TrustKit

Code Injection on iOS 8 for the Greater Good

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About Us

- Alban: Engineering/security lead at Data Theorem
- Eric: iOS R&D at Data Theorem
- Angela: Paranoids (security) at Yahoo

Agenda

- TrustKit: effortless SSL pinning for iOS and OS X
- Dynamic libraries and iOS 8
- Function hooking on a non-jailbroken device

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TrustKit

- Goal: Create an SSL pinning library for iOS
- Needed a usable solution that **works in real-world Apps**
- Collaborated with the Yahoo mobile & security teams

SSL Pinning at Yahoo

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  - Easy project, right?

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- But...
  - Technical challenges: What and how to pin?
  - Operational challenges: How to get buy-in from product team?

Technical Challenges

- What to pin?
  - Certificate or public key?
    - Best practice is Subject Public Key Info
      - No API on iOS to extract SPKI from a certificate…
- Most libraries and examples are doing it wrong
  - Comparing the whole certificate or public key

Technical Challenges

- How to pin?
  - Find and modify every single instance of *NSURLConnection*, *NSURLSession* ?
    - Or better: use method swizzling
  - Problem: no public API for customizing certificate validation in *UIWebView*
    - Not even swizzling would work

Operational Challenges

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Operational Challenges

- How to get buy-in from the product team?
  - Blocking attackers is a good cause but...
    - What if we block the wrong connections?
- Answer: a **report-only** mode
  - Shows what connections would be blocked and why
  - Easier to decide on whether pinning should be enforced or not

SSL Pinning at Yahoo

- No existing iOS library supported **any** of these requirements
    - SPKI pinning
    - Report-only mode
    - Easy to deploy but works on all networking APIs
- Met with Data Theorem and started a collaboration :)

TrustKit

- We solved these challenges

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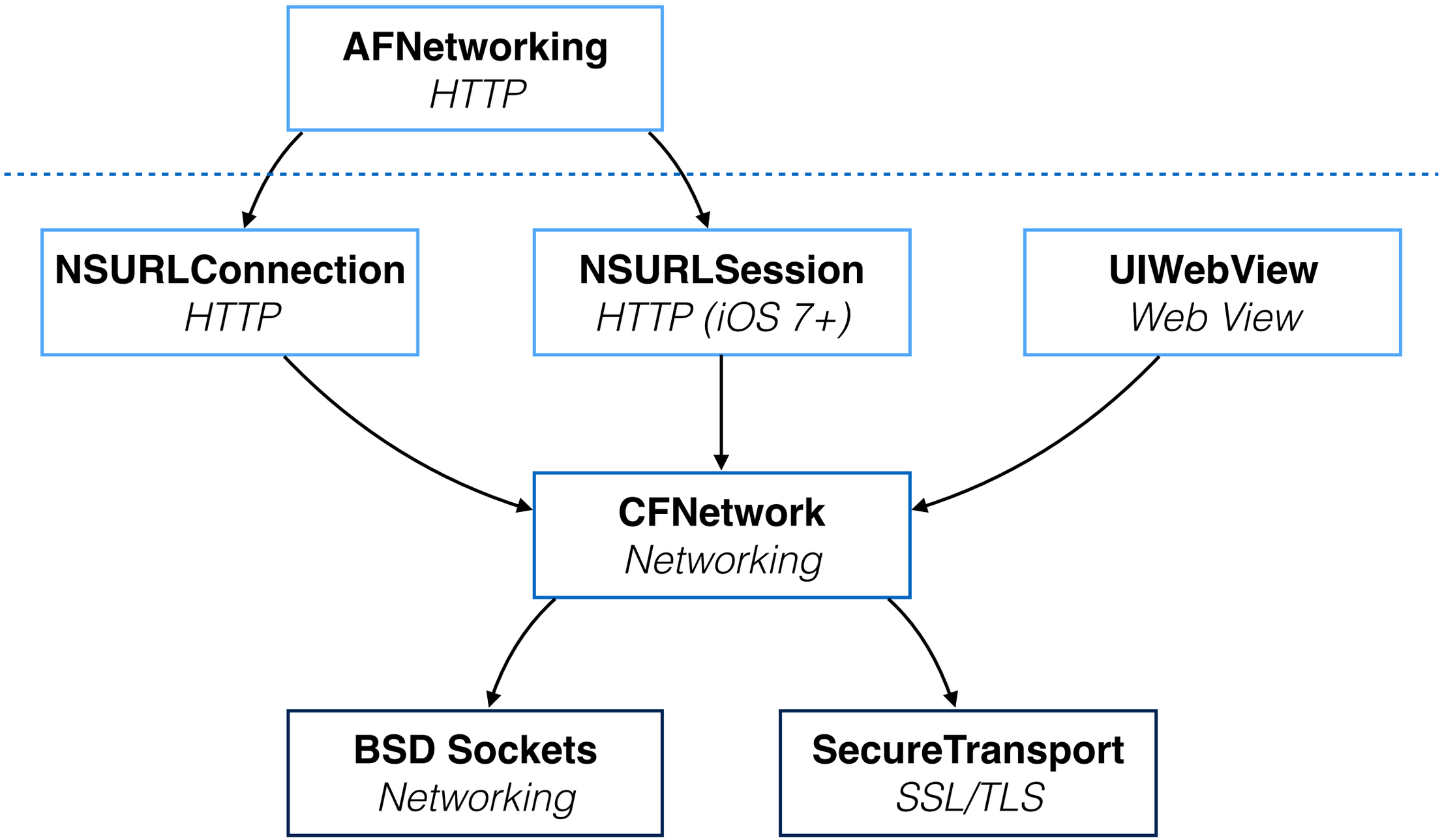
  - TrustKit works transparently on all Apple APIs

iOS Network Stack



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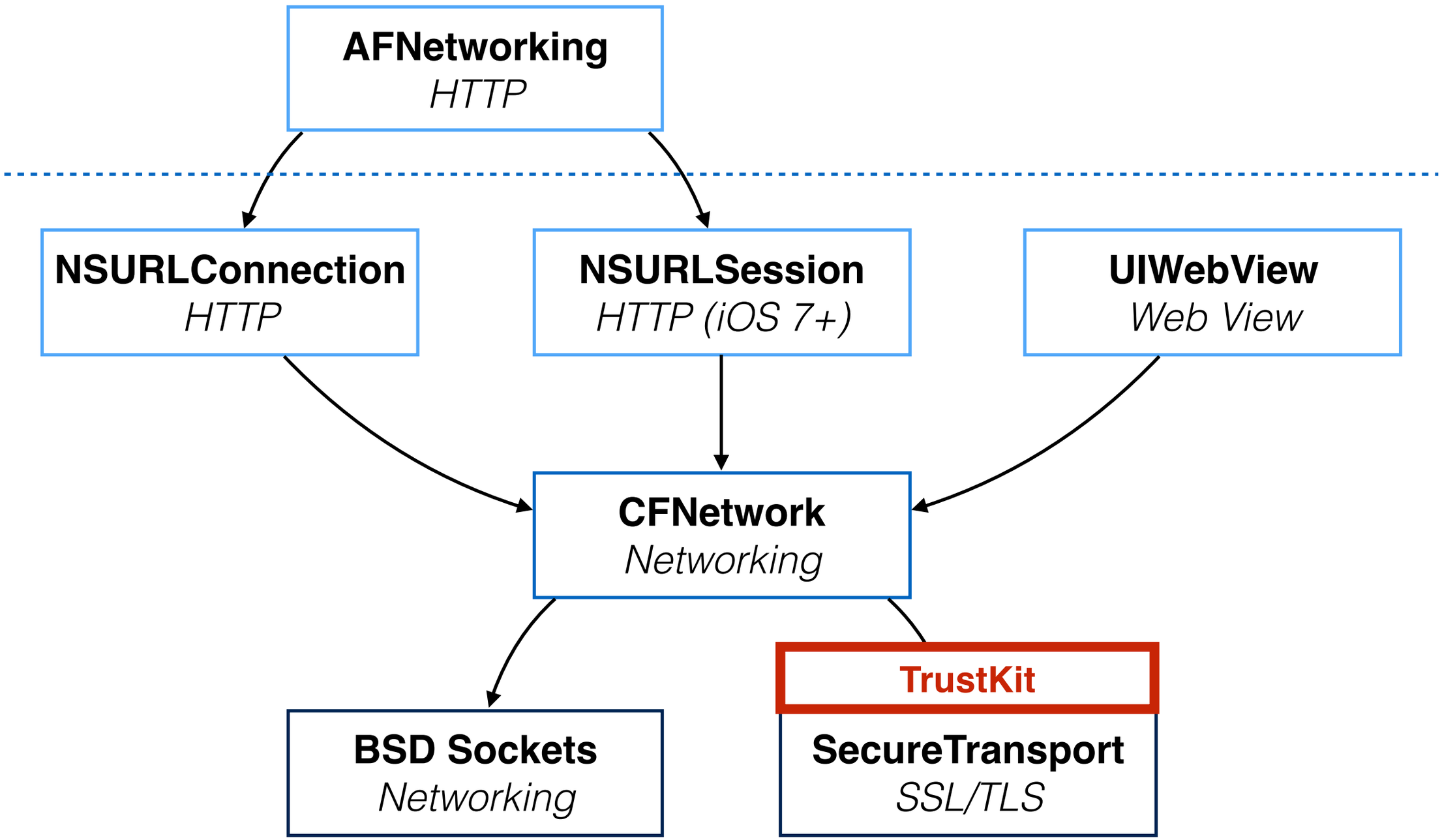

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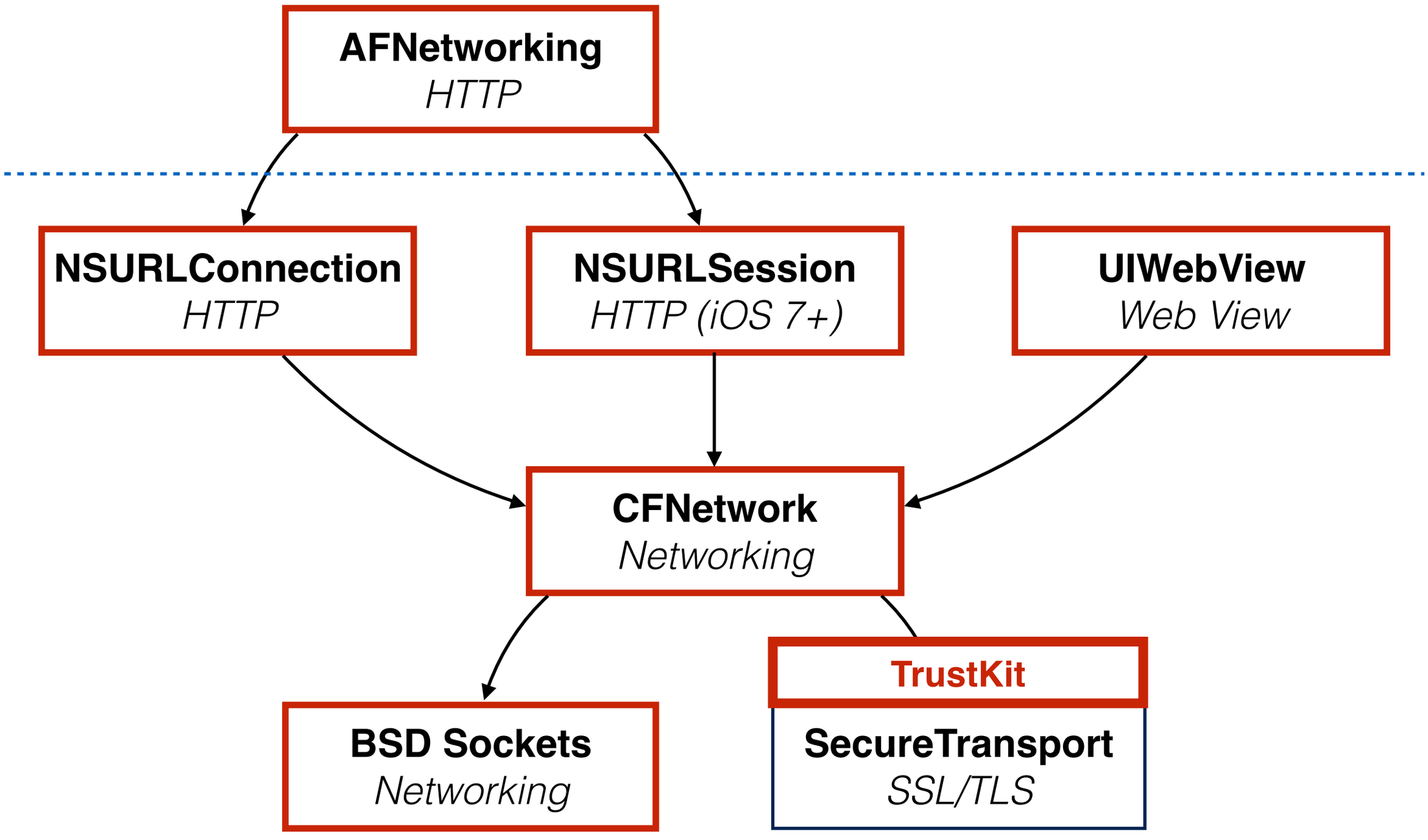

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    - Settings are heavily based on HTTP Public Key Pinning

TrustKit

General Capabilities Resource Tags Info Build Settings Build Phases Build Rules

Custom iOS Target Properties

Key	Type	Value
TSKConfiguration	Dictionary	(3 items)
www.yahoo.com	Dictionary	(2 items)
www.google.com	Dictionary	(2 items)
datatheorem.com	Dictionary	(5 items)
TSKPublicKeyHashes	Array	(2 items)
Item 0	String	HXXQgxueCIU5TTLHob/bPbwcKOKw6DkfsTWYHbxbqTY=
Item 1	String	0SDf3cRToyZJaMsoS17oF72VMavLxj/N7WBNasNuiR8=
TSKPublicKeyAlgorithms	Array	(1 item)
Item 0	String	TSKAlgorithmRsa2048
TSKEnforcePinning	Boolean	YES
TSKIncludeSubdomains	Boolean	YES
TSKReportUris	Array	(1 item)
Item 0	String	https://report-server.datatheorem.com
Bundle identifier	String	com.datatheorem.$(PRODUCT_NAME:rfc1034identifier)
InfoDictionary version	String	6.0

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  - SPKI pinning: Developer needs to specify the key algorithm
  - Report-only mode
    - Format similar to HPKP for pin failure reports

TrustKit


```
{
"port":443,
"include-subdomains":true,
"noted-hostname":"domain.com",
“hostname":"test.domain.com",
“app-bundle-id”:"com.test.testapp",
"validated-certificate-chain":
["-----BEGIN CERTIFICATE----
\nMIILyjCCCrKgAwIBAgIQQcm82qXxNZszqTblPwPAHDANBgkqhkiG9w0BAQUFADCB\r
\ntTELMAkGA1UEBhMCVVMxFzAVBgNVBAoTDlZlcmlTaWduLCBJbmMuMR8wHQYDVQQL\r
...
\nWkN/I4qtcE3vMxP8O17CkqegVaeI5nvFhca4r4f8MNYoUYT+6J07SxyA5cDsXQ==\n
-----END CERTIFICATE-----",
...
"-----BEGIN CERTIFICATE-----
\nMIIE0zCCA7ugAwIBAgIQGNrRniZ96LtKIVjNzGs7SjANBgkqhkiG9w0BAQUFADCB\r
...
LPKsEdao7WNq\n-----END CERTIFICATE-----"],
"date-time":"2015-06-29T18:12:30Z",
"known-pins":
[
"pin-sha256=\"JbQbUG5JMJUoI6brnx0x3vZF6jilxsapbXGVfjhN8Fg=\"",
“pin-sha256=\"WoiWRyIOVNa9ihaBciRSC7XHjliYS9VwUGOIud4PB18=\""
],
“app-version":"2413"
}
```

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Demo

TrustKit

- We’re open sourcing TrustKit today
  - MIT License
  - https://datatheorem.github.io/TrustKit
  - Also works in OS X Apps
- More on this at the end

TrustKit

- So how does TrustKit work?
  - Leveraged techniques usually used on jailbroken iOS
    - Code injection
    - Low-level C function hooking
- Could be applied to other things than SSL pinning

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- **Dynamic libraries** that modify Apps at runtime

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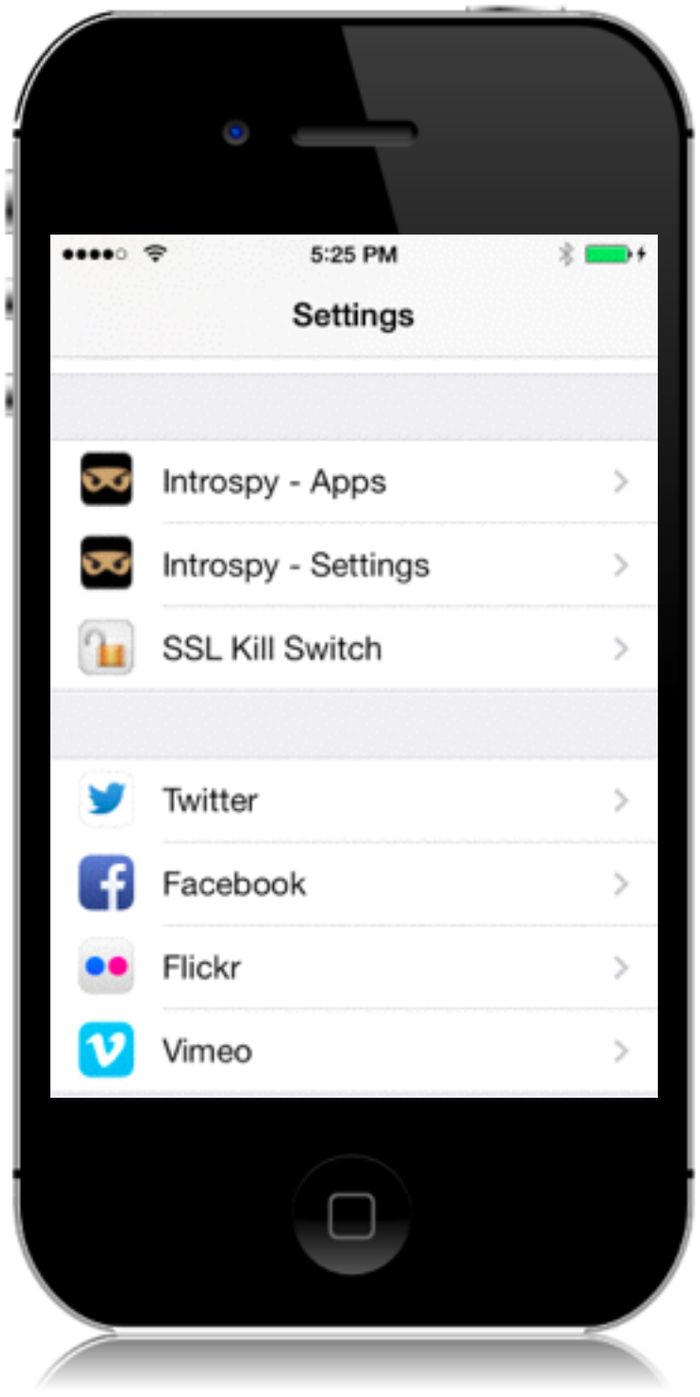

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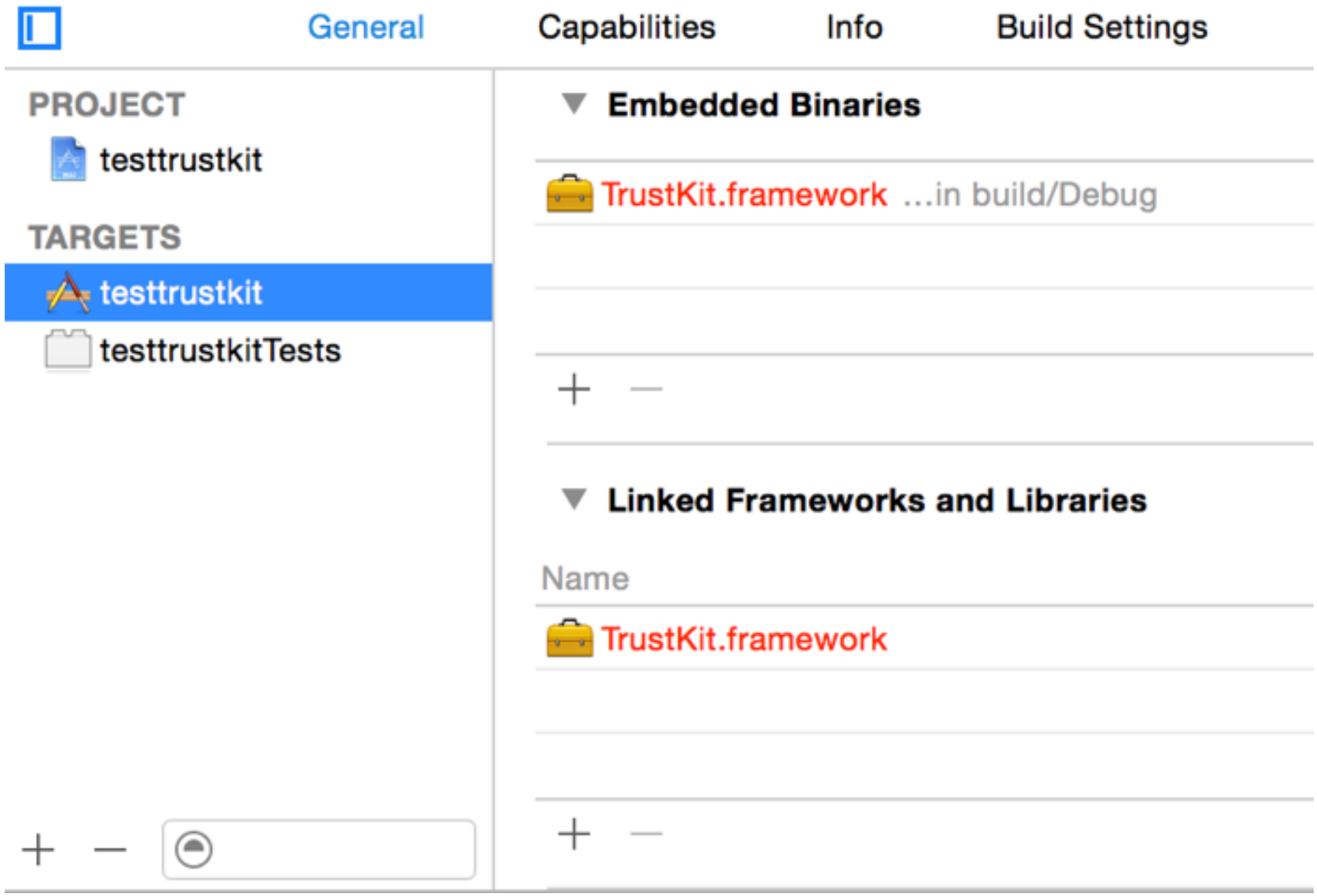
- Historically: no third-party dynamic libraries in Apps
  - System dylibs packaged with the OS
- Developer libraries: static linking only
  - Enforced via the App Store review process

Dylibs on iOS 8

- iOS 8: dynamic libraries now accepted
  - Apple calls them “Embedded Frameworks”
- Introduced to facilitate sharing code between Apps and their App Extensions
  - But… can be used regardless of whether the App actually has an Extension

Dylibs on iOS 8



Dylibs on iOS 8

- A dynamic library dependency is created in the Mach-O binary in a “load command” structure

- Mach-O is the binary file format for programs and libraries in iOS and OS X

- Executables interact with “dyld” to load their library dependencies at runtime.

Dylibs on iOS 8

- Sandboxing forces our dependencies to be packaged within the app's bundle

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- **dyld** uses prefixes inside the load command to locate them

- **@executable_path** points to the full path where the main executable is (the **.app** folder).

- **@rpath** defines library search path locations

    - In iOS, @rpath seems limited to one single location (a **"Frameworks"** directory inside app's bundle)

TrustKitTester

RAW RVA

Search

- Executable (ARM64_ALL)
  - Mach64 Header
  - Load Commands
    - LC_SEGMENT_64 (__PAGEZERO)
    - ▶ LC_SEGMENT_64 (__TEXT)
    - ▶ LC_SEGMENT_64 (__DATA)
    - LC_SEGMENT_64 (__LINKEDIT)
    - LC_DYLD_INFO_ONLY
    - LC_SYMTAB
    - LC_DYSYMTAB
    - LC_LOAD_DYLINKER
    - LC_UUID
    - LC_VERSION_MIN_IPHONEOS
    - LC_SOURCE_VERSION
    - LC_MAIN
    - LC_ENCRYPTION_INFO_64
    - LC_LOAD_DYLIB (TrustKit)
    - LC_LOAD_DYLIB (Foundation)
    - LC_LOAD_DYLIB (libobjc.A.dylib)
    - LC_LOAD_DYLIB (libSystem.B.dylib)
    - LC_LOAD_DYLIB (CoreFoundation)
    - LC_LOAD_DYLIB (UIKit)
    - LC_RPATH
    - LC_FUNCTION_STARTS
    - LC_DATA_IN_CODE
    - LC_DYLIB_CODE_SIGN_DRS
    - LC_CODE_SIGNATURE
  - ▶ Section64 (__TEXT,__text)
  - ▶ Section64 (__TEXT,__stubs)
  - ▶ Section64 (__TEXT,__stub_helper)
  - ▶ Section64 (__TEXT,__objc_methname)
  - ▶ Section64 (__TEXT,__cstring)
  - ▶ Section64 (__TEXT,__objc_classname)
  - ▶ Section64 (__TEXT,__objc_methtype)
  - Section64 (__TEXT,__unwind_info)
  - ▶ Section64 (__DATA,__got)
  - ▶ Section64 (__DATA,__la_symbol_ptr)
  - ▶ Section64 (__DATA,__cfstring)
  - ▶ Section64 (__DATA,__objc_classlist)

Offset	Data	Description	Value
000008F0	0000000C	Command	LC_LOAD_DYLIB
000008F4	00000040	Command Size	64
000008F8	00000018	Str Offset	24
000008FC	00000002	Time Stamp	Thu Jan 1 01:00:02 1970
00000900	00010000	Current Version	1.0.0
00000904	00010000	Compatibility Version	1.0.0
00000908	4072706174682F5…	Name	@rpath/TrustKit.framework/TrustKit

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    - LC_SOURCE_VERSION
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  - ▶ Section64 (__DATA,__la_symbol_ptr)
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Offset	Data	Description	Value
00000AA8	8000001C	Command	LC_RPATH
00000AAC	00000028	Command Size	40
00000AB0	0000000C	Str Offset	12
00000AB4	406578656375746…	Path	@executable_path/Frameworks

Dylib Constructors

- Dynamic libraries can have “constructors”
- Basically a C function that is called when the library is loaded in memory
- We use it to initialize our hooks (patches) and settings
- `__attribute__((constructor)) static void initializer()`

Dylibs Recap

- By adding to the App a load command with our dylib
    - The dylib will be automatically loaded when the App starts
    - The dylib's constructor will be run first
- Takes care of the “injection" process

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Hooking Jailbreak-Free

- First attempt
  - Tried packaging an actual Cydia Substrate tweak into an App Store App

Substrate in an App

```
Hardware Model:      iPhone6,1
Process:             TestSubstrate [1438]
Path:                /private/var/mobile/Containers/Bundle/Application/AF0E2FD7-BA47-4E57-95ED-
B2C3D6116E62/TestSubstrate.app/TestSubstrate
Identifier:          TestSubstrate
Version:             ???
Code Type:           ARM-64 (Native)
Parent Process:      launchd [1]
Date/Time:           2015-07-16 22:57:43.529 -0700
Launch Time:         2015-07-16 22:57:43.356 -0700
OS Version:          iOS 8.4 (12H143)
Report Version:      105
Exception Type:  EXC_BAD_ACCESS (SIGKILL - CODESIGNING)
Exception Subtype: unknown at 0x0000000186b346c4
Triggered by Thread:  0
Thread 0 name:  Dispatch queue: com.apple.main-thread
Thread 0 Crashed:
0   CydiaSubstrate                  0x00000001000931bc 0x100090000 + 12732
1   SSLKillSwitch.dylib             0x0000000100087d30 0x100084000 + 15664
2   dyld                            0x000000012006d234 0x12005c000 + 70196
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MSFunctionHook()
Dylib Contructor

Substrate in an App

- SIGKILL when calling *MSFunctionHook()*
  - Substrate hooks C functions by patching the function's prologue
- This requires RWX memory pages
  - Not possible on a non-jailbroken device…

Substrate in an App

- SIGKILL when calling *MSFunctionHook()*
  - Substrate hooks C functions by patching the function's prologue
- This requires RWX memory pages
  - Not possible on a non-jailbroken device…
  - …Unless running in a debugger

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Hooking Jailbreak-Free

- First attempt
  - Tried packaging an actual Cydia Substrate tweak into an App Store App
  - **Failed:** no way to package a Substrate tweak in an App Store App due to RWX requirement

Hooking Jailbreak-Free

- Second attempt
  - DYLD_INSERT_LIBRARIES and __interpose
    - Similar to LD_PRELOAD on Linux
    - Symbol rebinding: can only override exported functions

Hooking Jailbreak-Free

- Second attempt
  - DYLD_INSERT_LIBRARIES and __interpose
    - Similar to LD_PRELOAD on Linux
    - Symbol rebinding: can only override exported functions
- Requires setting an environment variable
  - **Failed:** can’t be done in an App Store App outside of Xcode

Hooking Jailbreak-Free

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  - Newer libraries for dynamic symbol rebinding

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- **Success:** We were able to create a dylib to automatically hook functions in an App Store App

Putting It All Together

- One concrete example: TrustKit for SSL pinning
- Adding TrustKit to the App's Xcode project:
  - Embeds the dylib in the App's bundle
  - Adds a load command to the App's executable

Putting It All Together

- The TrustKit dylib's constructor does all the work:
  - Reads the pinning policy from the App's Info.plist
  - Sets up the SecureTransport hooks
    - Runtime patch for *SSLHandshake()*
    - Uses *facebook/fishhook* for C function hooking

Putting It All Together

- The TrustKit dylib's constructor does all the work:
  - Reads the pinning policy from the App's Info.plist
  - Sets up the SecureTransport hooks
    - Runtime patch for *SSLHandshake()*
    - Uses *facebook/fishhook* for C function hooking
- No need to modify the App's source code or call a TrustKit initialization method!

Conclusion

- We’re open-sourcing TrustKit today - MIT license
  - Supports iOS 7+ and OS X10.9+
  - https://datatheorem.github.io/TrustKit/
- TrustKit is already live in a Yahoo App on the App Store
  - Partnered with other companies who will deploy it in their OS X and iOS Apps
- Feedback, comments and pull requests very welcome!

One Last Thing

- SSL pinning can be a challenge for security researchers
  - And is not designed to block an attacker running code as root on the device…
- So I also released SSL Kill Switch 2
  - https://github.com/nabla-c0d3/ssl-kill-switch2
  - Added support for TrustKit Apps (and OS X)

Thanks!