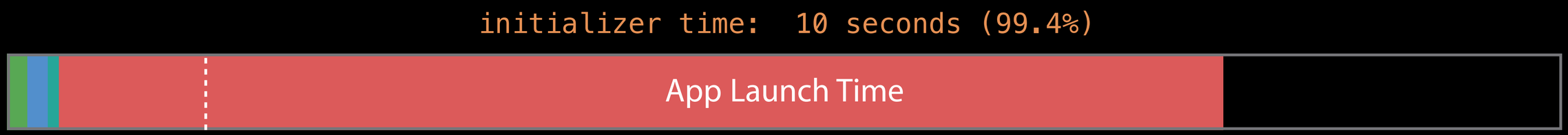
Initializers

Explicit

ObjC `+load` methods

- Replace with `+initiailize`

C/C++ __attribute__((constructor))



Initializers

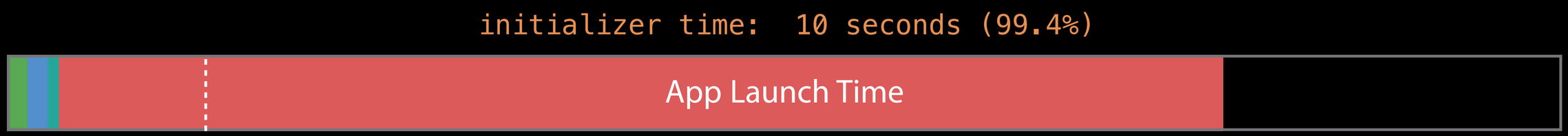
Explicit

ObjC `+load` methods

- Replace with `+initiailize`

C/C++ __attribute__((constructor))

Replace with call site initializers



Initializers

Explicit

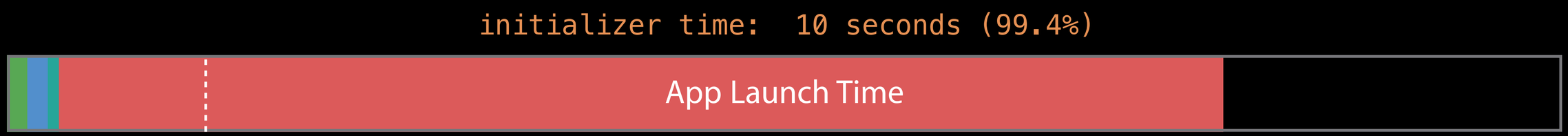
ObjC `+load` methods

- Replace with `+initiailize`

C/C++ __attribute__((constructor))

Replace with call site initializers

- `dispatch_once()`



Initializers

Explicit

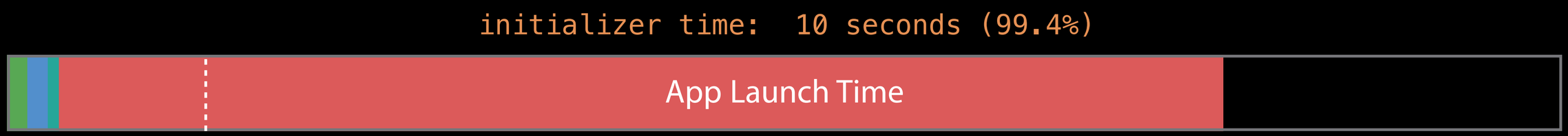
ObjC `+load` methods

- Replace with `+initiailize`

C/C++ __attribute__((constructor))

Replace with call site initializers

- `dispatch_once()`
- `pthread_once()`



Initializers

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ObjC `+load` methods

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C/C++ __attribute__((constructor))

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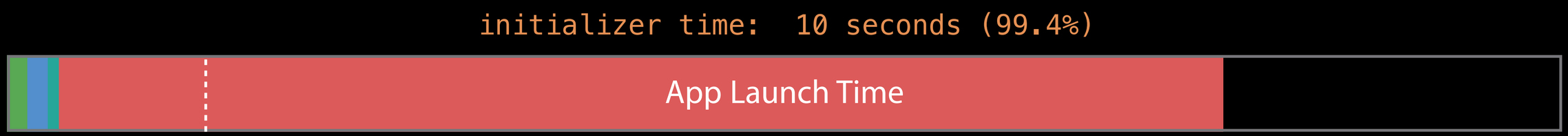
- `dispatch_once()`
- `pthread_once()`
- `std::once()`



Initializers

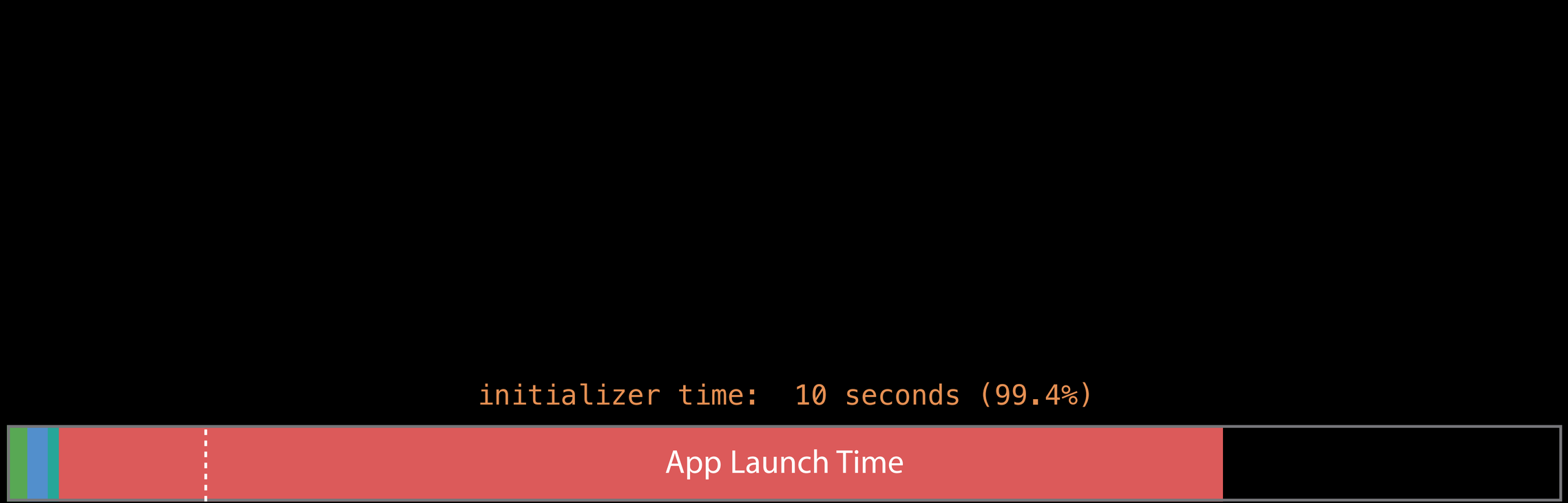
Implicit

initializer time: 10 seconds (99.4%)

Initializers

Implicit

C++ statics with non-trivial constructors



Initializers

Implicit

C++ statics with non-trivial constructors

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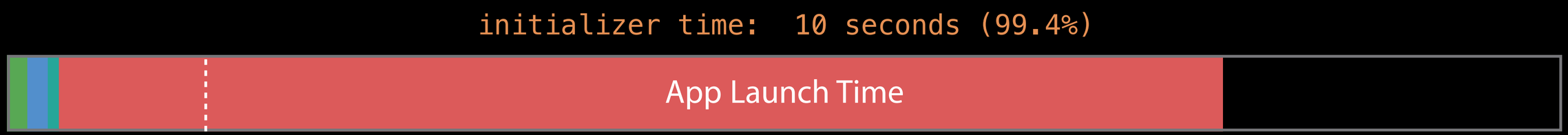
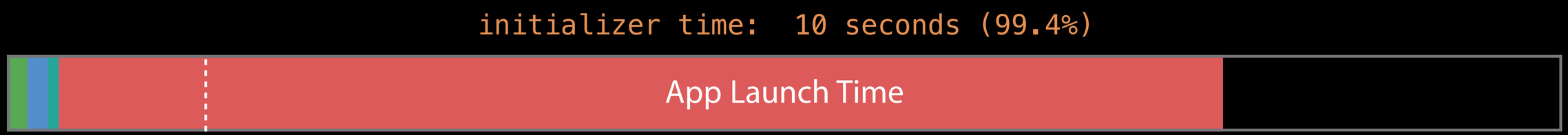


Initializers

Implicit

C++ statics with non-trivial constructors

- Replace with call site initializers
- Only set simple values (PODs)

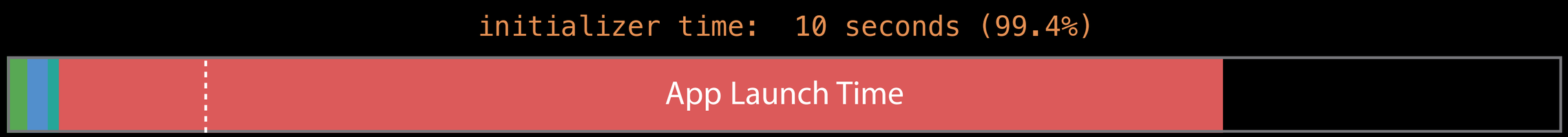


Initializers

Implicit

C++ statics with non-trivial constructors

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



Initializers

Implicit

C++ statics with non-trivial constructors

- Replace with call site initializers
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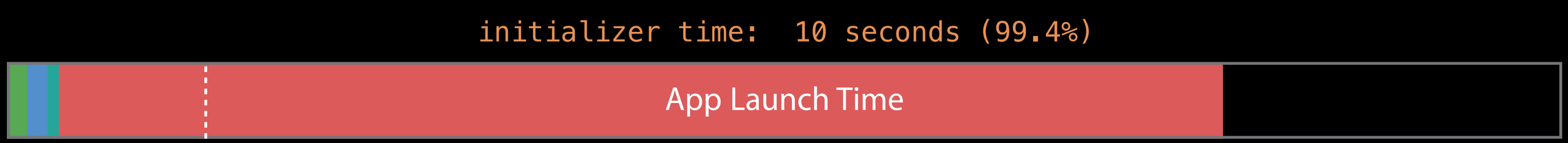
- Rewrite in Swift



Initializers

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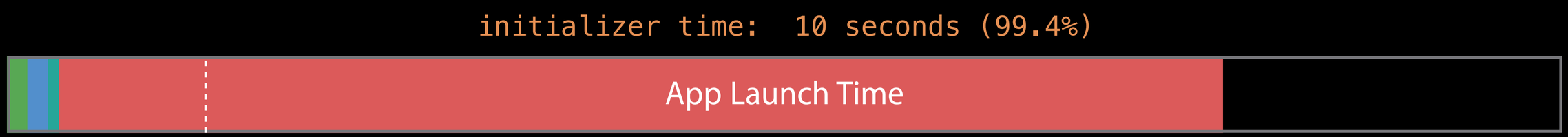
Do not call `dlopen()` in initializers



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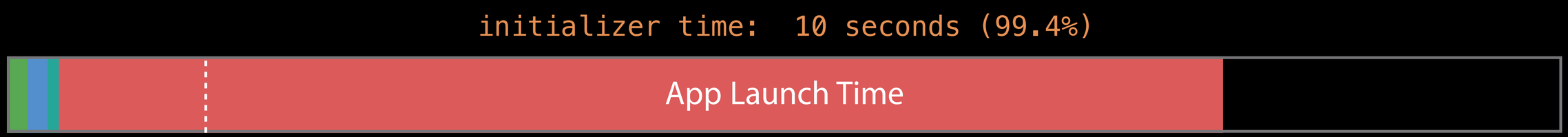
Do not create threads in initializers



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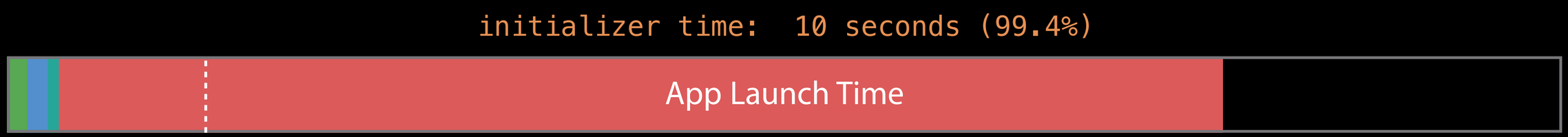
Do not call `dlopen()` in initializers

Do not create threads in initializers

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

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

Pause onLaunch(10);
```



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

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```
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%)
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TL;DR

Measure launch times with `DYLD_PRINT_STATISTICS`

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Reduce launch times by

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Reduce launch times by

- Embedding fewer dylibs

TL;DR

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- Consolidating Objective-C classes

TL;DR

Measure launch times with `DYLD_PRINT_STATISTICS`

Reduce launch times by

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- Consolidating Objective-C classes
- Eliminating static initializers

TL;DR

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Use more Swift

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Use more Swift

`dlopen()` is discouraged

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

WWDC16