iOS Forensics: Overcoming iPhone Data Protection

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Agenda

- iOS Forensics 101
- iOS Data Protection
- iOS Forensics
    - Passcode
    - Keychain
    - Storage

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 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 3GS and later can encrypt disk data

iOS Forensics 101

- iOS is modified version of Mac OS X
    - Familiar environment
- iOS enforces additional security
    - Code signing: can’t run unsigned executables
    - Sandboxing: access to system is limited
- Acquisition options:
    - Via exposed interfaces (i.e. Sync, Backup)
    - Via circumventing security and running own code

iOS Forensics 101

- Logical: iOS 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
  - Since iOS 4 filesystem is encrypted

Pre-iOS 4 Forensics

- Device passcode can be bypassed
- Storage is effectively not encrypted
  - Device transparently decrypts data
- Keychain data is encrypted
  - One can either decrypt all or nothing. Usually all.

Once you have code execution, the rest is easy

New in iOS 4

- Passcode protection is much more robust
- Storage is encrypted
    - Metadata is not encrypted
    - Contents of (almost) every file is encrypted
- New (and better) Keychain encryption
- New (and better) iTunes backup format

All these are part of iOS Data Protection

AES Keys

- All iOS devices have built-in AES processor with 2 hardcoded keys:
    - GID Key is shared by all devices of the same kind
    - UID Key is unique to each and every device (hardware key)
- More keys are computed during startup:
    - Key 0x835 = AES_encrypt (UID, 0101..01) (device key)
    - Derived keys depend solely on GID or UID and thus are fixed for the particular device

Protection Classes

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

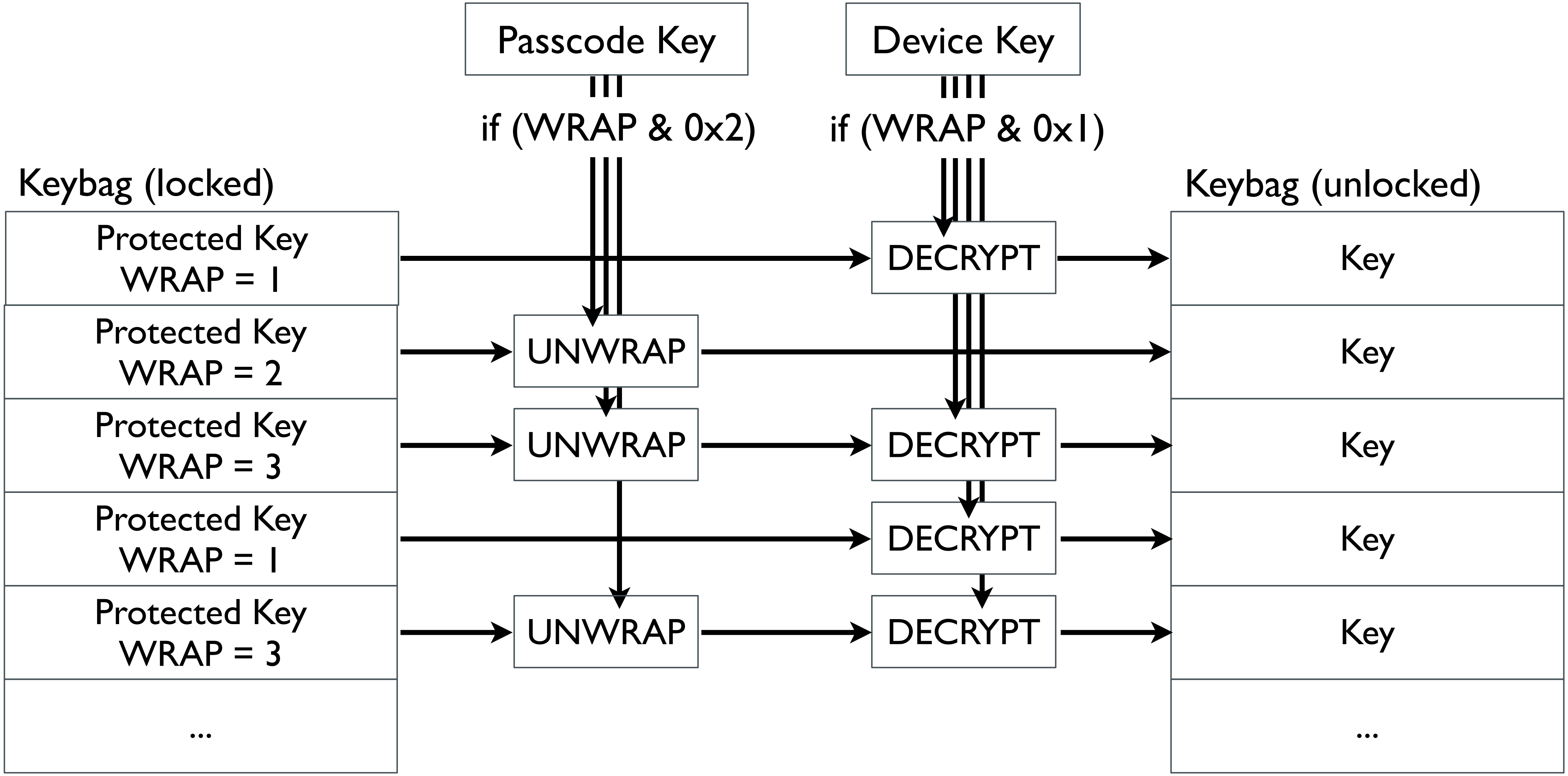
System Keybag

- Stores protected (encrypted) master keys
- Keybag payload is encrypted before writing to disk
- Stored in /private/var/keybags/systembag.kb
- File has NSProtectionNone protection class
    - Meaning it is encrypted
- 11 protection classes in total
    - All but NSProtectionNone are stored in systembag.kb
    - NSProtectionNone is stored in Effaceable Storage

Effaceable Storage

- Region of flash memory
- Facilitates storage of small amounts of data with ability to quickly erase them
- Items within effaceable storage are called lockers
- As of iOS 4: 960 bytes capacity, 3 lockers:
  - ‘BAG1’ – systembag.kb payload key and IV
  - ‘Dkey’ – NSProtectionNone class master key
  - ‘EMF!’ – Filesystem encryption key
- In iOS 5 ‘EMF!’ locker is replaced with ‘LwVM’, conceptually the same.

Unlocking Keybag



Passcode Key

Device Key

if (WRAP & 0x2)

if (WRAP & 0x1)

Keybag (locked)

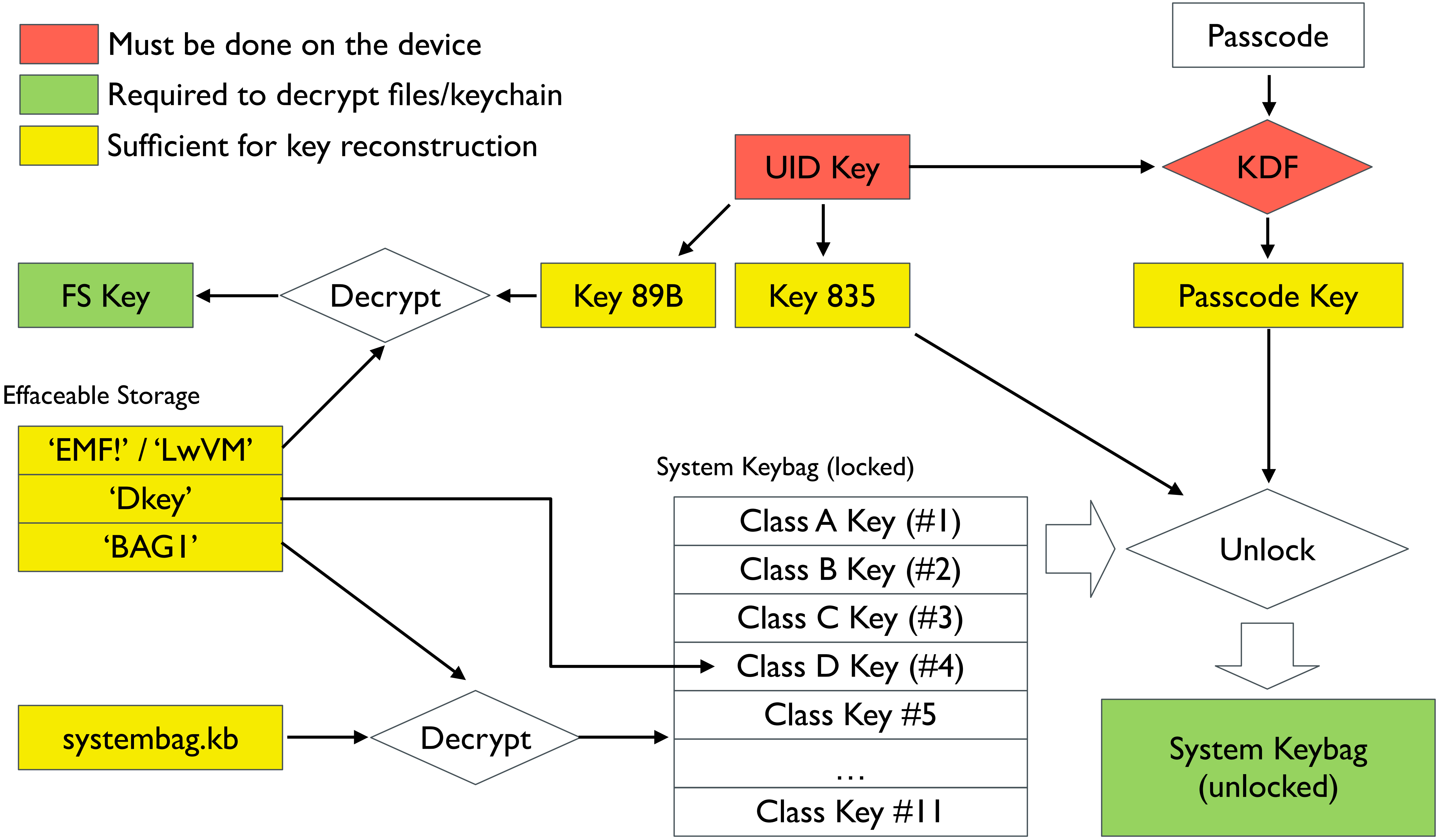
Keybag (unlocked)

Keybag (locked)			Keybag (unlocked)
Protected Key WRAP = 1		DECRYPT	Key
Protected Key WRAP = 2	UNWRAP		Key
Protected Key WRAP = 3	UNWRAP	DECRYPT	Key
Protected Key WRAP = 1		DECRYPT	Key
Protected Key WRAP = 3	UNWRAP	DECRYPT	Key
...			...

Escrow Keybag

- “Usability feature” to allows iTunes to unlock the device
- Contains same master keys as system keybag
- Stored on the computer side
- Protected by 256 bit random “passcode” stored on the device
- With iOS 4, escrow keybag gives same powers as knowing the passcode
- iOS 5 fixed this issue: device can read escrow keybag only if it has been unlocked

iOS 4/5 Key Hierarchy



🟥 Must be done on the device

🟩 Required to decrypt files/keychain

🟨 Sufficient for key reconstruction

Passcode

KDF

UID Key

Key 89B

Key 835

Passcode Key

FS Key

Decrypt

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

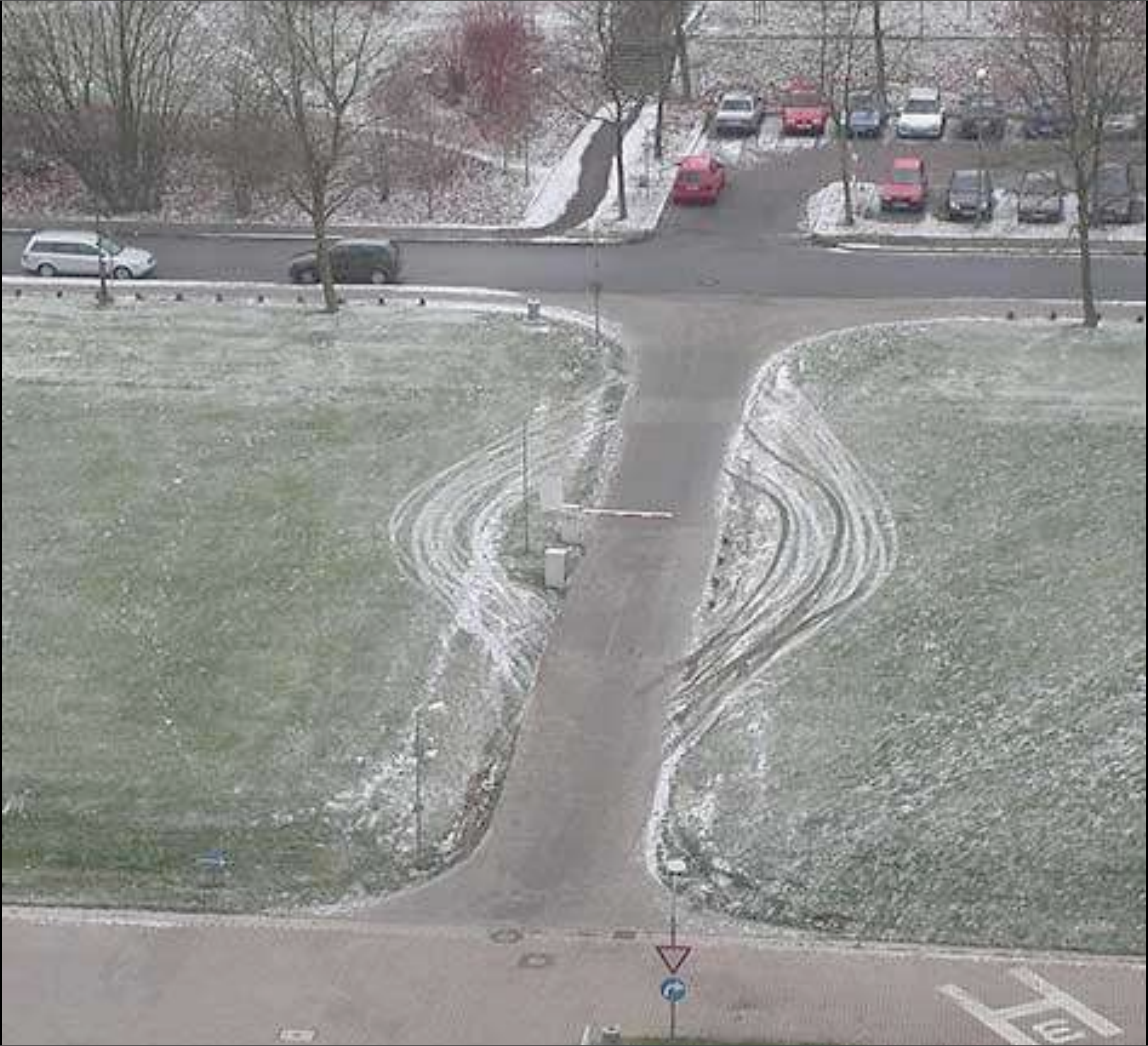
systembag.kb

Decrypt

System Keybag (unlocked)

Pre-iOS 4 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



iOS 4/5 Passcode

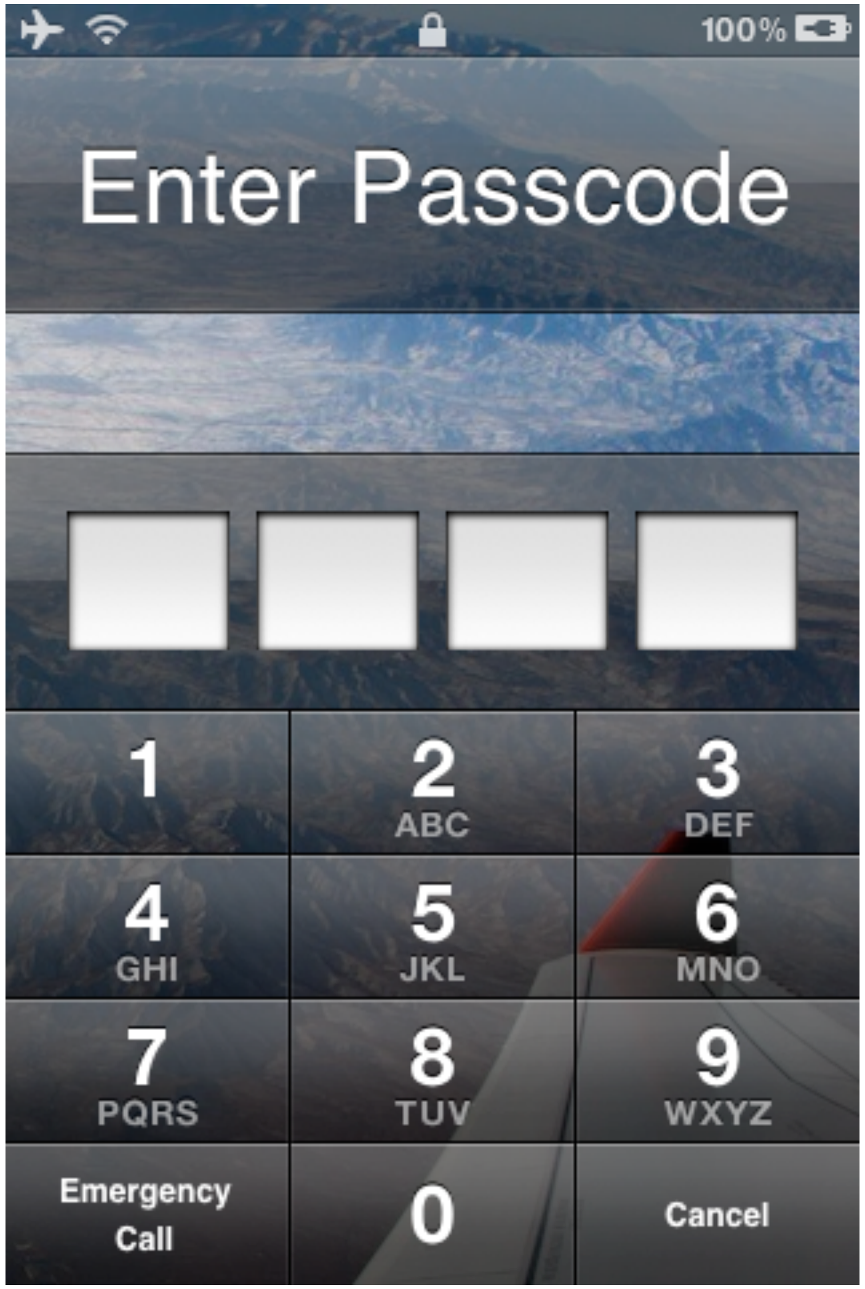
- Passcode is used to compute passcode key
  - Computation tied to hardware key
  - Same passcode will yield different passcode keys on different devices!
- Passcode key is required to unlock all but 3 master keys in system keybag
  - Most files are NSProtectionNone thus don’t need passcode
  - Most keychain items are accessible WhenUnlocked or AfterFirstUnlock thus DO require passcode

iOS 4/5 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

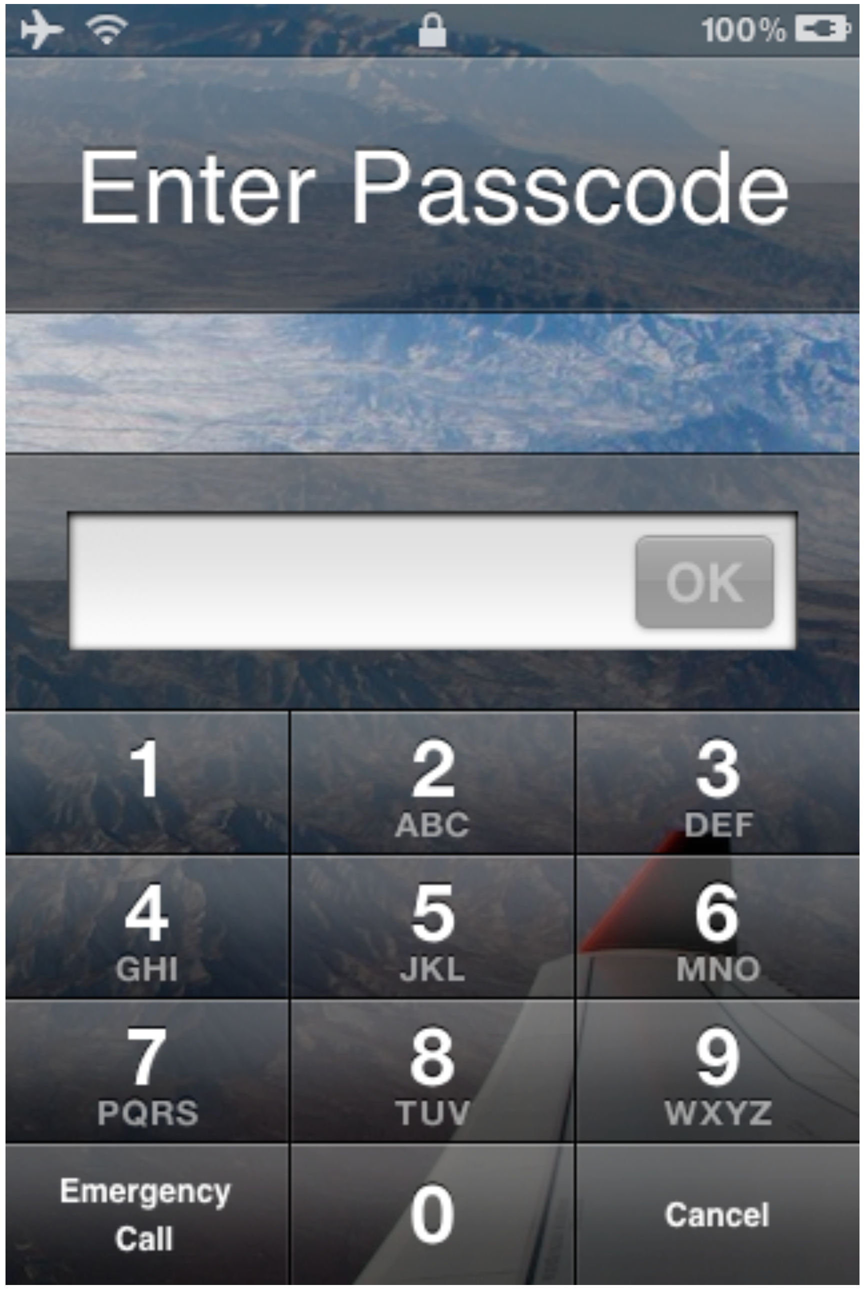
iOS 4/5 Passcode

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



iOS 4/5 Passcode

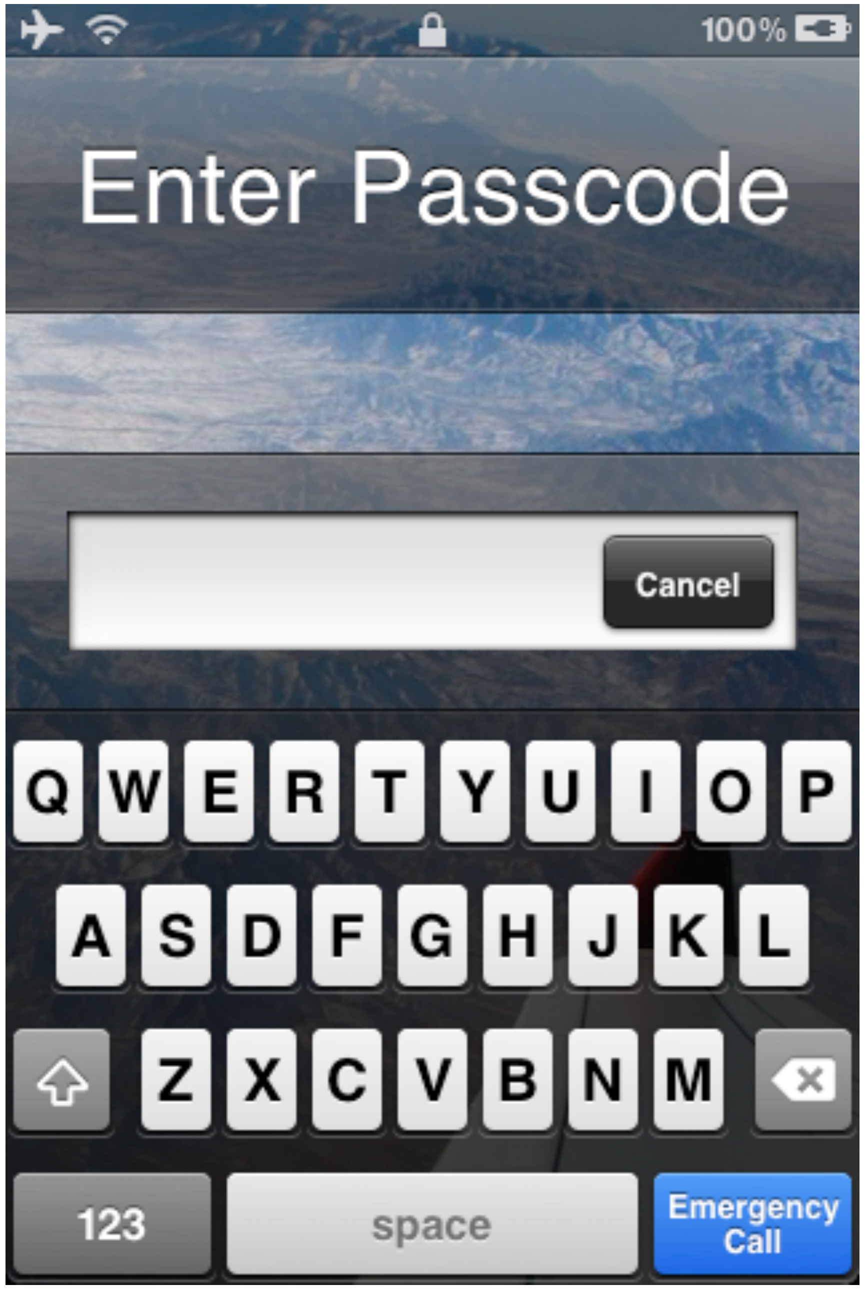
- 0 – digits only, length = 4 (simple passcode)
- 1 – digits only, length != 4



Enter Passcode

iOS 4/5 Passcode

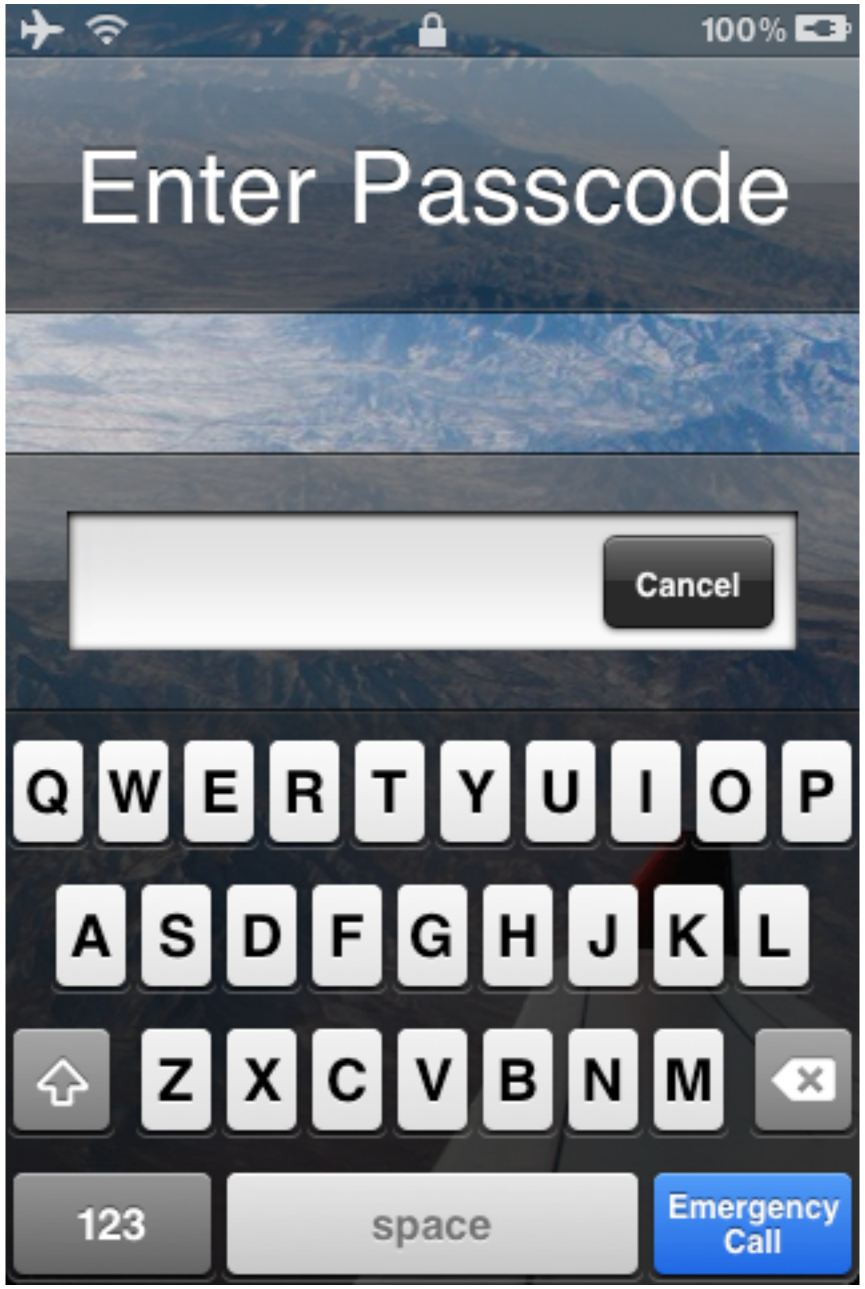
- 0 – digits only, length = 4 (simple passcode)
- 1 – digits only, length != 4
- 2 – contains non-digits, any length



iOS 4/5 Passcode

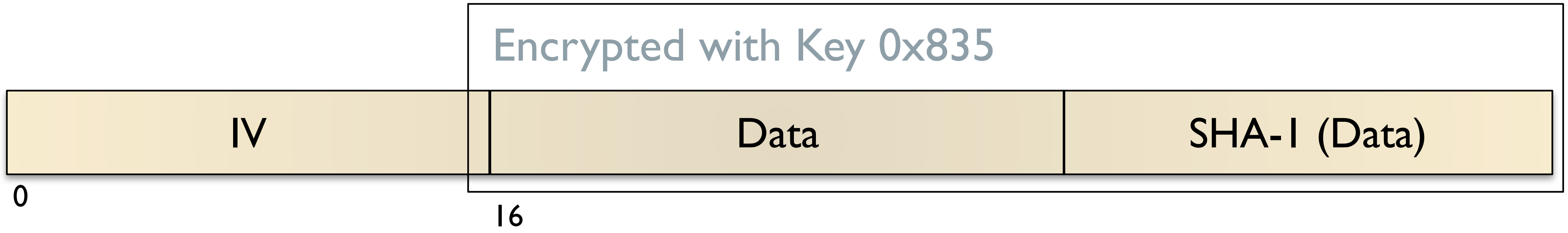
- 0 – digits only, length = 4 (simple passcode)
- 1 – digits only, length != 4
- 2 – contains non-digits, any length

Can at least identify weak passcodes



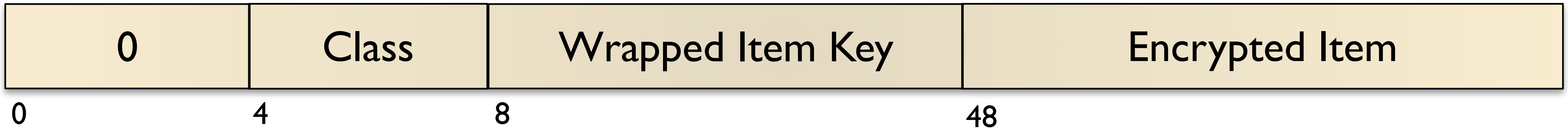
Pre-iOS 4 Keychain

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



iOS 4 Keychain

- SQLite3 Database, 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

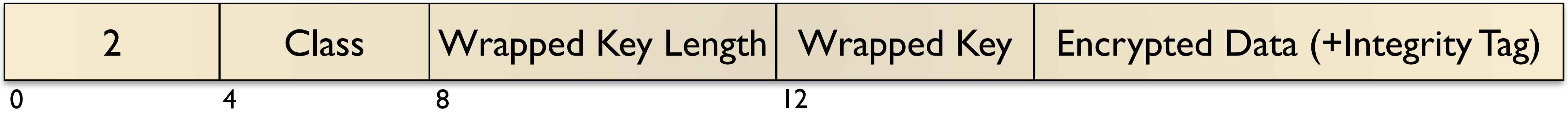


0	Class	Wrapped Item Key	Encrypted Item
0	4	8	48

iOS 5 Keychain

Almost the same as iOS 4, but...

- All attributes are encrypted (not only password)
- AES-GCM is used instead of AES-CBC
  - Allows to verify integrity



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

Pre-iOS 4 Storage

- No encryption before iPhone 3GS
- Starting with iPhone 3GS:
    - Encryption uses EMF key for everything
    - Provides fast wipe, not confidentiality
    - Transparent to applications
    - Filesystem acquisition is not affected

iOS 4 Storage

- Available protection classes:
  - NSProtectionNone
  - NSProtectionComplete
- If no protection class is specified, EMF key is used
  - Filesystem metadata and unprotected files
  - Transparent encryption and decryption (same as pre-iOS 4)
- If protection class is specified, per-file random key is used
  - Key protected with master key is stored com.apple.system.cprotect extended attribute

iOS 5 Storage

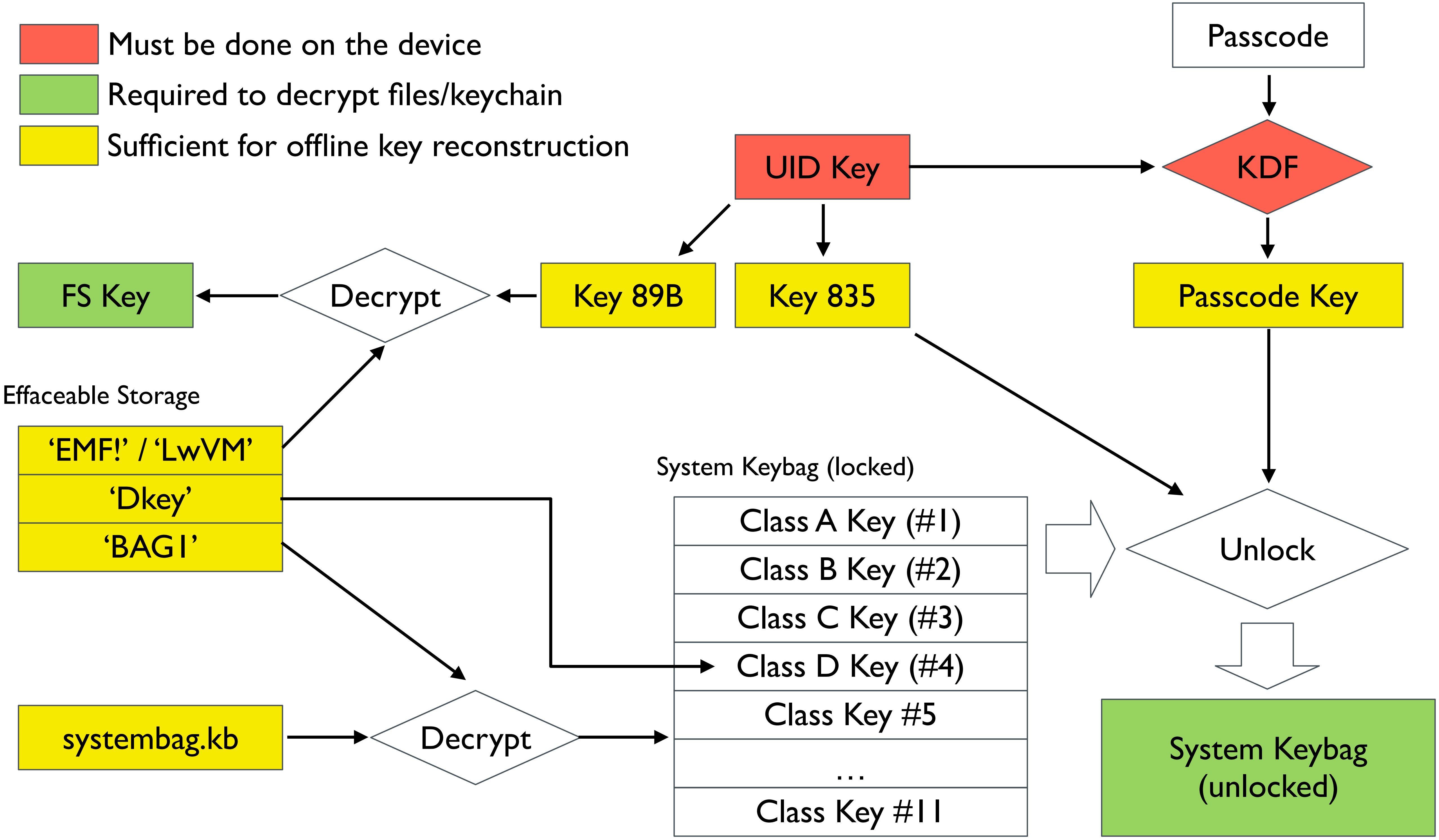
Almost the same as iOS 4, but...

- New protection classes:
  - NSFileProtectionCompleteUntilFirstUserAuthentication
  - NSFileProtectionCompleteUnlessOpen
- IV for file encryption is computed differently

iOS 4/5 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 4/5 Forensics



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Passcode Key

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Decrypt

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)

Conclusion

- iPhone physical analysis is possible
- Physical acquisition requires boot-time exploit
- Passcode is *usually* not a problem
- Both proprietary and open-source tools for iOS 4/5 forensics are available

Questions?

iOS Forensics: Overcoming iPhone Data Protection

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