TrustKit

Code Injection on iOS 8 for the Greater Good

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black hat USA 2015

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?

SSL Pinning at Yahoo

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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

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  - 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 :)

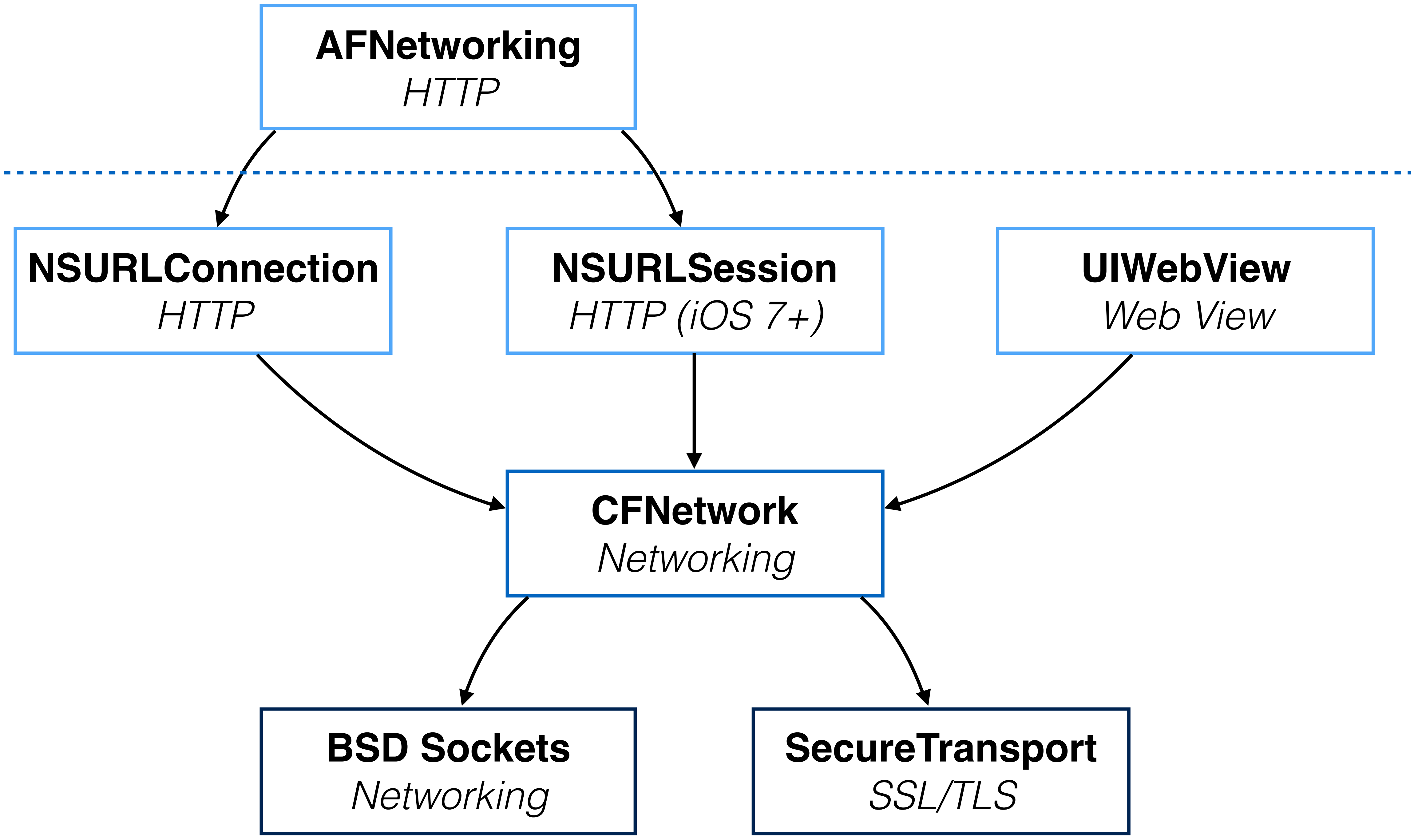
TrustKit

- We solved these challenges

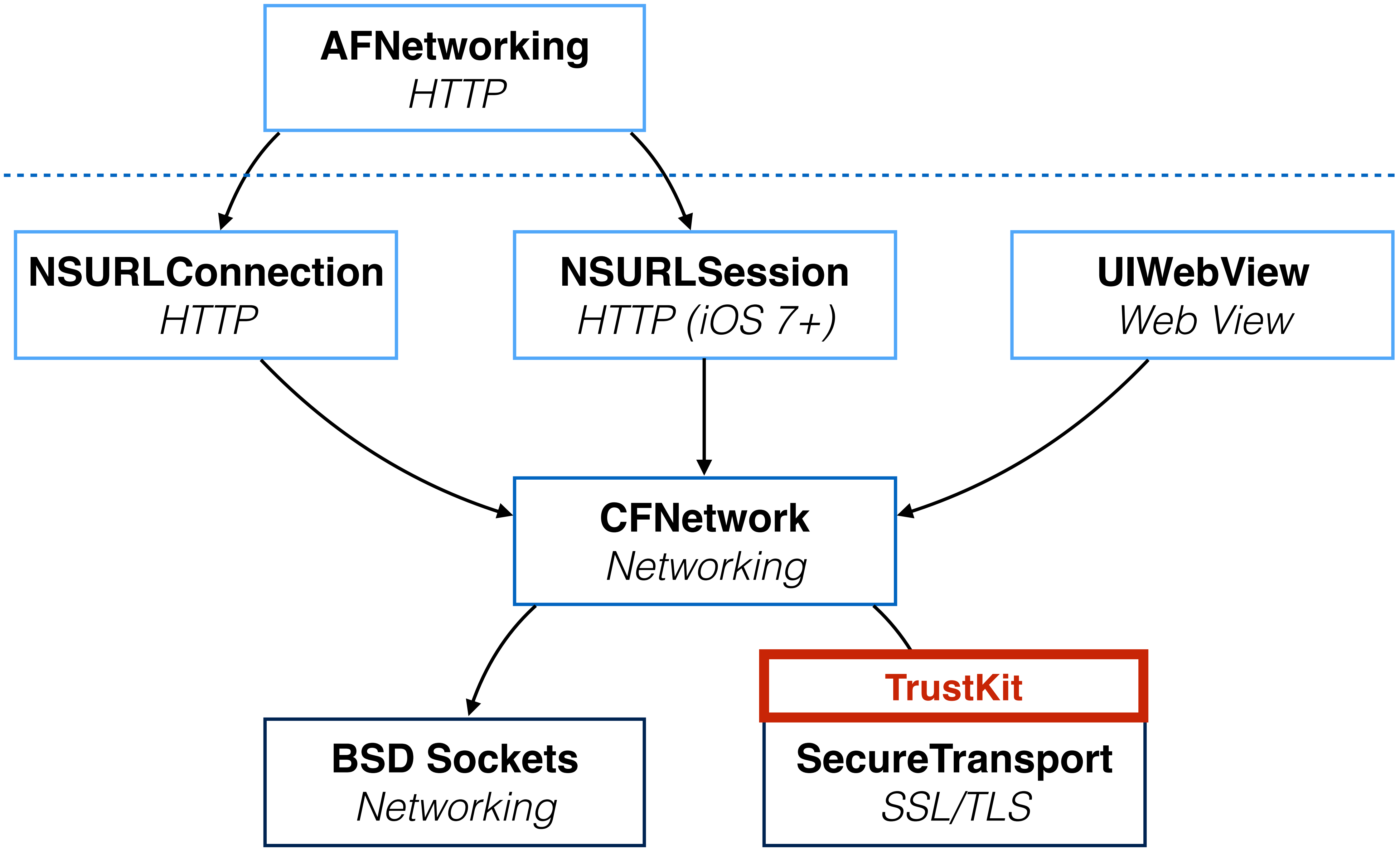
TrustKit

- We solved these challenges
    - TrustKit works transparently on all Apple APIs

iOS Network Stack



iOS Network Stack



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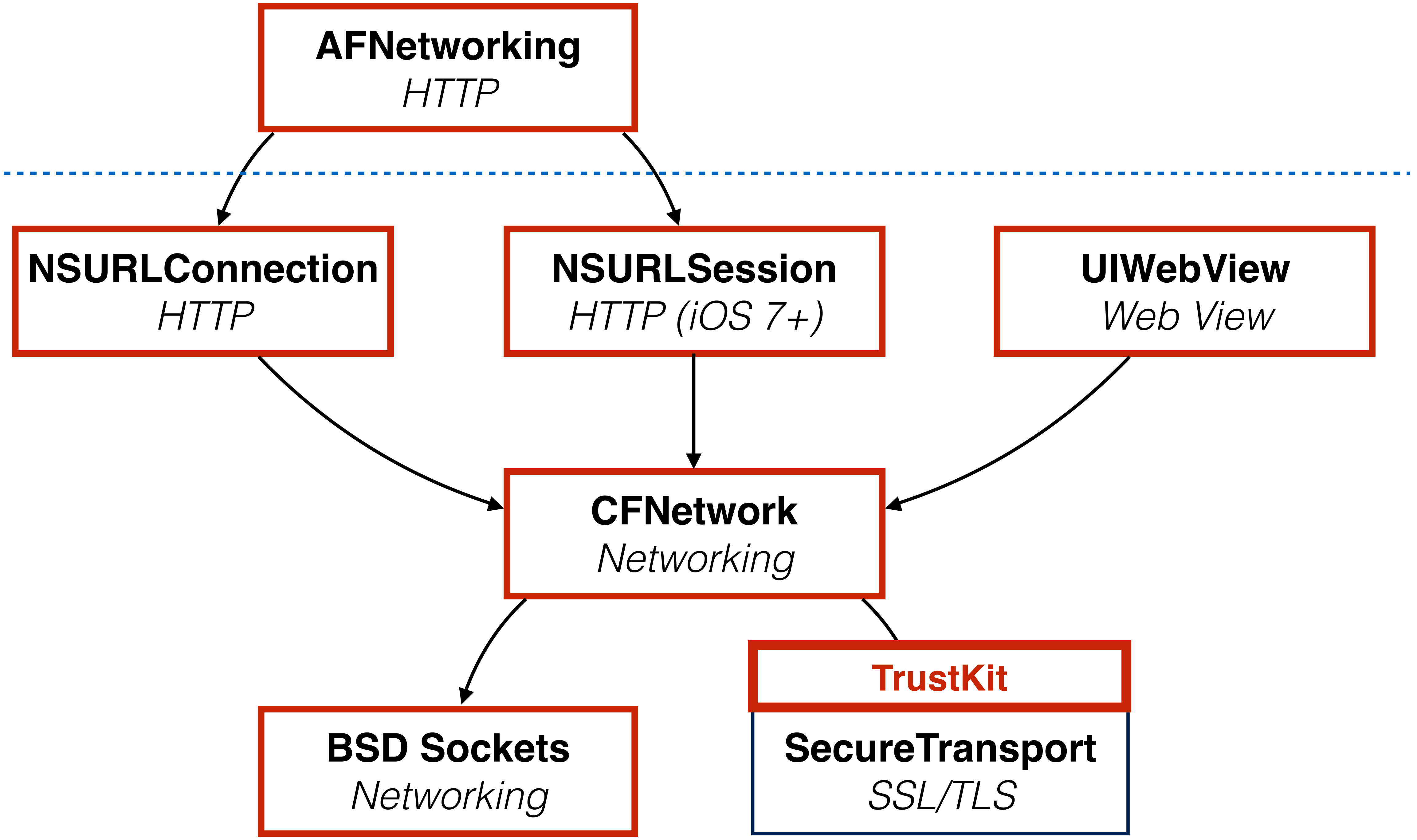

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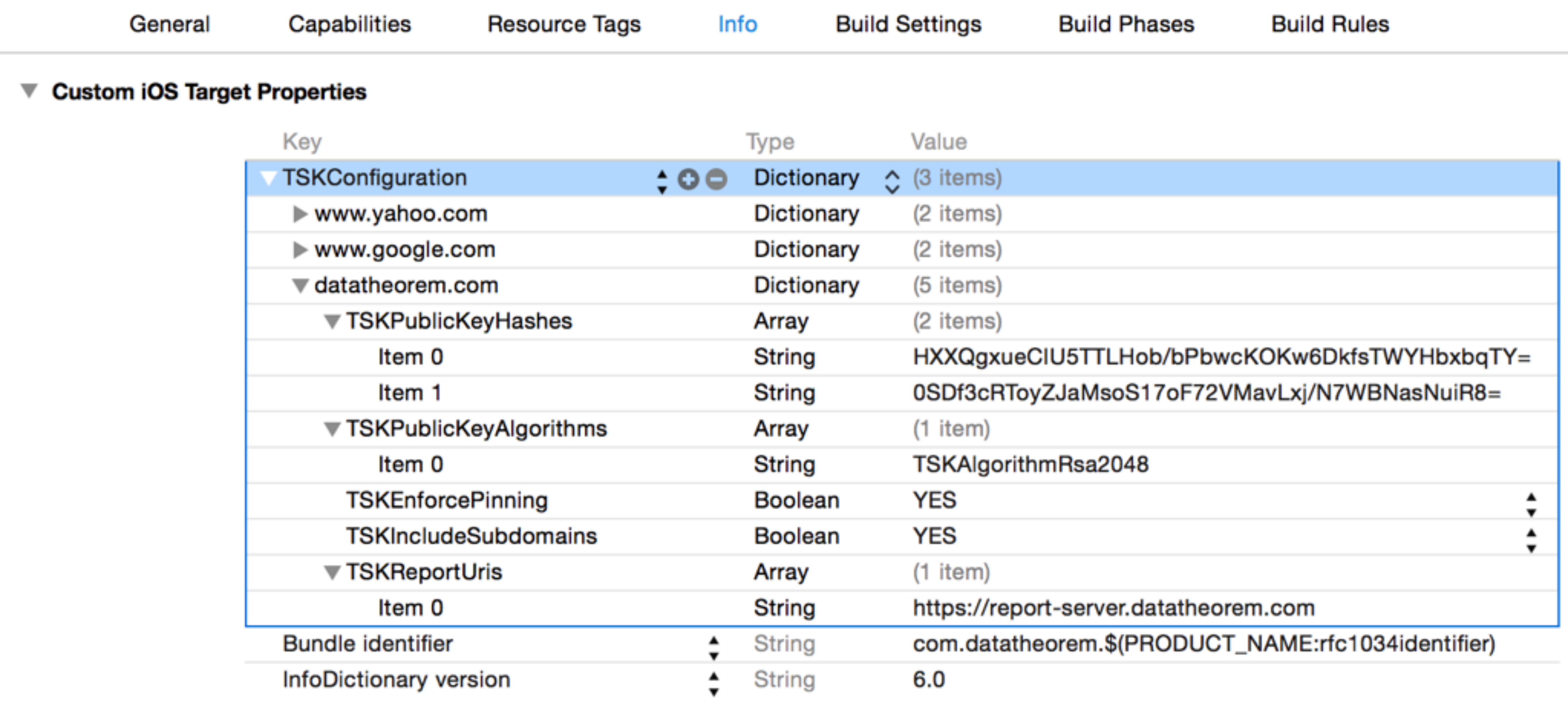

Custom iOS Target Properties

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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  - 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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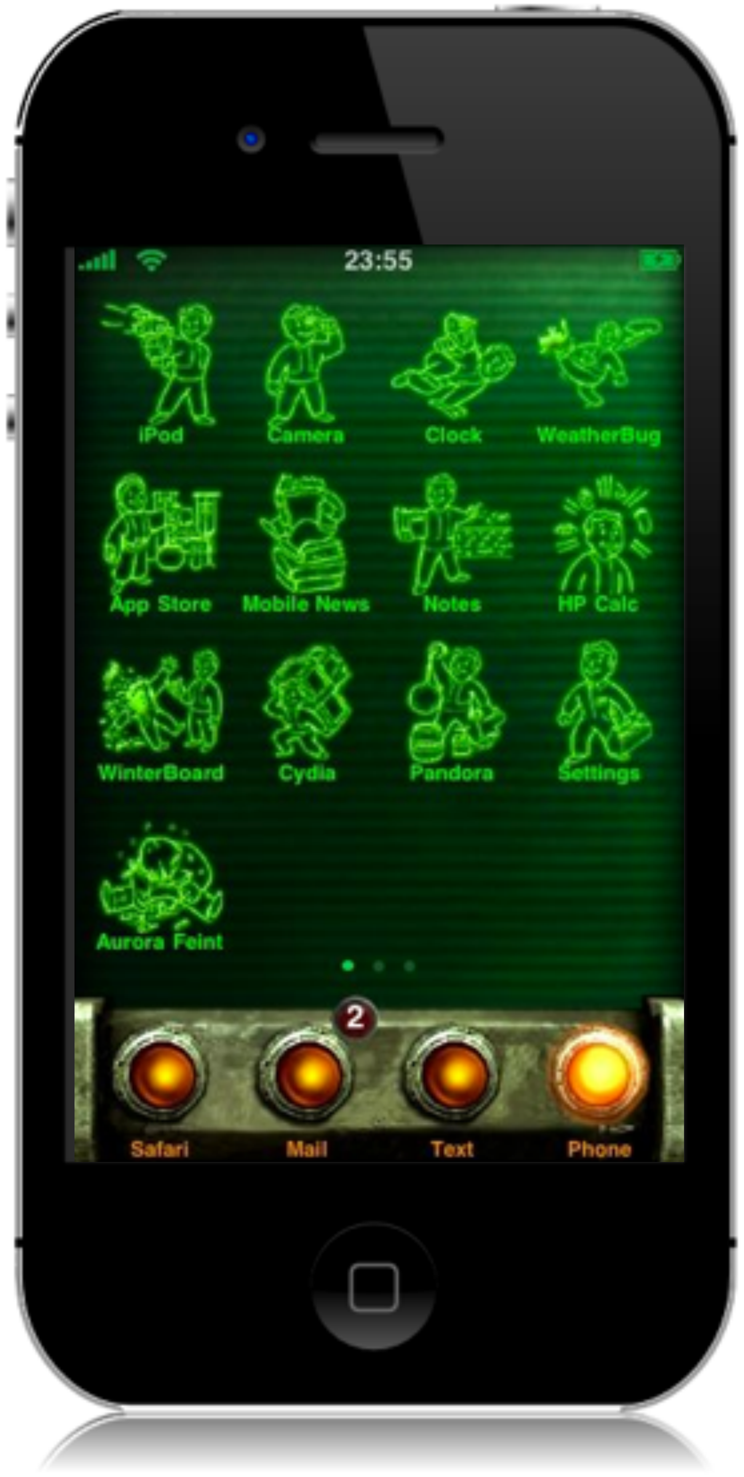

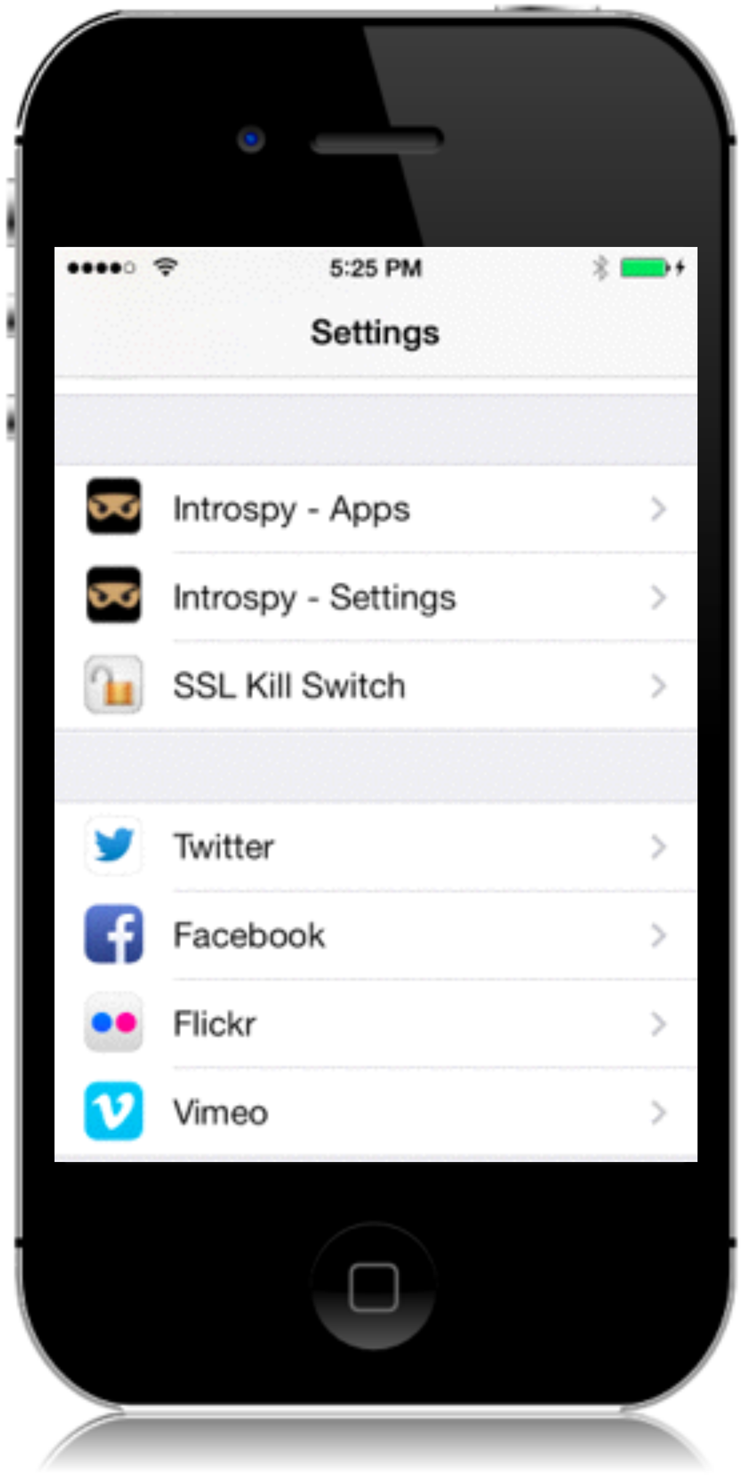
5:25 PM

Settings

Introspy - Apps

Introspy - Settings

SSL Kill Switch

Twitter

Facebook

Flickr

Vimeo

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Dylibs Before iOS 8

- Historically: no third-party dynamic libraries in Apps
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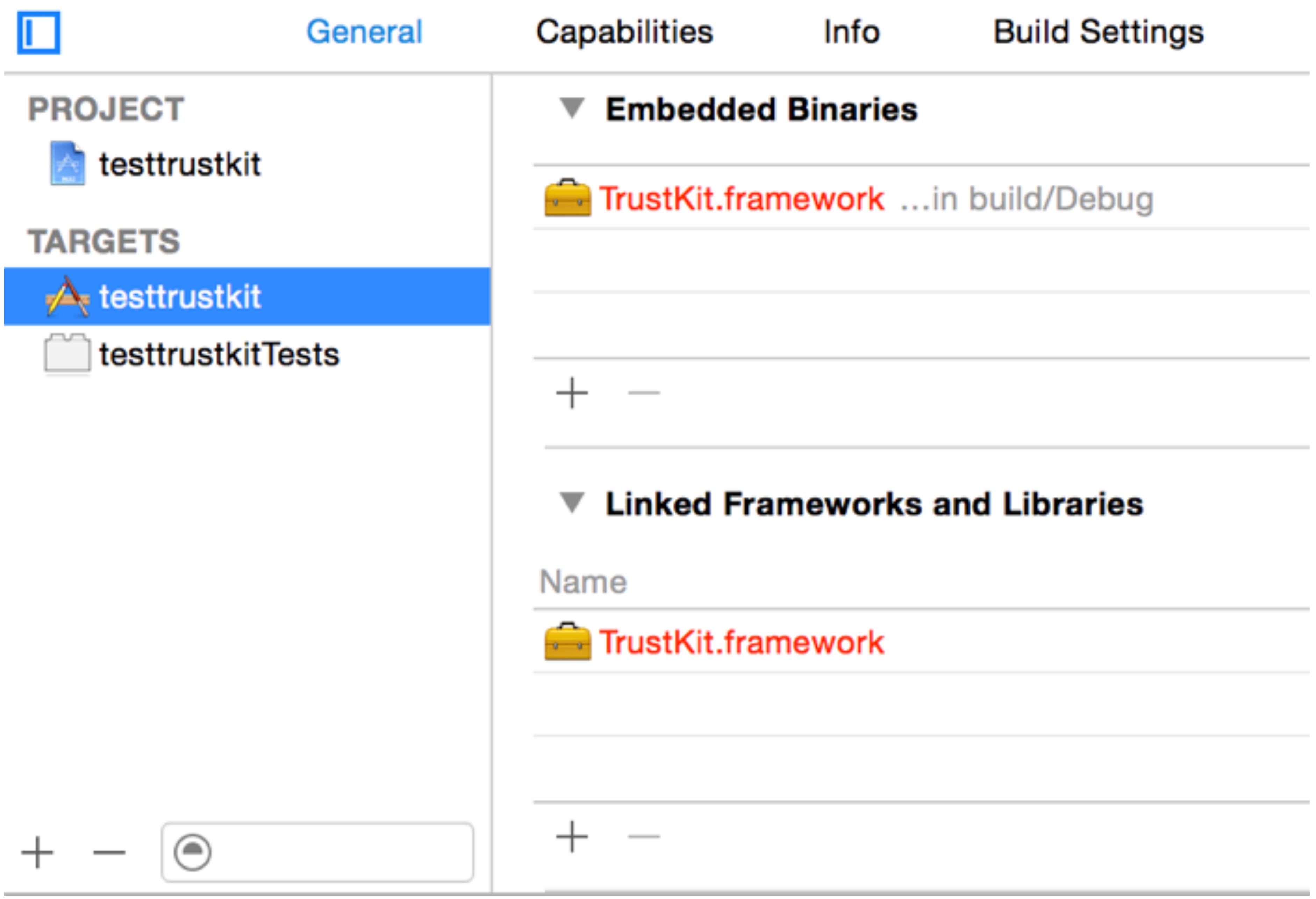
Dylibs Before iOS 8

- 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

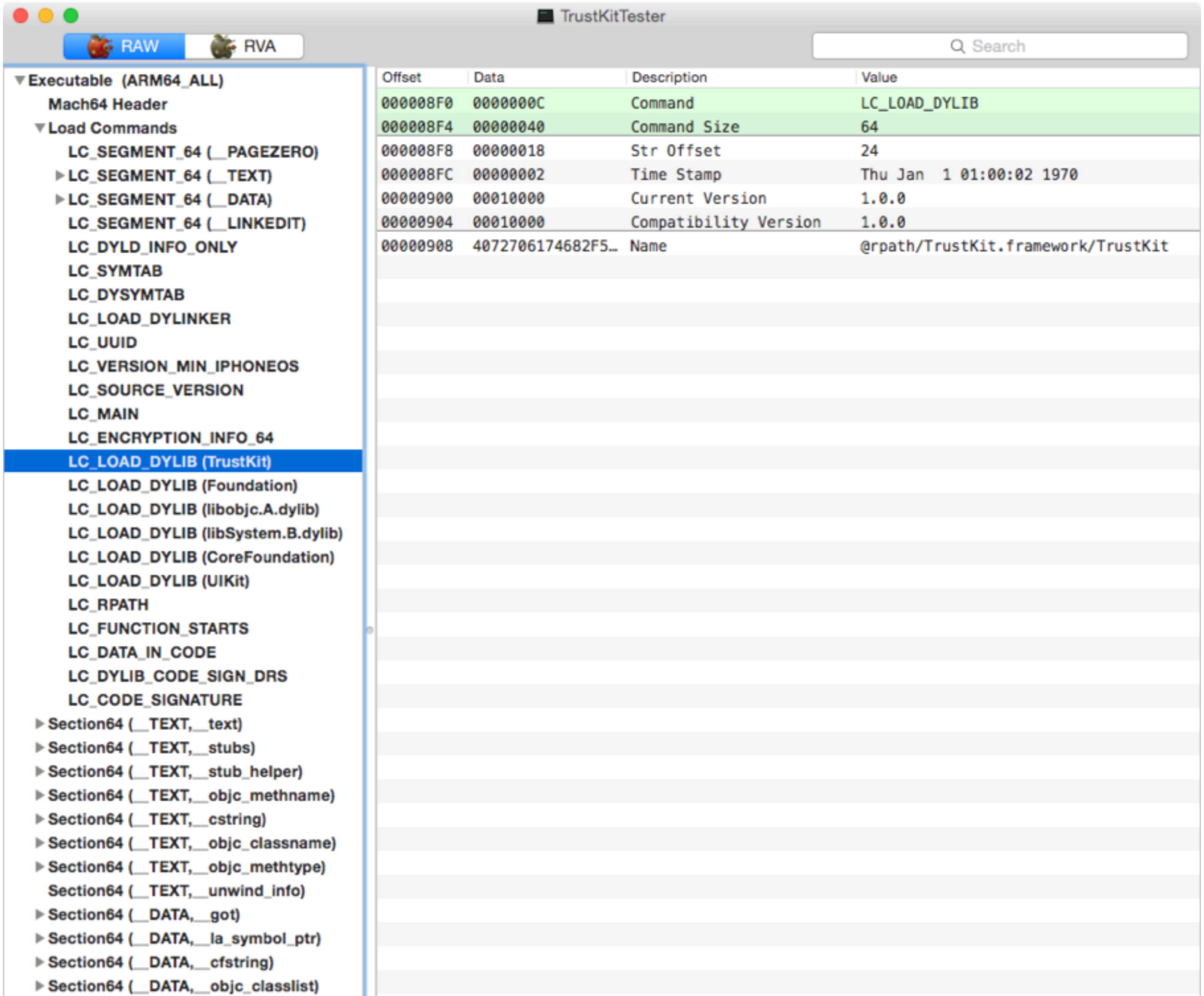
- Executables interact with “dyld” to load their library dependencies at runtime.

Dylibs on iOS 8

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

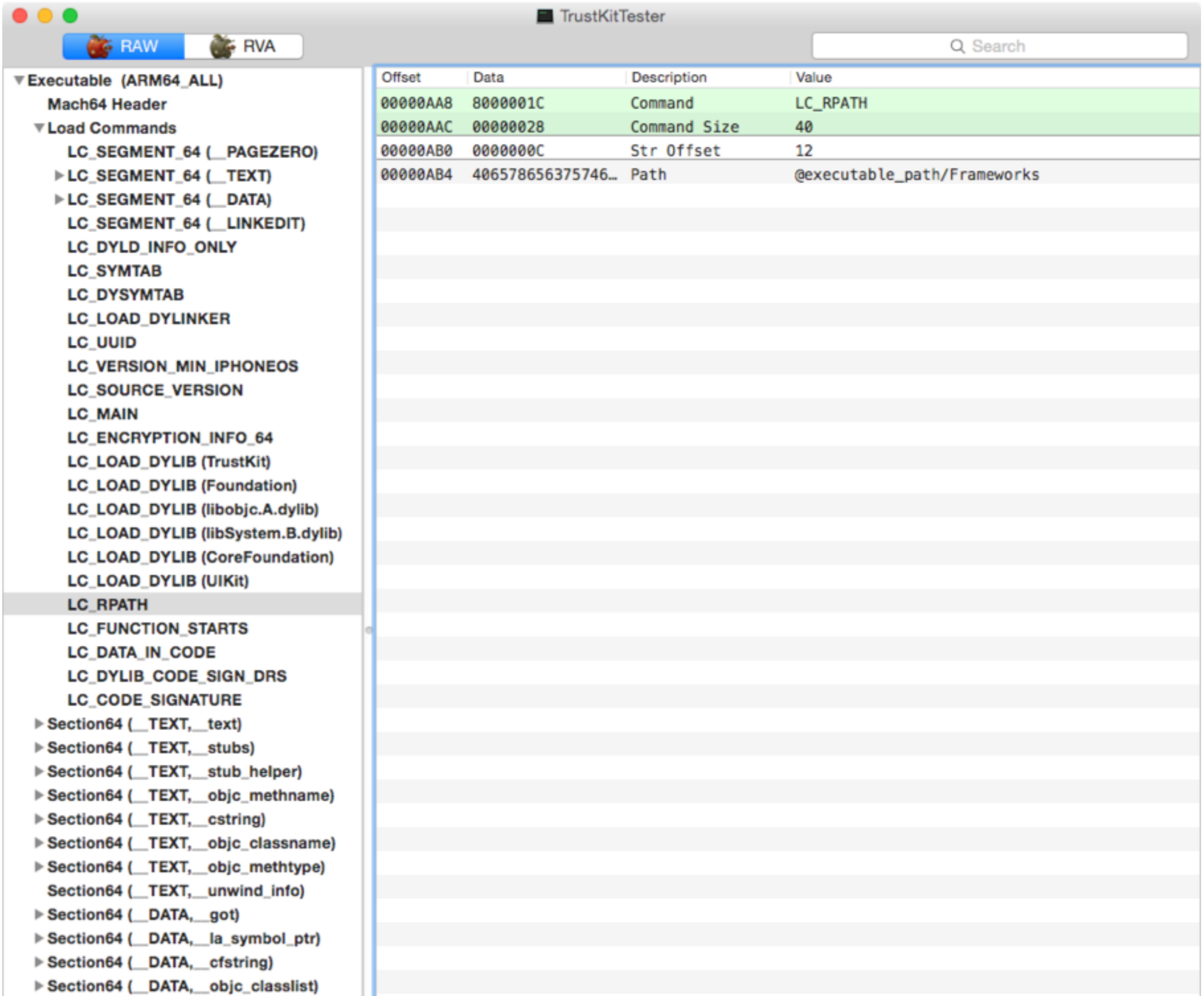
Dylibs on iOS 8

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



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_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)
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      LC_LOAD_DYLIB (CoreFoundation)
      LC_LOAD_DYLIB (UIKit)
      LC_RPATH
      LC_FUNCTION_STARTS
      LC_DATA_IN_CODE
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  ▶Section64 (__TEXT,__text)
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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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Substrate in an App

- SIGKILL when calling *MSFunctionHook()*
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    - 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

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    - 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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- **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()*
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  - 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!

black hat USA 2015