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Antidote 2.0 - ASLR in iOS

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Who am I?

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)
- Head of R&D at SektionEins GmbH

Part I

Introduction

iPhone Security in 2010

- iPhone security got strucked twice
    - first during PWN2OWN (SMS database stolen with ROP payload)
    - again by jailbreakme.com (full remote jailbreak)
- lack of ASLR in iOS recognized as major weakness
- in december Antid0te demonstrated an ASLR solution for jailbroken iPhones

iPhone Security in 2011

- Apple released their own ASLR implementation with iOS 4.3
- several iOS updates to solve remotely exploitable flaws in MobileSafari
- another iOS update to solve the location gate problem
- but no updates to fix local kernel vulnerability used for current jailbreaks
- more security researchers concentrate on iOS kernel vulnerabilities

Topics

- What were the challenges in adding ASLR to the iPhone
- How did Antid0te's ASLR work around them without the help of Apple
- How does Apple's own ASLR implementation work
- How combining both implementation is even more secure
- What are the limitations of ASLR on the iPhone

Part II

ASLR vs. iOS

ASLR vs. iOS

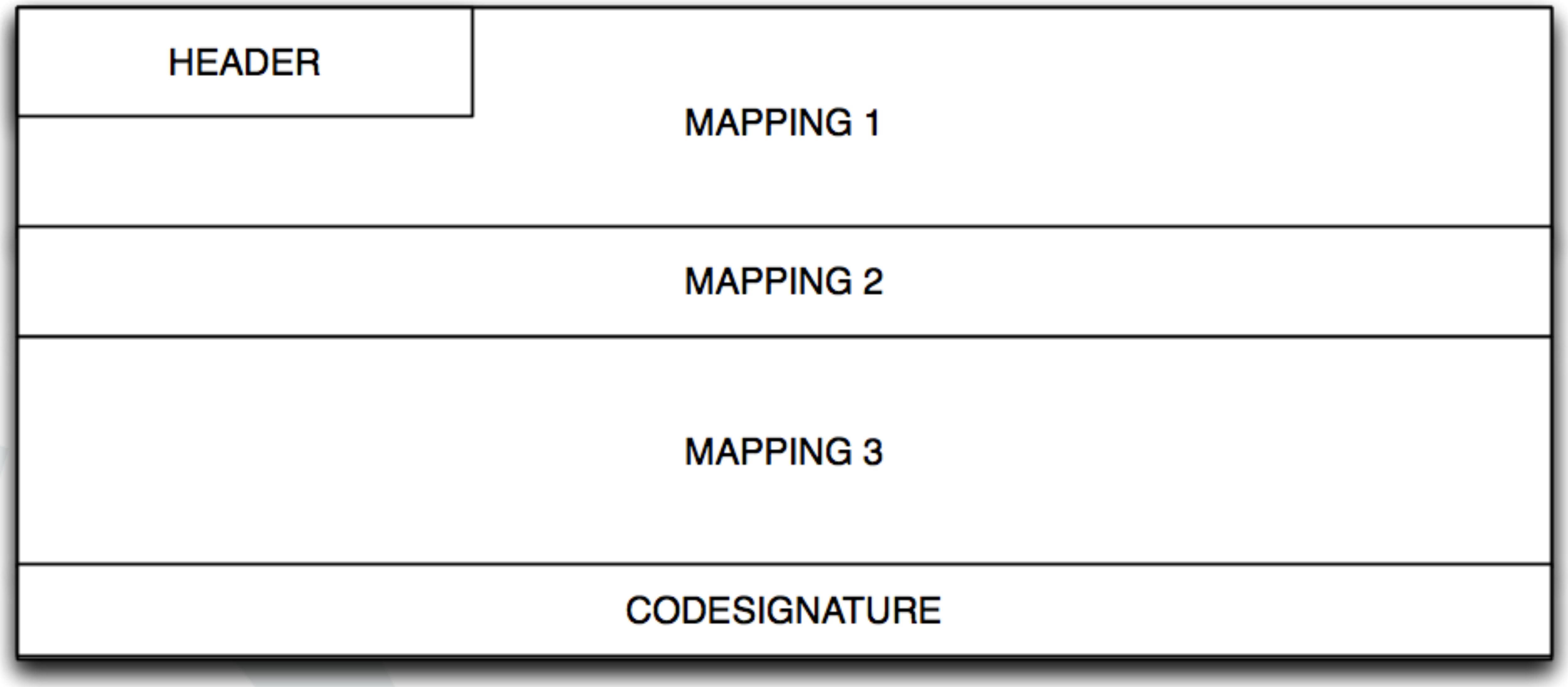
- iOS 4.2.x had no randomization at all (libs, dyld, stack, heap, ...)
- ASLR hard to implement due to Apple's optimizations (dyld_shared_cache)
- Codesigning major roadblock for adding effective ASLR
- binaries don't have relocation information

Libraries where are thou?

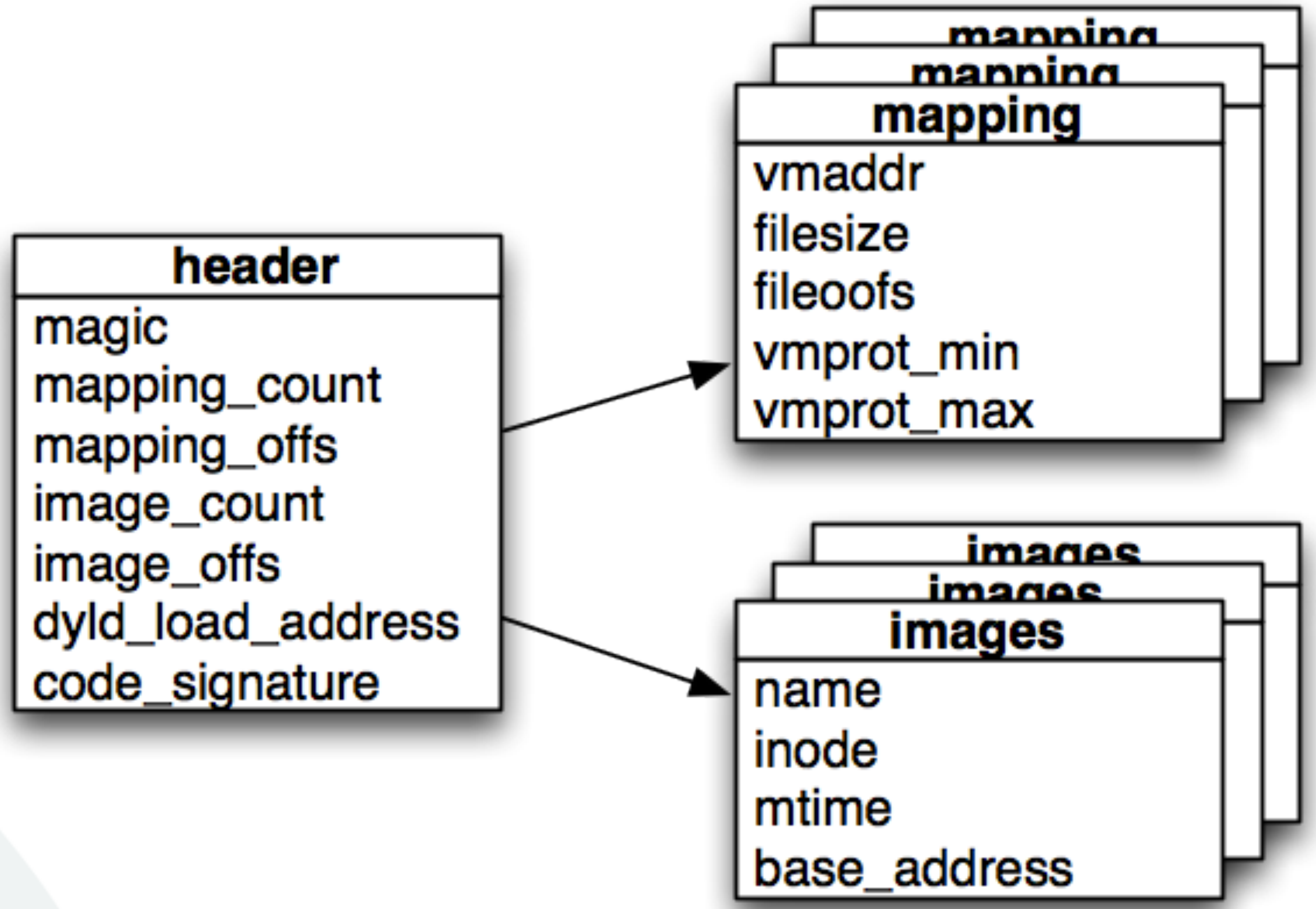
- since iPhoneOS / iOS 3.x shared libraries disappeared from the device
- because loading libraries is considered costly (time / memory)
- Apple moved all libraries into dyld_shared_cache
- technique also used in Snow Leopard

```
$ ls -la /Volumes/Jasper8C148.N90OS/usr/lib/
total 336
drwxr-xr-x  6 sesser  staff     476 17 Nov 09:56 .
drwxr-xr-x  7 sesser  staff     238 17 Nov 08:46 ..
drwxr-xr-x  5 sesser  staff     170 17 Nov 09:06 dic
-rwxr-xr-x  1 sesser  staff  232704 22 Okt 06:15 dyld
drwxr-xr-x  2 sesser  staff     102 22 Okt 05:49 info
lrwxr-xr-x  1 sesser  staff      59 17 Nov 09:56 libIOKit.A.dylib -> /System/Library/Frameworks/IOKit...work/Versions/A/IOKit
lrwxr-xr-x  1 sesser  staff      16 17 Nov 09:56 libIOKit.dylib -> libIOKit.A.dylib
lrwxr-xr-x  1 sesser  staff      16 17 Nov 09:06 libMatch.dylib -> libMatch.1.dylib
lrwxr-xr-x  1 sesser  staff      18 17 Nov 09:52 libcharset.1.0.0.dylib -> libcharset.1.dylib
lrwxr-xr-x  1 sesser  staff      15 17 Nov 09:52 libedit.dylib -> libedit.3.dylib
lrwxr-xr-x  1 sesser  staff      16 17 Nov 09:53 libexslt.dylib -> libexslt.0.dylib
lrwxr-xr-x  1 sesser  staff      18 17 Nov 09:23 libsandbox.dylib -> libsandbox.1.dylib
drwxr-xr-x  2 sesser  staff      68 22 Okt 06:10 libxslt-plugins
drwxr-xr-x  2 sesser  staff      68 22 Okt 05:47 system
```

dyld_shared_cache in iOS <= 4.2.x



dyld_shared_cache Header in iOS <= 4.2.x



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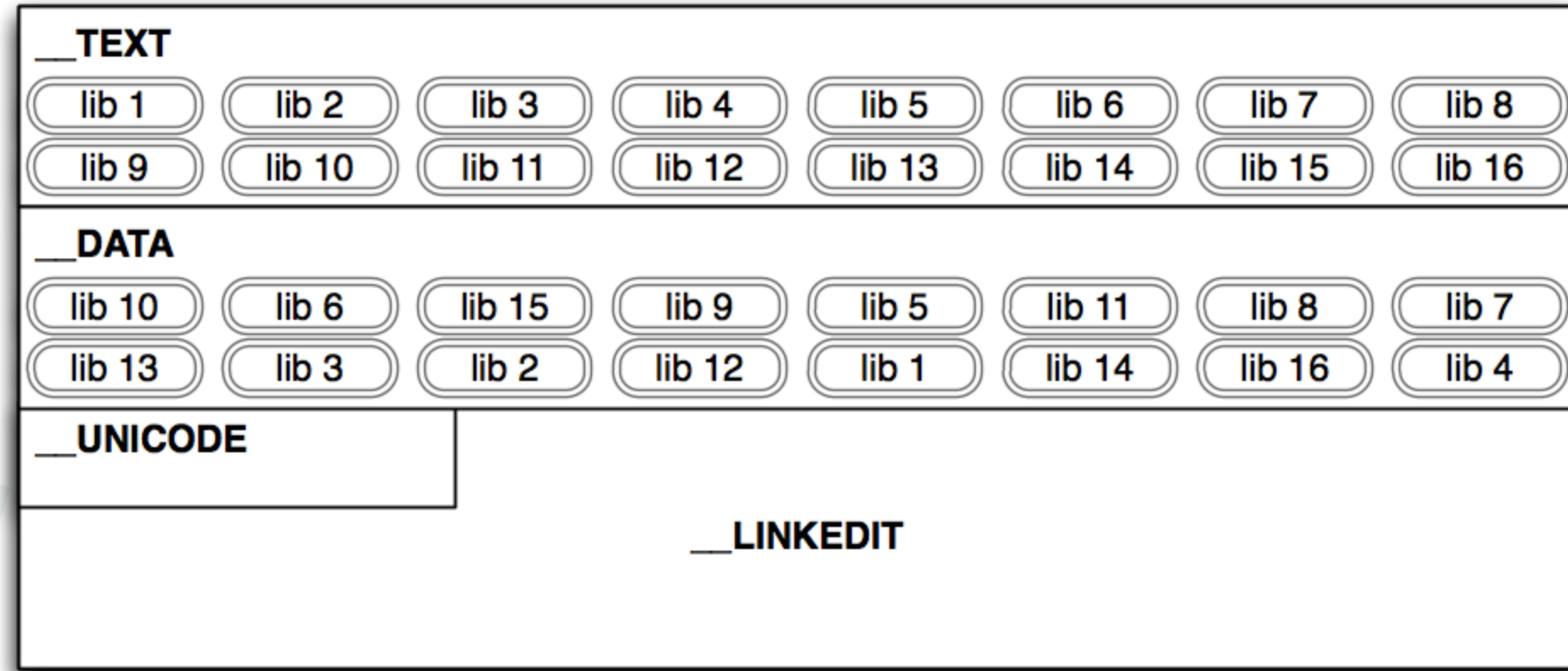
dyld_shared_cache in detail



dyld_shared_cache vs. ASLR

- libraries in cache are loaded at a fixed base address
- moving or shuffling requires to know fixup addresses
- no relocation information in binaries

- segment splitting - code and data compiled to specific delta
- moving or shuffling libraries requires to adjust delta
- positions of deltas unknown and also not in usual reloc info

Part III

Antid0te 1.0 - How did it work?

Antid0te

- Antid0te's goals were
  - to add ASLR to jailbroken iPhones
  - to not destroy the optimizations performed by Apple
- Codesigning not a problem because it is disabled on jailbroken phones
- Lack of relocation information major problem

Okay what did we do ?

looking at different shared caches revealed the following

- ➡ they seem to be made on the same machine
- ➡ the same binaries are used during construction
- ➡ library base addresses differ due to random load order

/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**

How does this help us ?

- same binaries but different load address allows diffing
- in theory memory should only differ in places that require relocation
- simply diffing two caches should get us all rebasing positions

➡ in reality it is not that simple => many complications

Obvious Complications

- different CPU type
  - ARMv6 => iPod 2G, iPhone 3G
  - ARMv7 => iPod 3G, iPod 4G, iPhone 3GS, iPhone 4, iPad
- iPod / iPhone / iPad have different features
  - libraries exist in one cache but not in the other
  - nothing to diff against ?

What to compare against each other ?

- diff against different CPU type => failed
- diff against beta version => failed
- diff against previous release => often fails
  - ➡ the 4.2, 4.2b, 4.2.1, 4.2.1a debacle ensured enough partners
  - ➡ the rushed release of 4.3 / 4.3.1 / 4.3.2 helps again
  - ➡ 4.3.3 for iPad is problematic
- merging diffs => works for some devices
  - ➡ merge diff between iPhone 3GS and iPhone 4G and diff between iPhone 4G and iPod 4G

Let's start diffing

- Python implementation
- uses macholib
- understands the dyld_shared_cache format
- diffs mach-o files
    - ensures same section (name, size, ...)
    - diffs section by section
    - diff is performed 4 byte aligned
    - ignores __LINKEDIT
- differences printed to stdout

Results of first diffing attempts

- found different types of differences
  - ➡ 2 large unknown values
  - ➡ 2 pointers inside the relocated binary
  - ➡ 2 pointers outside the relocated binary
  - ➡ 2 small unknown values
  - ➡ 1 small value vs. 1 pointer
  - ➡ 1 pointer vs. 1 small value

Analysing the results (I)

- **Expected results**
  - 2 pointers inside same binary => normal rebasing
  - 2 pointers outside binary => imports
- **Unexpected results**
  - 2 large values
  - 2 small values
  - 1 pointer vs. 1 small value

Analysing the results (II)

more careful evaluation revealed even worse fact

- ➡ when 2 pointers are found they do not always point to the same symbol
- ➡ luckily this only occurs inside some __objc_* sections
- ➡ thought -> must be some ObjC weirdness

```
__objc_const:3E7C33C8                 DCD 0xF
__objc_const:3E7C33CC                 DCD 7
__objc_const:3E7C33D0                 DCD 0x32CA2574
__objc_const:3E7C33D4                 DCD aV804               ; "v8@0:4"
__objc_const:3E7C33D8                 DCD __WebArchivePrivate_dealloc_+1
__objc_const:3E7C33DC                 DCD 0x32CA58FB
__objc_const:3E7C33E0                 DCD a804                ; "@8@0:4"
__objc_const:3E7C33E4                 DCD __WebArchivePrivate_init_+1

__objc_const:3E3593C8                 DCD 0xF
__objc_const:3E3593CC                 DCD 7
__objc_const:3E3593D0                 DCD aInitwithcorear     ; "initWithCoreArchive:"
__objc_const:3E3593D4                 DCD a1204Passrefptr     ; "@12@0:4{PassRefPtr<WebCore::LegacyWebAr"...
__objc_const:3E3593D8                 DCD __WebArchivePrivate_initWithCoreArchive__+1
__objc_const:3E3593DC                 DCD aSetcorearchive     ; "setCoreArchive:"
__objc_const:3E3593E0                 DCD aV1204Passrefpt     ; "v12@0:4{PassRefPtr<WebCore::LegacyWebAr"...
__objc_const:3E3593E4                 DCD __WebArchivePrivate_setCoreArchive__+1
```

What are the two large unknown values ?

- very common in __text section
- first believed to be a code difference
- using IDA to look at it revealed it is caused by different __DATA - __TEXT delta

```
__text:301FFB60
__text:301FFB60                 EXPORT _mach_init
__text:301FFB60 _mach_init                              ; CODE XREF: j__mach_init+4↓j
__text:301FFB60                                         ; DATA XREF: __la_symbol_ptr:_mach_init_ptr↓o
__text:301FFB60                 PUSH            {R7,LR}
__text:301FFB62                 ADD             R7, SP, #0
__text:301FFB64                 LDR             R0, =(_mach_init_inited - 0x301FFB6A)
__text:301FFB66                 ADD             R0, PC
__text:301FFB68                 LDR             R0, [R0]
__text:301FFB6A                 CBZ             R0, loc_301FFB70
__text:301FFB6C                 MOVS            R0, #0
__text:301FFB6E                 B               locret_301FFB7C
__text:301FFB70 ; ---------------------------------------------------------------------------
__text:301FFB70
__text:301FFB70 loc_301FFB70                            ; CODE XREF: _mach_init+A↑j
__text:301FFB70                 LDR             R3, =(_mach_init_inited - 0x301FFB78)
__text:301FFB72                 MOVS            R2, #1
__text:301FFB74                 ADD             R3, PC
__text:301FFB76                 STR             R2, [R3]
__text:301FFB78                 BLX             j__mach_init_doit
__text:301FFB7C
__text:301FFB7C locret_301FFB7C                         ; CODE XREF: _mach_init+E↑j
__text:301FFB7C                 POP             {R7,PC}
__text:301FFB7C ; End of function _mach_init
__text:301FFB7C
__text:301FFB7C ; ---------------------------------------------------------------------------
__text:301FFB7E                 ALIGN 0x10
__text:301FFB80 off_301FFB80    DCD _mach_init_inited - 0x301FFB6A
__text:301FFB80                                         ; DATA XREF: _mach_init+4↑r
__text:301FFB84 off_301FFB84    DCD _mach_init_inited - 0x301FFB78
__text:301FFB84                                         ; DATA XREF: _mach_init:loc_301FFB70↑r
__text:301FFB88
```

Large unknown values in libobjc.dylib

- inside libobjc.dylib there is a huge blob of unknown large values that differs
- had no idea what this was - made me fear a roadstop
- source code access or reversing libobjc.dylib required => see later

```
__objc_opt_ro:3003A6F8                DCB 1, 2, 0, 0x21, 9, 0, 0x2D, 1, 0xD, 0xC, 0x27, 0x33; 8125
__objc_opt_ro:3003A6F8                DCB 8, 0x1A, 0x30, 1, 0x23, 5, 0, 0xD, 0x42, 0x21, 0x26; 8137
__objc_opt_ro:3003A6F8                DCB 0xA, 0x19, 0x32, 0xB, 0x16, 0x20, 5, 0x3B, 0x13, 0x6C; 8148
__objc_opt_ro:3003A6F8                DCB 7, 0x23, 0x14, 4, 0x28, 0xB, 0x15, 0x2F, 0x49, 0x3C; 8158
__objc_opt_ro:3003A6F8                DCB 9, 0xA, 0x45, 2, 0x1B, 0x2D, 0, 0, 4, 2, 0, 3, 2, 2; 8168
__objc_opt_ro:3003A6F8                DCB 0x12, 0, 1, 0x17, 0x2D, 0x2A, 8, 5, 0, 8; 8182
__objc_opt_ro:3003C6F8 unknown_blob   DCD 0x92DE39, 0x10, 0xCB4F1E, 0x1DF6055, 0x51991C8, 0x1DE8D8B, 0x4A7AEA2, 0x159D4D9; 0
__objc_opt_ro:3003C6F8                DCD 0x1DE2C5C, 0x10, 0x10, 0x44FB7E1, 0x10, 0x643545, 0x10, 0x16C12A8; 8
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x502BA49, 0x10, 0x10, 0xB4FD74, 0x10, 0x10; 16
__objc_opt_ro:3003C6F8                DCD 0x10, 0x4F88B58, 0x38C998E, 0x10, 0x301AD1E, 0x10, 0x10, 0x502D3A5; 24
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x10, 0x181EF66, 0x50332AB, 0xB514EF, 0xAD48ED, 0x659FB0; 32
__objc_opt_ro:3003C6F8                DCD 0x3000CC8, 0x1C089C, 0x10, 0x10, 0x4A721CA, 0x4A808EF, 0x10, 0x10; 40
__objc_opt_ro:3003C6F8                DCD 0x303144, 0x10, 0x192D468, 0x10, 0x10, 0x1929C8C, 0x10, 0x10; 48
__objc_opt_ro:3003C6F8                DCD 0x373692, 0x10, 0x10, 0x10, 0x16CCB86, 0x518D681, 0x10, 0x10; 56
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x71A7B7, 0x30032DF, 0x37F3A21, 0xCFD239, 0x667AEC, 0x10; 64
__objc_opt_ro:3003C6F8                DCD 0x4A7CA11, 0x10, 0x302A14E, 0x1456CDF, 0x16CADEB, 0x3EA5C83, 0x65D426, 0x10; 72
__objc_opt_ro:3003C6F8                DCD 0x16C3C28, 0x518F304, 0xB51DAD, 0x10, 0x929605, 0x38B9575, 0x10, 0x38BBB68; 80
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x10, 0x10, 0x10, 0x38BC543, 0x358F300, 0xCB4622; 88
__objc_opt_ro:3003C6F8                DCD 0x19210DD, 0x439E260, 0x10, 0x439B50B, 0x11E0ED1, 0x1D0A19F, 0x935B53, 0x10; 96
__objc_opt_ro:3003C6F8                DCD 0x10, 0x502A363, 0x10, 0x301D7E8, 0x10, 0x10, 0x10, 0x53CB5D8; 104
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x10, 0x10, 0x93201E, 0x10, 0x10, 0x10; 112
__objc_opt_ro:3003C6F8                DCD 0x10, 0x30063BB, 0xB066A4, 0x306CDE, 0x300F9D1, 0x12540F8, 0x16D10CB, 0x10; 120
__objc_opt_ro:3003C6F8                DCD 0x64334B, 0x1DF475A, 0x666386, 0x10, 0x10, 0x53C9223, 0x136B47B, 0x10; 128
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x10, 0x10, 0x16C2281, 0x1AF9124, 0x4A82743, 0x10; 136
__objc_opt_ro:3003C6F8                DCD 0x358149B, 0x10, 0x2FEB479, 0x10, 0x10, 0x1B6DAA3, 0x1AFF725, 0x1C1AEEB; 144
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x66F48F, 0x10, 0x10, 0x3A97952, 0x38BA5C3, 0x644152; 152
__objc_opt_ro:3003C6F8                DCD 0x662FCB, 0x10, 0x10, 0x549A471, 0x2FEE06C, 0x37F35FC, 0x10, 0x10; 160
__objc_opt_ro:3003C6F8                DCD 0x10, 0x3026456, 0x10, 0x4A7E2D5, 0x1A7311B, 0x10, 0x10, 0x10; 168
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x124D1E2, 0x1BFB29C, 0x645850, 0x3032717, 0x10, 0x10; 176
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x10, 0x65B33D, 0x10, 0x10, 0x3018717, 0x10; 184
__objc_opt_ro:3003C6F8                DCD 0x10, 0x10, 0x10, 0x473DDA9, 0x124C4A5, 0x10, 0x660566, 0x3653799; 192
```

Small Values and Pointers

- some files contain small values that do not match
- sometimes there is a small value in one file and a pointer in the other
- occurs only in __objc_* sections
- emphasizes the need of objc reversing

```
055/321 /.../DataAccess.framework/DataAccess
---------
__text
---------
...
__objc_imageinfo
---------
__objc_const
small value + ptr 0000000f 337d1611
small value + ptr 00000012 32bcc832
ptr + small value 30b12832 0000000f
ptr + small value 30af14cd 0000000d
---------
__objc_selrefs
---------
__objc_classrefs
---------
__objc_superrefs
---------
__objc_data
---------
__data
global 10836
address 5917
delta 4916
sel 0
```

Reversing the objc differences

- grabbed objc-4 source code from http://developer.apple.com/
- tried to find the responsible code
- soon turned out to be more complicated
- source code matches only partially

iPhone libobjc does not match the source (I)

```
struct objc_selopt_t {

    uint32_t version;  /* this is version 3: external cstrings */
    uint32_t capacity;
    uint32_t occupied;
    uint32_t shift;
    uint32_t mask;
    uint32_t zero;
    uint64_t salt;
    uint64_t base;

    uint32_t scramble[256];
    /* tab[mask+1] */
    uint8_t tab[0];
    /* offsets from &version
       to cstrings
       int32_t offsets[capacity];
    */
}
```

```
_objc_opt_ro:3003A2D0 __objc_opt_data DCD 8                 ; DATA XREF: __nl_symbol_ptr:__objc_opt_data_ptr|o
_objc_opt_ro:3003A2D4 version         DCD 8
_objc_opt_ro:3003A2D8 capacity        DCD 131072
_objc_opt_ro:3003A2DC occupied        DCD 65801
_objc_opt_ro:3003A2E0 shift           DCD 47
_objc_opt_ro:3003A2E4 mask            DCD 0x1FFF
_objc_opt_ro:3003A2E8 zero_low        DCD 0
_objc_opt_ro:3003A2EC padding         DCD 0
_objc_opt_ro:3003A2F0 salt_low        DCD 0x72873569
_objc_opt_ro:3003A2F4 salt_high       DCD 0xBE1E08C4
_objc_opt_ro:3003A2F8 scramble        DCD 0, 0x5524, 0xA517, 0x1EB8E, 0x13D51, 0xAA74, 0x1B4AB, 0x1A10, 0xAAB,
_objc_opt_ro:3003A2F8                 DCD 0x14A98, 0x1B032, 0x7111, 0x1E8E8, 0xEF08, 0x640C, 0xDD, 0xD635,
_objc_opt_ro:3003A2F8                 DCD 0x5F9B, 0x19F1E, 0x1D870, 0x34BC, 0x1FADF, 0x11A70, 0x1E796, 0x1E71B,
_objc_opt_ro:3003A2F8                 DCD 0xDA6D, 0x1625A, 0x1D55F, 0x18649, 0x77BD, 0x11EA2, 0x11C9A, 0x1EF74,
_objc_opt_ro:3003A2F8                 DCD 0x1ACEC, 0x9C1B, 0x8DB, 0xF142, 0x16641, 0x32FD, 0x188C2, 0x73C6,
_objc_opt_ro:3003A2F8                 DCD 0x1628A, 0x188A0, 0x10214, 0xB2A0, 0x2A59, 0x15727, 0x244F, 0x409A,
_objc_opt_ro:3003A2F8                 DCD 0x7ACE, 0x15314, 0xECF0, 0x14C2D, 0xC38E, 0x1D7ED, 0xDC59, 0xA532,
_objc_opt_ro:3003A2F8                 DCD 0xBC6A, 0xBDBD, 0x9FE5, 0x1BC57, 0x8F60, 0x1A7F8, 0x3A39, 0x1187D,
_objc_opt_ro:3003A2F8                 DCD 0x158A, 0xF430, 0xC95D, 0x1E42C, 0x1EDF8, 0x12C86, 0x9217, 0x16EA9,
_objc_opt_ro:3003A2F8                 DCD 0x1589C, 0x8D11, 0xAD4C, 0x851F, 0x1D3D2, 0x13558, 0x10BC0, 0x7B07,
_objc_opt_ro:3003A2F8                 DCD 0x1187E, 0x1733F, 0xF2DC, 0x9406, 0x38B8, 0x10FBF, 0x14162, 0x19050,
_objc_opt_ro:3003A2F8                 DCD 0x13C2D, 0x17A59, 0x1AD64, 0xD486, 0x9FBB, 0x4604, 0x1E76B, 0x37A2,
_objc_opt_ro:3003A2F8                 DCD 0x1FF0B, 0x1D172, 0x9134, 0x10543, 0x1CB14, 0x12507, 0x1B562, 0x1599F,
_objc_opt_ro:3003A2F8                 DCD 0x10B24, 0x91B7, 0x6139, 0xC88, 0x18B62, 0x6661, 0x5A64, 0x1FD4F,
_objc_opt_ro:3003A2F8                 DCD 0x94AA, 0x1C179, 0x84E2, 0x15C1E, 0xE210, 0x6B04, 0x1A9F1, 0xBB59,
_objc_opt_ro:3003A2F8                 DCD 0x182E8, 0x16EE7, 0x4BC9, 0x77F1, 0x175B3, 0x1F725, 0x78E0, 0x178DD,
_objc_opt_ro:3003A6F8 tab             DCB 6, 0, 0x18, 1, 7, 0x22, 0xF, 0x12, 8, 0x1A, 2, 2, 8; 0
_objc_opt_ro:3003A6F8                 DCB 0, 6, 7, 0xD, 0x2D, 0xA, 5, 2, 0xE, 0, 0, 0, 0x23; 13
_objc_opt_ro:3003A6F8                 DCB 0, 5, 0x26, 0x3A, 4, 0x1F, 2, 0x1D, 9, 3, 6, 3, 0x1D; 26
_objc_opt_ro:3003A6F8                 DCB 0x53, 4, 7, 0xB, 3, 2, 3, 0x24, 1, 0x53, 2, 0xA, 3; 39
_objc_opt_ro:3003A6F8                 DCB 1, 0, 0x2A, 8, 0x45, 0xC, 7, 0, 0x1F, 0x13, 4, 2, 0xB; 52
_objc_opt_ro:3003A6F8                 DCB 0, 0x16, 0x4C, 0, 3, 4, 0, 1, 6, 0x32, 1, 2, 2, 0xE; 65
_objc_opt_ro:3003A6F8                 DCB 5, 0xE, 0x11, 7, 7, 0xE, 7, 0xF, 0xA, 0xB, 0xB, 0x15; 79
_objc_opt_ro:3003A6F8                 DCB 0xE, 1, 0x21, 2, 0x21, 8, 4, 0, 4, 1, 0, 5, 1, 0x22; 91
_objc_opt_ro:3003A6F8                 DCB 0xE, 8, 6, 0x10, 0, 0, 0xB, 0, 1, 2, 0x12, 2, 0x10; 105
_objc_opt_ro:3003A6F8                 DCB 0xF, 0, 0, 8, 0x39, 4, 0, 1, 0, 0x27, 1, 5, 0, 0x25; 118
_objc_opt_ro:3003A6F8                 DCB 0, 0, 4, 0, 3, 2, 0, 7, 0x14, 0, 4, 0, 5, 1, 2, 7; 132
_objc_opt_ro:3003A6F8                 DCB 4, 5, 3, 3, 0x28, 3, 0xE, 0xD, 8, 0x14, 0, 2, 0x41; 148
_objc_opt_ro:3003A6F8                 DCB 2, 6, 0, 0, 0x11, 6, 0, 0, 0xD, 2, 0x13, 9, 2, 5, 0; 161
_objc_opt_ro:3003A6F8                 DCB 3, 0, 7, 0x22, 0, 0x27, 5, 1, 0xB, 3, 0, 9, 0x1E, 0x1D; 176
_objc_opt_ro:3003A6F8                 DCB 4, 0, 8, 0, 1, 0, 0, 0x22, 0x10, 5, 6, 0, 8, 0, 0x1B; 190
_objc_opt_ro:3003A6F8                 DCB 0xD, 0xE, 1, 0, 0, 0, 0, 1, 0, 1, 0xA, 6, 0x25, 0; 205
_objc_opt_ro:3003A6F8                 DCB 8, 0x14, 7, 0x1E, 0, 0x13, 0, 3, 2, 0x16, 0x2F, 0xC; 219
```

iPhone libobjc does not match the source (I)

- unknown large blob is the offset table
- which is a list of offsets to selector names
- knowing the content it is easy to relocate

- on the iPhone the offset table is followed by an unknown table
- unknown table has capacity many entries of size 1 byte
- according to twitter it is a one byte checksum of the selector name

Analysing the different pointer problem

```
__objc_const:3E7C33C6                 DCB    0
__objc_const:3E7C33C7                 DCB    0
__objc_const:3E7C33C8                 DCD 0xF
__objc_const:3E7C33CC                 DCD 7
__objc_const:3E7C33D0                 DCD 0x32CA2574
__objc_const:3E7C33D4                 DCD aV804               ; "v8@0:4"
__objc_const:3E7C33D8                 DCD __WebArchivePrivate_dealloc_+1
__objc_const:3E7C33DC                 DCD 0x32CA58FB
__objc_const:3E7C33E0                 DCD a804                ; "@8@0:4"
__objc_const:3E7C33E4                 DCD __WebArchivePrivate_init_+1
__objc_const:3E7C33E8                 DCD aInitwithcorear     ; "initWithCoreArchive:"
__objc_const:3E7C33EC                 DCD a1204Passrefptr     ; "@12@0:4{PassRefPtr<WebCore::LegacyWebAr"...
__objc_const:3E7C33F0                 DCD __WebArchivePrivate_initWithCoreArchive__+1
__objc_const:3E7C33F4                 DCD aSetcorearchive     ; "setCoreArchive:"
__objc_const:3E7C33F8                 DCD aV1204Passrefpt     ; "v12@0:4{PassRefPtr<WebCore::LegacyWebAr"...
__objc_const:3E7C33FC                 DCD __WebArchivePrivate_setCoreArchive__+1
__objc_const:3E7C3400                 DCD aCorearchive        ; "coreArchive"
__objc_const:3E7C3404                 DCD aLegacywebarchi     ; "^{LegacyWebArchive=i{RefPtr<WebCore::Ar"...
__objc_const:3E7C3408                 DCD __WebArchivePrivate_coreArchive_+1
__objc_const:3E7C340C                 DCD 0x3507FFA8
__objc_const:3E7C3410                 DCD aV804               ; "v8@0:4"
__objc_const:3E7C3414                 DCD __WebArchivePrivate_.cxx_destruct_+1
__objc_const:3E7C3418                 DCD 0x3508088C
__objc_const:3E7C341C                 DCD a804                ; "@8@0:4"
__objc_const:3E7C3420                 DCD __WebArchivePrivate_.cxx_construct_+1
__objc_const:3E7C3424                 DCB 0x14
__objc_const:3E7C3425                 DCB    0
```

looking at it with IDA reveales that method tables are simply resorted

```
__objc_const:3E3593C6                 DCB    0
__objc_const:3E3593C7                 DCB    0
__objc_const:3E3593C8                 DCD 0xF
__objc_const:3E3593CC                 DCD 7
__objc_const:3E3593D0                 DCD aInitwithcorear     ; "initWithCoreArchive:"
__objc_const:3E3593D4                 DCD a1204Passrefptr     ; "@12@0:4{PassRefPtr<WebCore::LegacyWebAr"...
__objc_const:3E3593D8                 DCD __WebArchivePrivate_initWithCoreArchive__+1
__objc_const:3E3593DC                 DCD aSetcorearchive     ; "setCoreArchive:"
__objc_const:3E3593E0                 DCD aV1204Passrefpt     ; "v12@0:4{PassRefPtr<WebCore::LegacyWebAr"...
__objc_const:3E3593E4                 DCD __WebArchivePrivate_setCoreArchive__+1
__objc_const:3E3593E8                 DCD aCorearchive        ; "coreArchive"
__objc_const:3E3593EC                 DCD aLegacywebarchi     ; "^{LegacyWebArchive=i{RefPtr<WebCore::Ar"...
__objc_const:3E3593F0                 DCD __WebArchivePrivate_coreArchive_+1
__objc_const:3E3593F4                 DCD 0x33023574
__objc_const:3E3593F8                 DCD aV804               ; "v8@0:4"
__objc_const:3E3593FC                 DCD __WebArchivePrivate_dealloc_+1
__objc_const:3E359400                 DCD 0x330268FB
__objc_const:3E359404                 DCD a804                ; "@8@0:4"
__objc_const:3E359408                 DCD __WebArchivePrivate_init_+1
__objc_const:3E35940C                 DCD 0x335DEFA8
__objc_const:3E359410                 DCD aV804               ; "v8@0:4"
__objc_const:3E359414                 DCD __WebArchivePrivate_.cxx_destruct_+1
__objc_const:3E359418                 DCD 0x335DF88C
__objc_const:3E35941C                 DCD a804                ; "@8@0:4"
__objc_const:3E359420                 DCD __WebArchivePrivate_.cxx_construct_+1
__objc_const:3E359424                 DCB 0x14
__objc_const:3E359425                 DCB    0
```

Analysing the small values

- reason for differences in small values was not discovered until dyld_shared_cache was relocated and applications did not work
- objc applications could not find selectors
- problem was finally found with reverse engineering
- lower 2 bits of size field used as a flag
- method list sorted by selectors => allows faster lookup

```
typedef struct method_t {
    SEL name;
    const char *types;
    IMP imp;
} method_t;

typedef struct method_list_t {
    uint32_t entsize_NEVER_USE;  // low 2 bits used for fixup markers
    uint32_t count;
    struct method_t first;
} method_list_t;
```

What needs to be rebased?

- images must be shifted around
- image pointers in dyld_shared_cache header
- Mach-O-Headers
    - segment addresses / segment file offsets
    - section addresses / section file offsets
    - LC_ROUTINES
    - symbols
    - export trie
- section content according to collected differences
- __objc_opt_ro selector table in libobjc.dylib

Part IV

Apple's ASLR in iOS 4.3.x

How did ASLR end up in iOS?

- about three month into 2011 ASLR was discovered in the iOS 4.3 beta
- reason why it was introduced is unknown
- some believe it was introduced because Antid0te forced their hand
- but it is more likely that ASLR in Windows Phone 7 triggered it
- we will never know ...

Randomization in iOS 4.3

- jailbreakers with access to beta versions of iOS 4.3 posted crash dumps
- crash dumps revealed that
    - main binary load address is randomized
    - dyld load address is randomized
    - main binary and dyld are shifted by same offset (at execution time)
    - dyld_shared_cache load address is randomized (at boot time)

Randomization of Main Binary

- Applications are now compiled as position independent executables
- sets MH_PIE flag in mach-o header and adds relocation information
- no TEXT relocations therefore no problem with codesigning
- old applications cannot be randomized

➡ no magic, just using the features of mach-o that were already there

```
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
```

Randomization of Dyld

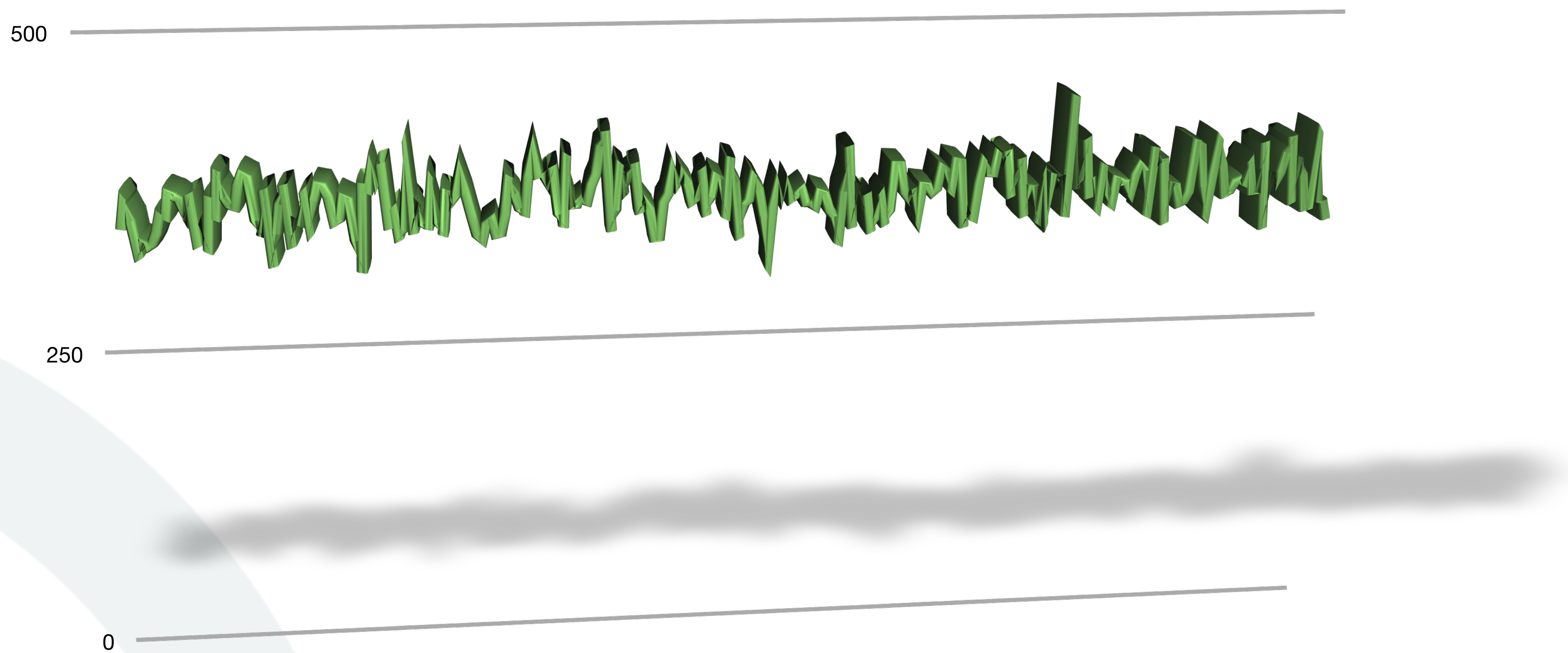
- dyld was already a PIE without TEXT relocs in older iOS versions
- even Antid0te could randomize it
- now randomization is done by the kernel on load
- however dyld is only slided the same amount as the main binary
- if main binary is not a PIE dyld is also not moved

```
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 ...
```

How Random is the Baseaddress?

- randomized on page boundary
- only 256 possible base addresses between 0x1000 and 0x100000



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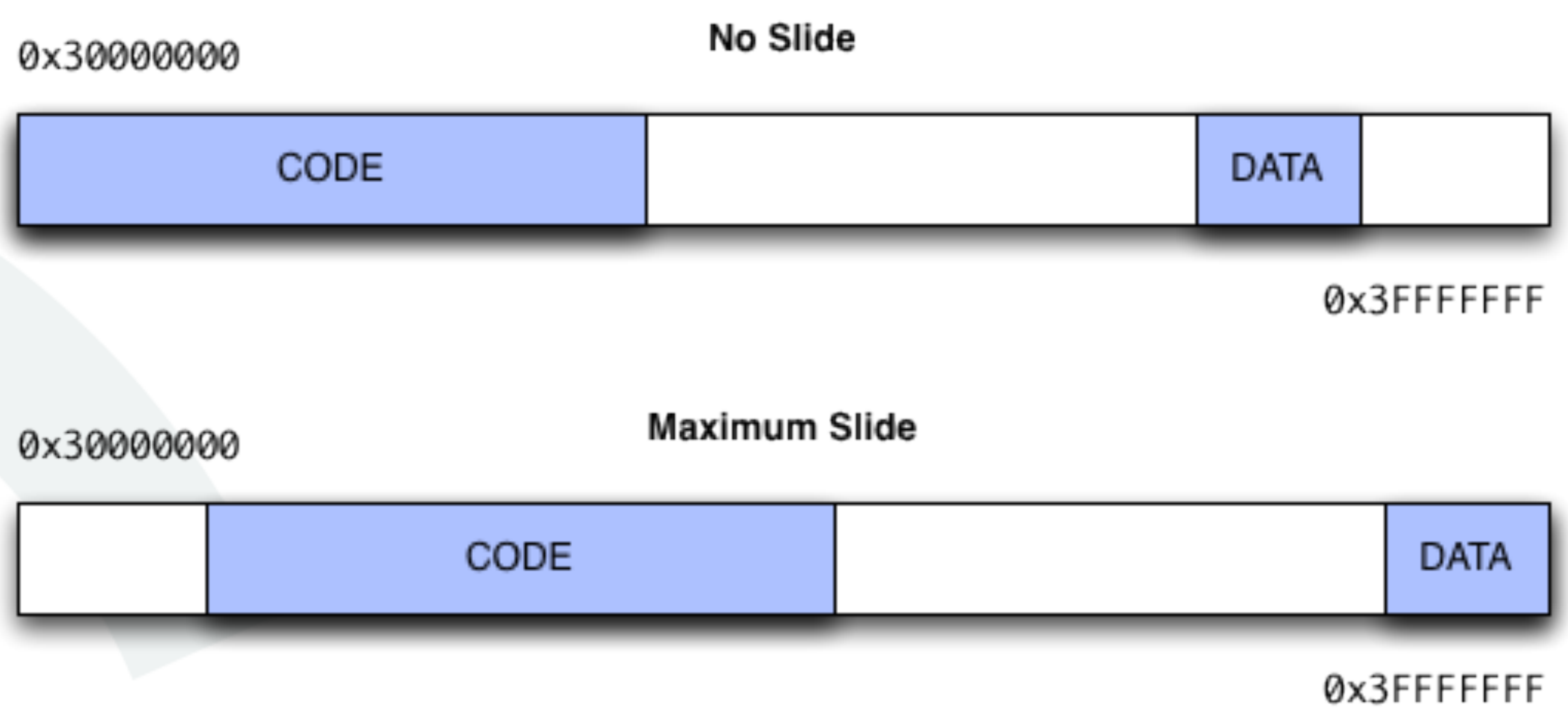
Randomization of dyld_shared_cache

- Sliding the dyld_shared_cache seems straight forward
- but Apple's implementation is complex and involves
    - randomization in dyld
    - a changed dyld_shared_cache file format
    - an undocumented relocation information format
    - a new syscall
    - a change in the memory page handling

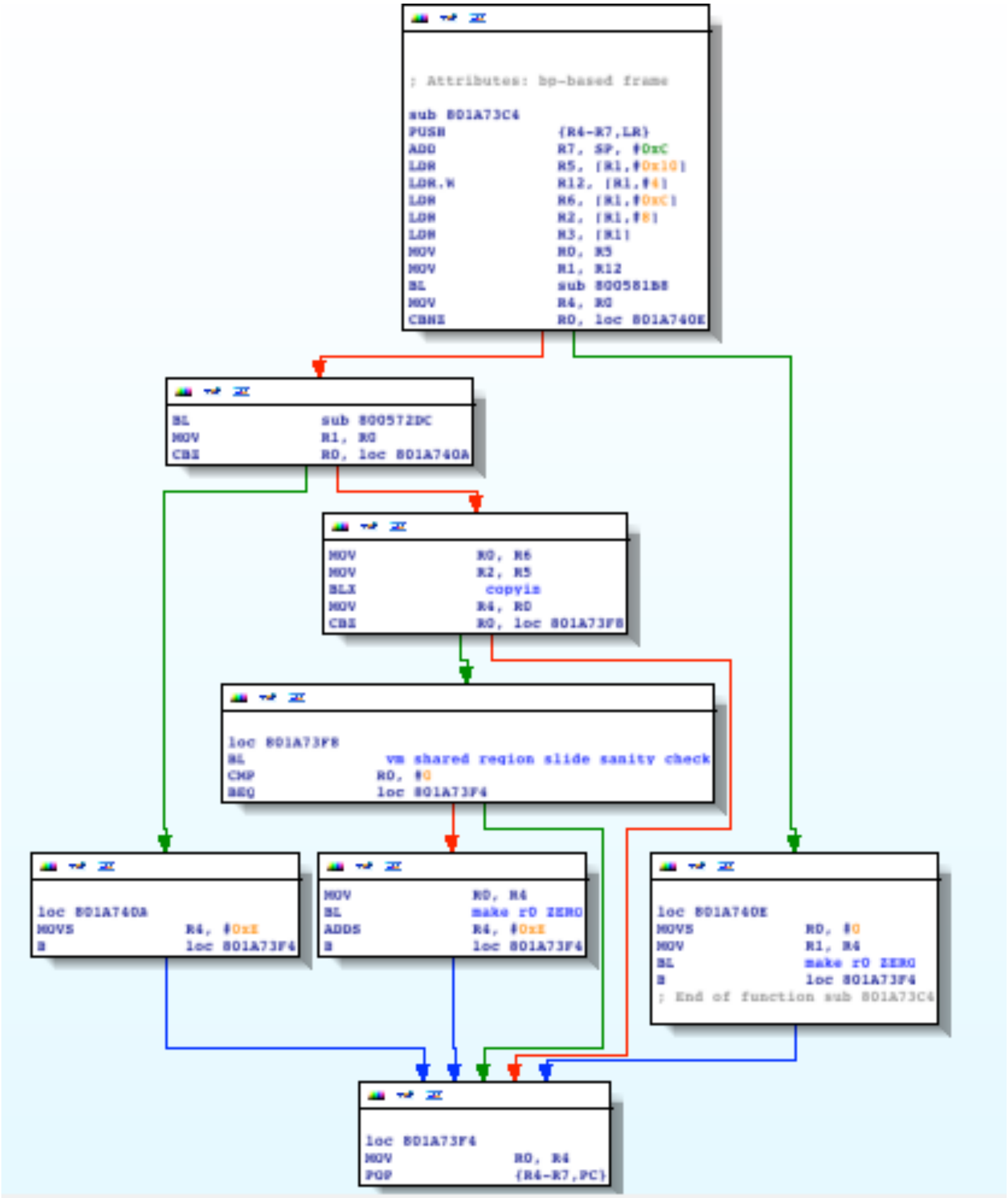
dyld_shared_cache sliding in dyld

- dyld has always been responsible for mapping the shared cache
- now it simply has to load it at a random address
- and tell the kernel about it (via new syscall)
- due to dyld_shared_cache structure only about 4200 different base addresses



New Syscall - vm_shared_region_slide

- iOS 4.3.x comes with a new syscall 437
- strings indicate that name is something like vm_shared_region_slide
- loads the dyld_shared_cache relocation information into kernel memory
- five parameters to this syscall
    1. slide delta
    2. address of region to slide
    3. size of region to slide
    4. address of reloc information
    5. size of reloc information



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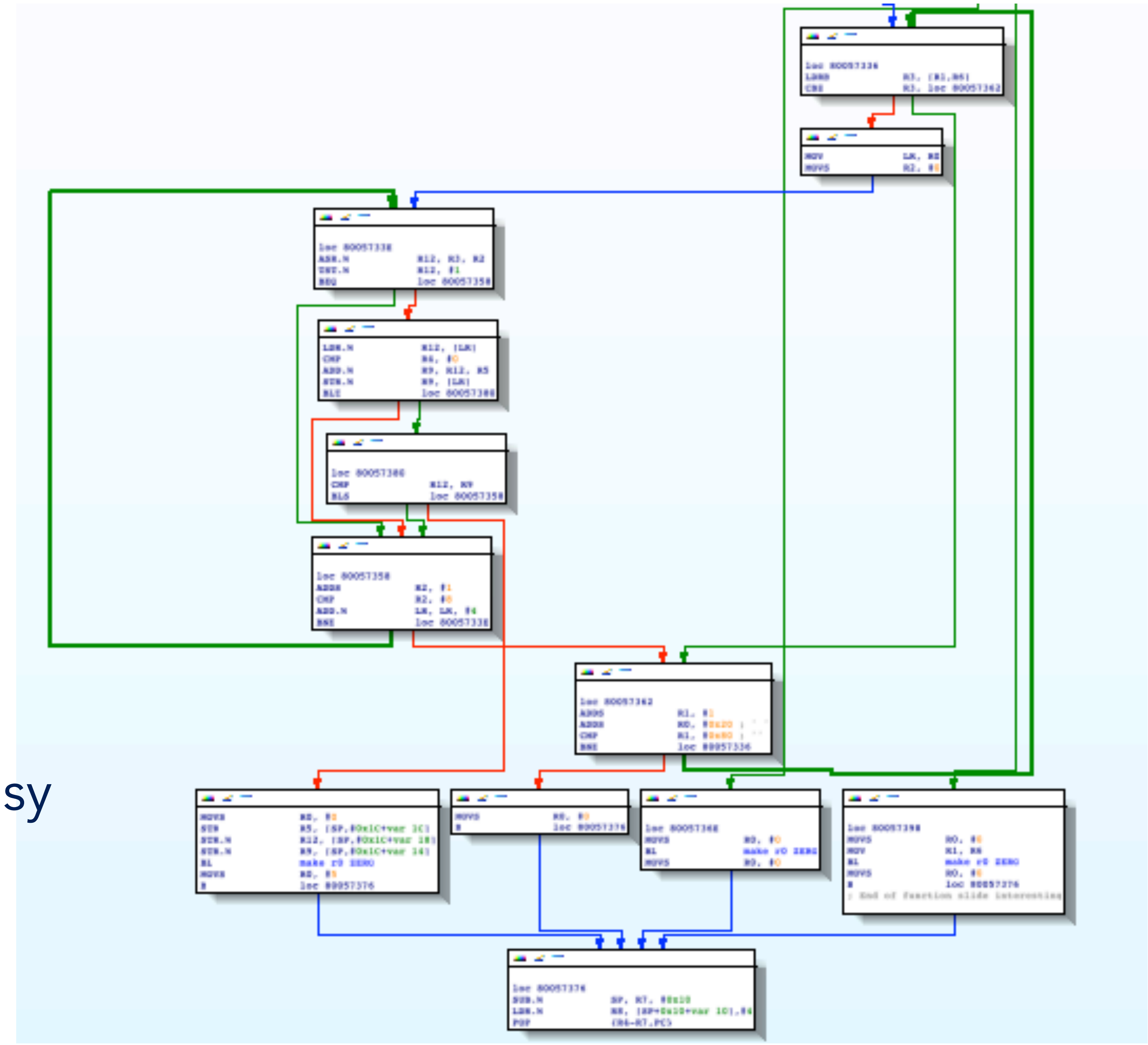
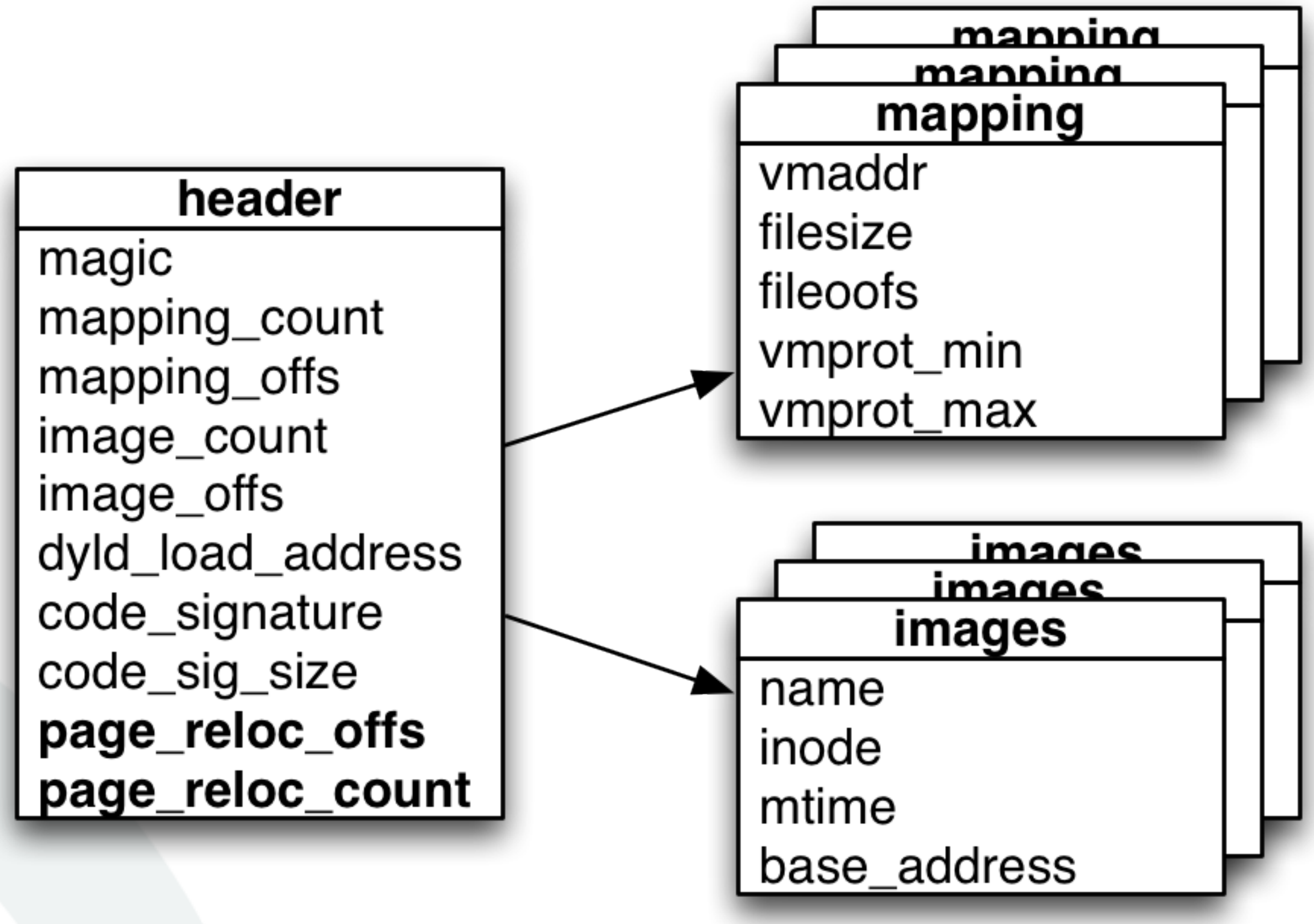
Changes in Memory Page Handling

- sliding whole cache is too slow
- Apple changed page handler to relocate each page on access
- works on the kernel buffer filled by syscall 437
- made decrypting the new dyld_shared_cache file format easy

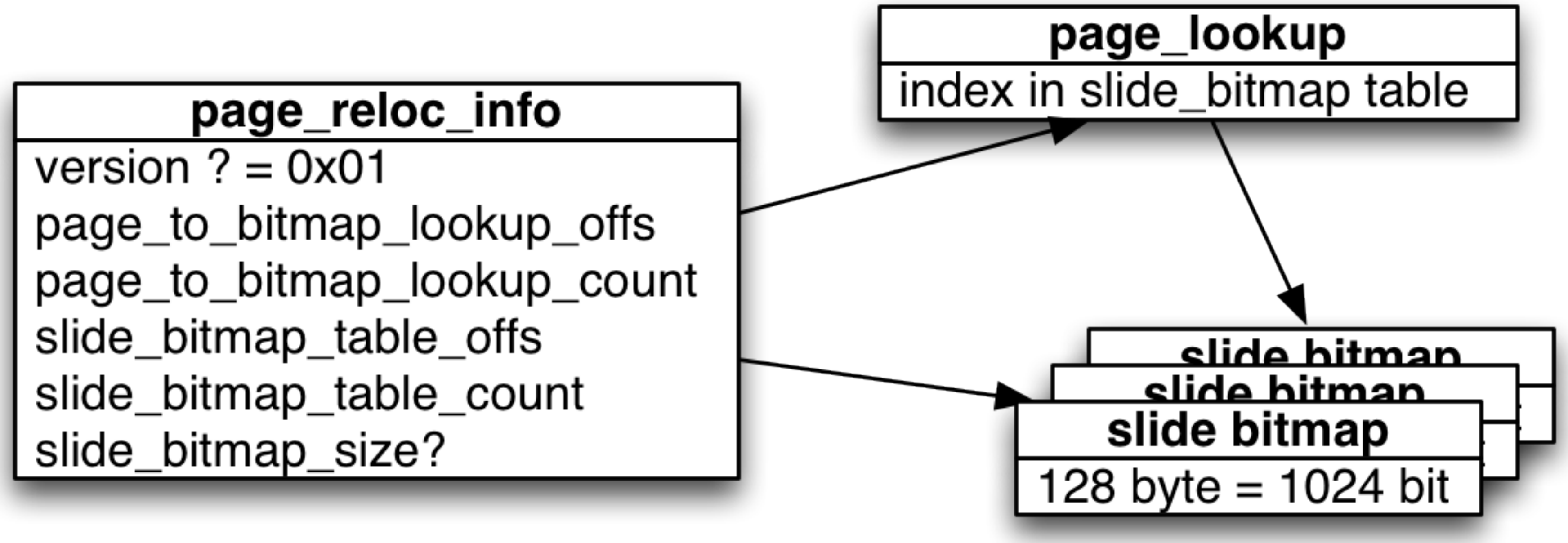


dyld_shared_cache Header in iOS 4.3.x



dyld_shared_cache relocation information

- relocation information is stored per page
- storage format 128 byte bitmap = 1024 bit
- each bit represents 4 aligned bytes
- if bit is set then add slide



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Part V

Antid0te 2.0 ???

Antid0te 2.0 ???

- did iOS 4.3.x make Antid0te useless?
  - no, because iPhone 3G only runs up to 4.2.1
  - no, because iPhone 4 (CDMA) only runs 4.2.7 (feasibility not tested)
  - no, because Antid0te can extend the ASLR of iOS 4.3.x

What is different with iOS 4.3.x? (I)

- with iOS 4.3.x binaries come with relocation entries
- allows to select device specific base addresses for
  - main binary
  - dyld
- stack can still be randomized on the fly
- possible extensions
  - slide main binary and dyld separately
  - on the fly randomization with better randomness

What is different with iOS 4.3.x? (II)

- dyld_shared_cache comes also with relocation entries
- helps to partly verify the fixups detected by Antid0te
- but Antid0te still needs to detect relocations by diffing
    - no relocation entries for „delta“ access
    - objective c selector table needs to be detected and resorted
- relocation bitmap table entries need to be sorted

What is different with iOS 4.3.x? (III)

- kernel level changes make replacing the cache harder
- old on-the-fly method using DYLD environment variables just crashes
- for now tethered jailbreak with modified kernel is required
- crash problem might be solvable with patches to syscall 437 and dyld

➡ work in progress

Part VI

How Secure is ASLR on the iPhone

Why is the iPhone more Secure with ASLR

- targets are not respawning daemons
- attacks usually against non-respawning clients
- best target MobileSafari
- exploits are one shot
- not getting it right = ***crash***

```
Hardware Model:      iPad1,1
Process:         MobileSafari [302]
Path:            /Applications/MobileSafari.app/MobileSafari
Identifier:      MobileSafari
Version:         ??? (???)
Code Type:       ARM (Native)
Parent Process:  launchd [1]

Date/Time:       2011-05-19 01:03:18.012 +0200
OS Version:      iPhone OS 4.3.3 (8J3)
Report Version:  104

Exception Type:  EXC_BAD_ACCESS (SIGSEGV)
Exception Codes: KERN_INVALID_ADDRESS at 0x55555554
Crashed Thread:  0

Thread 0 name:  Dispatch queue: com.apple.main-thread
Thread 0 Crashed:
0   ???                                0x55555554 0 + 1431655764
1   WebCore                            0x32584d10 0x32519000 + 441616
2   WebCore                            0x32584c0c 0x32519000 + 441356
3   WebCore                            0x32584b08 0x32519000 + 441096
4   WebCore                            0x32582364 0x32519000 + 430948
5   WebCore                            0x3258499e 0x32519000 + 440734

...

Thread 0 crashed with ARM Thread State:
    r0: 0x2fedfed4    r1: 0x00000000      r2: 0x00000098      r3: 0x00000020
    r4: 0x0129bf54    r5: 0x55555555      r6: 0x2fedfed4      r7: 0x2fedfeb8
    r8: 0x00000001    r9: 0x01299000     r10: 0x55555555     r11: 0x2fee02a8
    ip: 0x32acc908    sp: 0x2fedec18      lr: 0x32584d15      pc: 0x55555554
  cpsr: 0x600f0030
```

Theoretical Limitations of ASLR on iPhone

- main binary, dynamic libs, dyld, heap and stack share 29bit address room
  - 0x00000000 - 0x2FFFFFFF
- single randomized page could be in $2^{29} - 2^{12} = 2^{17}$ = 131072 places

- address space for dyld_shared_cache is only 27bit wide
  - 0x30000000 - 0x37FFFFFF __TEXT
  - 0x38000000 - 0x3FFFFFFF __DATA
- single page can only be in $2^{27} - 2^{12} = 2^{15}$ = 32786 places

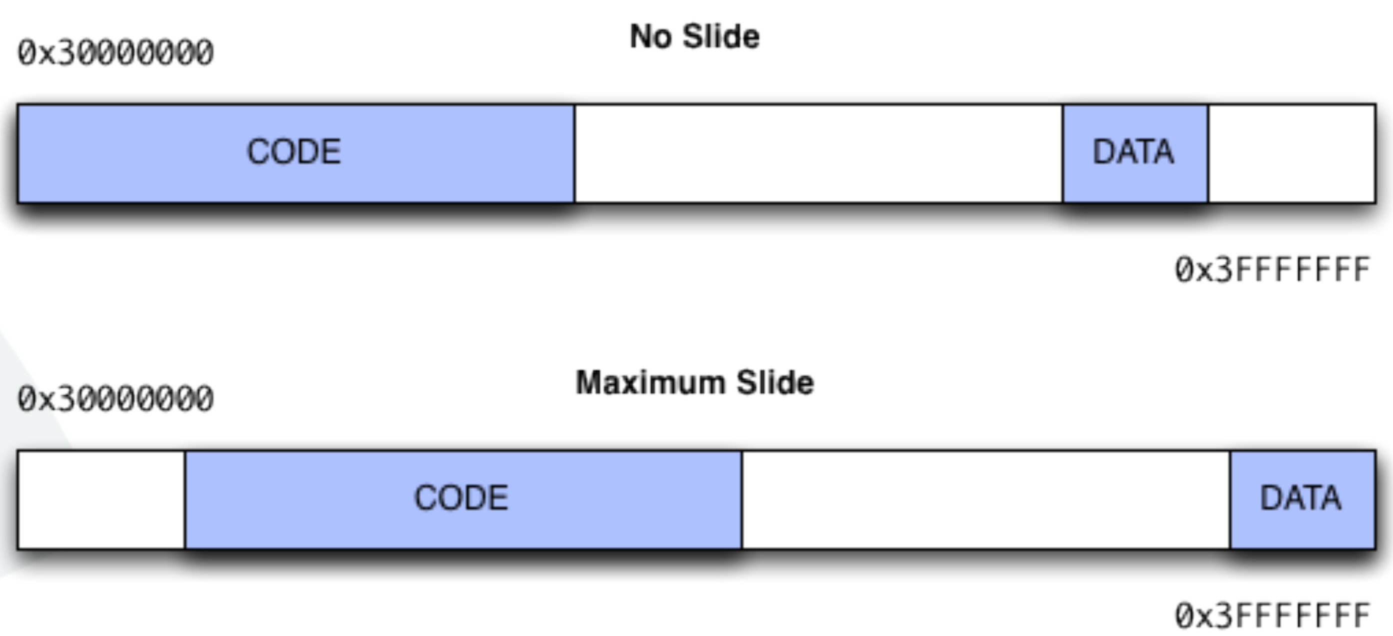
- ASLR implementations offer less randomization

Limitations of iOS 4.3.x ASLR (main binary/dyld)

- main binary and dyld slided same amount
- knowing address in one reveals addresses in the other
- only 256 possible base addresses
- stack always next to dyld base address
- if code segment is > 1 mb then page at 0x100000 is always readable

Limitations of iOS 4.3.x ASLR (dyld_shared_cache)

- whole dyld_shared_cache is slided as one block
- more than 100 mb of code can only be slided by 17 mb (about 4200 tries)
- large memory area is guaranteed to be readable
- order of libraries not randomized
- knowing the address of one symbol enough to know them all

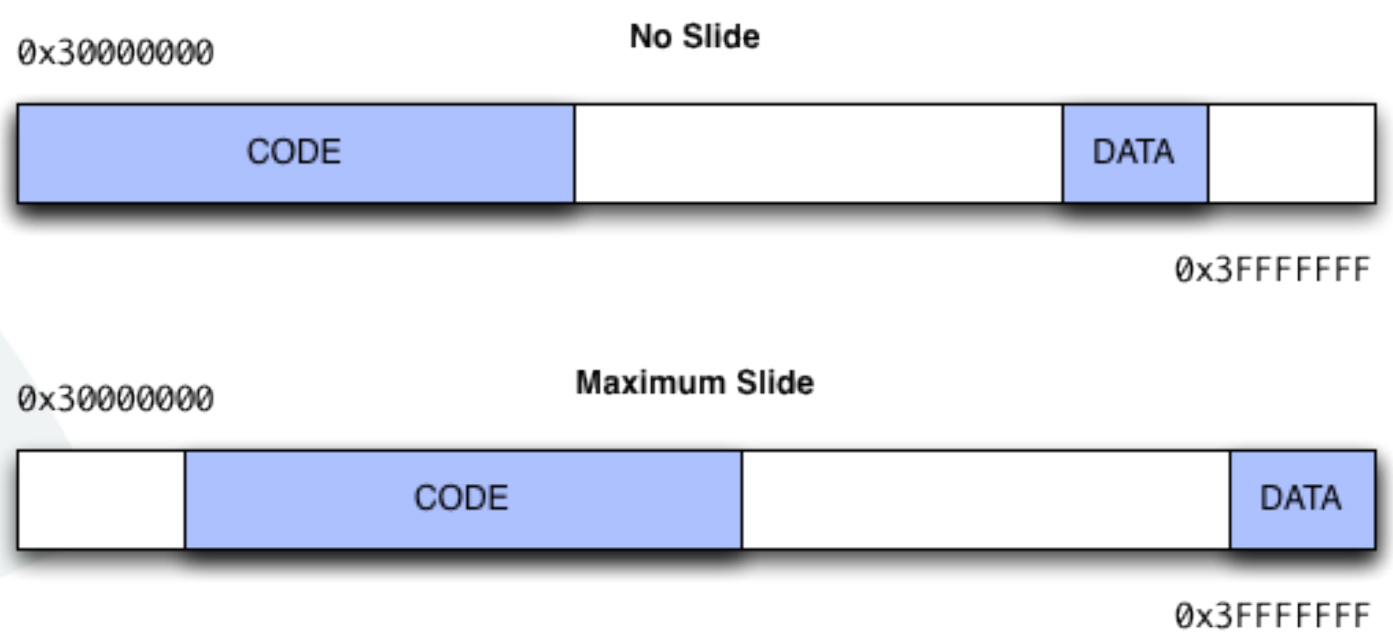


Limitations of Antid0te (main binary/dyld)

- only possible on jailbroken device
- standard base of main binary / dyld can be changed
- same limitations as iOS 4.3.x ASLR
- but base addresses different for every device

Limitations of Antid0te (dyld_shared_cache)

- does only work on jailbroken device (tethered for iOS 4.3.x)
- generating new caches only possible if comparison partners exists
- same sliding limitations as iOS 4.3.x but libraries are randomly shuffled
- extension could create unreadable memory gaps
- knowing the address of one symbol reveals addresses in same library



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Final Words

- Antid0te 1.0 works perfect for iOS 4.2.1
- Antid0te 2.0 still work in progress for iOS 4.3.x
- expected release of Antid0te 2.0 in June *finally*
- more security tools for jailbroken iPhones soon (around BlackHat USA)

Questions ???

THE ELEVATOR

because the JailBreak community demanded to see it in action...

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