Evolution of iOS Data Protection and iPhone Forensics: from iPhone OS to iOS 5

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Agenda

- Basics
- iOS Security before iOS 4
- iOS 4 Data Protection
- iOS 5 Data Protection Changes
- Summary

Forensics 101

Acquisition ➜ Analysis ➜ Reporting

GOALS:

1. Assuming physical access to the device extract as much information as practical

2. Leave as little traces/artifacts as practical

iOS: Why Even Bother?

- Almost 5 years on the market
- 250+ million iOS devices sold worldwide
- 6 iPhones, 4 iPods, 2 iPads
- “Smart devices” – they do carry a lot of sensitive data
- Corporate deployments are increasing

There was, is, and will be a real need in iPhone Forensics

iPhone Forensics 101

- Passcode
  - –Prevents unauthorized access to the device
  - –Bypassing passcode is usually enough
- Keychain
  - –System-wide storage for sensitive data
  - –Encrypted
- Storage encryption

iPhone Forensics 101

- Logical: iPhone Backup
  - Ask device to produce a backup
    - Device must be unlocked
    - Device may produce encrypted backup
    - Limited amount of information
- Physical: filesystem acquisition
  - Boot-time exploit to run unsigned code
    - Device lock state isn’t relevant
    - Can get all information from the device

The Inception

Runs iPhone OS (up to 3.1.3)

- Based on Mac OS X

Has a crypto co-processor

06/29/2007
iPhone

Hardware Keys

Two embedded AES keys:

- GID – shared by all devices of same family
- UID – unique for each and every device

No known ways to extract GID/UID keys

06/29/2007
iPhone

Device Keys

- To avoid unnecessary exposure, usage of UID/GID keys is limited
- Device keys are computed from hardware keys during boot:
  - `0x835 = AES_Enc (UID, 01010101010101010101010101010101);`
  - `0x836 = AES_Enc (UID, 00E5A0E6526FAE66C5C1C6D4F16D6180);`
  - `0x837 = AES_Enc (GID, 345A2D6C5050D058780DA431F0710E15);`
  - `0x838 = AES_Enc (UID, 8C8318A27D7F030717D2B8FC5514F8E1);`

iPhone OS Security

Relies on chain of trust:

- BootROM loads trusted iBoot
- iBoot loads trusted kernel
- Kernel runs trusted apps

Apps must be signed

- Developers can sign and run their apps on their devices ($99/yr)

Applications are sandboxed

Breaking Free

- Jailbreak – circumventing iOS security in order to run custom code
- Boot-level or application-level
- Tethered or untethered

Breaking Free

- App-level JB gets kernel code execution by exploiting apps
  - –e.g. JailbreakMe
  - –Can be fixed by new firmware
- Boot-level JB breaks loads custom kernel by breaking chain of trust
  - –e.g. limera1n
  - –Can’t be fixed if exploits vulnerability in BootROM

Jailbreak+Forensics=?

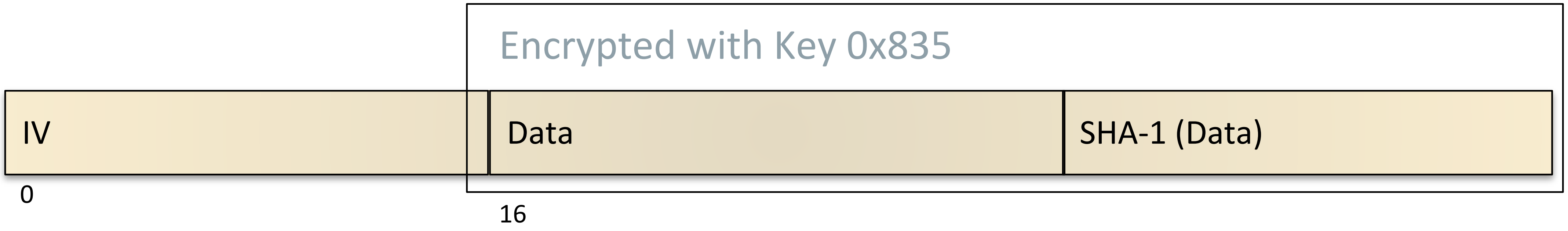
- Tethered JB
  - –Host connection is required to boot into JB state
  - –Exploit(s) are sent by the host
  - –May leave minimal traces on the device
- Untethered JB
  - –Device is modified so that it can boot in jailbroken state by itself
  - –Leaves permanent traces

iPhone OS Passcode

- Lockscreen (i.e. UI) is the only protection
- Passcode is stored in the keychain
  - Passcode itself, not its hash
- Can be recovered or removed instantly
  - Remove record from the keychain
  - And/or remove setting telling UI to ask for the passcode

iPhone OS Keychain

- SQLite3 DB, only passwords are encrypted
- All items are encrypted with the device key (0x835) and random IV
- Key can be extracted (computed) for offline use
- All past and future keychain items from the device can be decrypted using that key



iPhone OS Storage Encryption

- No encryption.

iPhone 3G

Hardware is very similar to original iPhone

No real security improvements over previous model

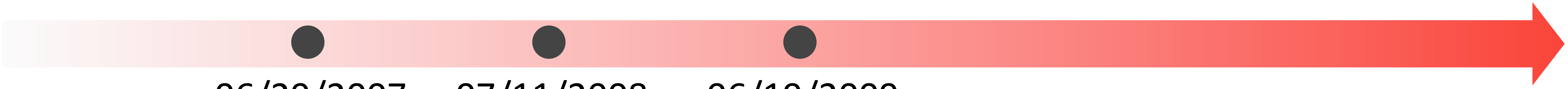
06/29/2007
iPhone

07/11/2008
iPhone 3G

iPhone 3GS

New application processor

Hardware storage encryption



06/29/2007
iPhone

07/11/2008
iPhone 3G

06/19/2009
iPhone 3GS

iPhone 3GS Forensics

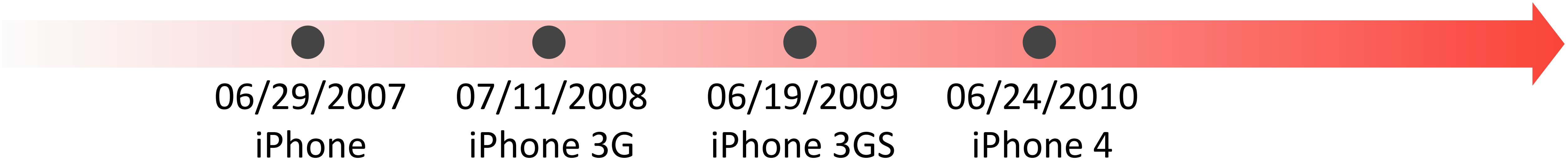
- Passcode: same as before
- Keychain: same as before
- Storage encryption:
  - Only user partition is encrypted
  - Single key for all data (FDE)
  - Designed for fast wipe, not confidentiality
  - Transparent for applications
  - Does not affect physical acquisition

This is true only for iPhone 3GS running iPhone OS 3.x

iPhone 4

No notable enhancements in security hardware over iPhone 3GS

Shipped with iOS 4 with major security improvements



06/29/2007
iPhone

07/11/2008
iPhone 3G

06/19/2009
iPhone 3GS

06/24/2010
iPhone 4

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Dmitry Sklyarov

iOS 4 Data Protection

- More robust passcode protection
- Better storage encryption
  - Metadata is encrypted transparently (same as before)
  - Per-file encryption keys
- Better Keychain encryption
- New backup format
  - Slower password recovery
  - Keychain items can migrate to another device

Protection Classes

- Content grouped by accessibility requirements:
  - –Available only when device is unlocked
  - –Available after first device unlock (and until power off)
  - –Always available
- Each protection class has a master key
- Master keys are protected by device key and passcode
- Protected master keys form system keybag
  - –New keys created during device restore

Effaceable Storage

- Special region of flash memory to store small data items with ability to quickly erase them
- Items within effaceable storage are called lockers
- As of iOS 4: 960 bytes capacity, 3 lockers:
  - ‘BAG1’ – System Keybag payload key and IV
  - ‘Dkey’ – NSProtectionNone class master key
  - ‘EMF!’ – Filesystem encryption key

System Keybag

- /private/var/keybags/systembag.kb
- Three layers of encryption:
  - –System keybag file is encrypted by Data Protection
  - –Keybag payload is encrypted before writing to disk
  - –Master keys are encrypted with device key and/or passcode key

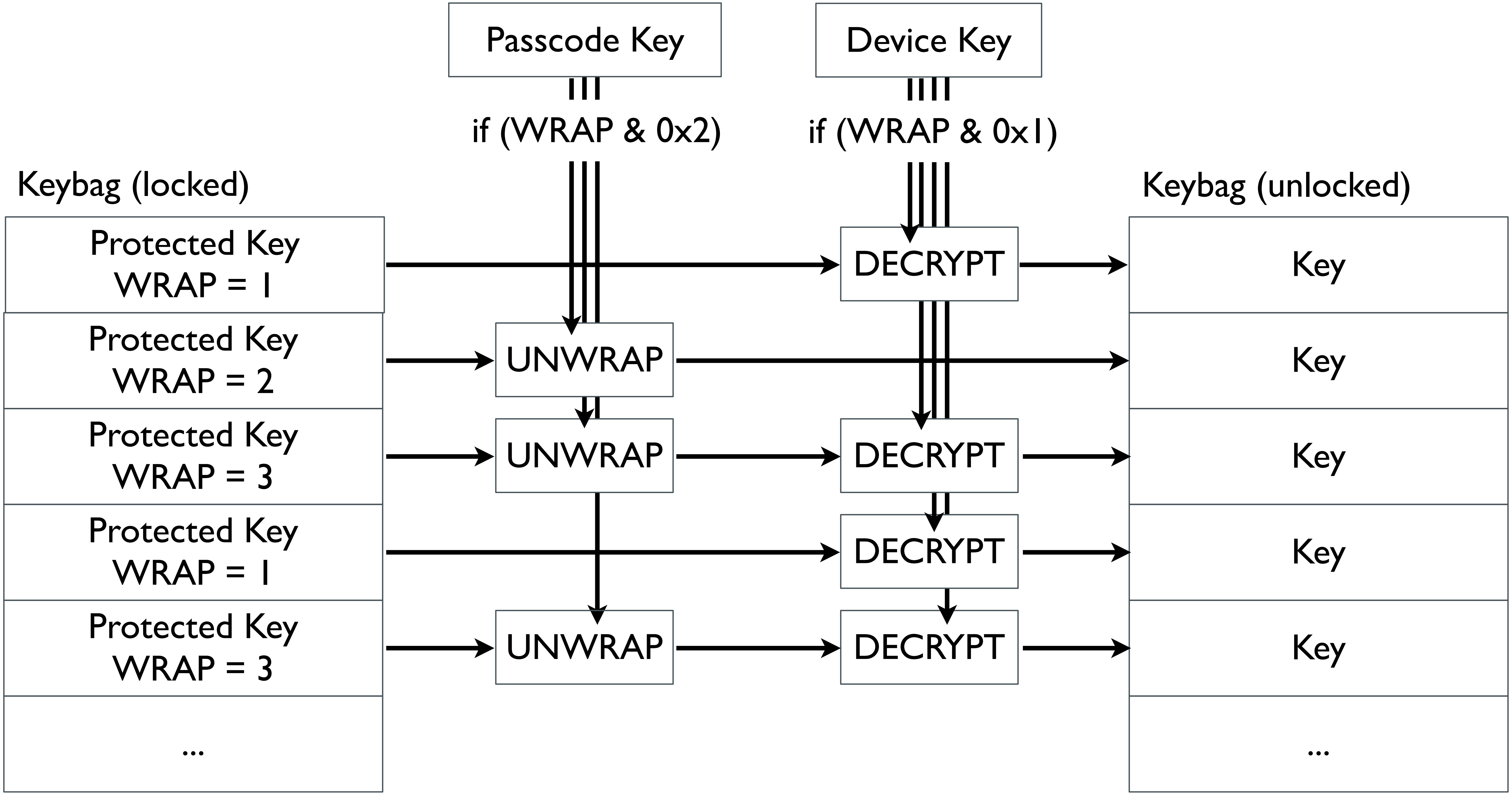
Escrow Keybag

- “Usability feature” to allow iTunes to unlock the device
- Contains same master keys as system keybag
- Stored on the iTunes side
- Protected by 256 bit random “passcode” stored on the device
- With iOS 4, escrow keybag gives same powers as knowing the passcode

Backup Keybag

- Included in the iOS backups
- Holds keys to decrypt files and keychain items included with the backup
- New keys are generated for each backup

Unlocking Keybag



Passcode Key

if (WRAP & 0x2)

Device Key

if (WRAP & 0x1)

Keybag (locked)

Protected Key
WRAP = 1

Protected Key
WRAP = 2

Protected Key
WRAP = 3

Protected Key
WRAP = 1

Protected Key
WRAP = 3

...

UNWRAP

UNWRAP

UNWRAP

DECRYPT

DECRYPT

DECRYPT

DECRYPT

Keybag (unlocked)

Key

Key

Key

Key

Key

...

iOS 4 Passcode

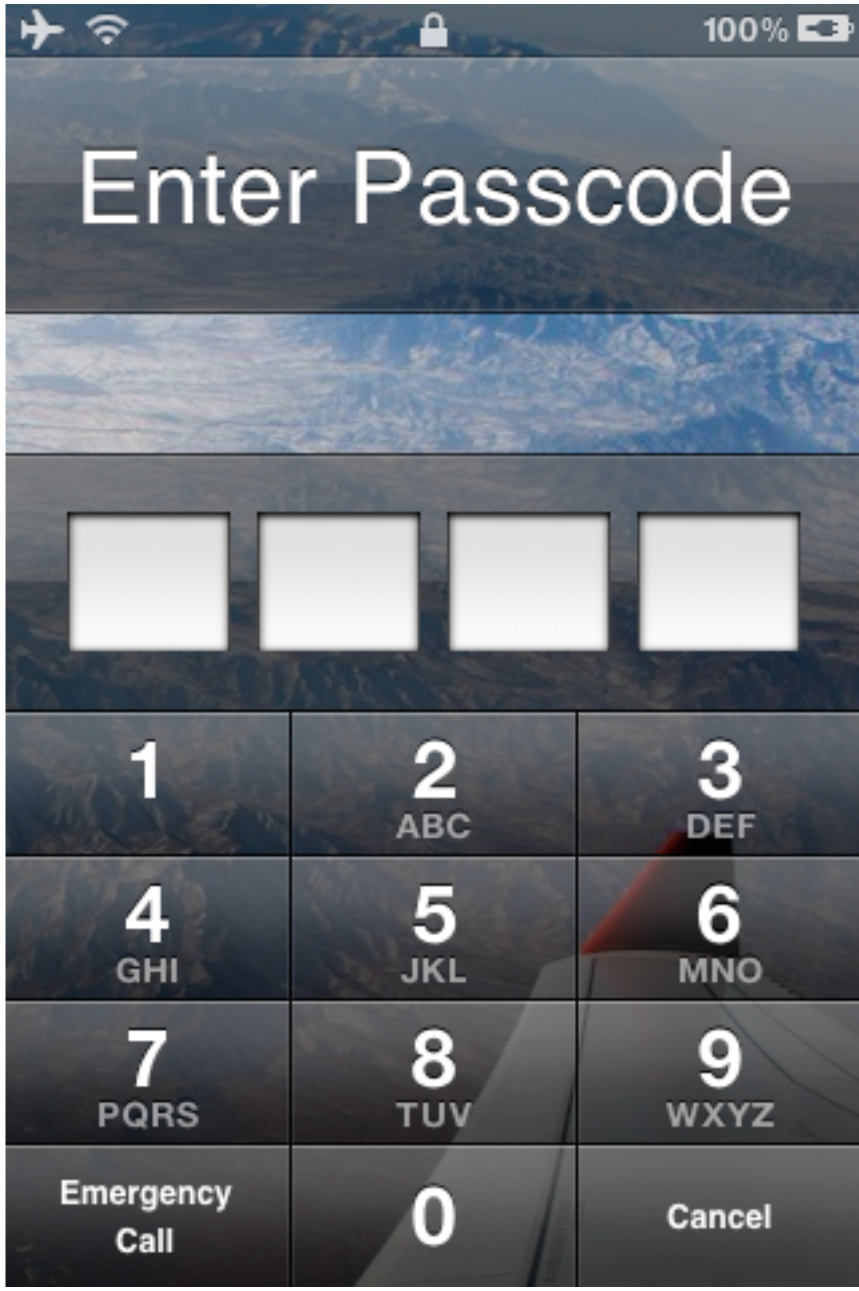
- Passcode is used to compute passcode key
  - Computation tied to hardware key
  - Same passcode will yield different passcode keys on different devices!
- Passcode key is required to unlock most keys from the system keybag
  - Most files are protected with NSProtectionNone and don’t require a passcode
  - Most keychain items are protected with ...WhenUnlocked or ...AfterFirstUnlock and require a passcode

iOS 4 Passcode

- Passcode-to-Key transformation is slow
- Offline bruteforce currently is not possible
  - Requires extracting hardware key
- On-device bruteforce is slow
  - 2 p/s on iPhone 3G, 7 p/s on iPad
- System keybag contains hint on password complexity

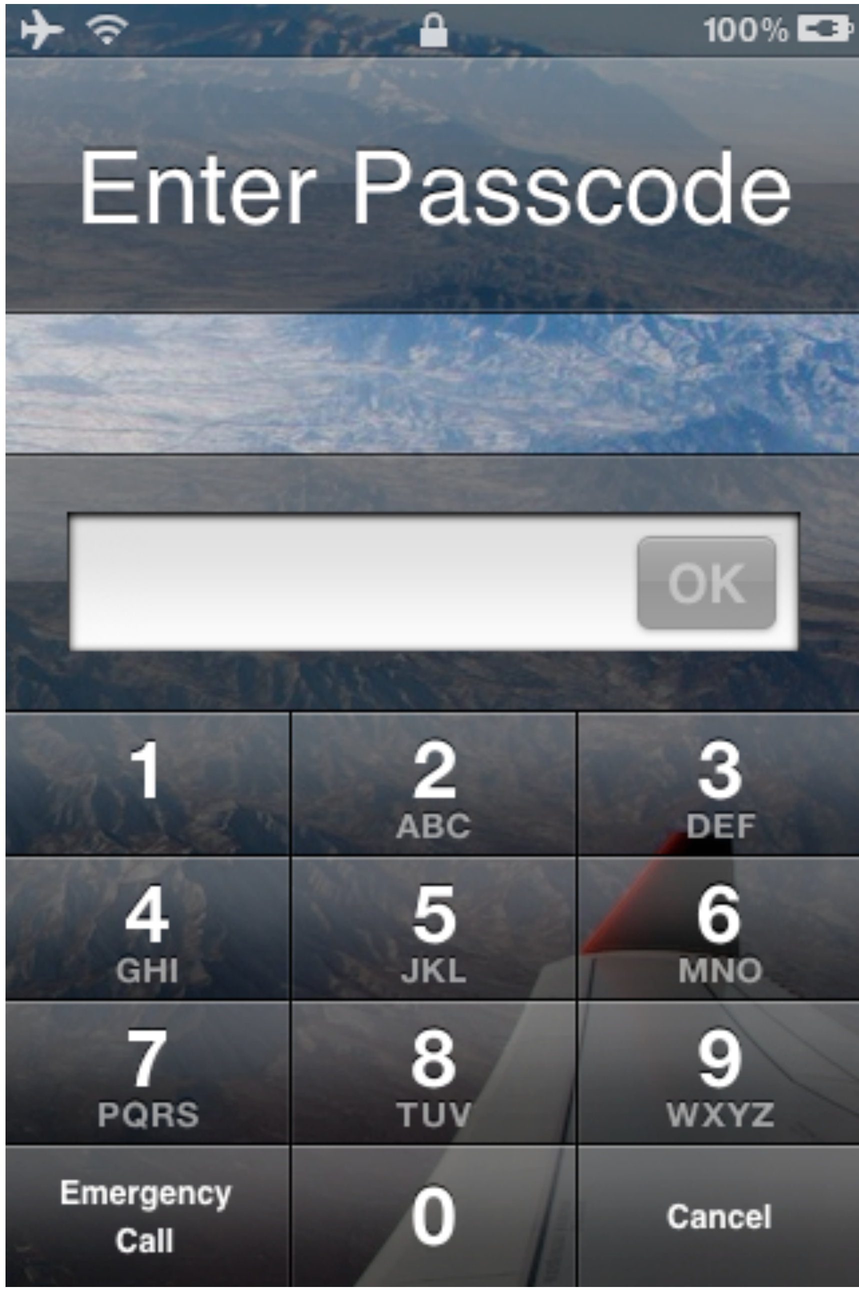
iOS 4 Passcode

- 0 – digits only, length = 4 (simple passcode)



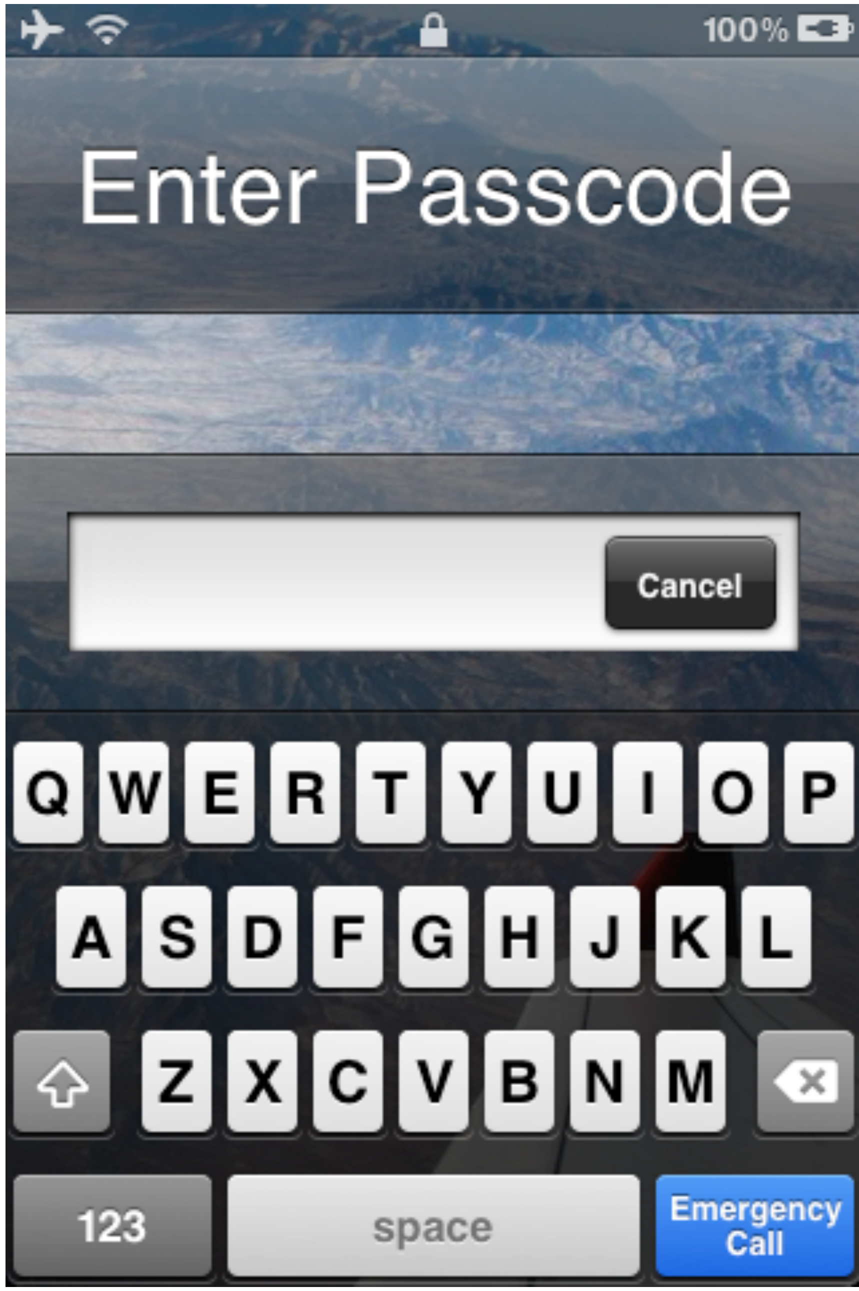
iOS 4 Passcode

- 0 – digits only, length = 4 (simple passcode)
- 1 – digits only, length != 4



iOS 4 Passcode

- 0 – digits only, length = 4 (simple passcode)
- 1 – digits only, length != 4
- 2 – contains non-digits, any length

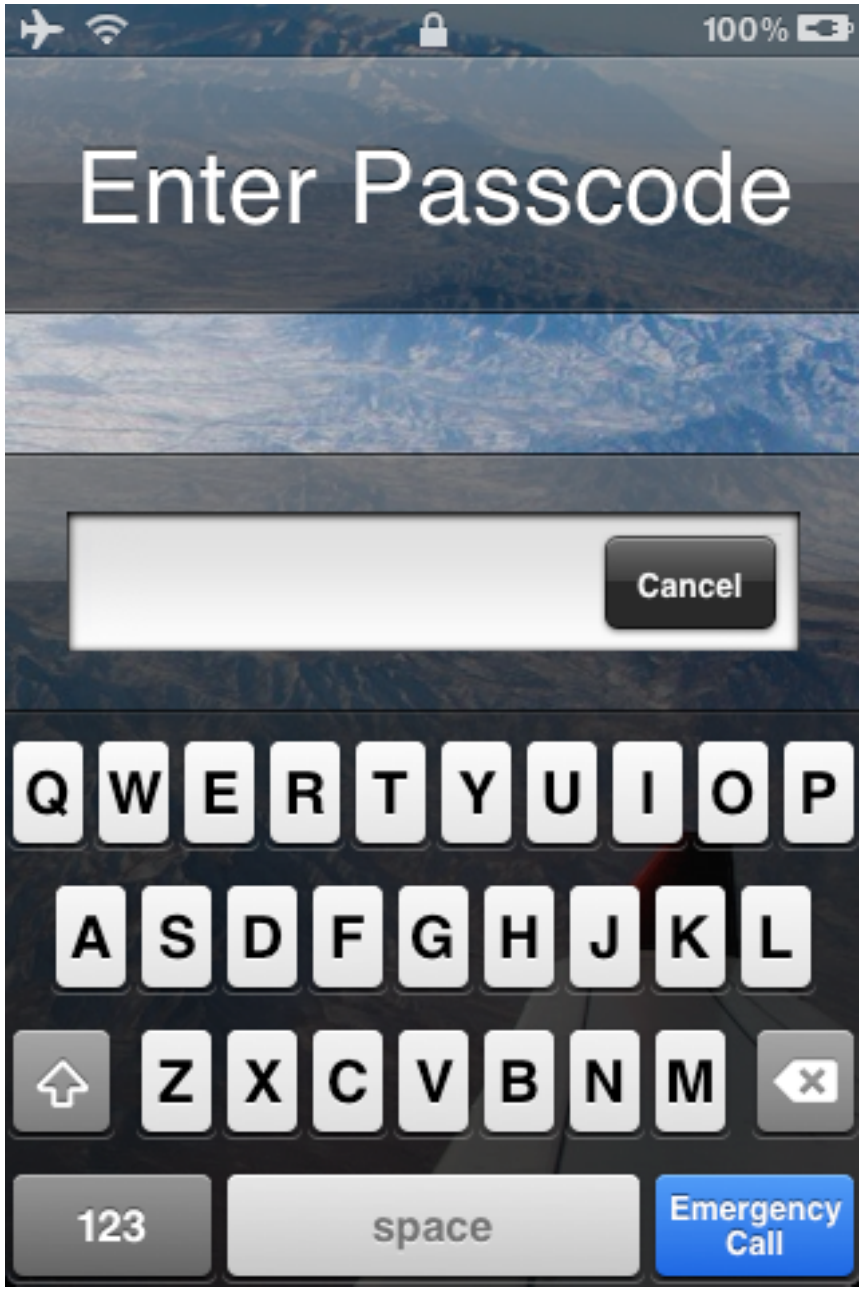


Enter Passcode

iOS 4 Passcode

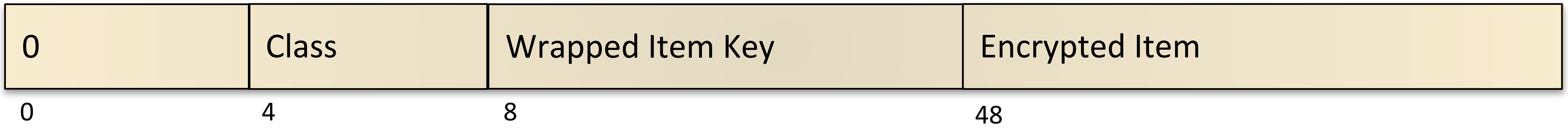
- 0 – digits only, length = 4 (simple passcode)
- 1 – digits only, length != 4
- 2 – contains non-digits, any length

Can at least identify weak passcodes



iOS 4 Keychain

- SQLite3 DB, only passwords are encrypted
- Available protection classes:
  - kSecAttrAccessibleWhenUnlocked (+ ...ThisDeviceOnly)
  - kSecAttrAccessibleAfterFirstUnlock (+ ...ThisDeviceOnly)
  - kSecAttrAccessibleAlways (+ ...ThisDeviceOnly)
- Random key for each item, AES-CBC
- Item key is protected with corresponding protection class master key



0	Class	Wrapped Item Key	Encrypted Item
0	4	8	48

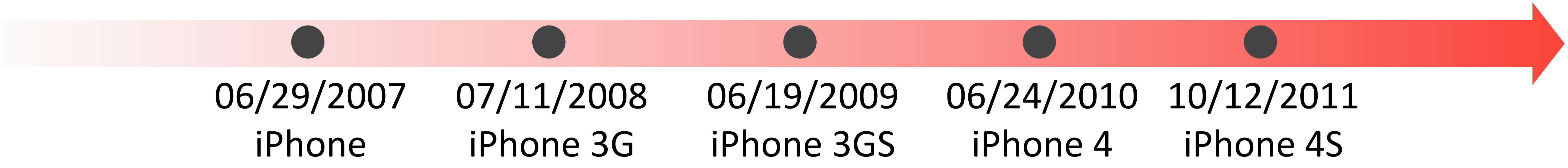
iOS 4 Storage

- Only User partition is encrypted
- Available protection classes:
  - NSProtectionNone
  - NSProtectionComplete
- When no protection class set, EMF key is used
  - Filesystem metadata and unprotected files
  - Transparent encryption and decryption (same as pre-iOS 4)
- When protection class is set, per-file random key is used
  - File key protected with master key is stored in extended attribute com.apple.system.cprotect

iPhone 4S

No known security enhancements in hardware over iPhone 4

Shipped with iOS 5 with some security improvements



06/29/2007
iPhone

07/11/2008
iPhone 3G

06/19/2009
iPhone 3GS

06/24/2010
iPhone 4

10/12/2011
iPhone 4S

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Andrey Belenko

iOS 5 Passcode

- Very similar to iOS 4
- Passcode key computation utilizes new hardware key UID+
  - UID is used instead of UID+ on devices before iPad 2 and iPhone 4S
  - Not clear for iPad 2 and iPhone 4S

iOS 5 Keychain

- All attributes are now encrypted (not only password)
- AES-GCM is used instead of AES-CBC
  - Enables integrity verification

2	Class	Wrapped Key Length	Wrapped Key	Encrypted Data (+Integrity Tag)
0	4	8	12	

iOS 5 Storage

- New partition scheme
  - “LwVM” – Lightweight Volume Manager
- Any partition can be encrypted
- New protection classes
  - NSFileProtectionCompleteUntilFirstUserAuthentication
  - NSFileProtectionCompleteUnlessOpen
- IV for file encryption is computed differently

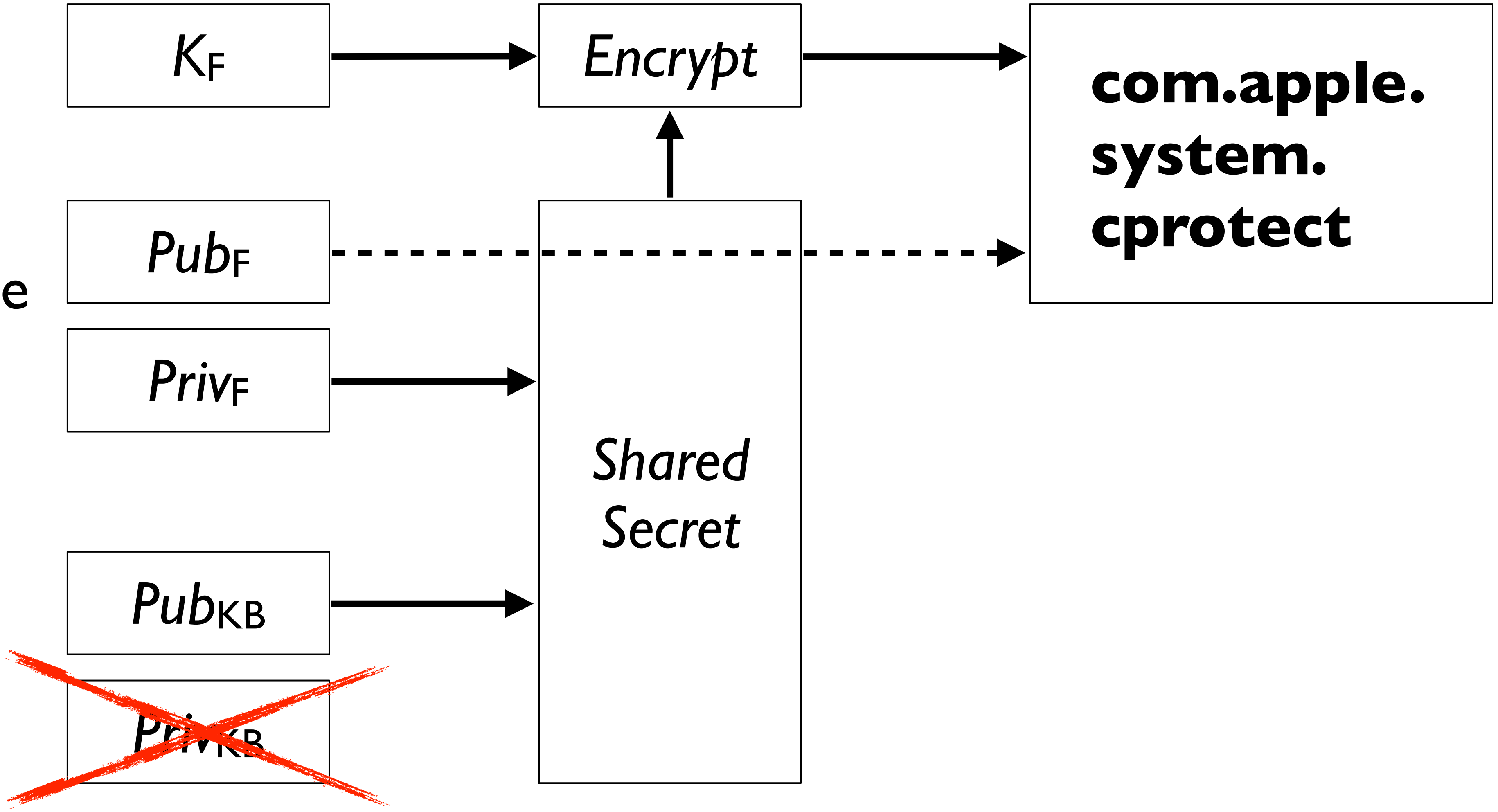
Creating the File

NSFileProtectionCompleteUnlessOpen

Generate random file key (AES)

Generate file public/private keys (ECC)

Master key from the system keybag (ECC)



K_F

Pub_F

$Priv_F$

Pub_{KB}

~~$Priv_{KB}$~~

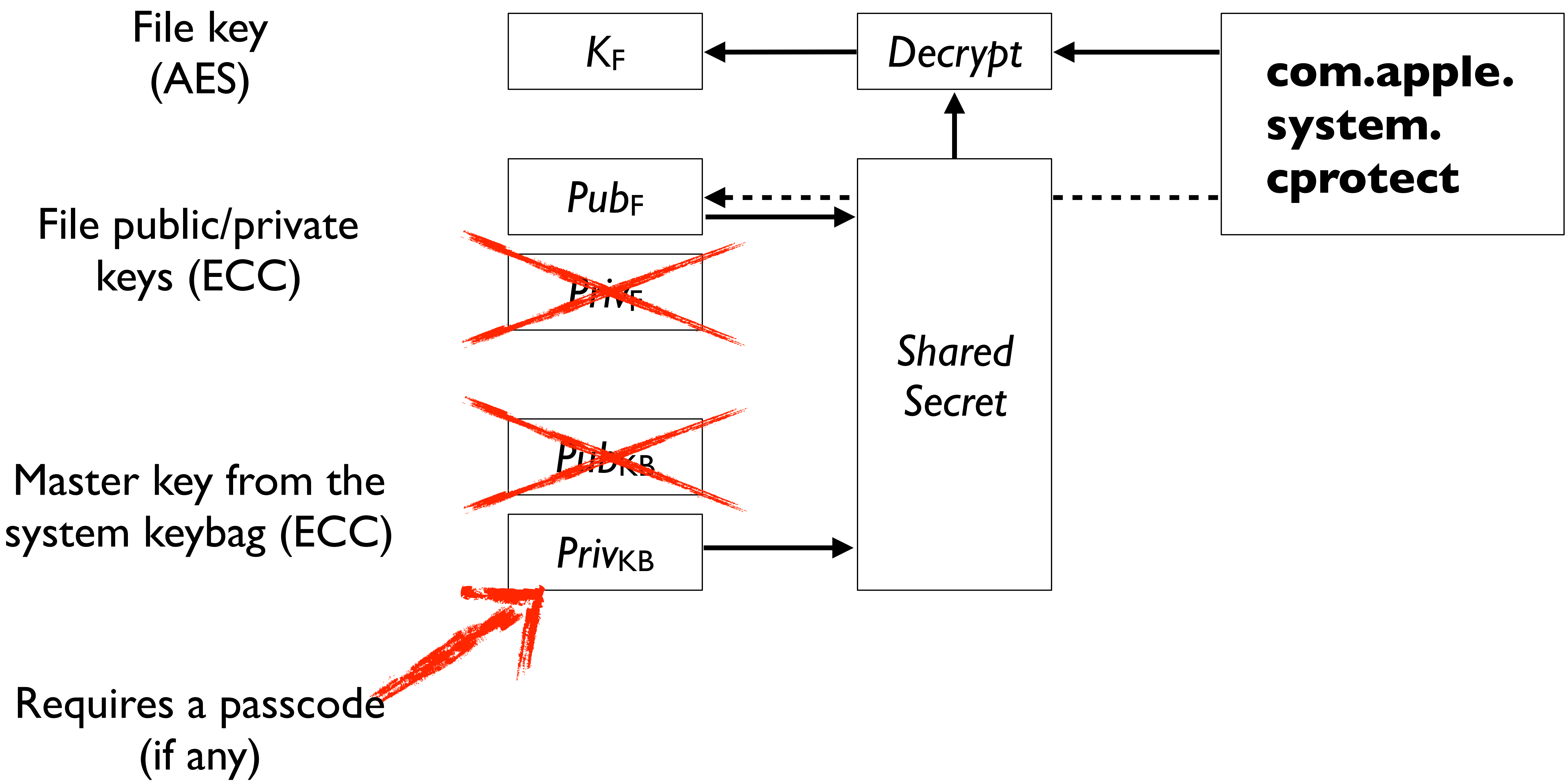
Encrypt

Shared Secret

com.apple.system.cprotect

Reading the File

NSFileProtectionCompleteUnlessOpen



File key
(AES)

K_F

Decrypt

**com.apple.
system.
cprotect**

File public/private
keys (ECC)

Pub_F

~~$Priv_F$~~

*Shared
Secret*

Master key from the
system keybag (ECC)

~~Pub_{KB}~~

$Priv_{KB}$

Requires a passcode
(if any)

Reading the File

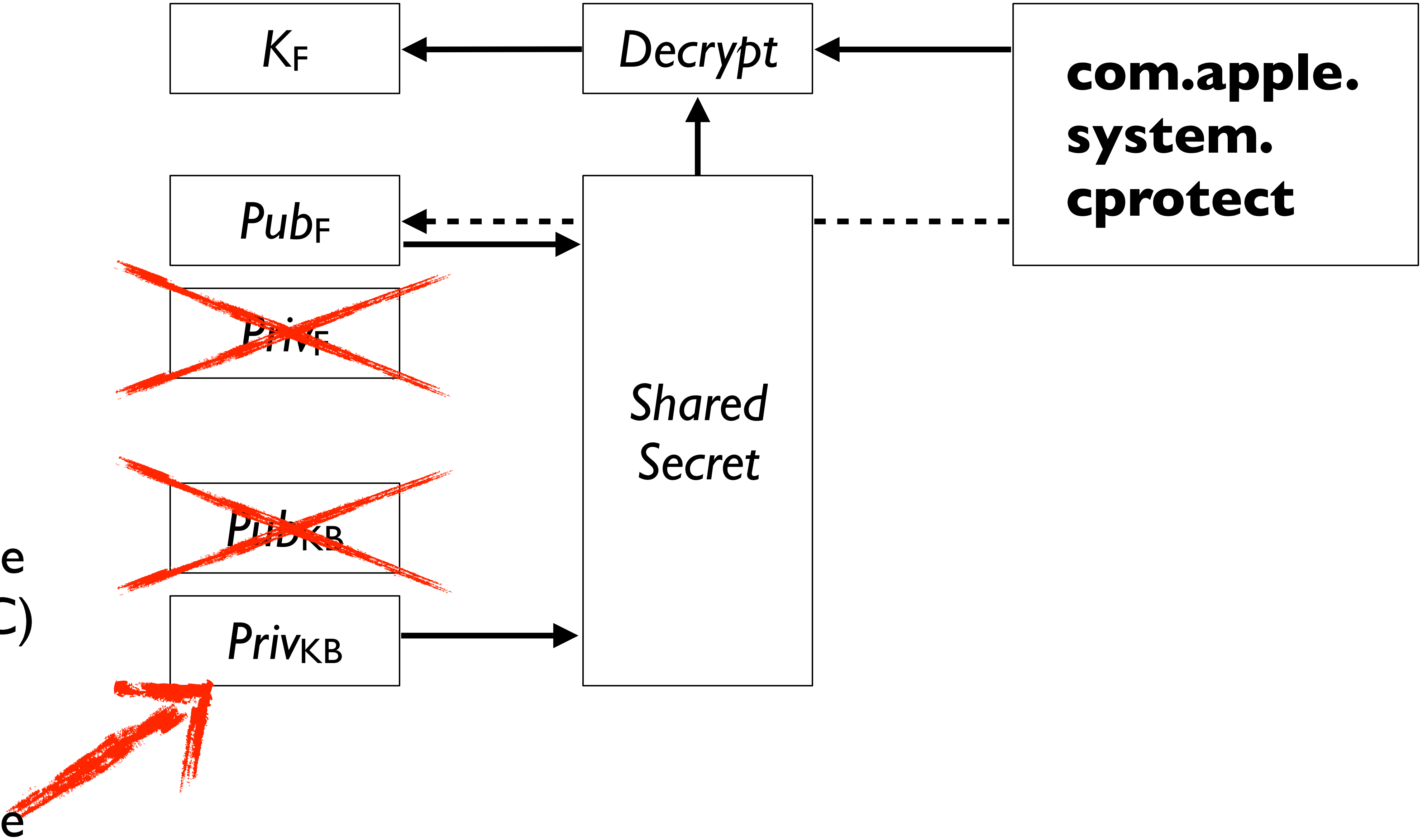
NSFileProtectionCompleteUnlessOpen

File key
(AES)

File public/private
keys (ECC)

Master key from the
system keybag (ECC)

Requires a passcode
(if any)

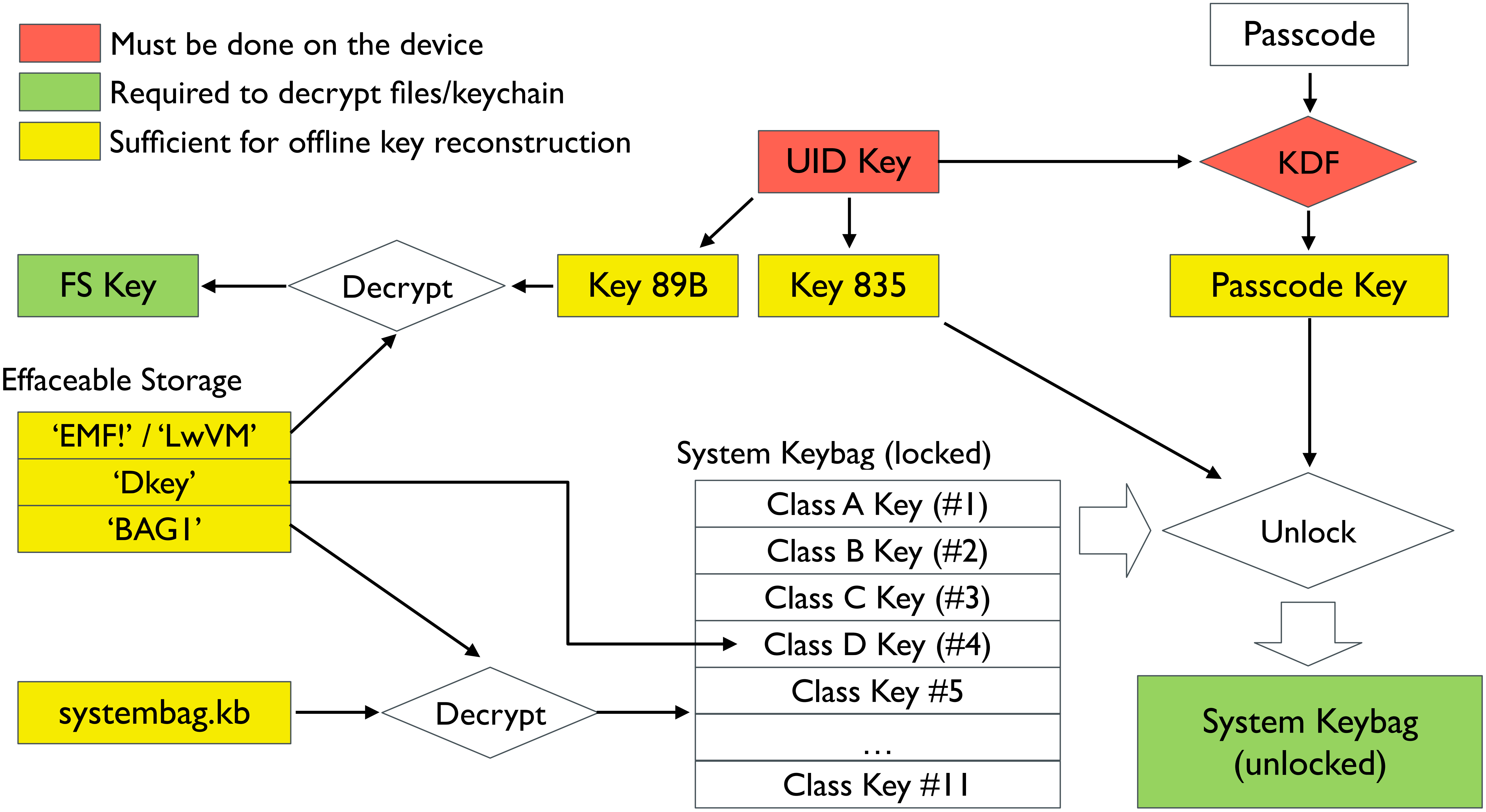


Looks pretty much like BlackBerry way to receive emails while locked :-)

iOS Forensics

- Acquiring disk image is not enough for iOS 4+
  - Content protection keys must also be extracted from the device during acquisition
  - Effaceable Storage contents are also needed to decrypt dd images.
- Passcode ~~or escrow keybag~~ is needed for a complete set of master keys
- In real world it might be a good idea to extract source data and compute protection keys offline

iOS Forensics



🟥 Must be done on the device

🟩 Required to decrypt files/keychain

🟨 Sufficient for offline key reconstruction

Passcode

UID Key

KDF

FS Key

Decrypt

Key 89B

Key 835

Passcode Key

Effaceable Storage

‘EMF!’ / ‘LwVM’

‘Dkey’

‘BAG1’

System Keybag (locked)

Class A Key (#1)

Class B Key (#2)

Class C Key (#3)

Class D Key (#4)

Class Key #5

…

Class Key #11

Unlock

systembag.kb

Decrypt

System Keybag (unlocked)

iOS Forensics

<table>
<tr><th></th><th>iPhone
iPod Touch 1</th><th colspan="2">iPhone 3G
iPod Touch 2</th><th colspan="2">iPhone 3GS
iPod Touch 3
iPad 1</th><th>iPhone 4
iPod Touch 4</th><th>iPhone 4S
iPad 2</th></tr>
<tr><td>iOS version</td><td colspan="2">3.1.3</td><td>4.2.1</td><td>3.1.3</td><td>5.0.1</td><td>5.0.1</td><td>5.0.1</td></tr>
<tr><td>Physical acquisition</td><td colspan="2">+</td><td>+</td><td>+</td><td colspan="2">+</td><td>–</td></tr>
<tr><td>Passcode recovery</td><td colspan="2">instant</td><td>+</td><td>instant</td><td colspan="2">+</td><td></td></tr>
<tr><td>Keychain decryption</td><td colspan="2">+</td><td>+</td><td>+</td><td colspan="2">+</td><td></td></tr>
<tr><td>Disk decryption</td><td colspan="4">not encrypted</td><td colspan="2">+</td><td></td></tr>
</table>

Conclusions

- iPhone physical analysis is possible
- Physical acquisition requires boot-time exploit
- Passcode is *usually* not a problem
  - Due to technology before iOS 4
  - Due to human factor with iOS 4/5
- Both proprietary and open-source tools for iOS 4/5 acquisition are available

THANK YOU

QUESTIONS?

Please do not forget
to complete your
feedback survey forms!