
# 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?

- More than 5 years on the market
- 360+ million iOS devices sold worldwide
- 6 iPhones, 4 iPods, 3 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
  - Get backup from iCloud
- Physical: filesystem acquisition
  - Boot-time exploit to run unsigned code
    - Device lock state isn't relevant
    - Can get all information from the device
- Physical+: flash memory acquisition
  - Same requirements as for physical
  - Also allows recovery of deleted files!

# 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 or services
  - –e.g. Absinthe, JailbreakMe
  - –Can be fixed by new firmware
- Boot-level JB loads custom kernel by breaking chain of trust
  - –e.g. limera1n
  - –Can't be fixed if exploits vulnerability in BootROM

# Jailbreak+Forensics=?

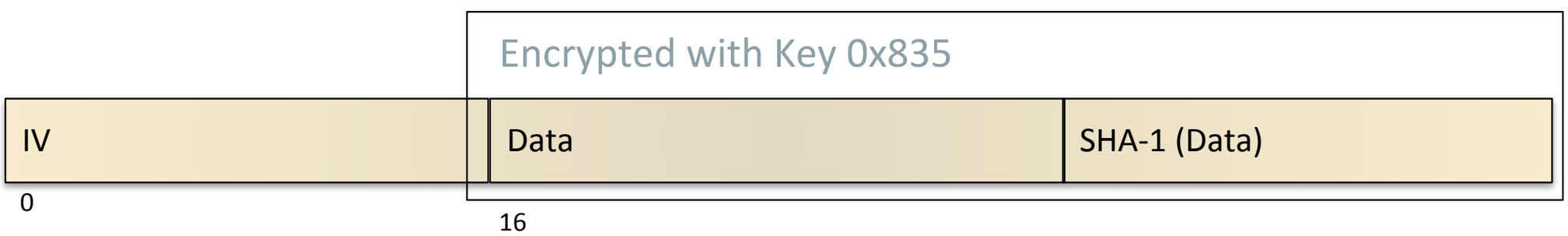
- Tethered JB
  - Host connection is required to boot into JB state
  - Exploit(s) are sent by the host
  - May leave minimal traces on the device
- Untethered JB
  - Device is modified so that it can boot in jailbroken state by itself
  - Leaves permanent traces

# Passcode (Before iOS 4)

- 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

# Keychain (Before iOS 4)

- 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



# Storage Encryption (Before iOS 4)

- No encryption.

# iPhone 3G

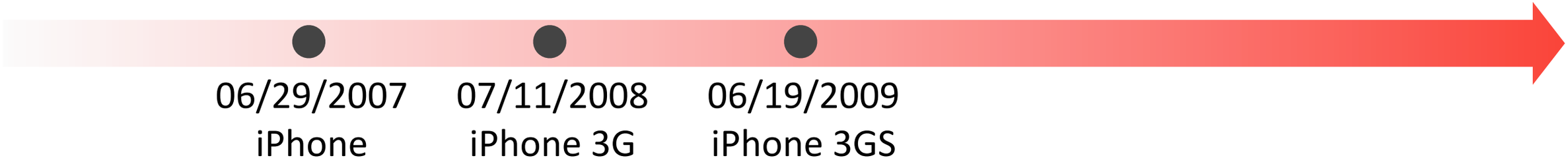
Hardware is very similar to original iPhone

No real security improvements over previous model

# iPhone 3GS

New application processor

Hardware storage encryption



# iPhone 3GS Forensics

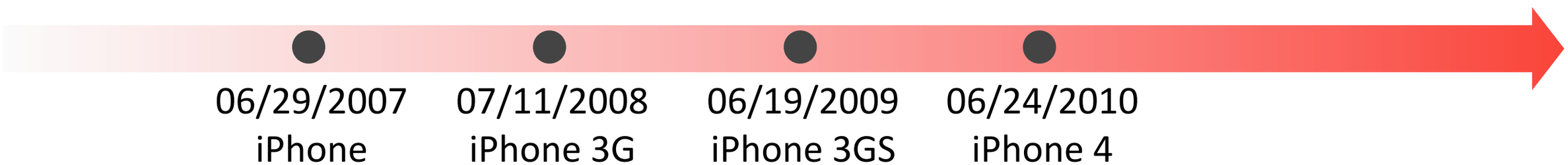
- Passcode: same as before
- Keychain: same as before
- Storage encryption:
  - Only user partition is encrypted
  - Single key for all data (FDE)
  - Designed for fast wipe, not confidentiality
  - Transparent for applications
  - Does not affect physical acquisition

**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



# 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

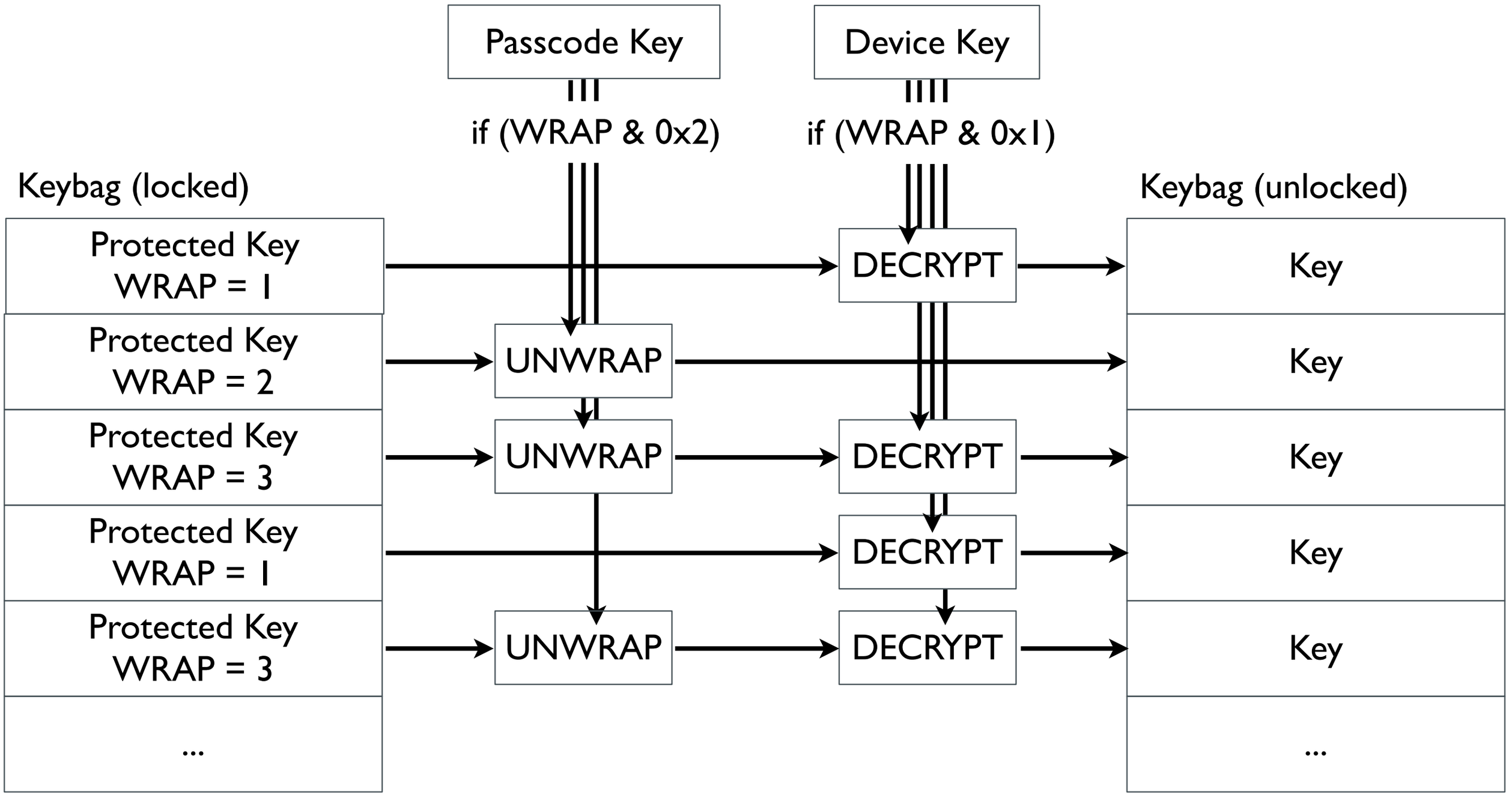
# Escrow Keybag

- "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



# iOS 4 Passcode

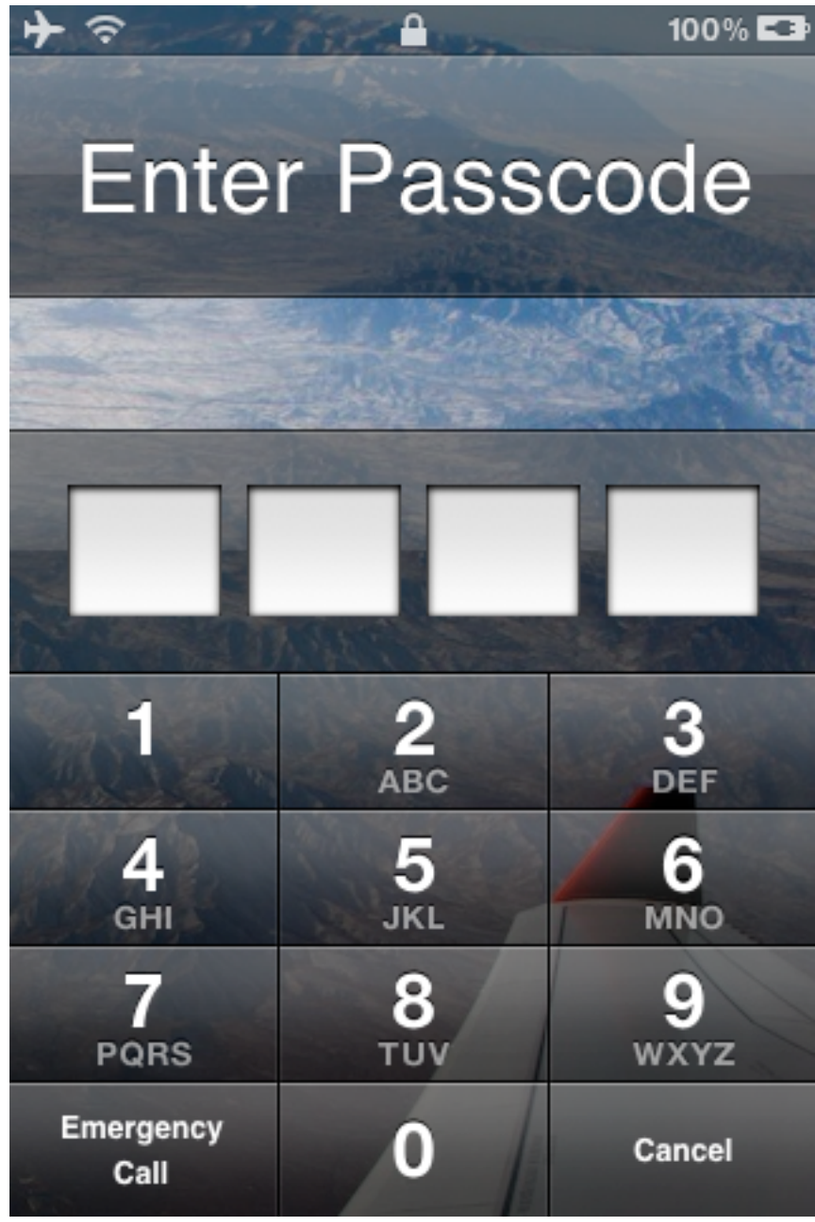
- Passcode is used to compute passcode key
  - –Computation tied to hardware key
  - –Same passcode will yield different passcode keys on different devices!
- Passcode key is required to unlock most keys from the system keybag
  - –Most files are protected with NSProtectionNone and don't require a passcode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

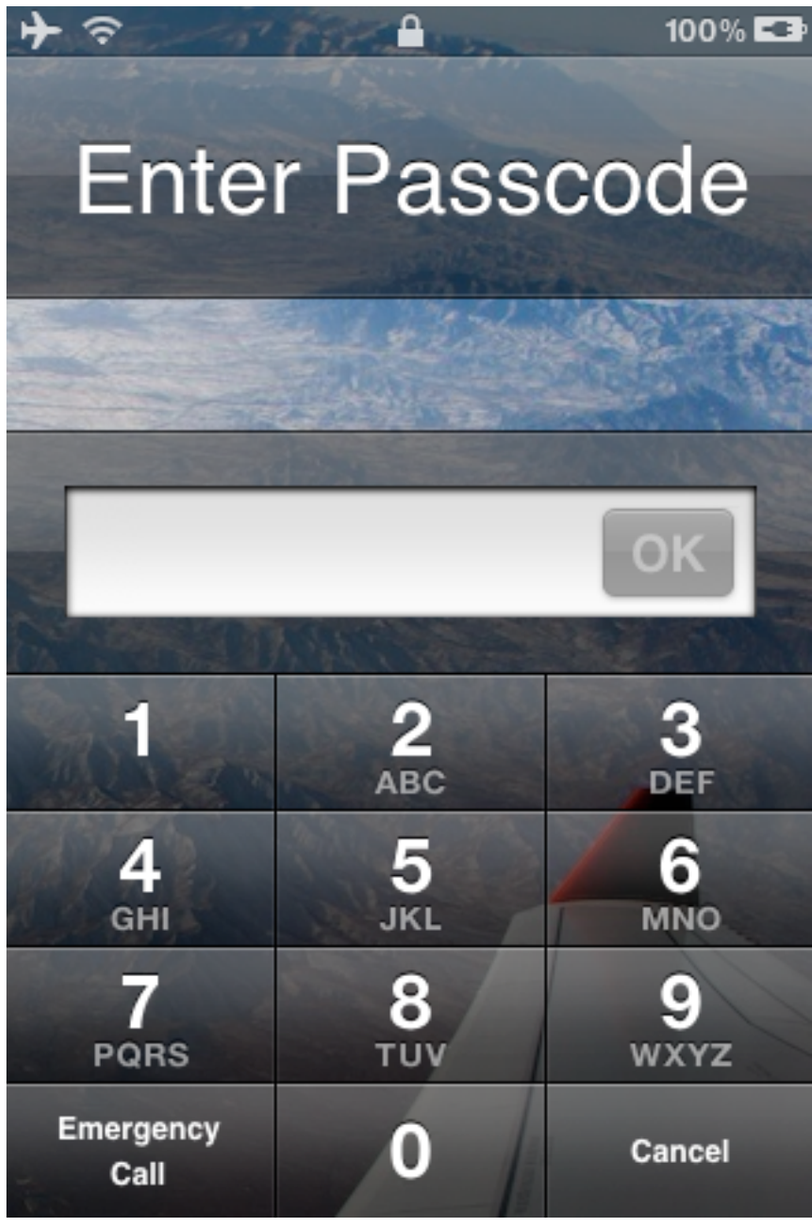
# iOS 4 Passcode

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



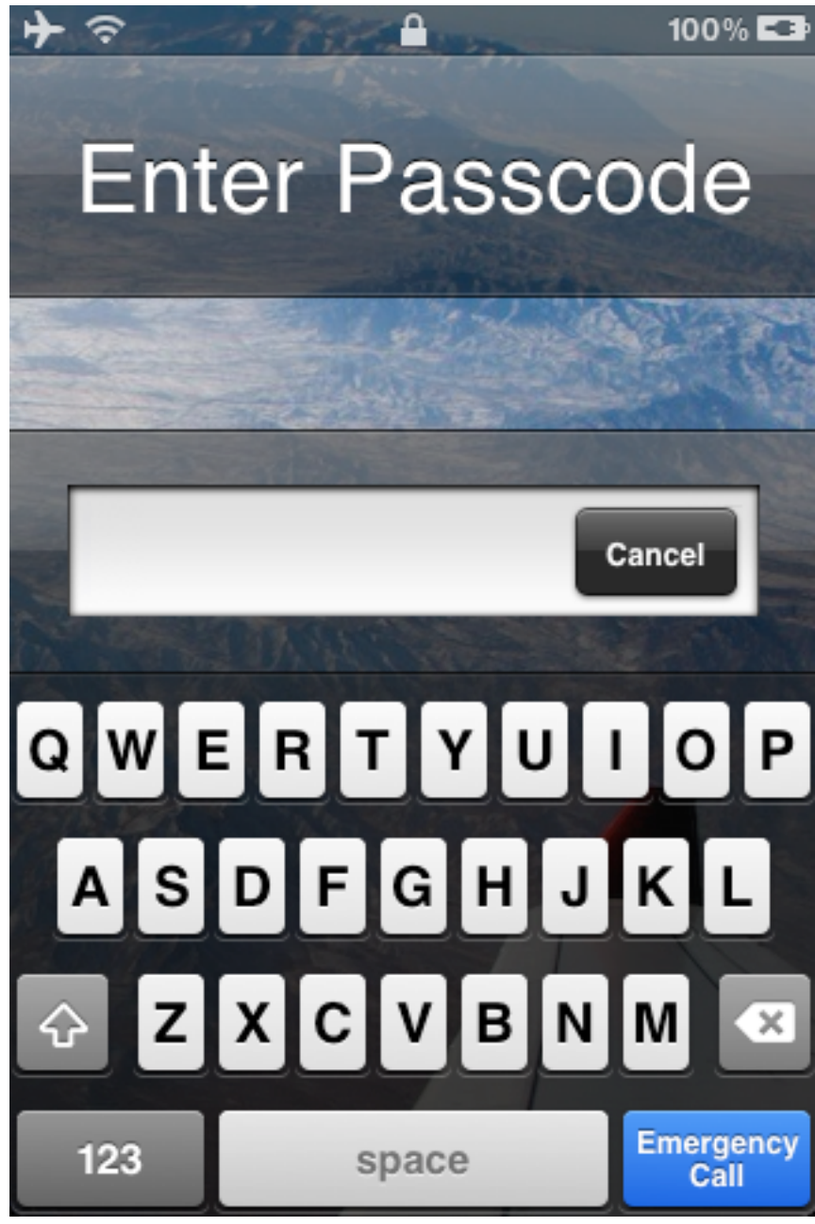
# iOS 4 Passcode

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



# iOS 4 Passcode

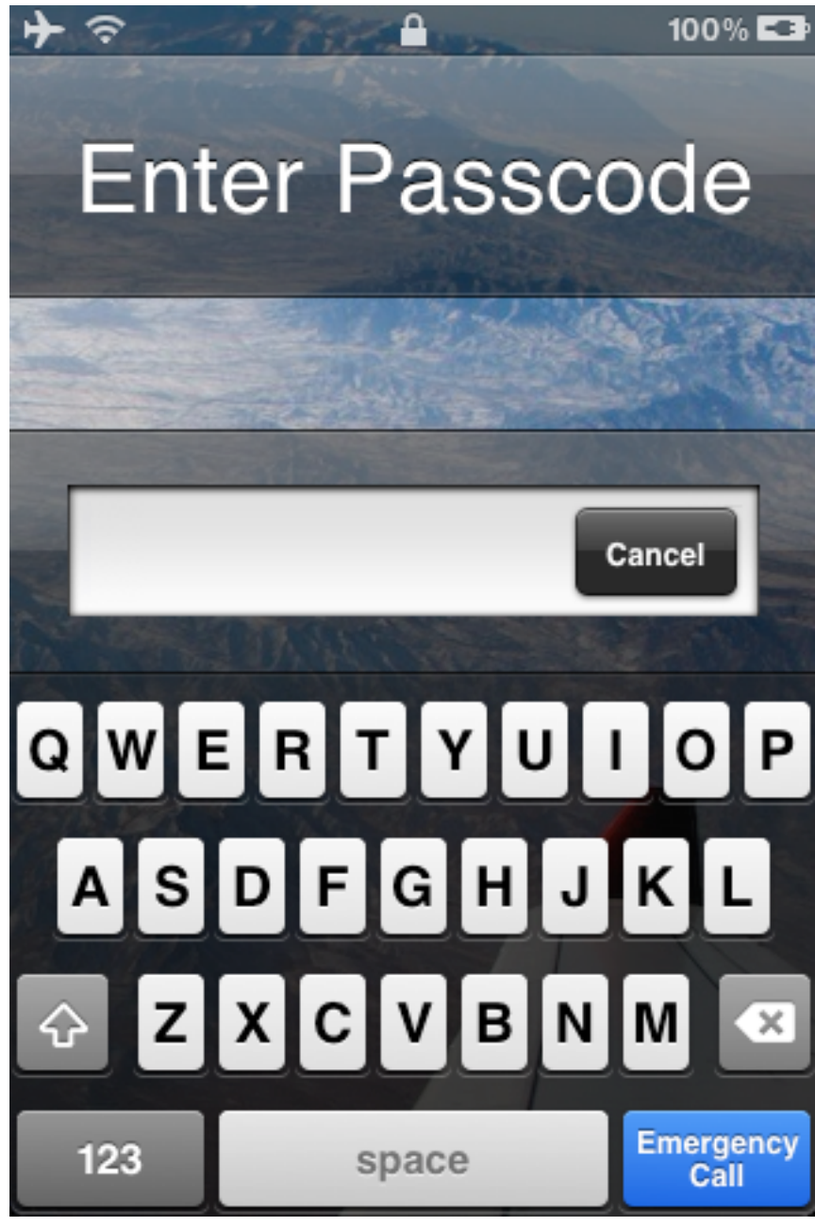
- 0 – digits only, length = 4 (simple passcode)
- 1 – digits only, length ≠ 4
- 2 – contains non-digits, any length



# iOS 4 Passcode

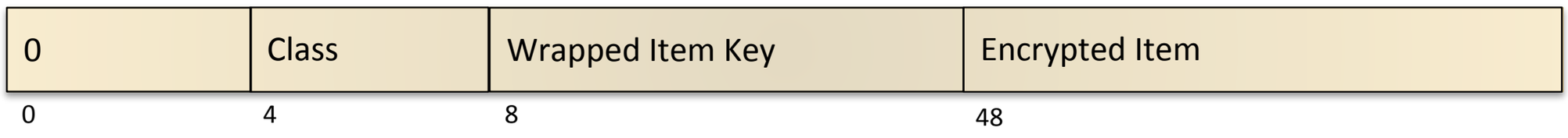
- 0 – digits only, length = 4 (simple passcode)
- 1 – digits only, length ≠ 4
- 2 – contains non-digits, any length

**Can 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



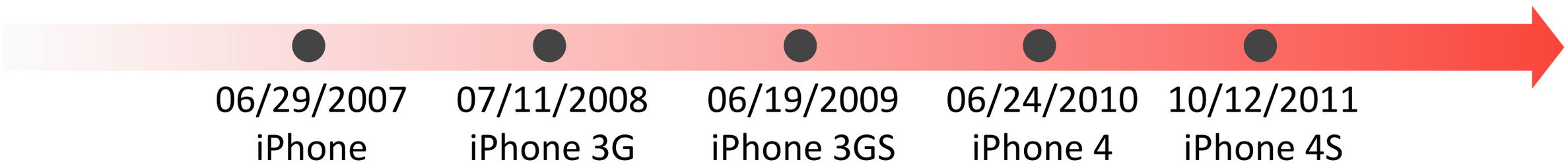
# iOS 4 Storage

- 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

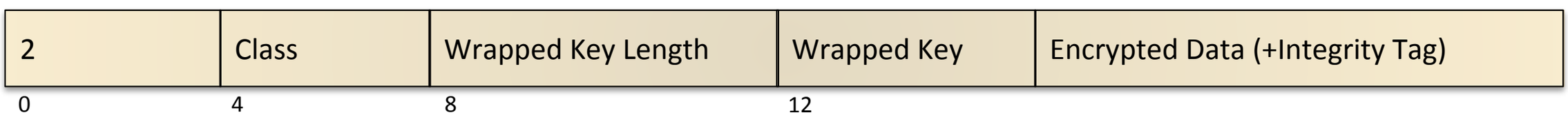


# iOS 5 Passcode

- Similar to iOS 4
- iPad 3 utilizes new hardware key UID+
  - –Algorithm is also slightly different
  - –No significant changes from practical point of view

# iOS 5 Keychain

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



# 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

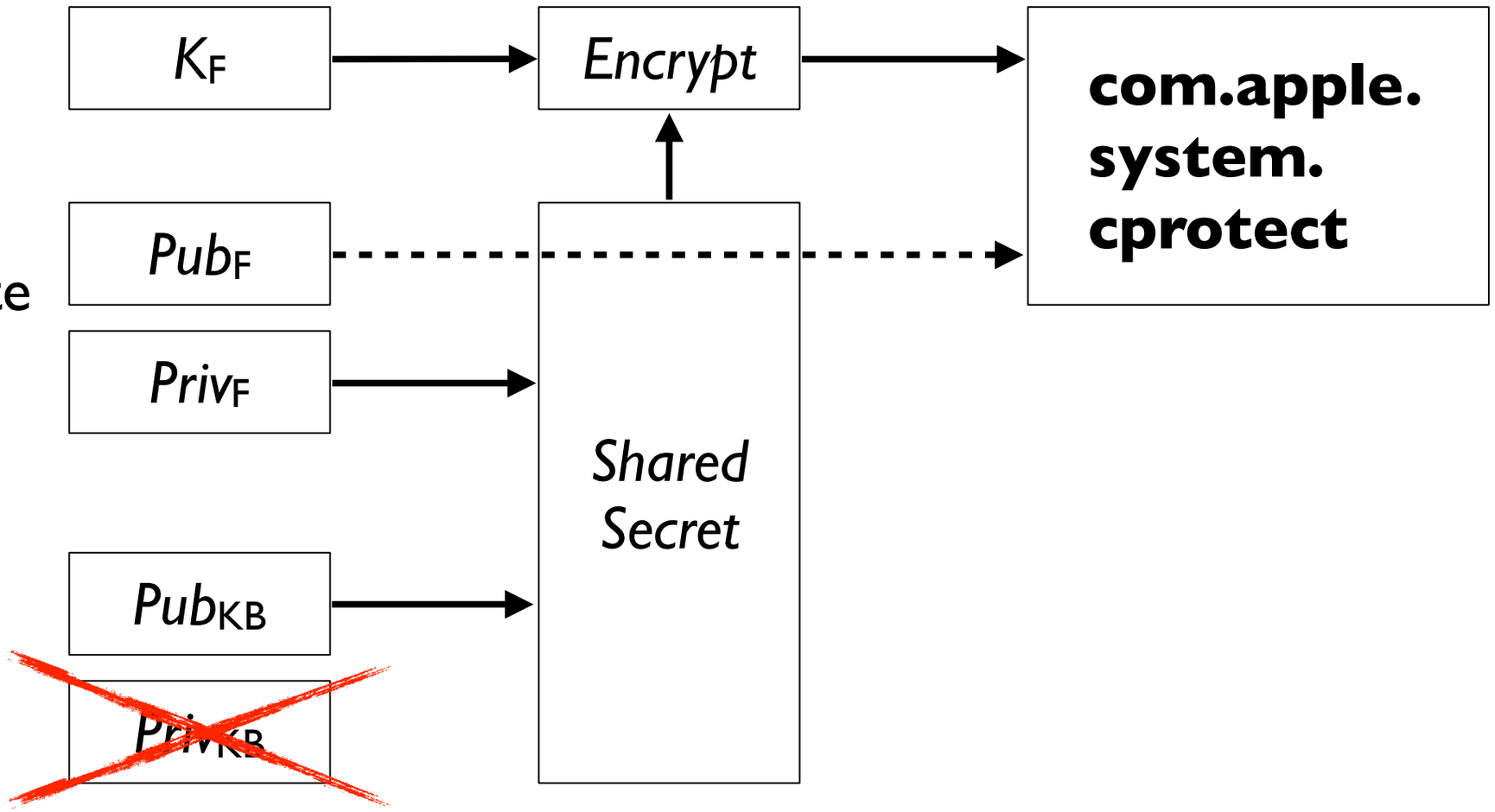
# Creating the File

NSFileProtectionCompleteUnlessOpen

Generate random file key (AES)

Generate file public/private keys (ECC)

Master key from the system keybag (ECC)



# Reading the File

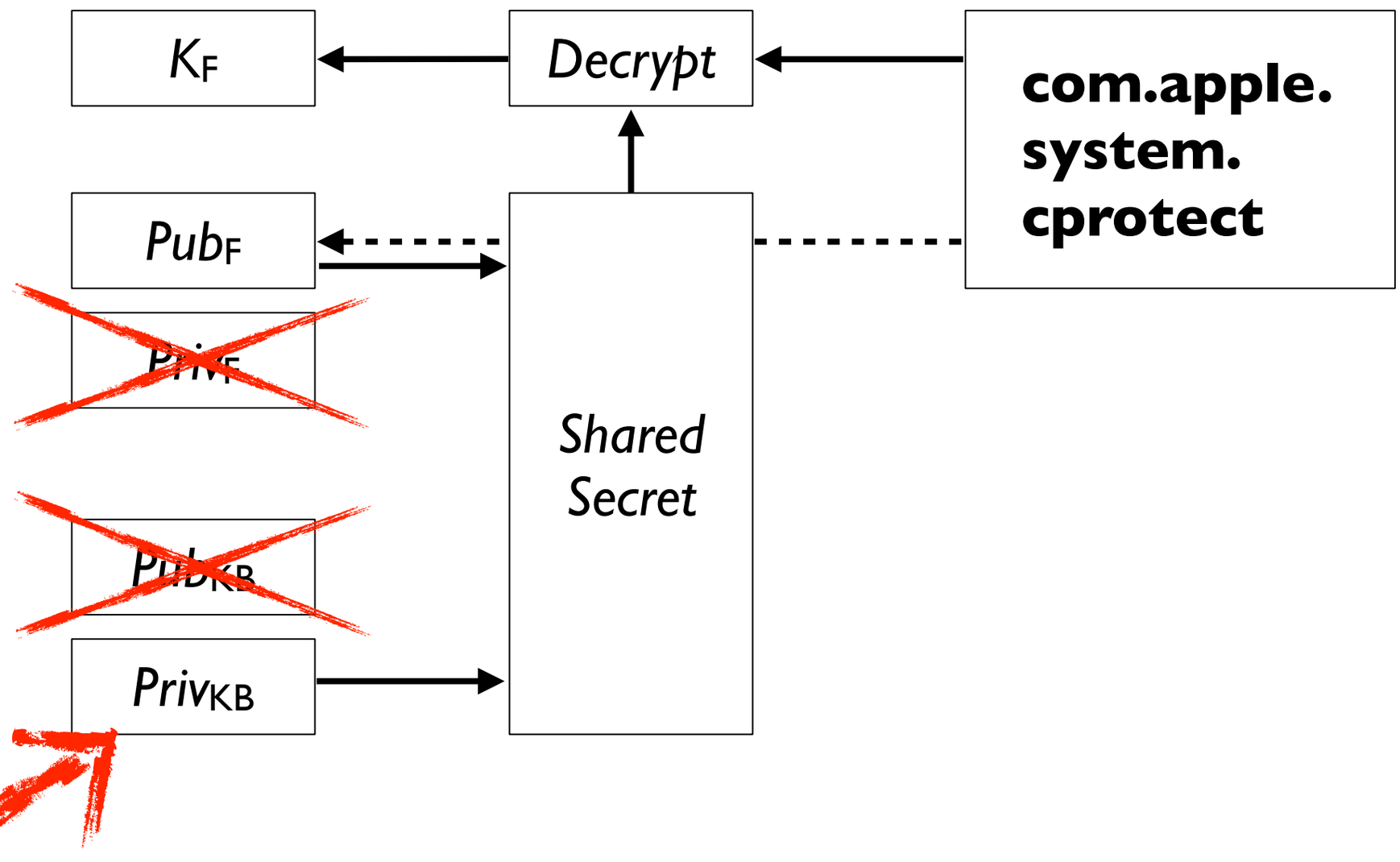
NSFileProtectionCompleteUnlessOpen

File key (AES)

File public/private keys (ECC)

Master key from the system keybag (ECC)

Requires a passcode (if any)



# Reading the File

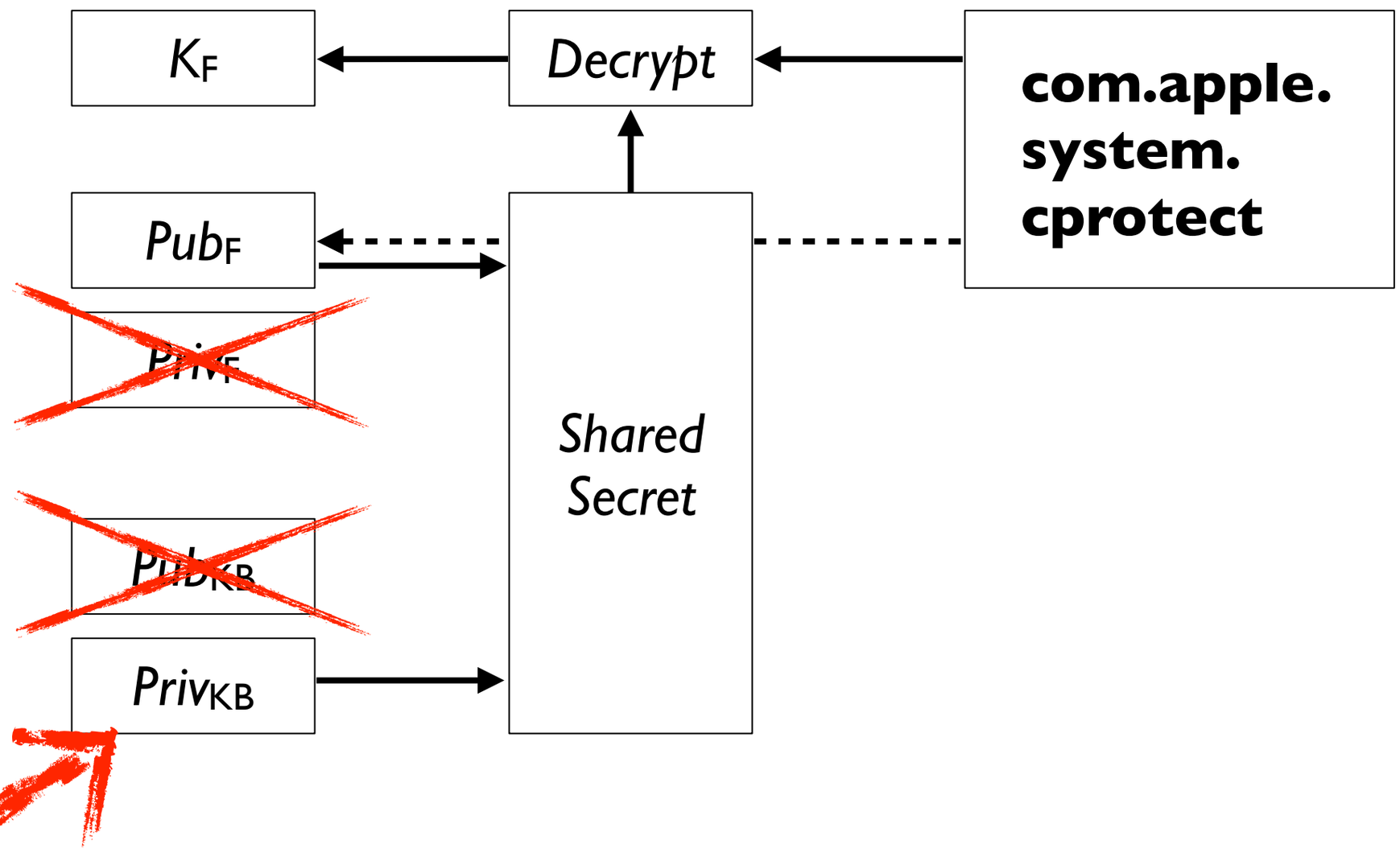
NSFileProtectionCompleteUnlessOpen

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 6

# iOS Forensics

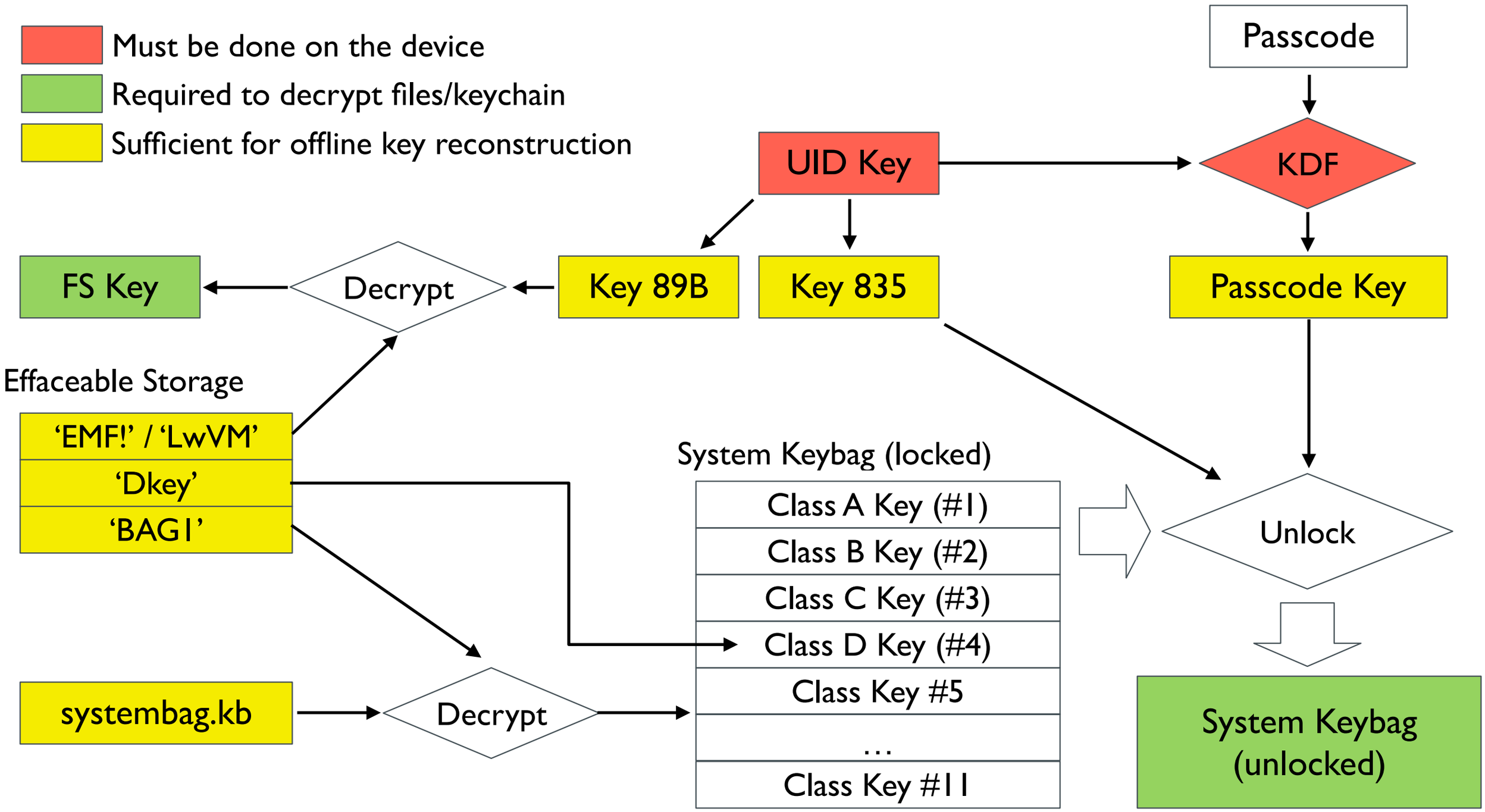
- Acquiring disk image is not enough for iOS 4+
  - Content protection keys must also be extracted from the device during acquisition
  - Effaceable Storage contents are also needed to decrypt dd images.
- Passcode ~~or escrow keybag~~ is needed for a complete set of master keys
- In real world it might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



# iOS Forensics

| | iPhone<br>iPod Touch 1 | iPhone 3G<br>iPod Touch 2 | iPhone 3GS<br>iPod Touch 3<br>iPad 1 | | iPhone 4<br>iPod Touch 4 | iPhone 4S<br>iPad 2, iPad 3<br>(JB) |
|---|---|---|---|---|---|---|
| iOS version | 3.1.3 | 4.2.1 | 3.1.3 | 5.1.1 | 5.1.1 | 5.0.1, 5.1.1 |
| Physical acquisition | + | + | + | + | | + |
| Passcode recovery | instant | + | instant | + | | + |
| Keychain decryption | + | + | + | + | | + |
| Disk decryption | not encrypted | | | + | | + |

# 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?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