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Data integrity protection with cryptsetup tools

What is the Linux dm-integrity module and why we extended dm-crypt to use authenticated encryption.

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Agenda

- Data integrity protection and disk encryption?
- dm-integrity and dm-crypt Linux kernel modules
- dm-integrity standalone mode
- dm-crypt authenticated encryption
- LUKS2

Full Disk Encryption (FDE)

- Disk sector level
  - Sectors accessed independently
  - 4k sector size today
- Data-at-rest protection
- Confidentiality
- Length-preserving encryption
  - plaintext size = ciphertext size
  - **No data integrity protection**

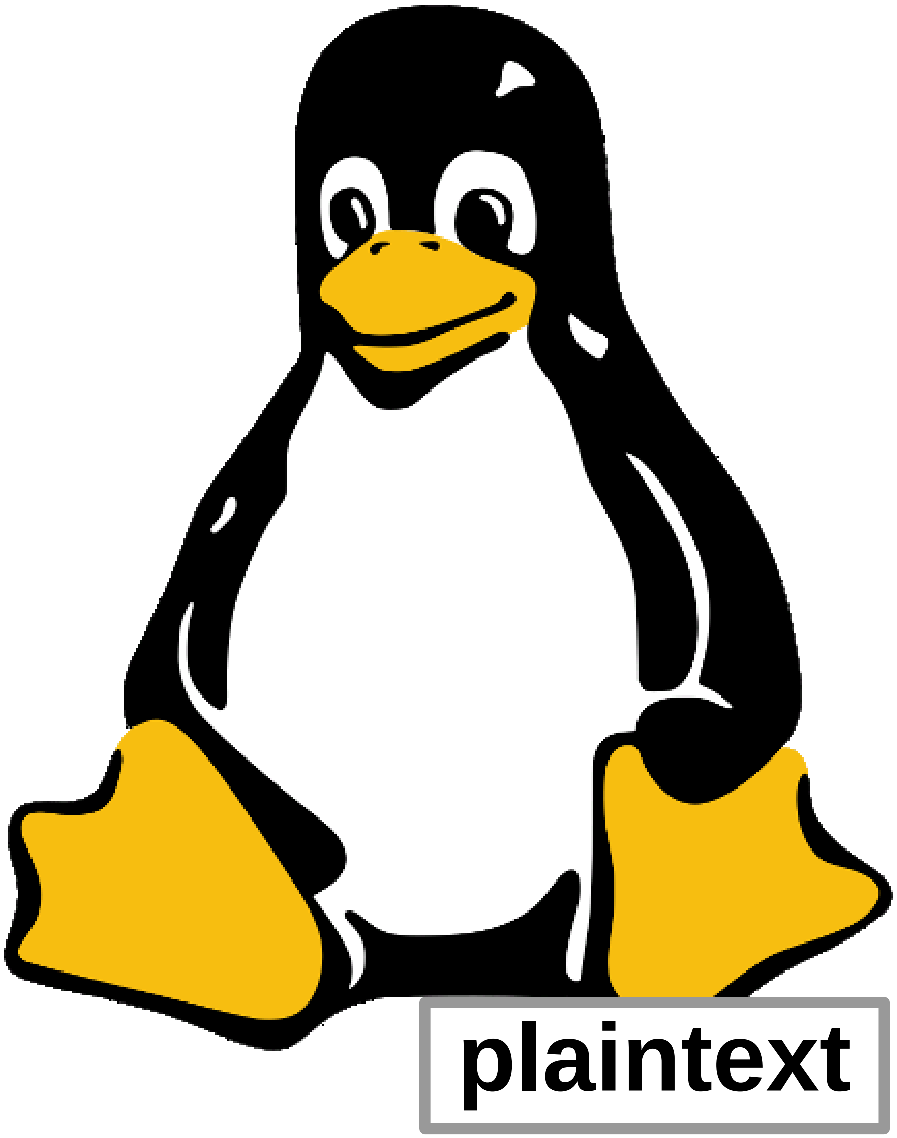
FDE images with Tux

... not only kind of glitch-art :-)

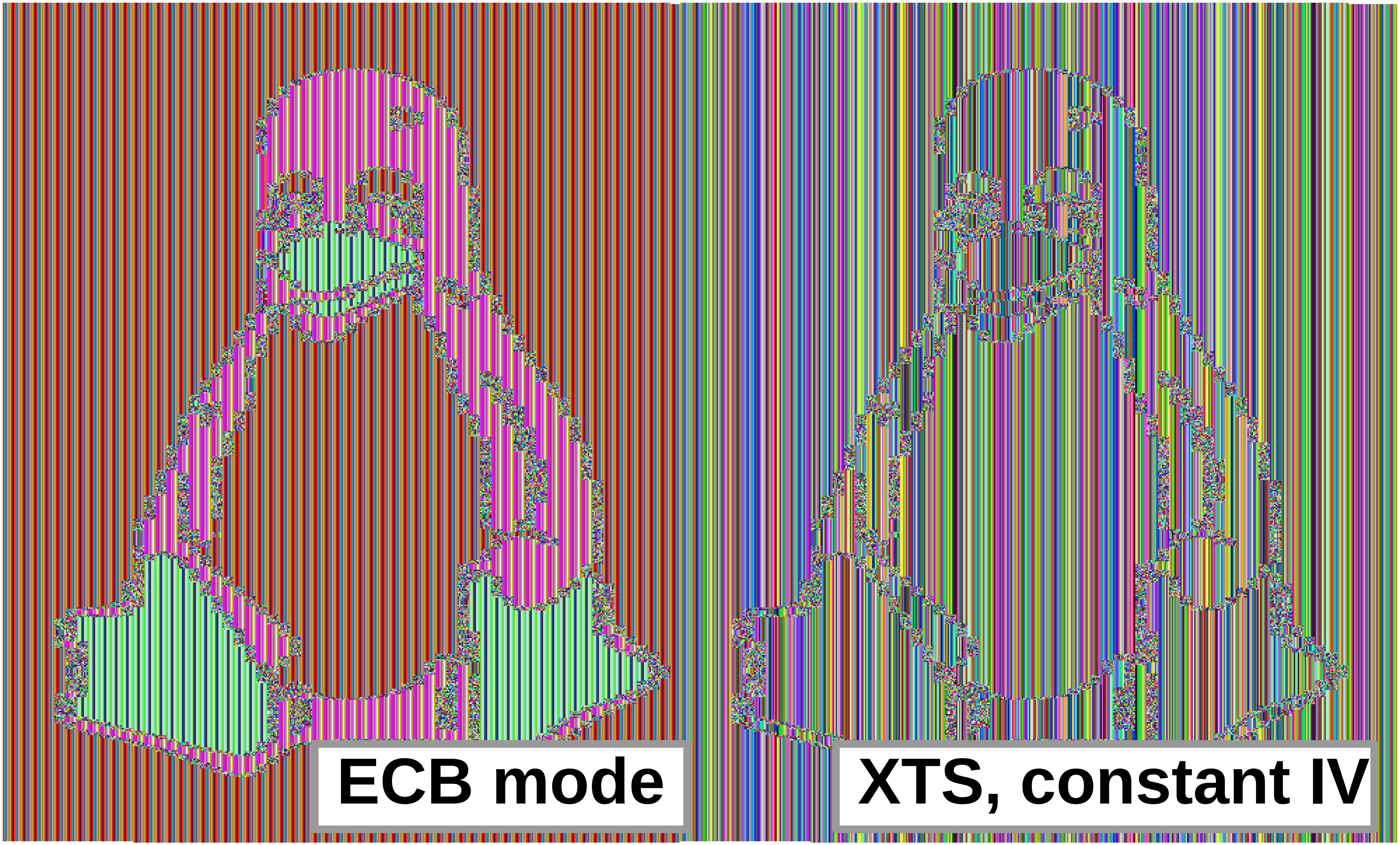
- Visualization of real on-disk encrypted data
- Generated with dm-crypt & cryptsetup
- BMP image (no check-sums)

FDE encryption example

AES-XTS, IV is sector offset



Wrongly used modes, IVs, nonces ciphertext patterns



Length-preserving encryption

no integrity, garbage-in, garbage-out

mangled ciphertext

decrypted plaintext

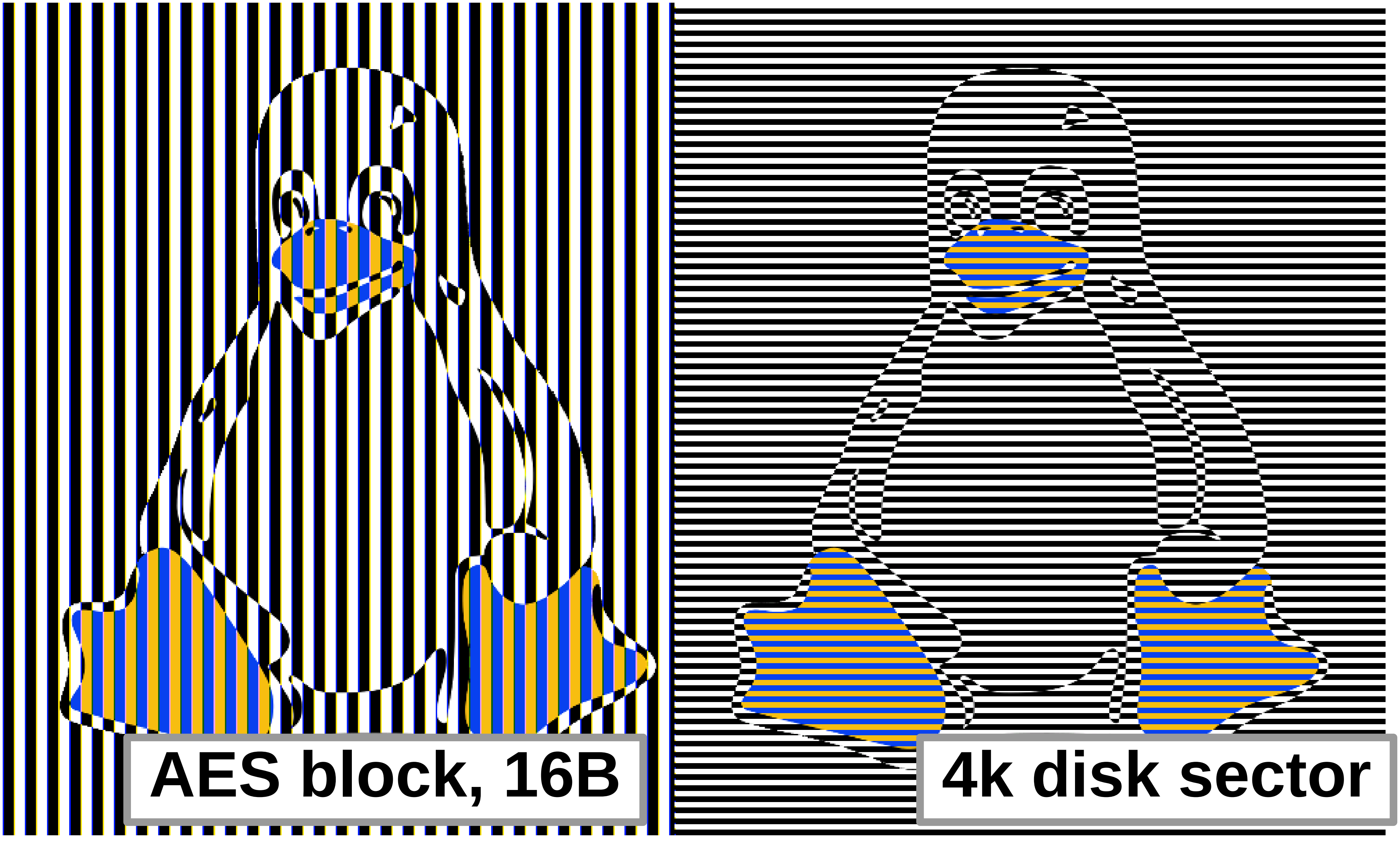
FDE threat model?

- **Stolen device, disk in repair, ...**
  - Length-preserving, confidentiality only
  - Data never used again
- **Our model: Returned device**
  - Silent data corruption
  - Implanted data without owner knowledge
- **Could this happen?**
  - Lost disk returns to owner
  - Devices traveling separately...

Another FDE trade-offs

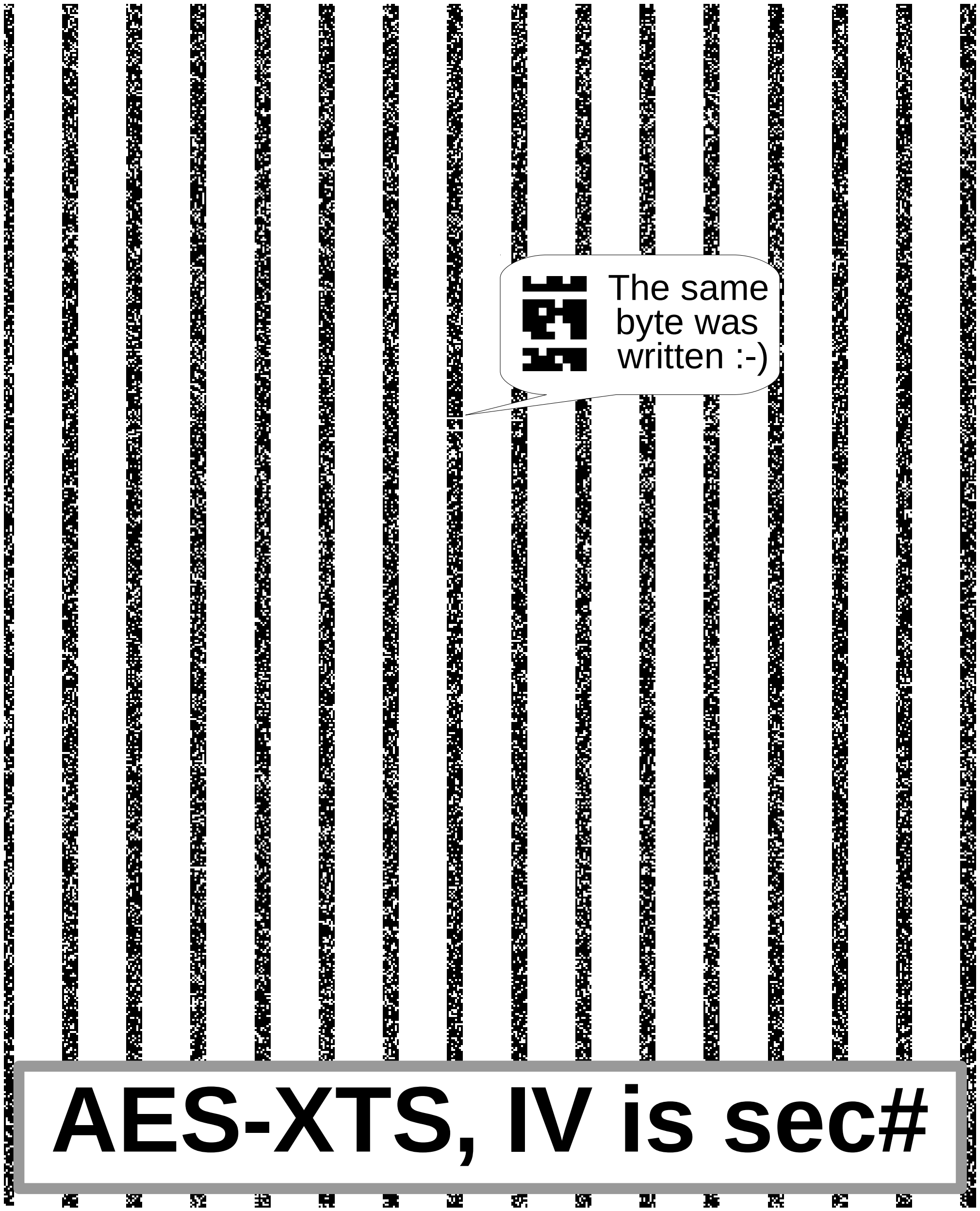
- **Whole sector not pseudo-randomly changed on every write.**
  - Granularity of ciphertext change
  - Same plaintext = same ciphertext (in the same sector)
  - Could we have randomized IVs?
- **Replay attacks**
  - Revert to old valid content
  - Need trusted store for root hash (Merkle tree)

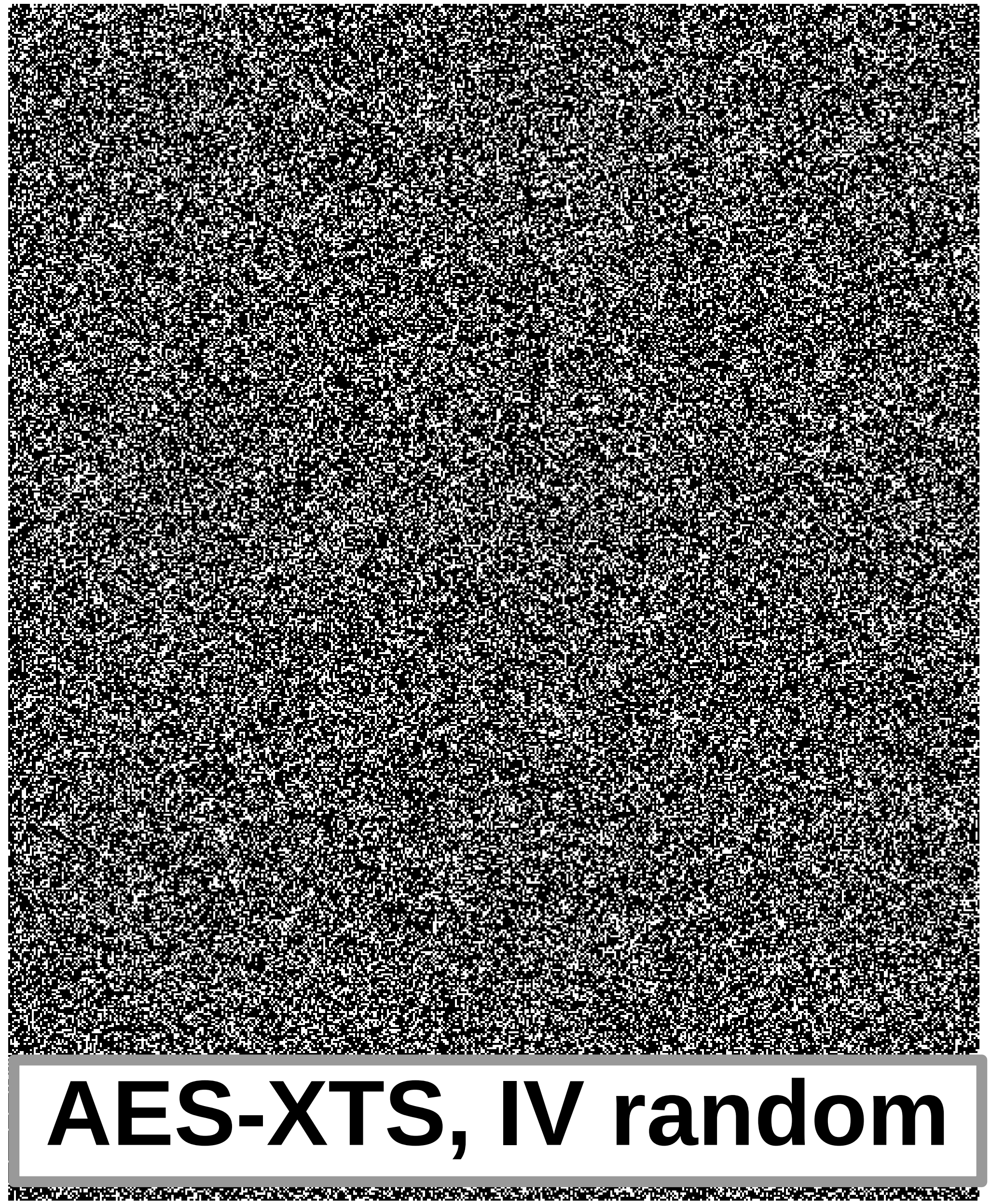
Encryption block granularity
(each following block is inverted here)



XTS Encryption block trade-off

Every 64 byte re-written, ciphertext diff.





What is missing?

- Confidentiality + data integrity protection

  => **authenticated encryption (AEAD)**

- Ciphertext change granularity

  => **randomized IV** (or wide encryption modes)

- Pseudo-random change on every write

  => **randomized IV**

- **Additional metadata per-sector**

FDE with data integrity protection

- FreeBSD GELI – different approach
- **Our requirements**
  - No special HW
  - Commercial of-the-shelf SSDs
  - Configurable per-sector metadata
  - Use native sector size
  - Reliable recovery on power fail
  - Algorithm agnostic
  - Free code & algorithms, no patents

Separation of storage and crypto

- **dm-integrity**
  - Emulates per-sector metadata
  - Optionally standalone mode (CRC32)
- **dm-crypt**
  - Authenticated encryption
  - Randomized IV
  - Tags and IVs stored in per-sector metadata
- **cryptsetup**
  - LUKS2 on-disk format
  - User friendly activation

dm-integrity on-disk layout

- Superblock (SB) – persistent parameters
- **Journal area**
  - Can be deactivated (write performance penalty)
- Metadata per 4k sector (packed)
  - 32bits metadata (CRC32) – 0.1% of storage
  - 256bits metadata (SHA256) – 0.78% of storage

dm-integrity standalone mode

- **Non-cryptographic data check-sums**
  - Detects silent data corruption
  - CRC32 or hash
- Per-sector check-sum
  - **Reads** (validate) / **Writes** (update)
- **No encryption of data**
- **Integritysetup** tool

Integritysetup example

```
# integritysetup format /dev/sdb [ -I crc32c ]
 Formatted with tag size 4, internal integrity crc32c.
 Wiping device to initialize integrity checksum.

# integritysetup open /dev/sdb test [ -I crc32c ]

# integritysetup status test
  type:    INTEGRITY
  tag size: 4
  integrity: crc32c
  device:  /dev/sdb
  sector size:  512 bytes
  interleave sectors: 32768
  size:    2064392 sectors
  mode:    read/write
  journal size: 8380416 bytes
  journal watermark: 50%
  journal commit time: 10000 ms

# mkfs -t xfs /dev/mapper/test
....
```

dm-crypt authenticated encryption

- Authenticated request

AAD		DATA	AUTH TAG
authenticated		authenticated + encrypted	
sector	IV	data in/out	tag

- **Position must be authenticated**
    - Misplaced sector
- **Random IV** (nonce)
    - On every write from RNG
    - Collision probability **negligible (!)**
- **No protection to replay attacks**

Authenticated algorithms

- **No perfect algorithm in kernel for FDE!**
- Length-preserving modes + HMAC (too slow)
- **Authenticated modes**
  - AES-GCM (96-bit nonce – collision is fatal)
  - ChaCha20-Poly1305 (RFC7539, 96-bit nonce)
- **Future: CAESAR** (crypto competition finalists)
  - AEGIS performs well
- Reason it remains experimental feature.

LUKS2 with integrity protection

```
# cryptsetup luksFormat --type luks2 /dev/sdb $PARAMS
$PARAMS AES-XTS+HMAC:   --cipher aes-xts-plain64 --integrity hmac-sha256
$PARAMS ChaCha20-poly1305: --cipher chacha20-random --integrity poly1305

# cryptsetup open /dev/sdb test
# lsblk /dev/sdb
```

```
NAME         MAJ:MIN SIZE
sdb            8:16    1G
└─test_dif   253:0   952M
  └─test     253:1   952M
```

```
NAME         MAJ:MIN SIZE
sdb            8:16    1G
└─test_dif   253:0 959.5M
  └─test     253:1 959.5M
```

```
# cryptsetup status test
  type:    LUKS2
  cipher:  aes-xts-plain64
  keysize: 512 bits
  key location: keyring
  integrity: hmac(sha256)
  integrity keysize: 256 bits
  device:  /dev/sdb
  sector size:  512
  size:    1949704 sectors
  mode:    read/write
```

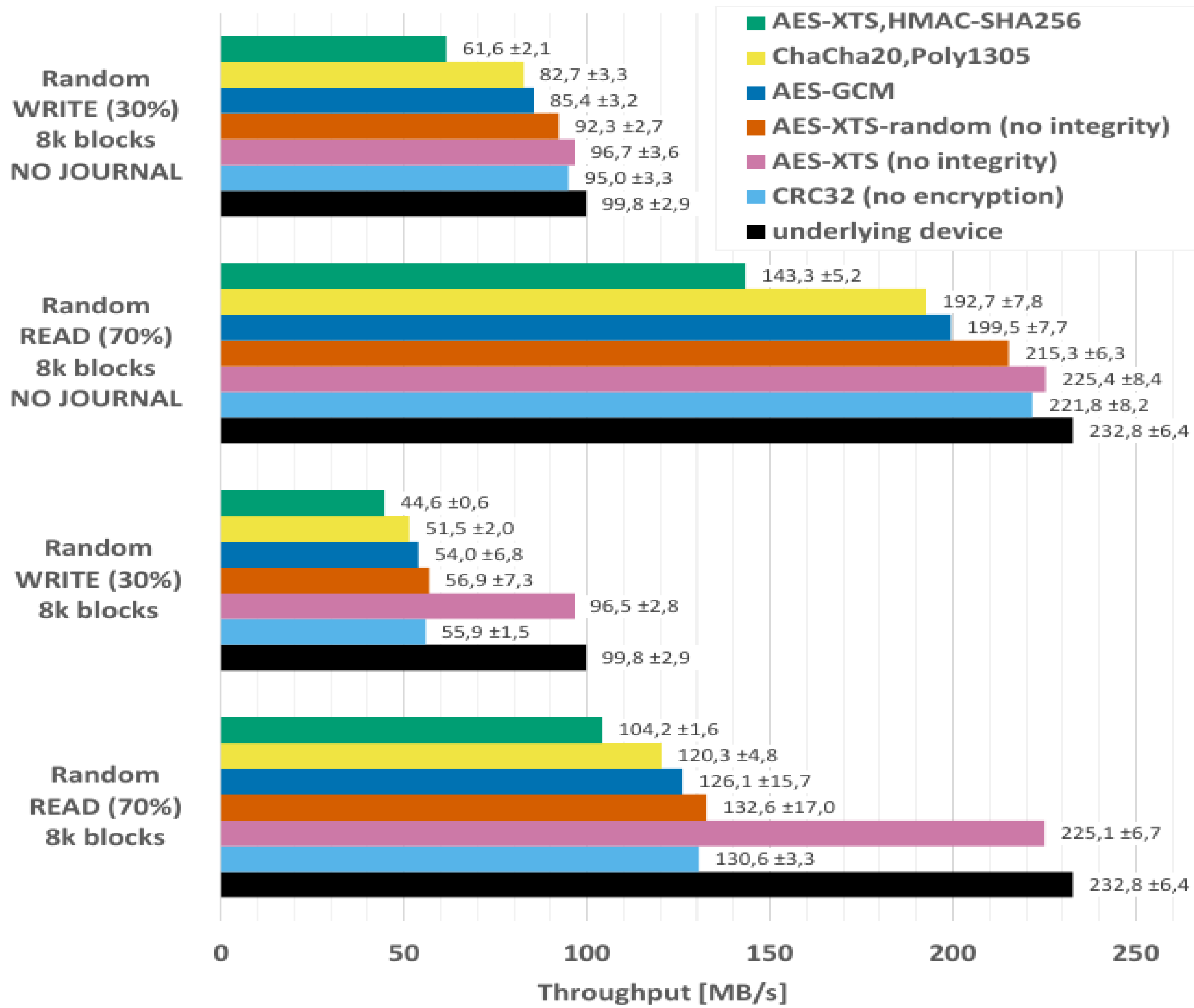
```
  type:    LUKS2
  cipher:  chacha20-random
  keysize: 256 bits
  key location: keyring
  integrity: poly1305

  device:  /dev/sdb
  sector size:  512
  size:    1965064 sectors
  mode:    read/write
```

```
# cryptsetup close test
```

Performance (example: fio simulated)

- SSD, 30% writes / 70% reads (very inefficient case)



Summary

- **Try it**
  - cryptsetup 2.0.x, Linux kernel 4.12+
- We need new AEAD algorithms
- Integrity protection on higher layer better?
- dm-integrity in future?
  - Replaced by persistent memory
  - Variable sector with inline metadata.

LUKS2 (in cryptsetup2)

- LUKS is a key management
- LUKS2 is on-disk format for LUKS extensions
- Metadata replicated (not keyslots)
- JSON metadata
- Argon2 key derivation function
- Kernel keyring

- **Cryptsetup does not handle HW tokens directly.**

  => token concept (metadata + external program)

- LUKS1 supported forever :-)

LUKS2 & tokens

- Token – metadata object in header

  => **How to get a passphrase for a keyslot.**

1) **Keyring token (internal)**
   - External app for HW (TPM, Smartcard, ...)
   - Passphrase in kernel keyring
   - Cryptsetup activation is automatic
2) **External token types**
   - LUKS2 stores metadata
   - External app uses libcryptsetup to activation
   - Tokens ignored by cryptsetup

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Thanks for your attention.

Q & A ?

or use dm-crypt mailing list later

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