Security Analysis and Decryption of FileVault 2

IFIP WG 11.9

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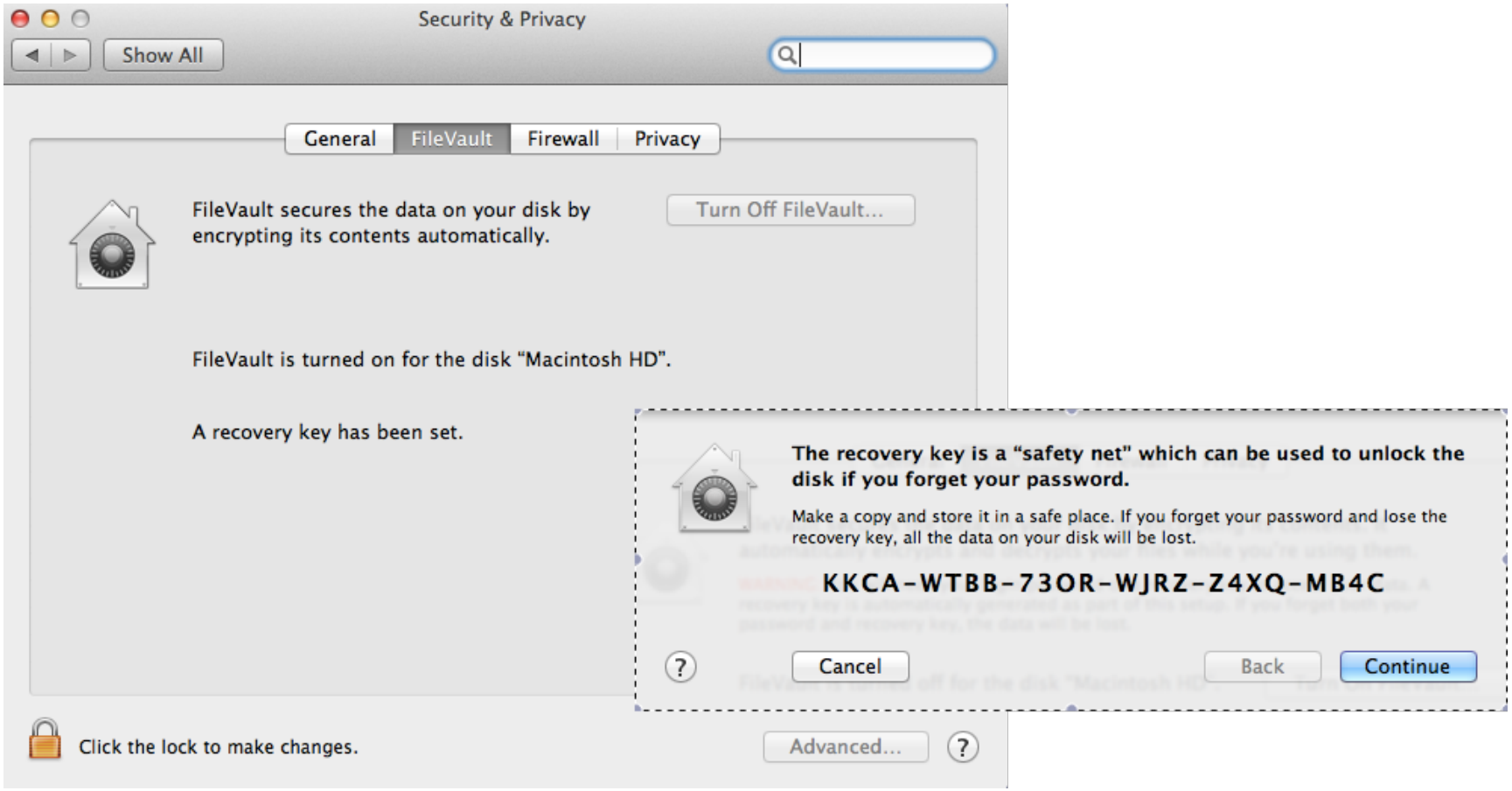
FileVault 2


Security & Privacy
Show All
General
FileVault
Firewall
Privacy
FileVault secures the data on your disk by encrypting its contents automatically.
Turn Off FileVault...
FileVault is turned on for the disk "Macintosh HD".
A recovery key has been set.
The recovery key is a "safety net" which can be used to unlock the disk if you forget your password.
Make a copy and store it in a safe place. If you forget your password and lose the recovery key, all the data on your disk will be lost.
KKCA-WTBB-73OR-WJRZ-Z4XQ-MB4C
Cancel
Back
Continue
Click the lock to make changes.
Advanced...

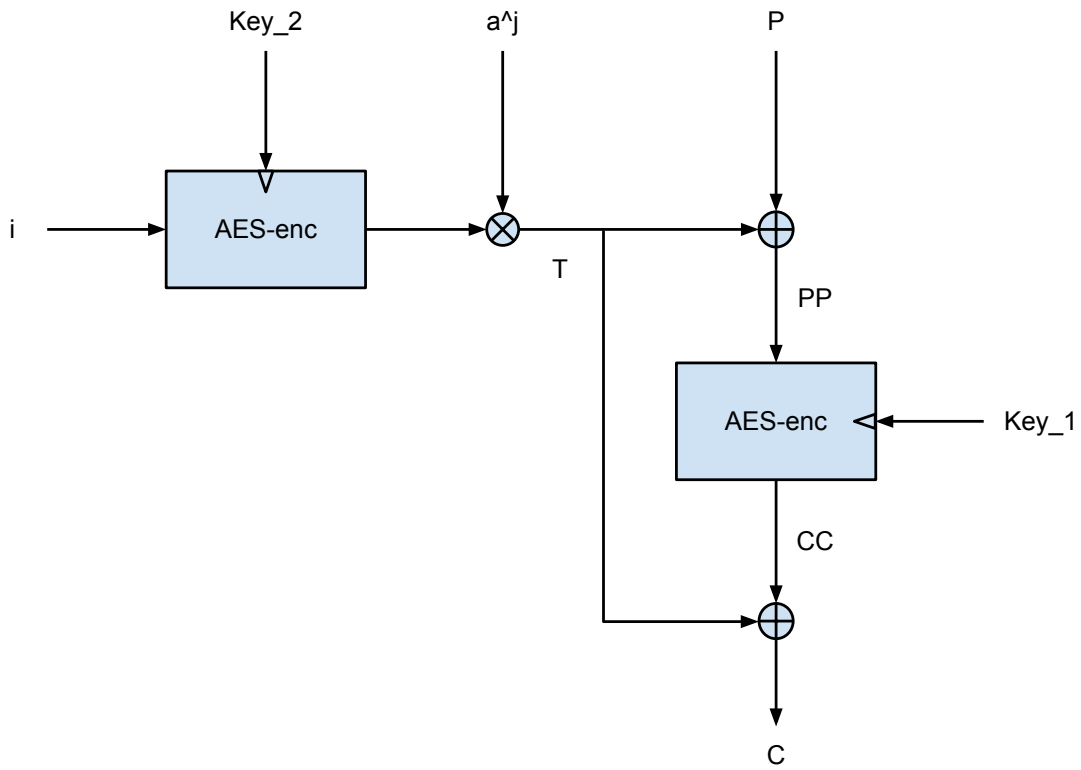
Goals and Motivations

- Goals
  - Reverse engineer and analyse FileVault 2
  - Develop our own tool to read encrypted volumes
- Motivations
  - Need to know if secure
  - Use in forensic investigations
  - Cannot trust OS if compromised
  - Interoperability, need to access files remotely

Full Disk Encryption

- Need to encrypt all data
- Encryption requires a key that must be stored or derived somehow
- Practical requirement to encrypt disk sectors independently for fast access

AES-XTS: tweakable encryption

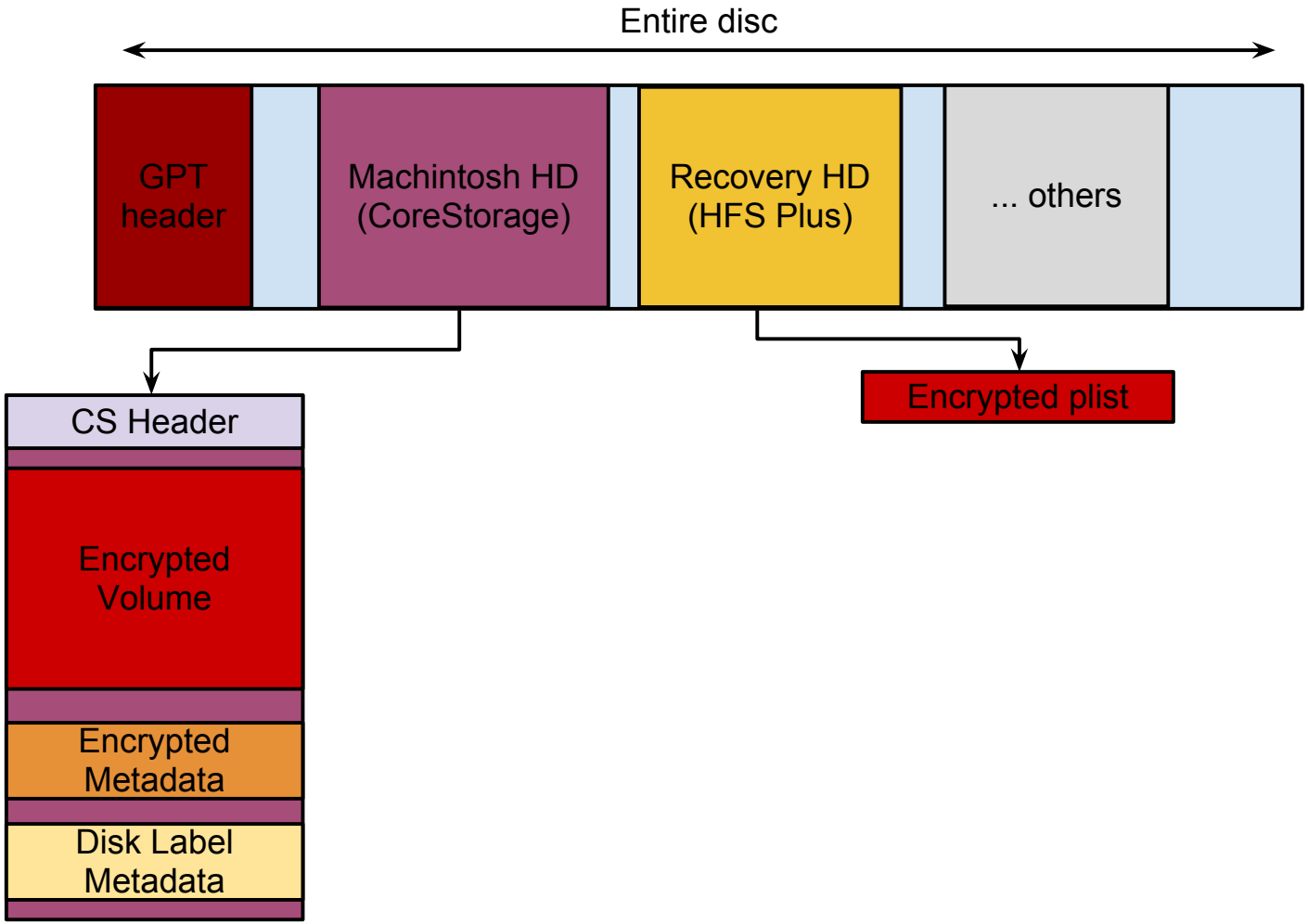


- Uses AES-ECB
- 2 keys
  - volume key (key 1)
  - tweak key (key 2)
- tweak value per sector (modified per AES block)

Tools

- GDB
- IDA Pro
- 3 MacBooks
- The Sleuth Kit

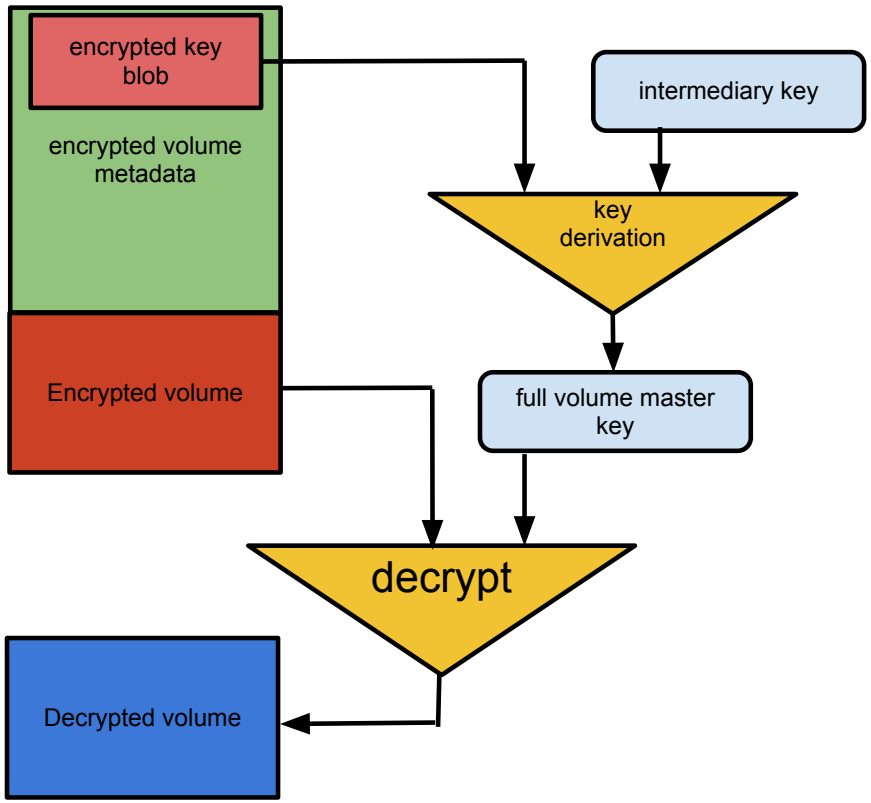
Structure analysis



The quest

- What are the key derivation mechanisms?
- How is the data encrypted?

General volume encryption architecture



EncryptedRoot.plist file

- File encrypted with AES-XTS using key from volume header
- Data for different users (including recovery key)
- Key encryption key (KEK) and volume key encrypted structures
- Unknown algorithms (found by reverse engineering)

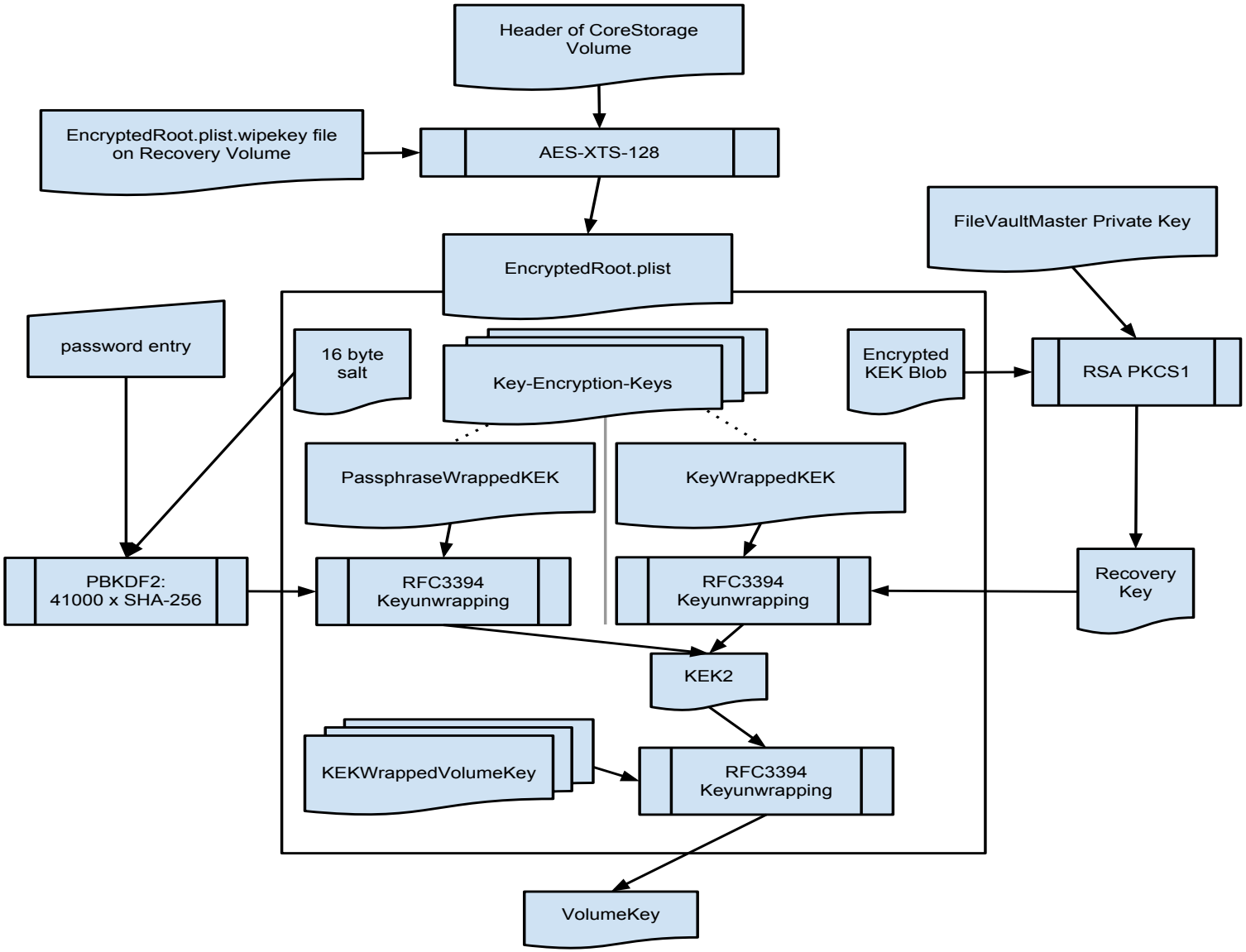
PBKDF2

- Output keys of arbitrary lengths from any text
- Slow brute force attacks on passwords by iterating hash
- 3 parameters: iterations, salt, password
- Option of PRF (e.g. HMAC-SHA256)
- Used in FileVault 2 to derive a KEK from user password or recovery key
- salt and iterations* given in EncryptedRoot.plist

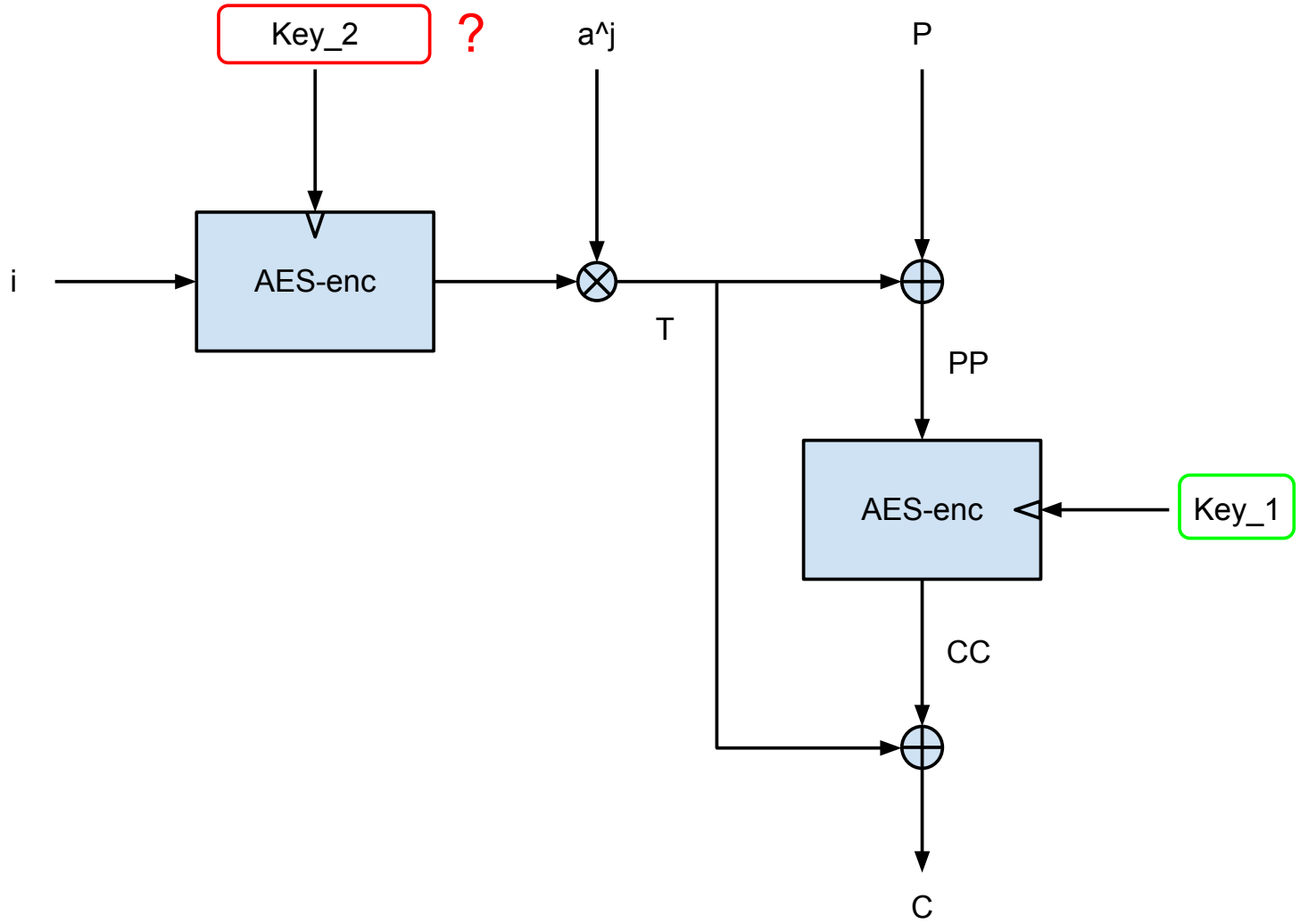
AESWrap

- Used to encrypt a key with another key
- Based on AES
- Needs IV, useful to verify correct decryption
- Used in FileVault 2 to decrypt volume KEK and volume key

FileVault 2 key derivation overview



Tweak key?



Searching the tweak key

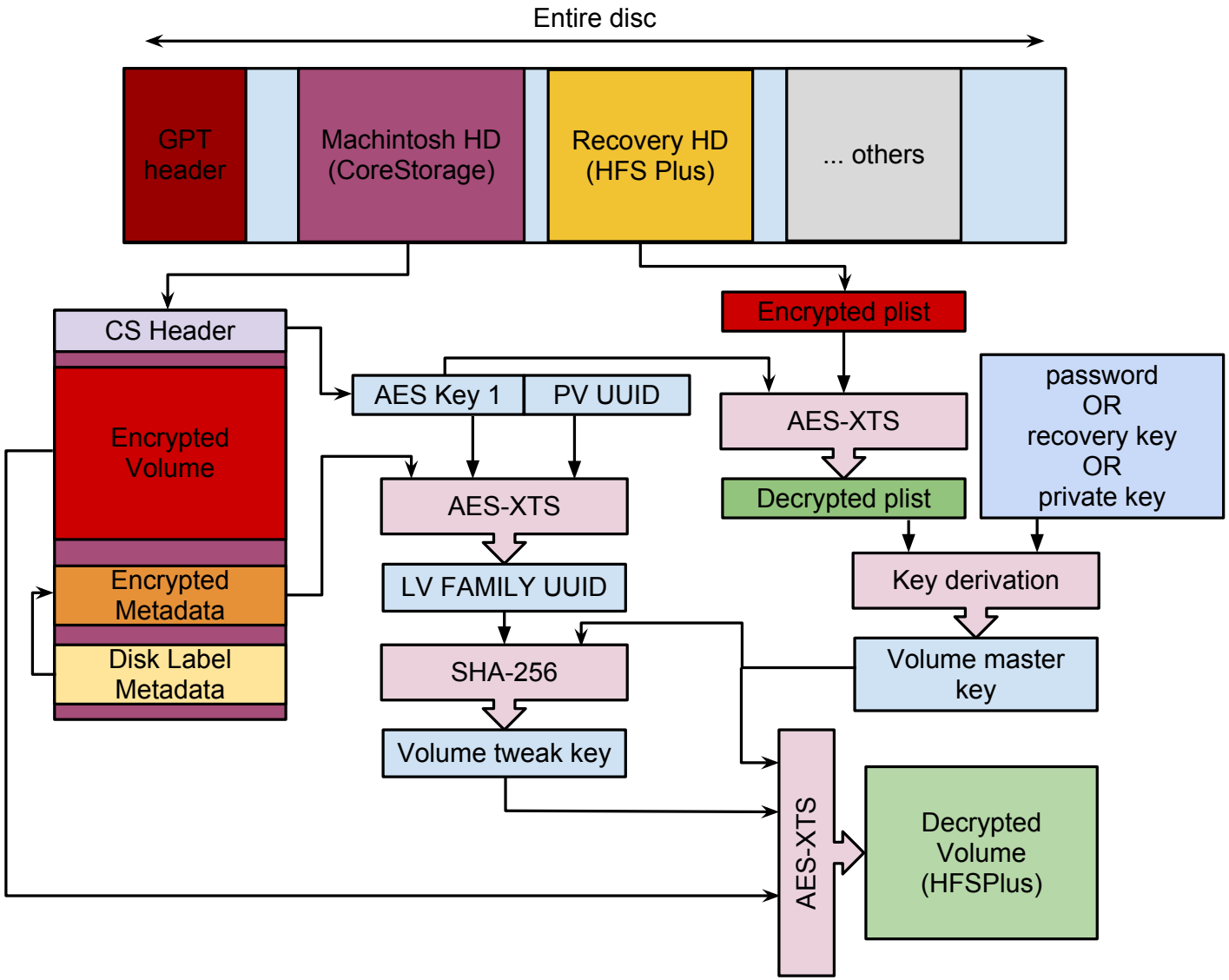
- Looking at HFS+ metadata (misleading, found/fixed bug)
- Searching metadata
- Chasing encryption via GDB (no luck, found many unknown keys)
- Comparing memory with disk data (found encryption parameters, not our key)
- Finally found using IDA Pro (difficult due to C++)

Computing the tweak key

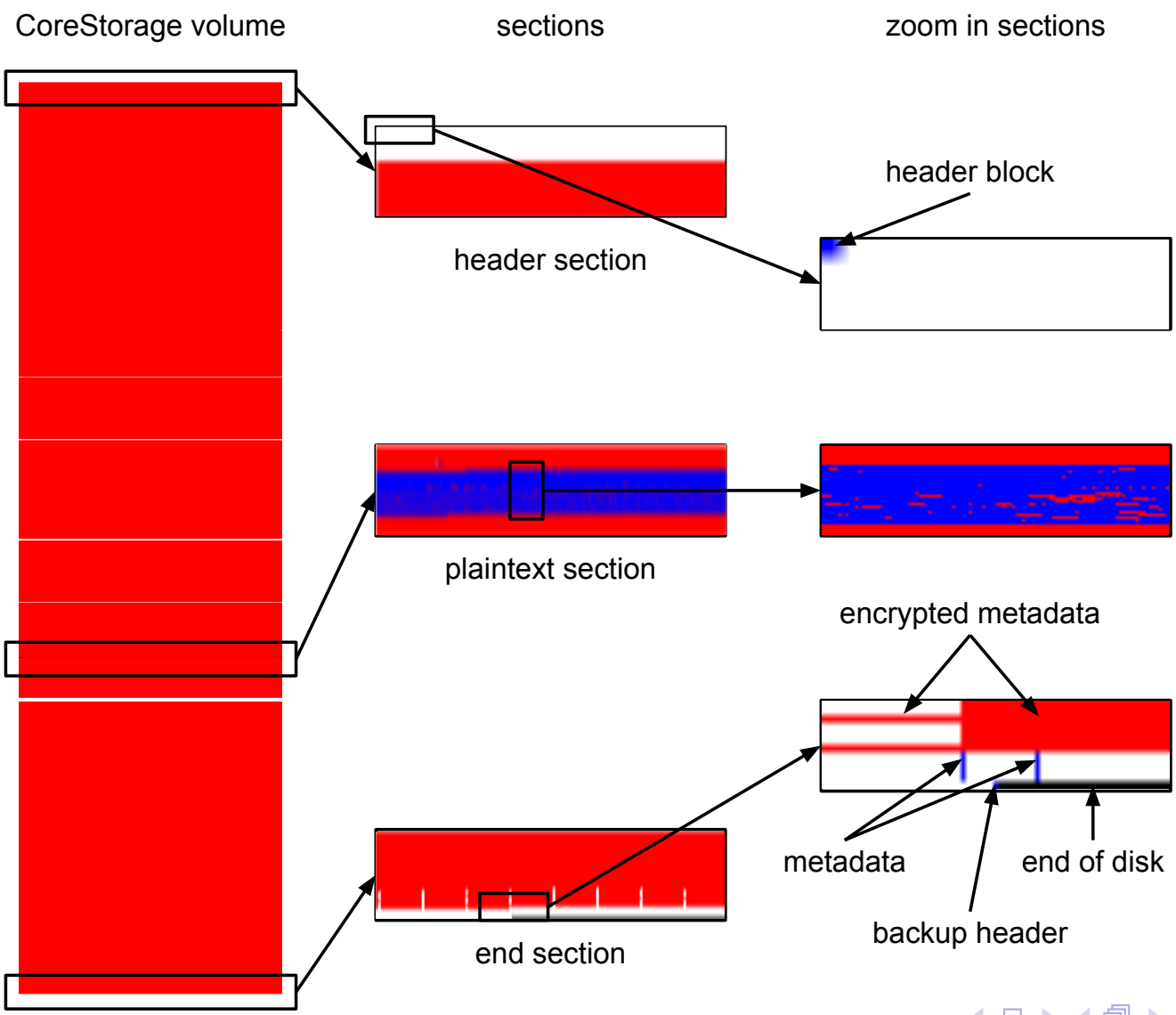
- Get volume key
- Find metadata blocks and decrypt some blocks which are encrypted
- Obtain logical volume family (lvf) UUID
- Compute the tweak key as follows:

$$\mathit{tweak\_key} = \mathrm{trunc}_{128}(\mathrm{SHA256}(\mathit{volume\_key} \mid \mathit{lvf\_UUID}))$$

FileVault 2 Overview



Volume layout



Random number generator

- Used for derivation of recovery key (and possibly other keys)
- Randomness taken from /dev/random
- Performed detailed analysis and seems OK (see paper)

libfvde

- Open source tool to decrypt and mount CoreStorage volumes
- Available at Google code:
  `http://code.google.com/p/libfvde/`
- Ongoing investigation for the more general CoreStorage format and how to handle partially encrypted disks

Questions?

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How to use the AES block cipher?

- Straight AES-CBC is not suitable
- Random IV in metadata does not allow independent sector encryption
- Constant IV poses problems of watermarking data
- Sector-based IV is better
- Tweakable encryption is the best option now

Other issues with FileVault 2

- Keys can be extracted from memory, so cold boot attacks possible
- Even the good password derivation mechanism does not protect against very bad passwords

How to use libfvde

- Get EncryptedRoot.plist.wipekey file (e.g. via mmls/fls/icat)
- Then run the tool to mount the volume or image:

  fvdemount -e EncryptedRoot.plist.wipekey -r 35AJ-AC98-TI1H-N4M3-HDUQ-UQFG /dev/sda2 /mnt/fvdevolume/

- Finally mount the underlying HFS+ file system:

  mount -o loop,ro /mnt/fvdevolume/fvde1 /mnt/hfs_file_system