PV204 Security technologies

File and disk encryption

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Cryptography and Security

Data storage encryption

- Lecture
  - File and disk encryption
  - Distributed storage encryption
  - Abstraction layers, hardware acceleration
  - Cryptography basic principles
    - Confidentiality and integrity protection
    - Encryption modes
    - Key management
  - Tool examples
  - Attacks and common issues
- Lab – disk encryption attack examples

File and disk encryption

MOTIVATION & STORAGE LAYERS OVERVIEW

Motivation

Offline, "Data at Rest" protection

notebook, external drives, data in cloud, backups

Key removal = easy data disposal

Confidentiality protection

company policy to encrypt all mobile devices

prevents data leaks (stolen device)

Data integrity protection (not often yet)

Overview

(Distributed) Storage Stack

layers accessing storage through blocks (sectors)

near future: non-volatile byte-addressable memory

distributed => adding network layer

Full Disk Encryption (FDE)

self-encrypted drives

(software) sector-level encryption

Filesystem-level encryption

general-purpose filesystem with encryption

cryptographic file systems

Storage stack & encryption layers

Userspace	**Application**	(Application specific)
OS kernel	**Virtual file-system** (directories, files, …)	**File-system encryption**
	Specific file-system (NTFS, ext4, XFS, …)	
	Volume Management (partitions, on-demand allocation, snapshots, deduplication, …)	**Disk encryption**
	Block layer (sectors I/O)	
	Storage transport (USB, SCSI, SAS, SATA, FC, …)	**HW-based encryption** self-encrypted drives, inline (slot) encryption, chipset-based encryption, hardware security module
	Device drivers	
“Hardware”	**Hardware** (I/O controllers, disks, …)	

Clustered and distributed storage

Clustered => cooperating nodes
Distributed => storage + network

Software Defined Storage/Network (SDS, SDN)
- commodity hardware with abstracted storage/network logic
- encryption is “just” one logic function
- usually combination with classic storage (and encryption)

Distributed storage & encryption

Shared volumes (redundancy)

=> disk encryption

Clustered file-system

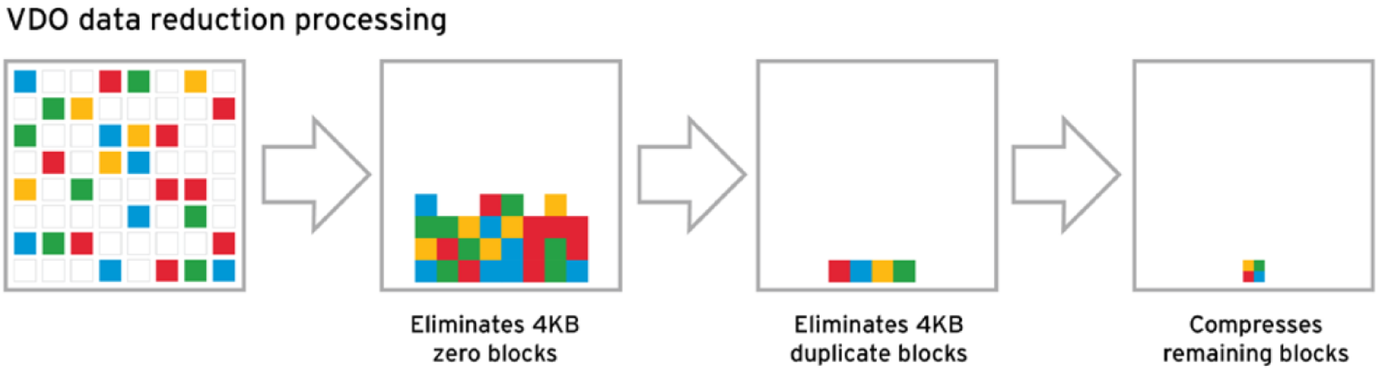
=> file-system encryption

Distributed Object Store

- Direct object encryption or
- Underlying storage encryption

Cloud storage – common features

Deduplication – avoid to store repeated data


VDO data reduction processing
Eliminates 4KB zero blocks
Eliminates 4KB duplicate blocks
Compresses remaining blocks

Compression – generic algorithms

- special case: zeroed blocks

Data snapshots (in time)

- COW (copy on write)

Cloud storage & encryption

Encryption with storage backend and compression & deduplication & snapshots …

Encryption on client side (end-to-end)

- efficiency for deduplication/compression is lost

~ in future homomorphic encryption?

Encryption on server side

- confidentiality for clients is partially lost
- server has access to plaintext

Full Disk Encryption (FDE)

Block device – transparent disk sector level

- Disk, partition, VM disk image
- Ciphertext device / virtual plaintext device
- Atomic unit is sector (512 bytes, 4k, 64k)
- Consecutive sector numbers
- Sectors encrypted independently

One key decrypts the whole device

- Media (volume) key – one per device
- Unlocking passphrases/keys
- Usually no integrity support (only confidentiality)

Filesystem-level Encryption

File/Directory

- Atomic unit is filesystem block
- Blocks are encrypted independently
- **Generic filesystems with encryption**
  - Some metadata can be kept in plaintext (name, size, …)
- **Cryptographic filesystems**
  - Metadata encrypted
  - ~ stacked layer over generic filesystem

Multiple keys / multiple users

File vs. disk encryption

Full disk encryption

+ for notebook, external drives (offline protection)
+ transparent for filesystem
+ no user decision later what to encrypt
+ hibernation partition and swap encryption
- more users – whole disk accessible
- key disclosure – complete data leak
- usually no integrity protection

File vs. disk encryption

Filesystem based encryption

+ multiple users
+/- user can decide what to encrypt
+ copied files keeps encryption in-place
+ more effective (only really used blocks)
+ should provide integrity protection (not always!)
- more complicated sw, usually more bugs
- unusable for swap partitions

File vs. disk encryption

Combination of disk & file encryption

Distributed storage

- **Must** use also network layer encryption
- Difference in network and storage encryption (replay attack resistance, integrity protection, …)

File and disk encryption

CRYPTOGRAPHY

Cryptography algorithms primitives

- **Symmetric encryption**
  - block ciphers
  - cipher block mode
  - hash algorithms
- **Key management**
  - Random Number Generators (RNG)
  - Key Derivation Functions (KDF)
  - Asymmetric cryptography
- **Deniable encryption / Steganography**

Data confidentiality & integrity

Confidentiality

Data are available only to authorized users.

Integrity

Data are consistent.
Data has not been modified by unauthorized user.
=> All modifications must be detected.

Note: replay attack (revert to old snapshot) detection cannot be provided without separate trusted store (TEC – Tamper Evident Counter, Merkle tree root hash, …)

Data integrity / authenticated encryption

Poor man's authentication (= no authentication)

- User is able to detect unexpected change
- Very limited, cannot prevent old content replacement

Integrity – additional overhead

- Where to store integrity data?
- Encryption + separate integrity data
- Authenticated modes (combines both)

File and disk encryption

DATA ENCRYPTION MODES

Symmetric encryption (examples)

AES, Cammelia, Adiantum,
Serpent, Twofish, (Specks, Kuznyechik, …)

Encryption-only modes

- Storage encryption mostly CBC, XTS
- Length-preserving encryption, block tweak

Authenticated modes (encryption + integrity)

- Integrity protection often on higher layer.

Storage standards like IEEE 1619 and FIPS/NIST

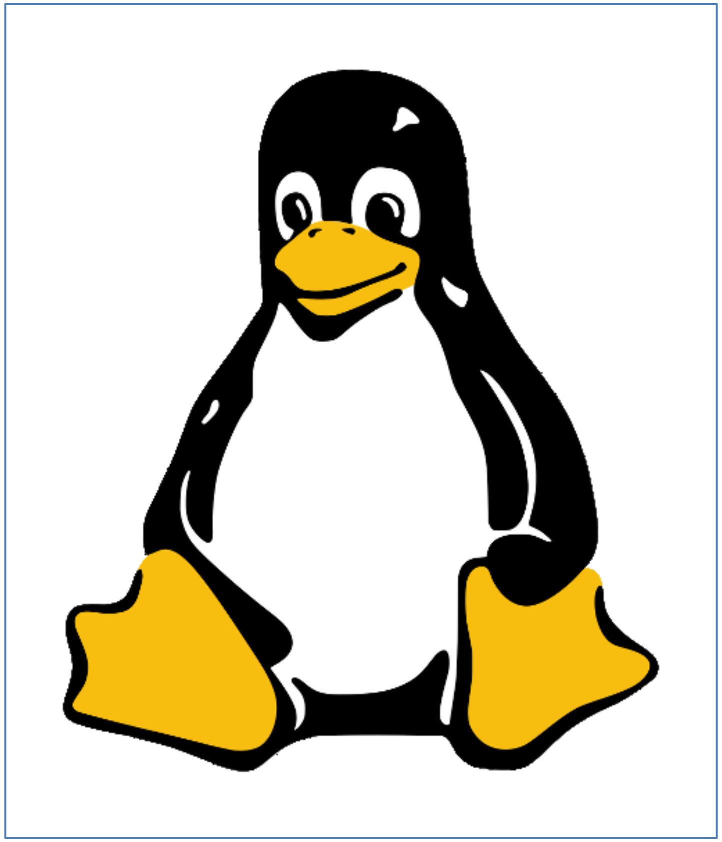
Propagation of plaintext changes

A change in the plaintext sector should transform to randomly-looking change in the whole ciphertext sector.

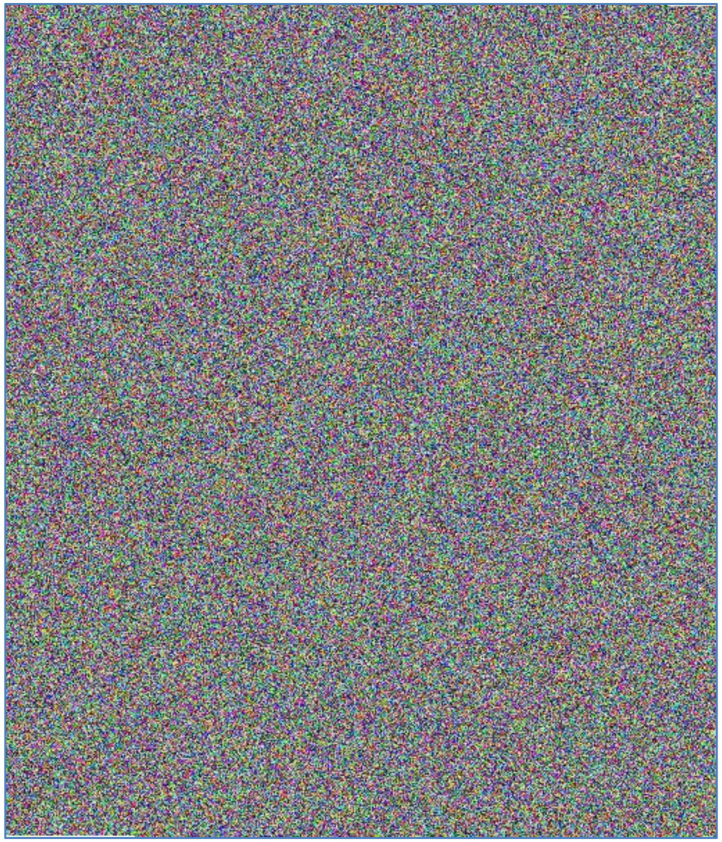
Solutions:

- Ignore it ☺ and decrease granularity of change
  => change location inside ciphertext sector
- Use wide mode (encryption block size = sector size)
  - requires at least 2x encryption loop
  - modes are patent encumbered
- Additional operations
  - Elephant diffuser in Windows Bitlocker
  - Google Adiantum (cipher composition)

Encryption example – AES-XTS

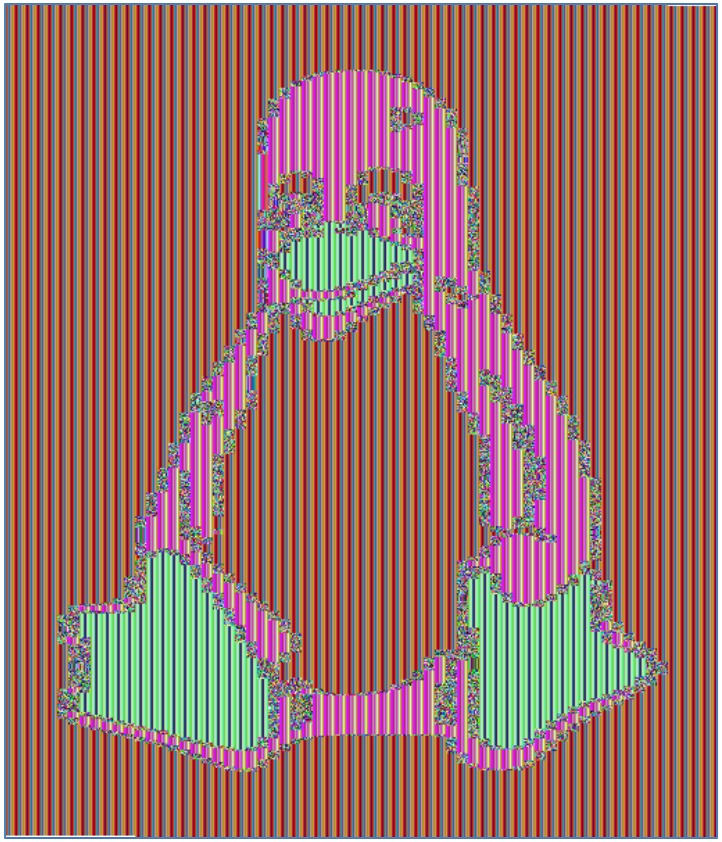


plaintext

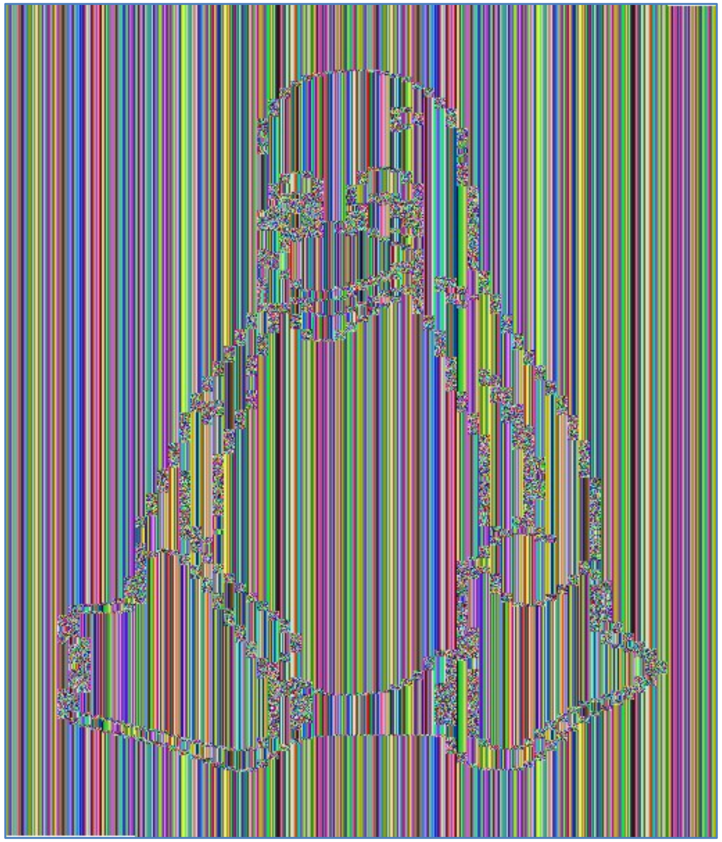


ciphertext

Wrongly used modes – ciphertext patterns



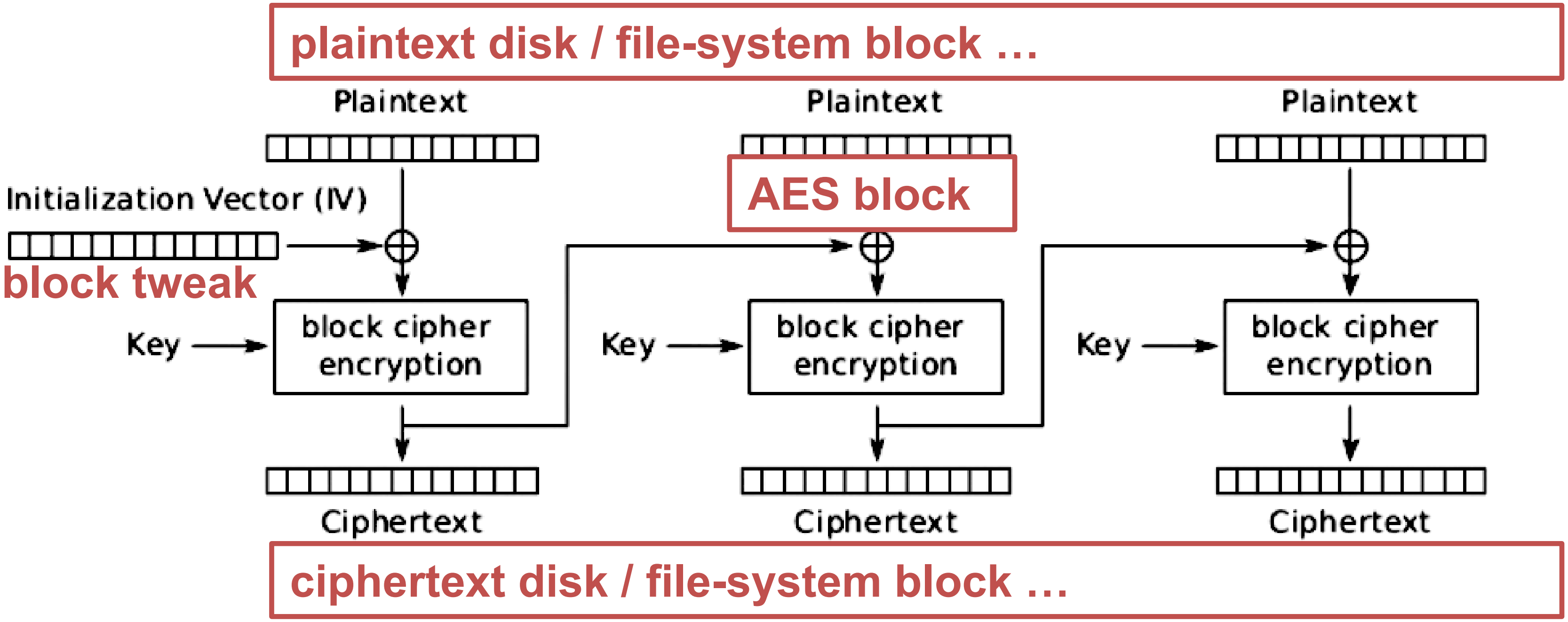
ECB mode



AES-XTS & constant IV

Cipher-Block-Chaining (CBC) mode

- Blocks cannot be encrypted in parallel
- Blocks can be decrypted in parallel
- Tweak must be non-predictable (watermarking!)



plaintext disk / file-system block …

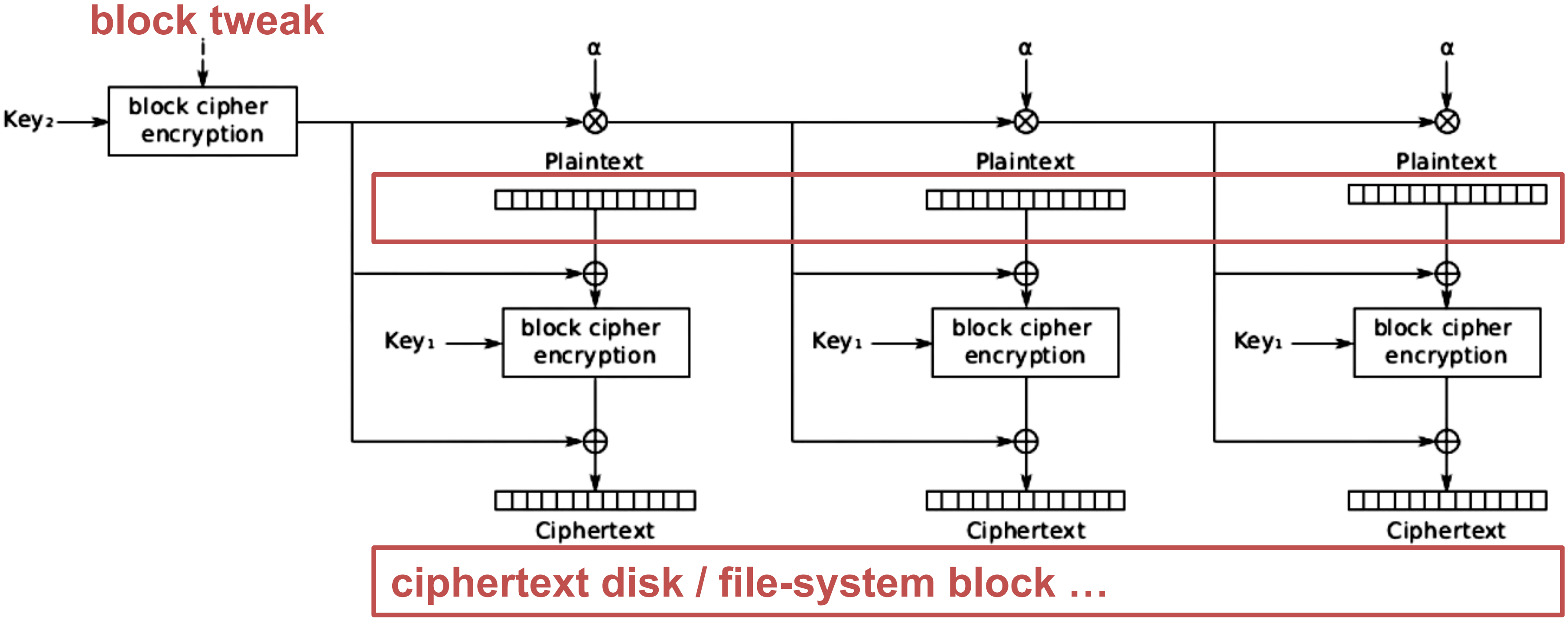
AES block

block tweak

ciphertext disk / file-system block …

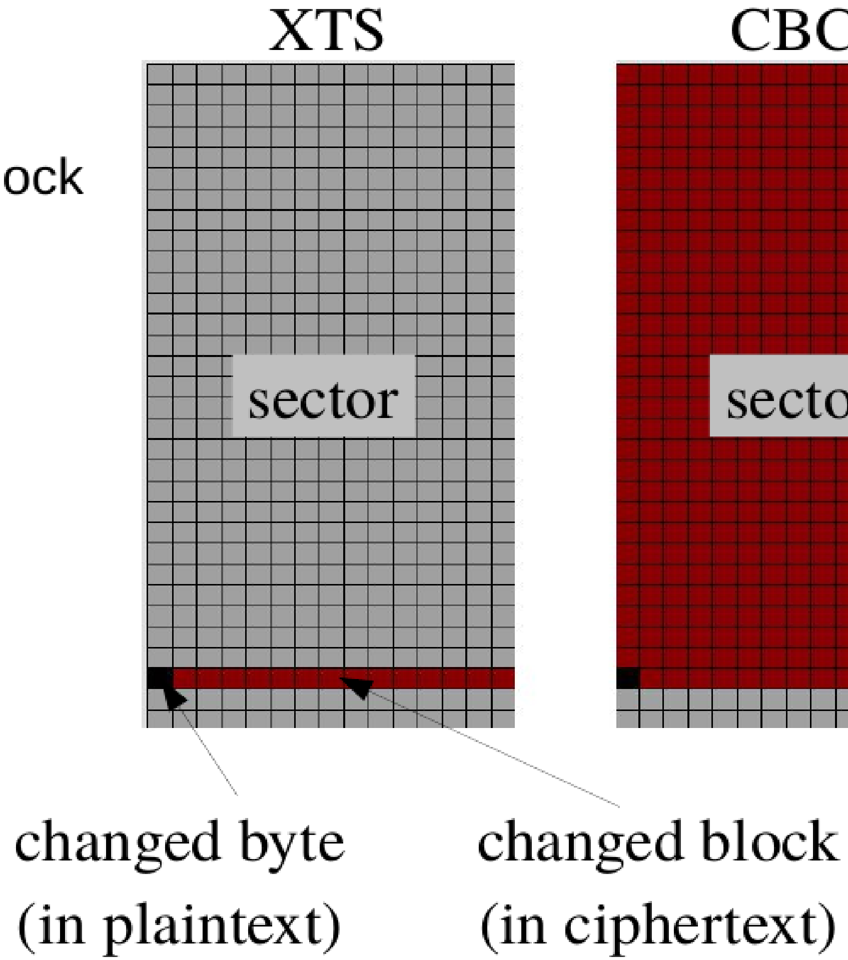
XOR-Encrypt-XOR (XEX/XTS) mode

- Encryption/decryption can be run in parallel
- Tweak can be predictable nonce – sector number (offset)



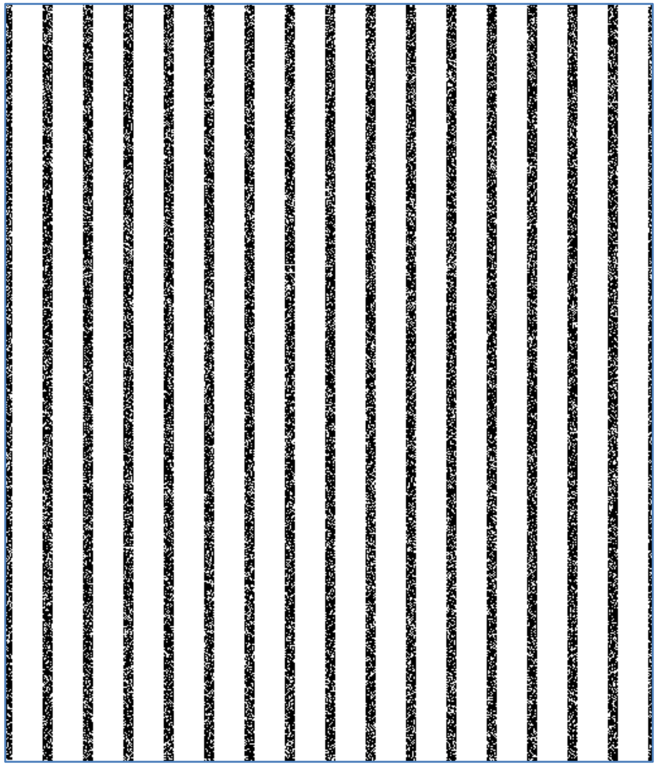
CBC and XTS change propagation

- **CBC** – cipher block chaining
  - ciphertext XOR with next block
- **XTS / XEX** (XOR encrypt XOR)
  - internally 2 keys
    - key for tweak
    - encryption key

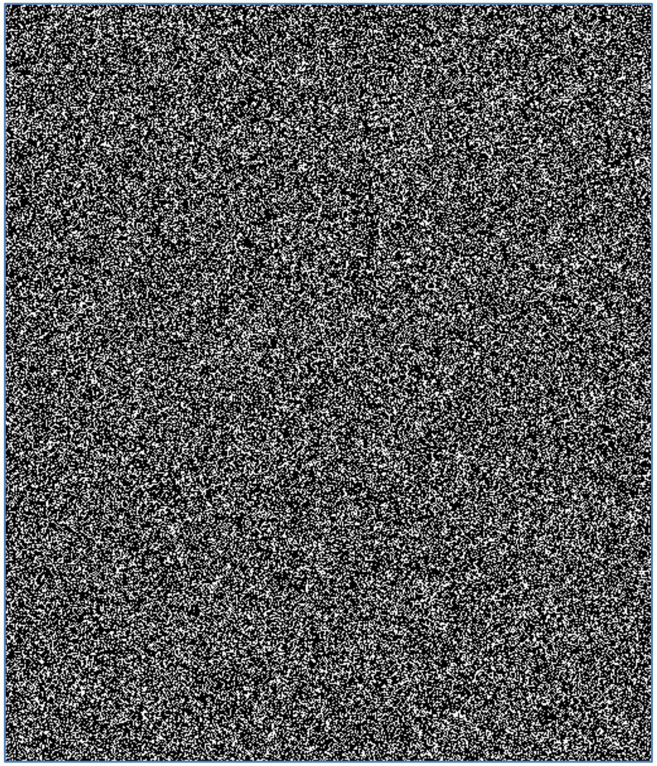


AES-XTS IV mode – sector# vs random

Every 64 byte changed (ciphertext differences)



IV is sector number



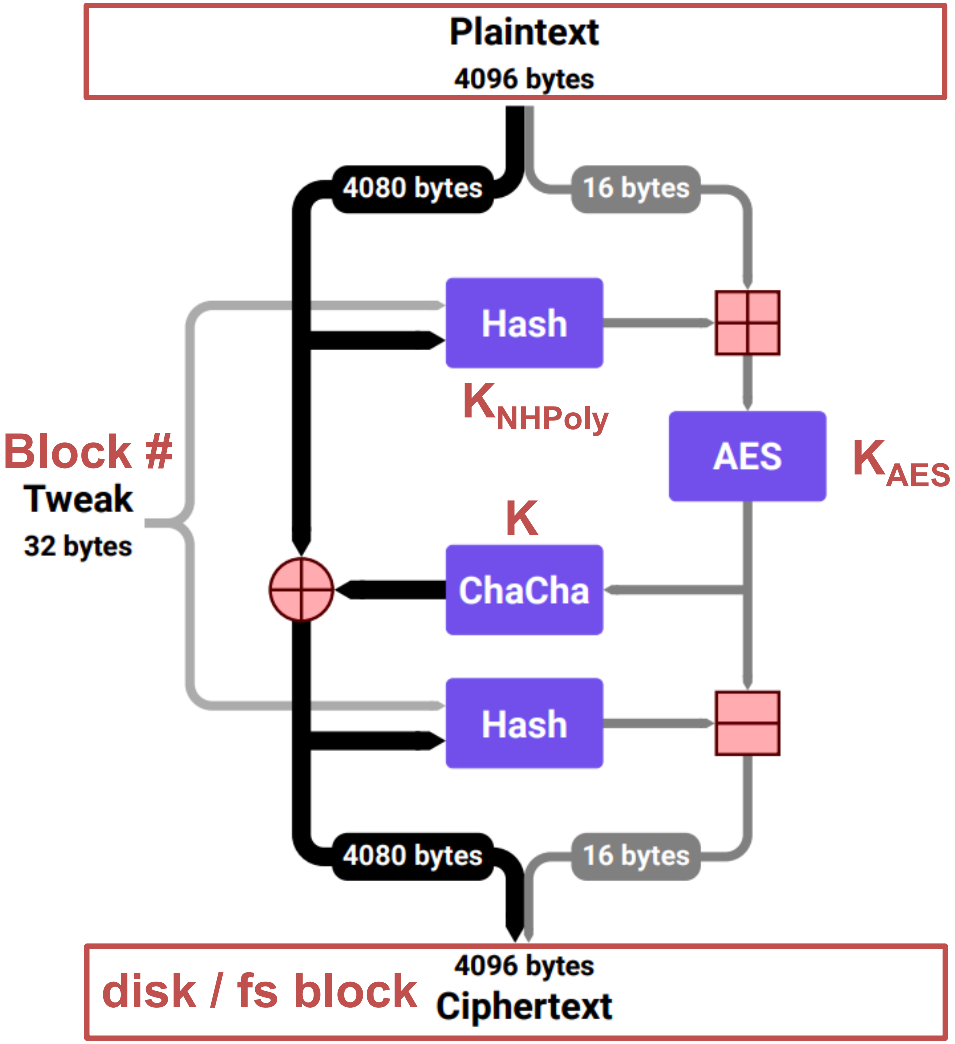
randomized IV

Adiantum

- Low-end mobile device disk / file encryption
- Wide "mode"

- HBSB composition:
  - Hash – NHPoly1305)
  - Block Cipher – AES
  - Stream Cipher – XChaCha12,20
  - Hash – NHPoly1305

- Key derivation
  $K_{AES} || K_{NHPoly}$ = XChaCha(K,1|0..0)



https://eprint.iacr.org/2018/720
https://security.googleblog.com/2019/02/introducing-adiantum-encryption-for.html

Steganography / deniable encryption

Plausible deniability:

existence of encrypted file/disk is deniable
if adversary cannot prove that it exists

Steganography

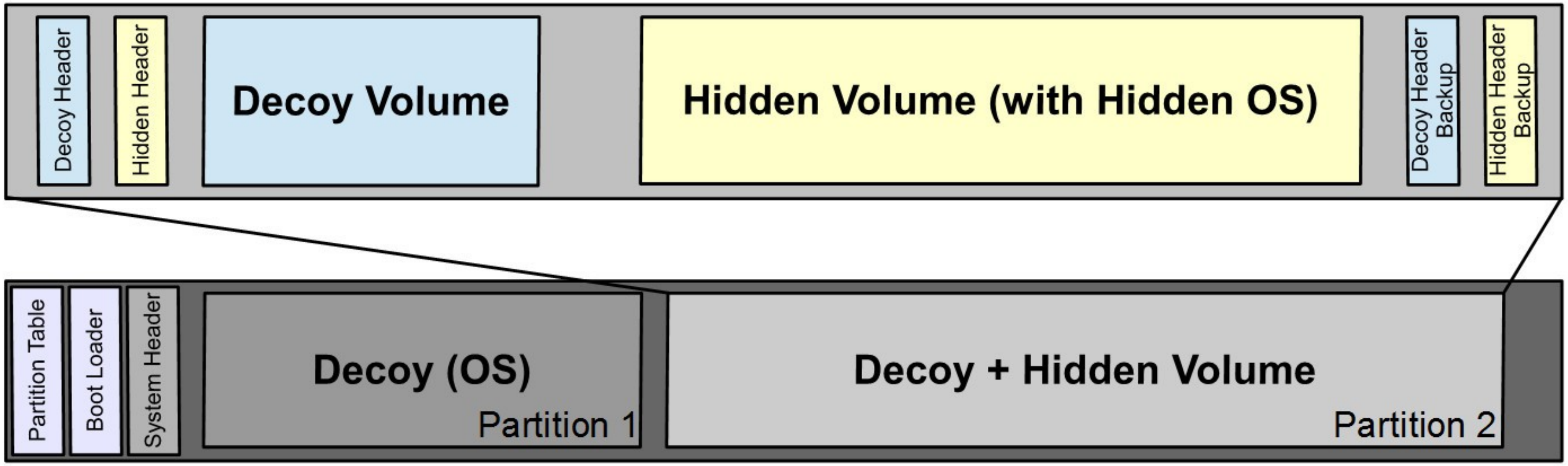
hiding data in another data object

Steganographic file-systems

Deniable disk encryption

Trivial example: VeraCrypt hidden disk

- FAT linear allocation
- Hide another disk in unallocated space



Deniable encryption problems

Side-channels

tracking activity that cannot be explained for decoy system

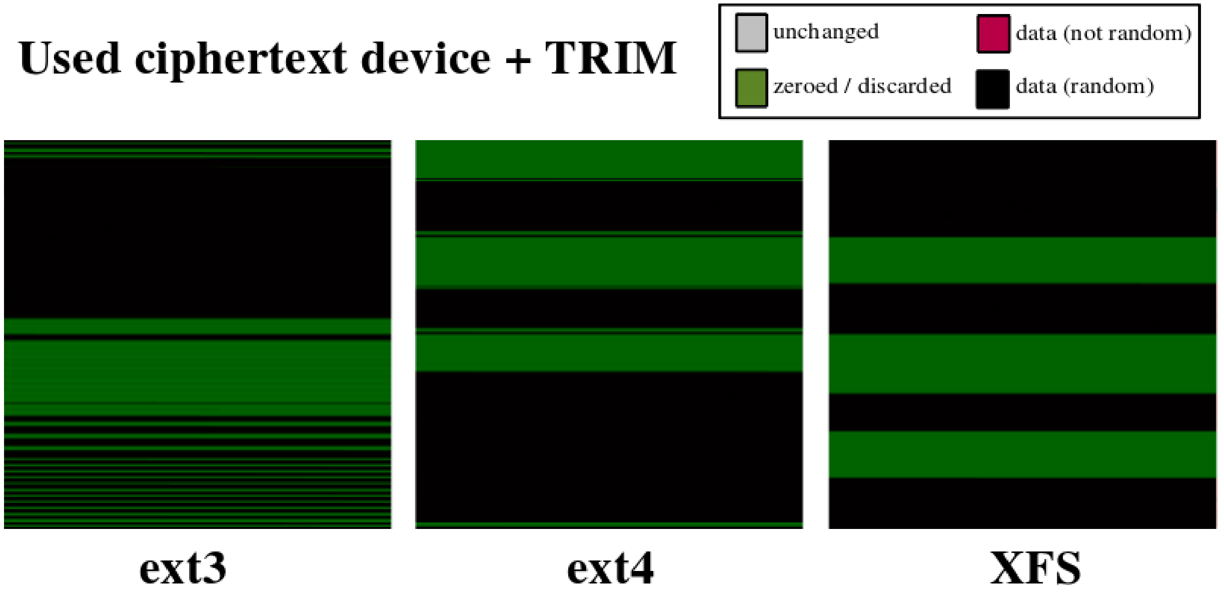
- Software: link to recently open documents, …
  Suspicious parameters (FAT), disabled TRIM, …
- Hardware: internal SSD block allocations
  (access to "unused" areas)

Social engineering / "rubber hose" analysis

Incompatibility with new drives (TRIM)

TRIM / discard and encryption

- TRIM informs SSD drive about unused space
- Unused space is detectable
- Pattern recognition example
- Incompatible with deniable encryption



File and disk encryption

KEY MANAGEMENT

Key generation

Encryption key (~ Media Encryption Key – MEK)

- Used to encrypt device
    - change means complete reencryption
- Usually generated by a secure RNG

Unlocking key (~ Key Encryption Key – KEK)

- Independent key change (MEK remains the same)
- Can be derived from passphrase
    - PBKDF2 (Password Based Key Derivation)
    - scrypt, Argon2 (memory-hard KDFs)
- Can use key wrapping

Key storage

Outside of encrypted device / filesystem

- Another device, file, token, SmartCard, TPM, HSM
- On a key server (network)
- Protected by another key (KEK).

On the same disk (with encrypted data)

- Metadata on-disk – key slots
- Brute force and dictionary attack resistance

Integration with key management tools

- LDAP, Active Directory, ...

Combination of above

Key removal and recovery

Key removal (wipe of key) = data disposal

- intended (secure disk disposal)
- unintended (error) => complete lost of data

Key recovery

- Trade-off between security and user-friendly approach
- Metadata backups
- Multiple metadata copies
- Key Escrow (key backup to different system)
- Recovery key to regenerate encryption key

File and disk encryption

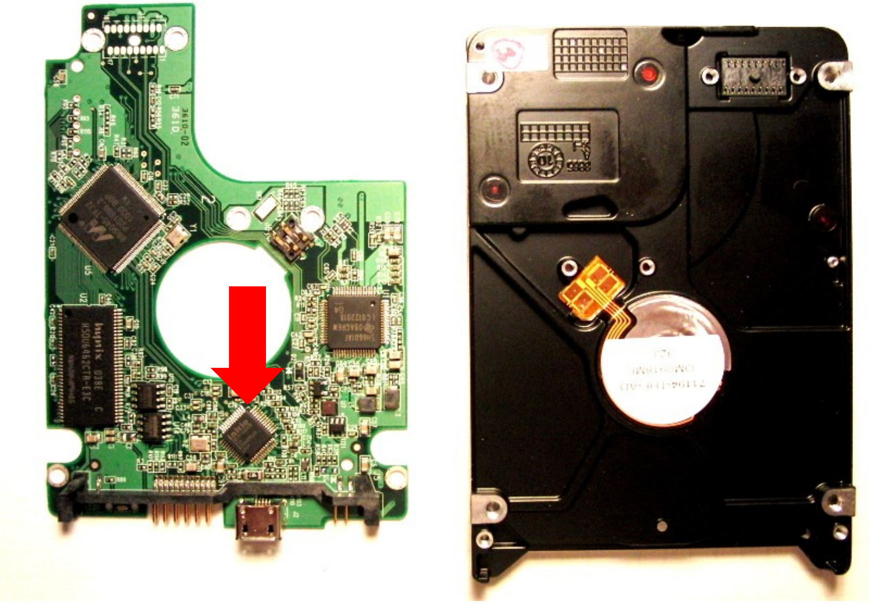
COMMON TOOLS

Examples of HW-based encryption

- **Self-encrypting drives (SED), OPAL standard**
  - Encryption on the same chip providing media access
- **Inline encryption**
  - HW Encryption, slots for keys (through OS context)
- **Chipset-based encryption**
  - Encryption on controller chip (e.g. USB bridge)
- **Hardware acceleration**
  - AES-NI, accelerators, ASICs, GPUs, …
- **Secure hardware / tokens**
  - HSM, TPM, SmartCards, ...

Examples of HW-based encryption

SATA disk
Encryption on USB-bridge



Examples of tools – filesystem encryption

Windows EFS

Linux

- **eCryptfs** – stacked encrypted file-system
- **fscrypt API** – support in ext4, F2FS, UBIFS

ZFS (Solaris and ports)

- supports GCM/CCM authenticated modes

Examples of tools – full disk encryption

Windows Bitlocker

- Optionally eDrive – self-encrypting drives
- Combination with secure boot and TPM

VeraCrypt

Linux LUKS / dm-crypt

MacOS FileVault

File and disk encryption

ATTACK EXAMPLES

Attacks always get better, they never get worse.

- **Against algorithm design**
  - Wrongly used encryption mode
  - Insufficient initialization vector
- **To implementation**
  - Insufficient entropy (broken RNG)
  - Weak derivation from weak passwords
  - Side channels
- **Obtaining key or passphrase in open form**
  - Cold Boot
  - “Black bag analysis” - Malware, key-logger
  - Social engineering
  - “Rubber-hose cryptoanalysis”

Integrity attacks

No integrity protection

- Inserted random block
  => undetected data corruption
- Inserted block from other part of disk
- Random error (RAM bit flip)
  => “silent data corruption”

Weak integrity protection

- Inserted previous content of (ciphertext) block
  => replay attack

Example: Disk encryption

- Some chipsets use ECB mode
- Weak key derivation (brute-force possible)
- Trivial unlocking mode (1-bit password is ok/bad)
- Weak key-escrow (backup key in EEPROM, …)
- SED – switch power attacks
- SED – ransomware and unconfigured passphrase
- Cold boot – key in memory
- Key loggers
- Weak RNG (key is not random)

…

LAB

Laboratory – FDE attack examples

Basic understanding of some tools and hw

- VeraCrypt, LUKS, chip-based encryption

Scanning memory image for encryption key

- ColdBoot attack principle

Optional: flawed algorithm and watermarking

- Revealing TrueCrypt hidden disk existence (CBC)

HW key-logger attack