Smartphone Keystores *2017 Edition*

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Smartphone Keystores

- What is a keystore?
- Points of comparison
- Platforms
  - iOS
  - Android
  - Windows Phone
  - BB10
- Other options

What is a keystore?

- The place in the phone where cryptographic keys and (sometimes) other critical secrets are stored.
- Examples:
  - PKCS#12 files
  - Encrypted databases of key blobs
  - Smartcards/PIV cards
  - Secure microSD devices
  - Other hardware security modules (HSM)
- What's in there?
  - Asymmetric keypairs
  - Symmetric keys
  - Passwords
  - Other secret stuff

From the “Ten Immutable Laws Of Security (Version 2.0)”

(By Scott Culp, Microsoft, 2000)

Law #3: If a bad guy has unrestricted physical access to your computer, it's not your computer anymore

Law #7: Encrypted data is only as secure as its decryption key.

What can a keystore do?

- Typical Keystore functions
  - Add/remove key
  - Find key
  - Export key
  - “Use” key in a crypto operation
    - Hopefully by reference - and not by export
- Enforce Access Control Lists (ACLs) on certain functions

How to access - Keystore APIs

- “Standard” interfaces are rare
  - Minimal true cross-platform APIs
  - Standard within a specific platform
  - Cross-platform development always done with an isolation layer
- Java Cryptography Architecture (JCA) and Android APIs
- Apple Keychain
- BlackBerry Certificate Manager API
- MS CAPI
- PKCS11/cryptoki

Where is the keystore?

- A file or database in the file system...hopefully encrypted
- A “protected” part of the device
  - Trusted Execution Environment (TEE)
  - ARM TrustZone
  - Trusted Platform Module (TPM)
  - Dedicated processor
- A secure element
  - SIM/UICC card?
  - NFC secure element?
  - Not likely....

How is the keystore protected?

- User, OS, and hardware level defenses
- User
  - “What you know” - User PIN/Password/Pattern
  - “What you are” - Fingerprint
- Hardware/OS defenses
  - OS Secure boot
  - Integrity checks - software and hardware

When are the keys accessible?

- Device unlocked
- Within *x* time of user authentication to device
- Right after boot
- Device locked
  - Some apps require access to keys while device is sleeping/locked

Who can access the keys?

- One user/multiple users
- One app/multiple apps
- One vendor/cross-vendor

OK...so how do they compare?

It’s complicated...

vs.

Features vary by version - *Fragmentation*

- Android (http://developer.android.com/about/dashboards/index.html)

Nougat	v7+7.1	7.1% (+7.1%)
Marshmallow	v6	31.2% (+23.7%)
Lollipop	v5+5.1	32.0% (-3.6%)
KitKat	v4.4	18.8% (-13.7%)
Jelly Bean	v4.3	1.3% (-1.6%)
Everything else...		9.6% (-11.9%)

- iOS (https://developer.apple.com/support/app-store/)

10.x	79% (+79%)
9.x	16% (-68%)
Everything else...	5%

Android Keystore

- `Keystore` - App-isolated PKI keypairs
- `KeyChain` - Special instance of `Keystore` with System global visibility
- KeyMaster - Hardware Abstraction Layer (HAL) for encryption of keys
- Keys stored in flat files, highlighting user-and-app-level KeyChain isolation
  - /data/misc/keystore/user_X/AppUID_keyname, as before (where X is the Android user ID, starting with 0 for the primary user)
  - Encryption of key files depends on Android version and TEE availability
- If keystore not hardware backed, lockscreen password used to derive keys for protecting keystore with PBKDF
- Beyond this...it is version dependent
- Most OEMs use ARM TrustZone-based keystores - many on QSEE or Trustonic TEE

Android - The Older 52%

- Android J (v4.1, 4.2, 4.3)
  - `AndroidKeyStore` Provider - create/import/store/use(sign+verify) private RSA keys, not usable by other apps
  - `isBoundKeyType` method - allows applications to confirm that system-wide keys are bound to a hardware root of trust for the device (Subsequently deprecated in Android M)
  - As of 4.2: default `SecureRandom` provider is OpenSSL.
- Android K (v4.4)
  - `AndroidKeyStore` adds support for EC keys + DSA/ECDSA
  - `SecretKeyFactory` with `PBKDF2WithHmacSHA1` uses all available bits of Unicode passphrase per PKCS #5.
- Android L (v5.x)
  - TLS with AES-GCM

Marshmallow/v6 (31.2%)

- Major revisions to Keystore + Keymaster
  - Support for symmetric keys + primitives
  - Access control system for specific users, apps, time ranges
  - Key usage restrictions - encr/decr, sign/verify, block mode, padding - stored with key and mandatory for usage in accordance with parms
- Can require authentication on per-key basis and dictate auth validity duration
- Supports complicated crypto operations of potentially arbitrary size with begin/update/finish pattern

Nougat/v7 - This year's model... (7.1%)

- Relevant core OS hardening:
  - Verified Boot now strictly enforced to prevent compromised devices from booting - and blocks access to the keystore.
  - Hardware-backed keystore mandatory (TEE or better)
  - User and MDM-installed root CA's no longer globally trusted by default...APIs added to enable trust.
  - Cross-OEM-standardized trusted CAs
- RNG changes:
  - `SHA1PRNG` algorithm and "`Crypto`" provider deprecated
    - `SecureRandom.getInstance("SHA1PRNG", "Crypto")` Will only work for M and below
  - If `SHA1PRNG` is requested without explicit Provider, OS will return an instance of `OpenSSLRandom`.

Android: Gotchas

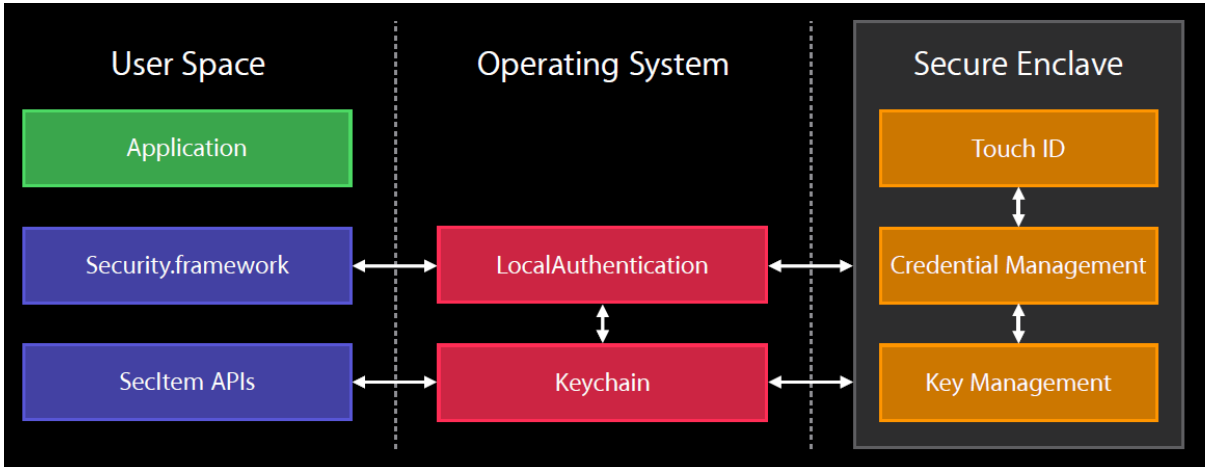
- Android Keystore protected by device lock
  - Changing screen lock type (None/PIN/Pattern/PW) wipes keystore in older devices
  - The bug: https://issuetracker.google.com/issues/36983155
    - (Or for detailed analysis: https://doridori.github.io/android-security-the-forgetful-keystore/)
  - Android J, K, and some M: *Any* lock screen type transition wipes keystore without warning
  - Newer versions of Android survive *most* transitions or warn the user if the particular transition will wipe the keys.
- Restricted access to public keys in Android M/v6.0
  - ACL rules set for private key also get applied to public keys (Workaround: extract/store public key material outside keystore)

iOS Keychain

- Can store passwords, keys, certificates, and blobs
  - With one exception, does not appear to restrict key extraction by apps
- Implemented as a single SQLite database stored on the file system, owned by *securityd*
- Key Item Access Control Lists (ACL)
  - kSecAttrAccessGroup - WHAT app can access key
    - Short version: Keychain items can *only* be shared between apps from the same developer/vendor
  - kSecAttrAccessible - WHEN can the key be accessed
  - kSecAttrAccessControl - What type of authentication is needed
- ACL decisions are made in the Secure Enclave Processor
- Keychains can be collected and managed in groupings called “Keybags”

iOS Secure Enclave Processor (SEP)

- iPhone 5s and later
  - A distinct processor + kernel inside the SoC for TouchID and KeyStore
  - *Distinct* from the main CPU's ARM TrustZone (which appears to be dedicated to Kernel Patch Protection)
  - Stores its own data in device storage but uniquely keyed and unknown to ANYONE
  - May be used to protect KeyChain items via TouchID or device password
- Can generate/store/use unexportable EC P256 keys
  - Enables protected calls to `SecKeyRawSign()` and `SecKeyRawVerify()`
  - Preservation of the associated public key left as an exercise for the student...



From Keychain and Authentication with Touch ID - WWDC14

iOS Keychain protection attributes

`kSecAttrAccessible` ACL's control when a key can be accessed

Data Protection	Availability
`kSecAttrAccessibleAfterFirstUnlock`	After user enters passcode for 1st time after reboot (recommended for background services)
`kSecAttrAccessibleAfterFirstUnlockThisDeviceOnly`	Same as above...but cannot be backed up to iCloud and then restored to a different device
`kSecAttrAccessibleAlways`	Key accessible anytime after boot (deprecated in iOS 9)
`kSecAttrAccessibleAlwaysThisDeviceOnly`	Same as above...but...
`kSecAttrAccessibleWhenUnlocked`	DEFAULT mode. Key accessible when device unlocked
`kSecAttrAccessibleWhenUnlockedThisDeviceOnly`	Same as above...but...
`kSecAttrAccessibleWhenPasscodeSetThisDeviceOnly`	Added in iOS 8. Key accessible when device unlocked, but password MUST exist. NEVER backed-up.

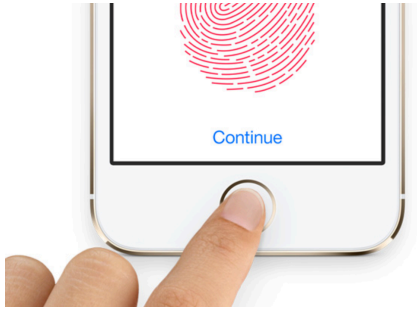
iOS Roots of Trust and RNG

- UID - 256-bit Unique ID/key - generated in SEP at Mfg
  - Used in file system encryption key heirarchy
- GID - 256-bit Group ID/key - inserted in SEP at Mfg
  - Common across all devices in a processor family
  - Firmware encryption
- iOS devices use a feature called Effaceable Storage to securely erase critical keys from NAND
  - Bypasses NAND wear-leveling to directly address and erase a small number of blocks at a very low level
- SEP includes a “true hardware random number generator based on multiple ring oscillators post processed with CTR_DRBG”
- All other cryptographic keys are created in the OS using an algorithm based on CTR_DRBG.

APIs

- Lower-level methods with very granular attribute control
  - `SecItemAdd` to add an item to a keychain
  - `SecItemUpdate` to modify an existing keychain item
  - `SecItemCopyMatching` to find a keychain item and extract information from it
  - `SecItemDelete` to delete an item
- Minimal crypto functions that are actually performed *inside* the keystore
  - Keys have to come up to app space
- iOS 10 `CryptoTokenKit` API adds native support for Smart Cards and USB crypto tokens
  - iOS 10 also added APIs and algorithms for asymmetric cryptographic operations which are now unified across iOS and macOS

iOS TouchId



- Biometric user authentication
- Hardware sensor and Secure Enclave get pre-shared secret at Mfg time
- Provides further granularity to key access and bind a credential more closely to Touch ID
- Used with attribute `kSecAttrAccessControl`

Attribute	Control
`UserPresence`	Require TouchID and fallback to passcode
`TouchIDAny`	TouchId with no fallback
`TouchIDCurrentSet`	Only allows access if enrolled TouchID has not changed since item stored Someone with device passcode *cannot* login, add finger to TouchID, and then access credential
`DevicePasscode`	Passcode only
`ApplicationPassword`	Password from App required to decrypt credential Password entered by user or perhaps from a live server
`PrivateKeyUsage`	Leverage asymmetric private key that never leaves the KeyStore EC P256, supporting sign and verify

iOS other tidbits/gotchas

- Watch out for iCloud Keychain
  - Some passwords/keys can be shared across devices
  - Set attribute kSecAttrSynchronizable to false to prevent sync or use ...`ThisDeviceOnly` ACL
- Keys cannot be shared between apps from different vendors
  - Complications for provisioning derived credentials for use by apps from multiple vendors
- iPhone “memory pressure” issue - key access denied (https://forums.developer.apple.com/message/185130)
- Items written to Keychain are not removed when app uninstalled

Windows Phone/Mobile Keystore

- Two more or less distinct keystores
- Credential Locker
  - Apps can only access their own credentials
  - Credentials “roam” between a user’s devices along with the user Microsoft account
- Virtual Smart Card
  - Keys are bound to the hardware and can only be accessed when user PIN is provided
  - Potentially more “traditional” Derived Credential approach
  - Built on top of TPM
- TPM (Trusted Platform Module) mandatory in Windows Phone 8.1 and Windows 10 Mobile
  - Protect cryptographic calculations, virtual smart cards, and certificates
- Native support for biometrics

BlackBerry 10 Keystore

- Keys managed by BlackBerry Certificate Manager API
  - Keystore is implemented with ARM TrustZone
  - Supports PKI (with caveats) and passwords
  - Permits binding of items to User, App, or Enterprise (aka, BES)
  - Allows blocking export/backup of private keys
  - Appears to support user password prompting to unlock keystore
- **BUT**...the PKI keystore is only available to native Email, VPN, Browser apps
  - There is no native PKI keystore capability for 3rd party vendors
  - Right now only supports secure password storage

Keystores and FIPS

- Which keystores use or provide FIPS 140-2 validated crypto?
  - Windows Phone - Definitely
  - Apple - Definitely
  - Android - It depends... (Samsung flagships - probably)
  - BlackBerry 10 - Definitely
- Caveat #1: All are FIPS 140-2 Level 1
- Caveat #2: Lots of OpenSSL deployed with mobile OS's...some *probably* FIPS. (Samsung using BoringSSL fork)
- Caveat #3: Exceedingly difficult to determine if crypto used by OS is running in FIPS Mode, as APIs are buried.

Other options

- What if FIPS 140-2 Level 1 is not good enough?
- Smart cards?
  - Tethered or Bluetooth sleds are cumbersome
  - Device-tailored cases/sleeves cannot keep up with device shape
  - NFC-based smartcards would be a great option
- Secure microSD devices
  - PKI Smart Card in a microSD form factor (Such as GoTrust)
  - FIPS 140-2 Level 3
  - Provide PKCS#11 or full ISO 7816 APDU interfaces
  - Supported on iOS and Android
  - iOS requires adapters...which brings us back to smart card challenges
  - Overall: a potential solution when higher grade crypto is essential

Parting thoughts...

- Market fragmentation makes availability of key features unpredictable
- Different platforms have different strengths
- Disparate API's/features makes writing common key management a challenge
- Mobile keystores continue to evolve in a generally positive direction
  - Improving in strength and features

Awesome references

- https://nelenkov.blogspot.com/2015/06/keystore-redesign-in-android-m.html
- http://www.samsung.com/hk_en/business-images/insights/2015/Android_security_maximized_by_Samsung_KNOX_0315_online-0.pdf
- https://www.blackhat.com/docs/us-16/materials/us-16-Mandt-Demystifying-The-Secure-Enclave-Processor.pdf
- https://www.apple.com/business/docs/iOS_Security_Guide.pdf
- http://us.blackberry.com/content/dam/blackBerry/pdf/business/english/BlackBerry-Security-Brochure.pdf
- http://video.ch9.ms/sessions/teched/na/2014/WIN-B220.pptx (TechEd - Windows Phone 8.1 Security for Developers)
- https://www.cs.ru.nl/E.Poll/papers/AndroidSecureStorage.pdf (Analysis of Secure Key Storage Solutions on Android)
- https://developer.android.com/training/articles/keystore.html

Thank you!

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