Speeding Up Linux Disk Encryption

Ignat Korchagin

@ignatkn

$ whoami

- Performance and security at Cloudflare
- Passionate about security and crypto
- Enjoy low level programming

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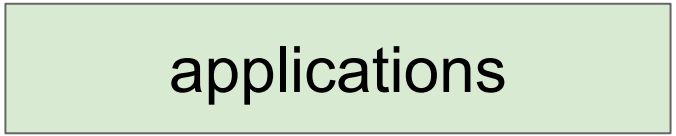
Encrypting data at rest

The storage stack



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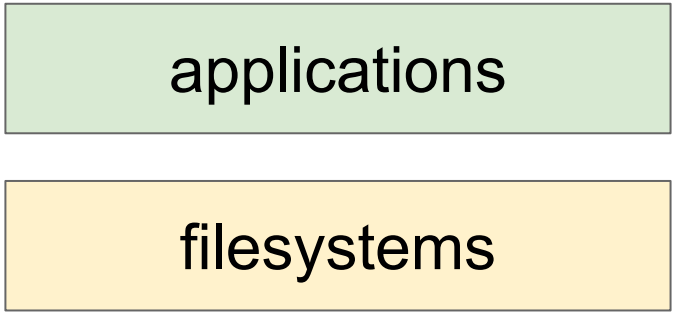

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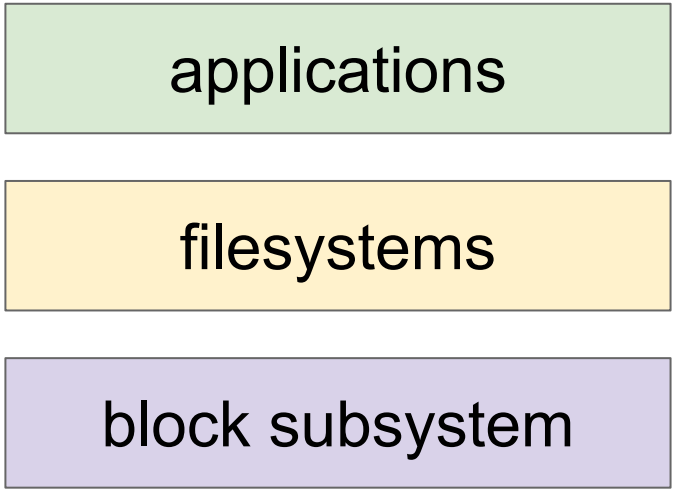

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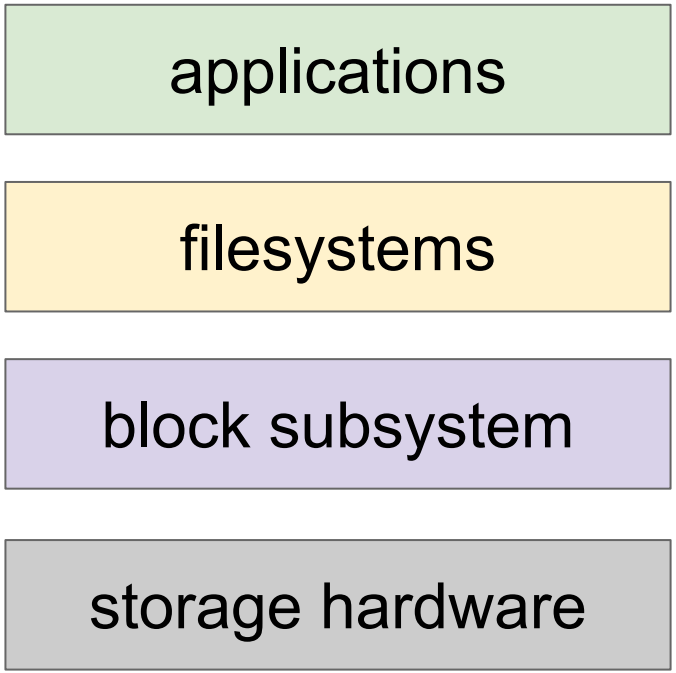

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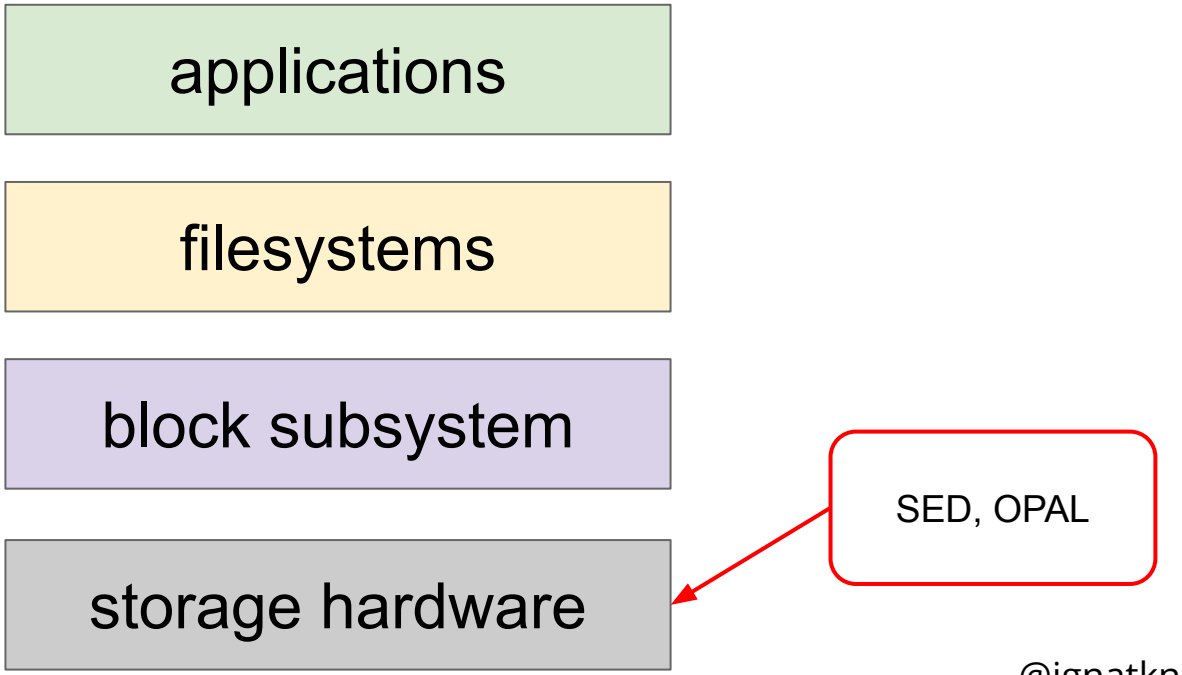
Encryption at rest layers



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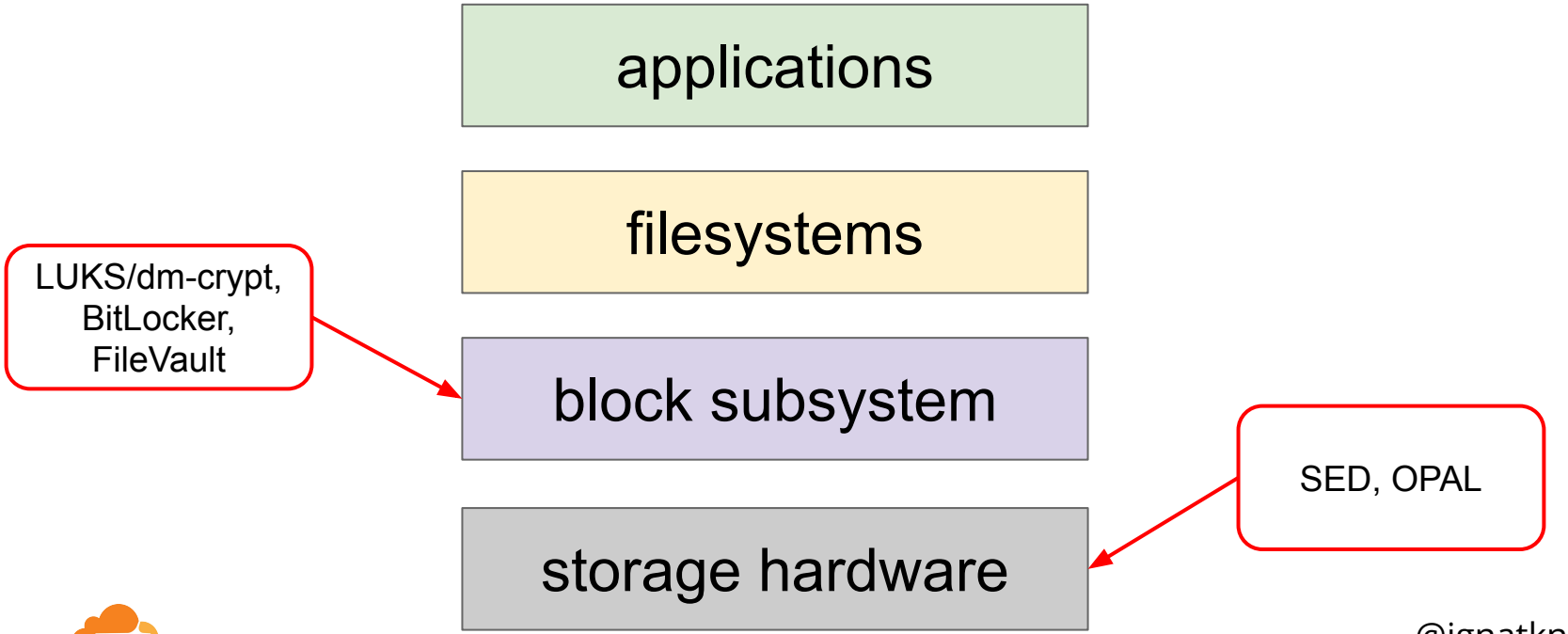

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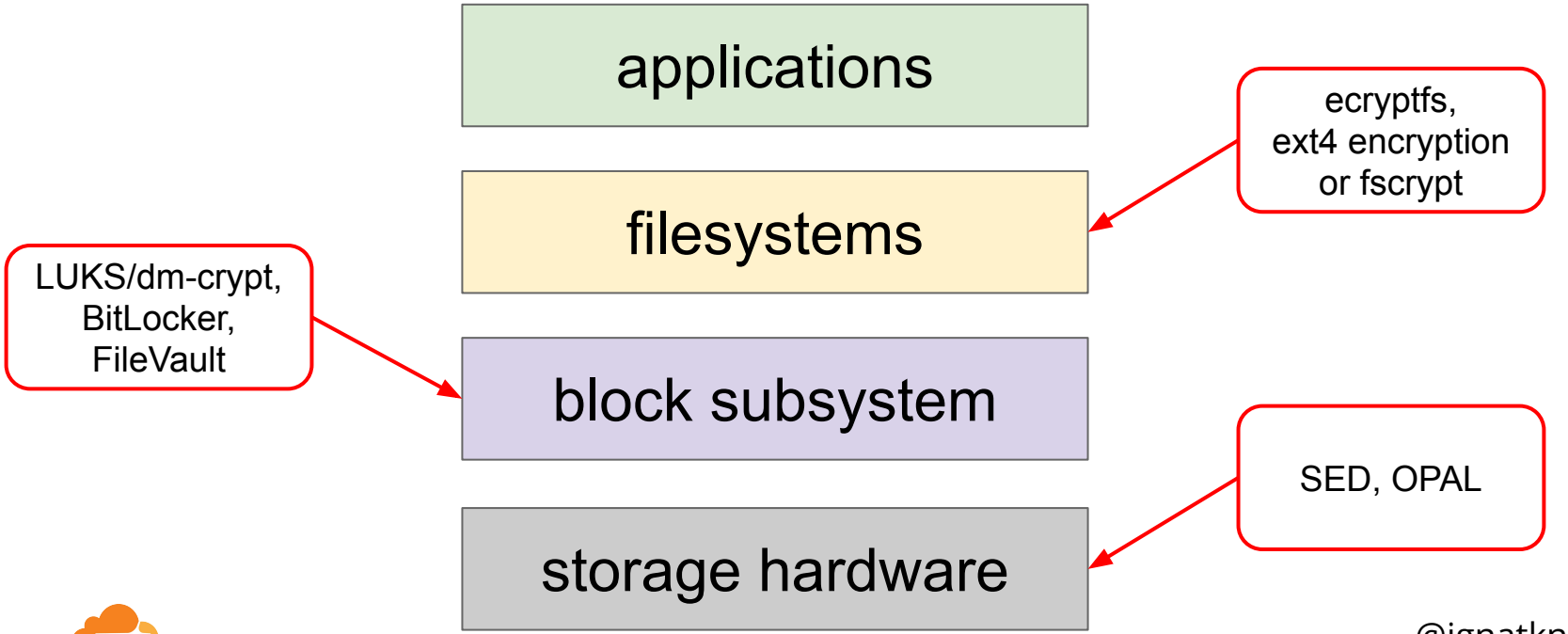

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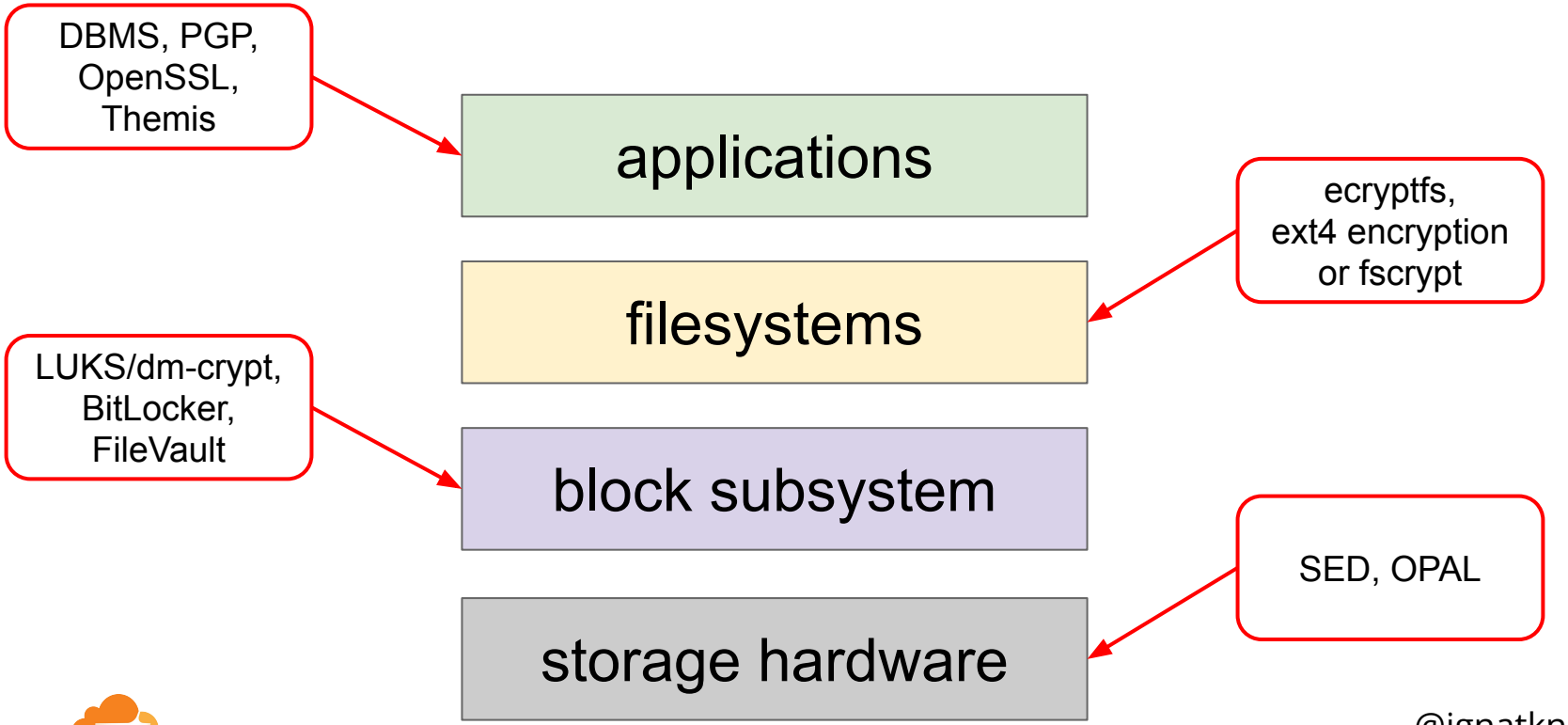

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Storage hardware encryption

Pros:

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- usually faster than other layers

Cons:

- no visibility into the implementation
- no auditability
- sometimes poor security

https://support.microsoft.com/en-us/help/4516071/windows-10-update-kb4516071

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LUKS/dm-crypt

Device mapper in Linux

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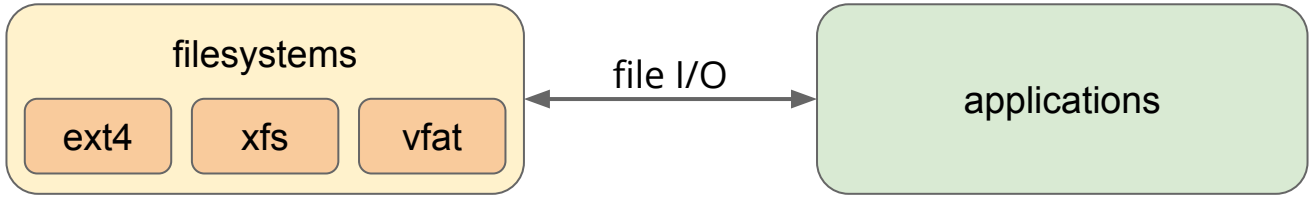

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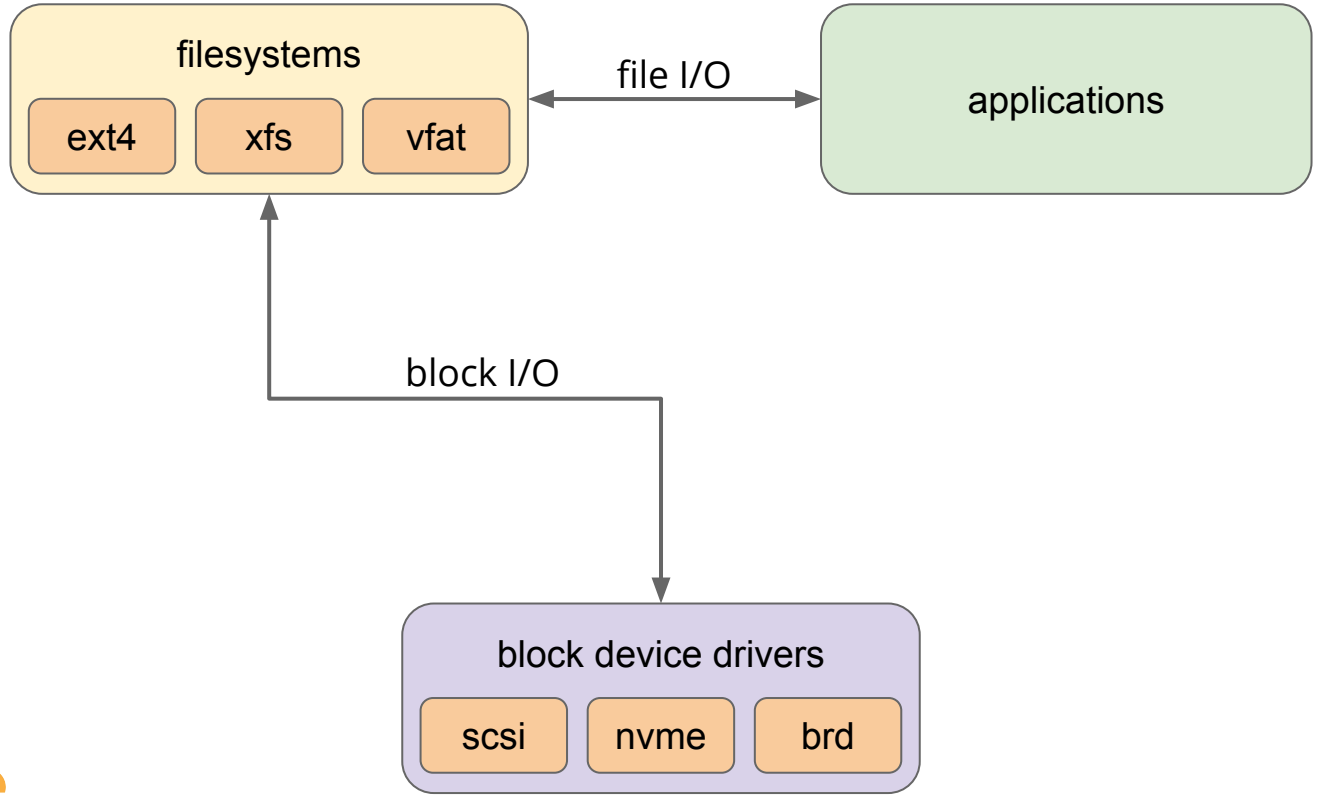

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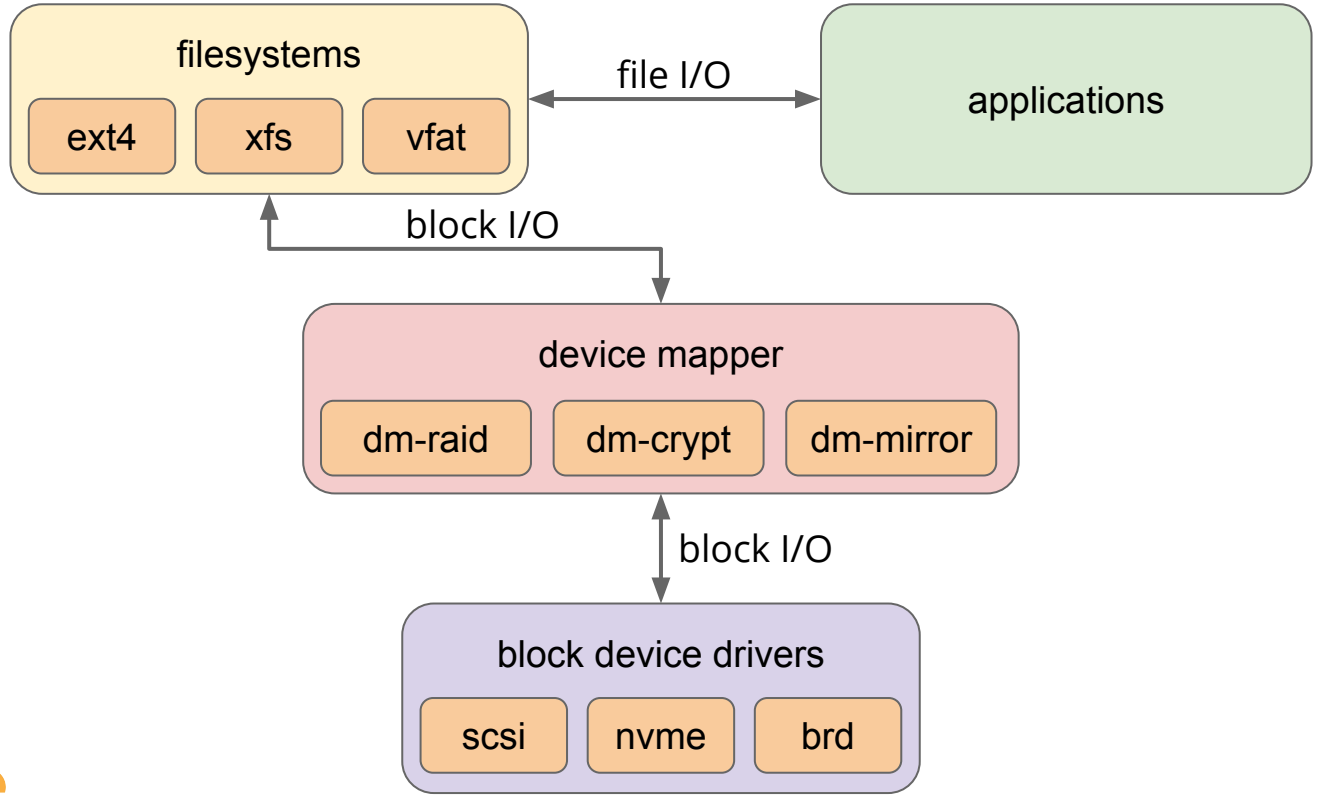

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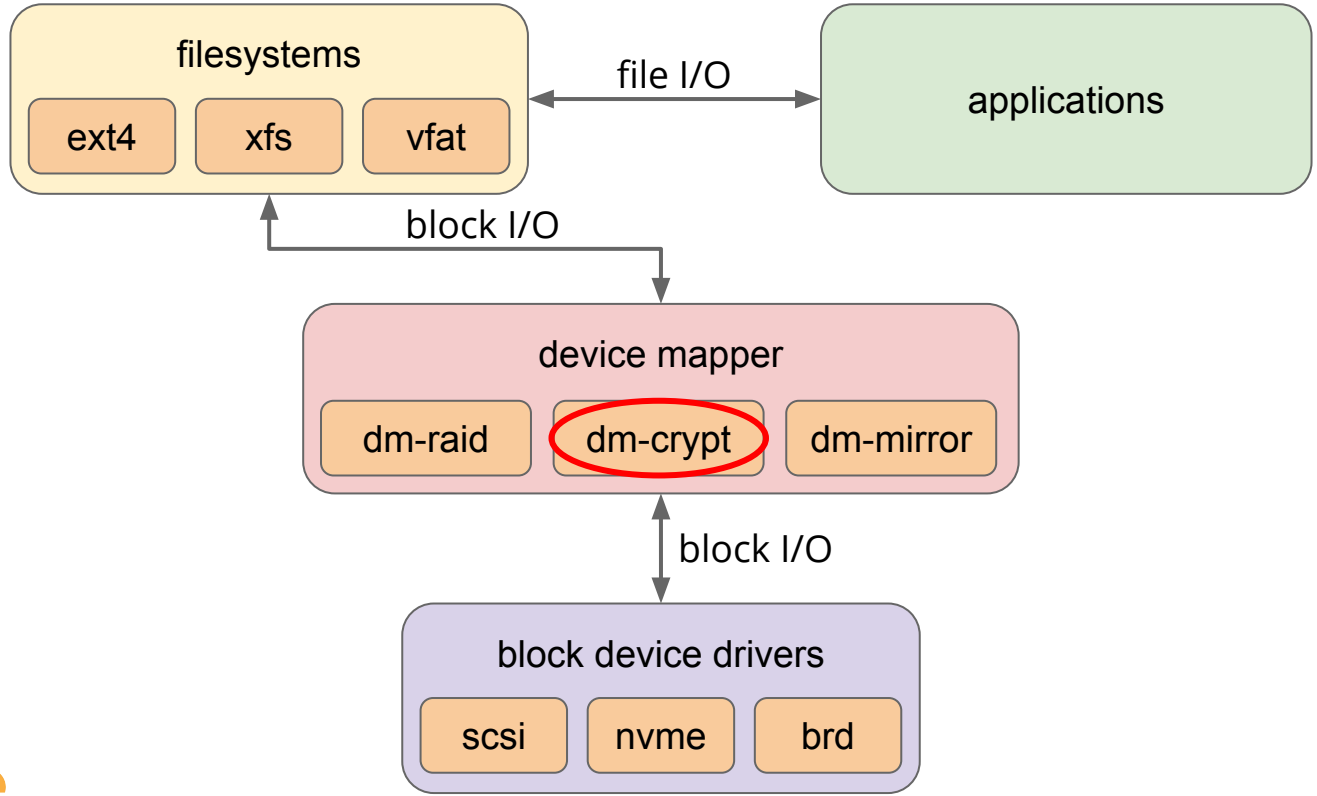

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dm-crypt (idealized)

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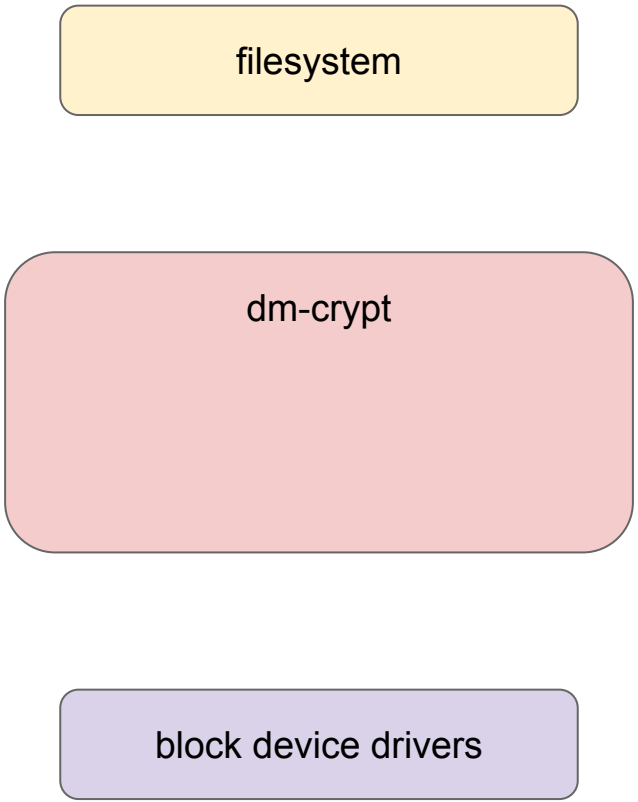

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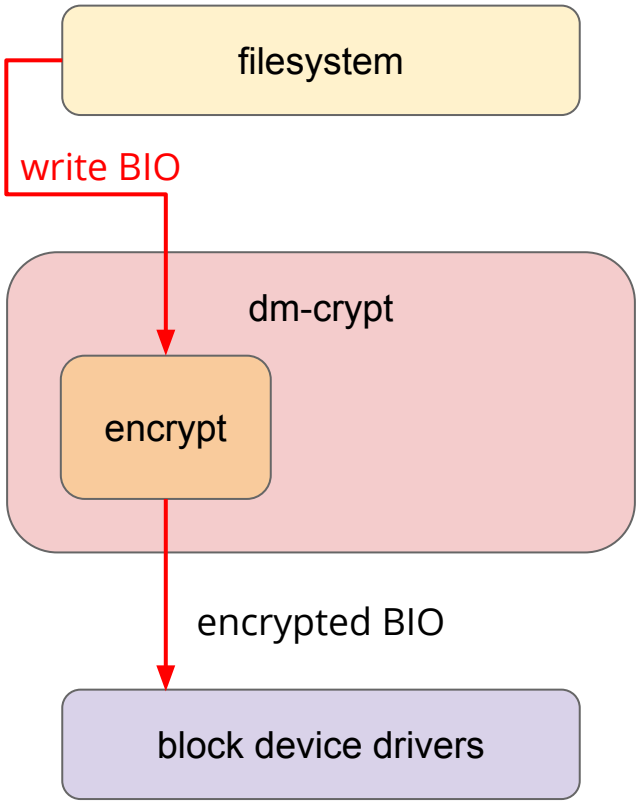

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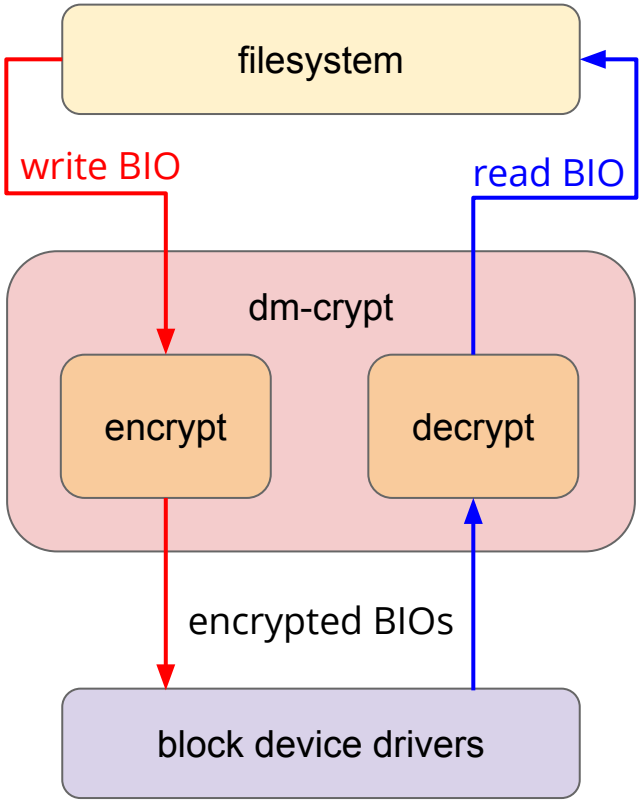

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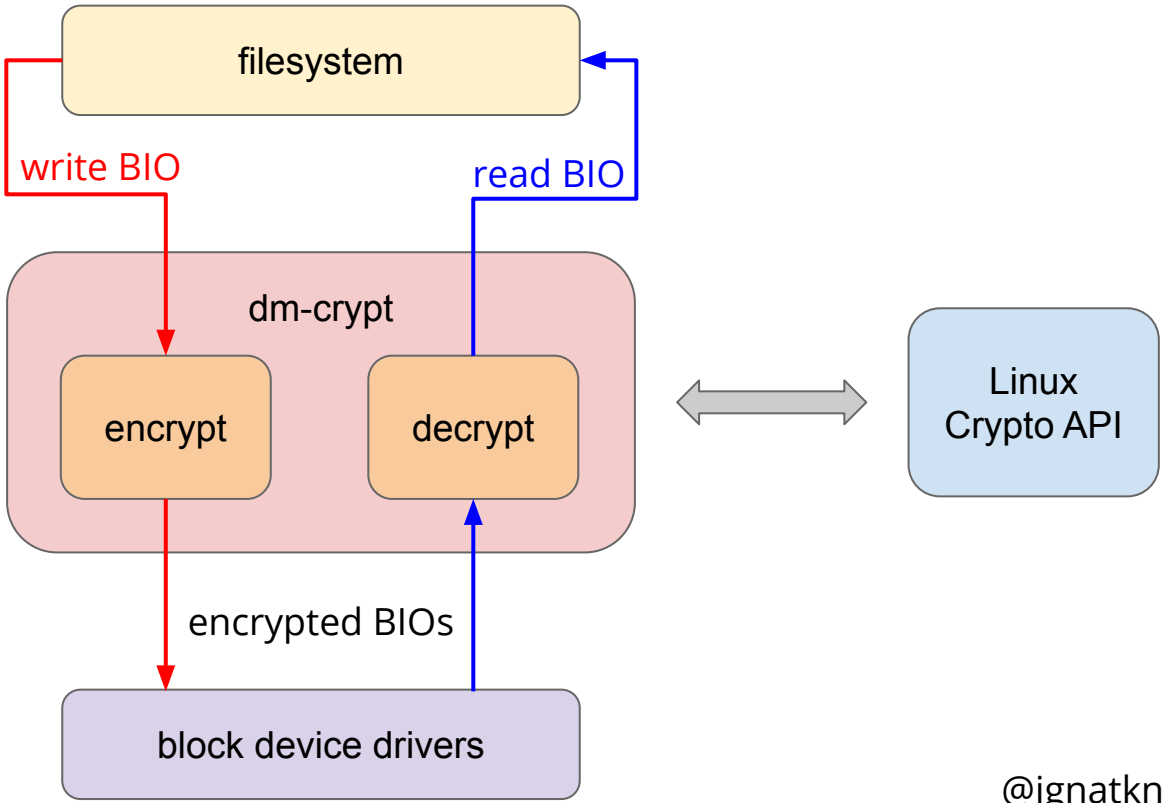

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dm-crypt benchmarking

Test setup: RAM-based encrypted disk

```
$ sudo modprobe brd rd_nr=1 rd_size=4194304
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$ sudo cryptsetup open --header crypthdr.img \
/dev/ram0 encrypted-ram0
```

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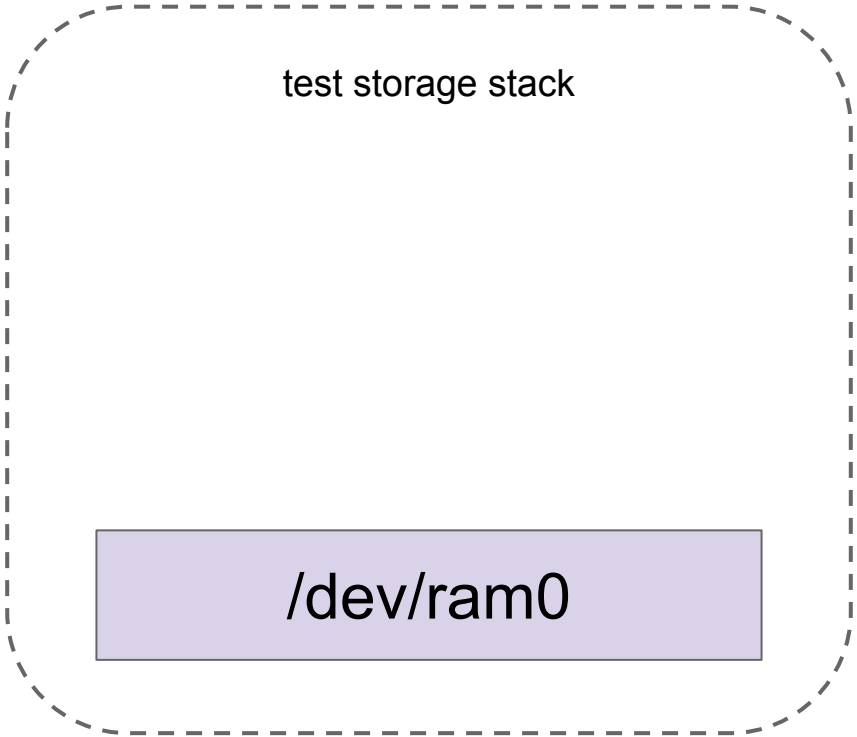

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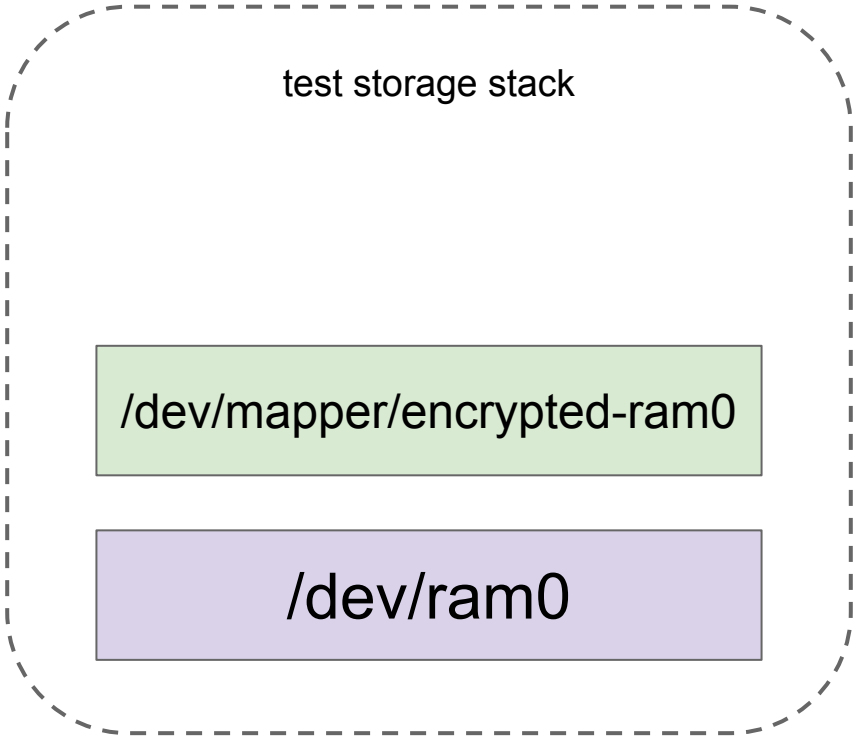

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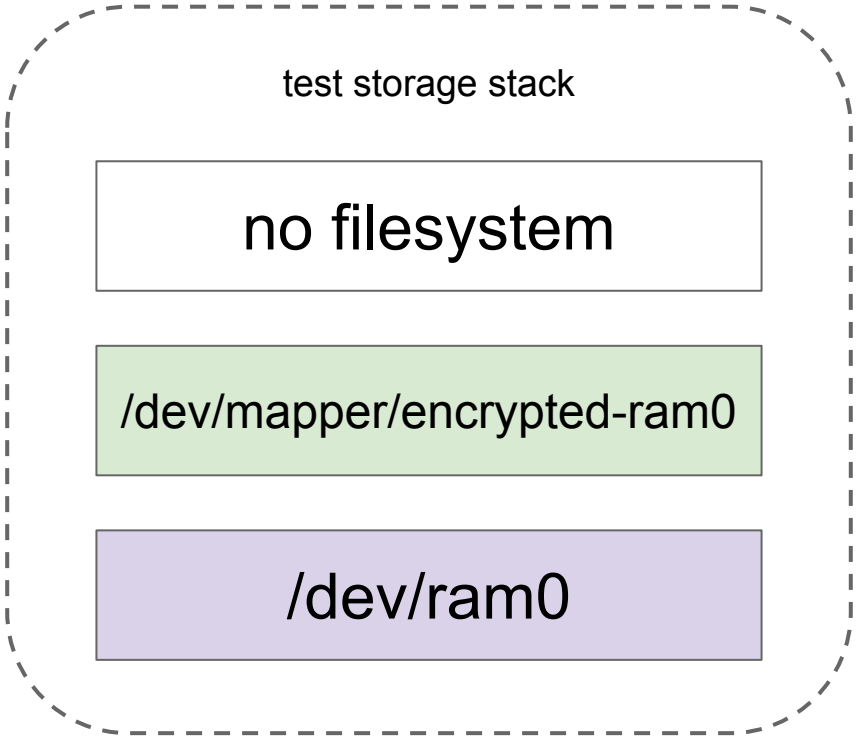

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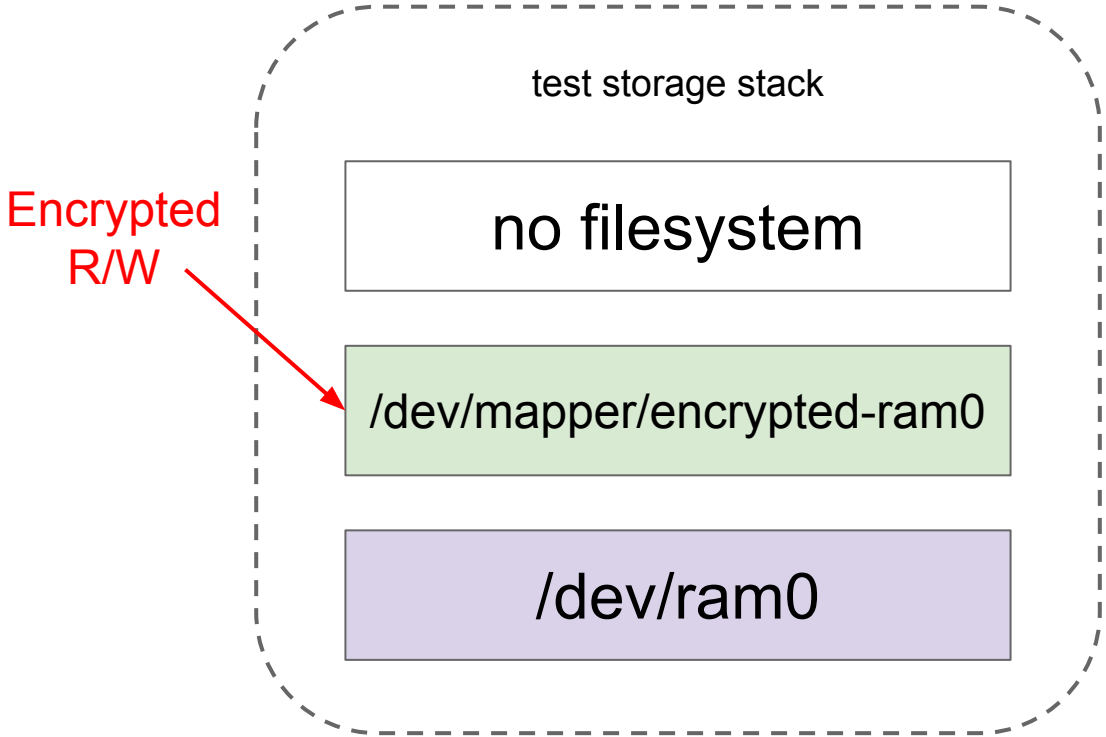

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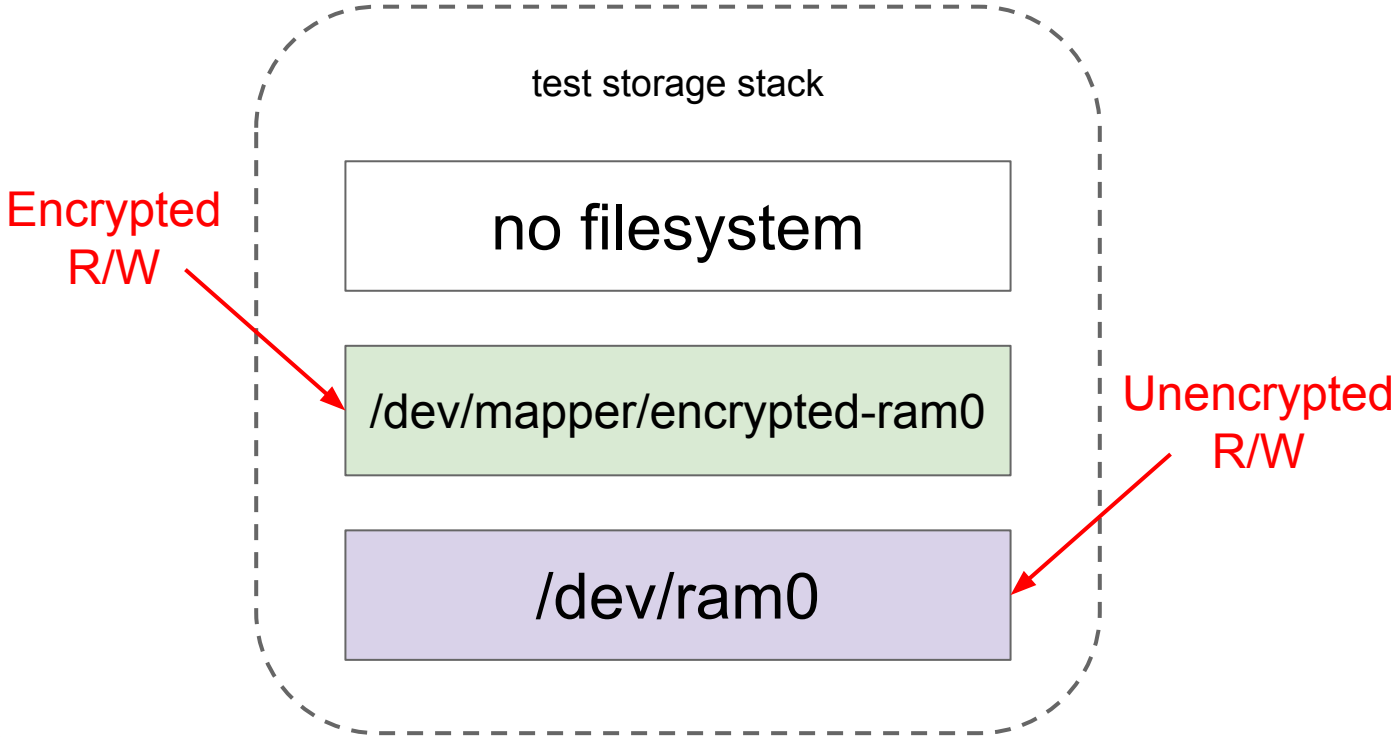

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Test setup: sequential reads

```
$ sudo fio --filename=/dev/ram0 \
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$ sudo fio --filename=/dev/ram0 \
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...
   READ: io=21013MB, aggrb=1126.5MB/s

  WRITE: io=21023MB, aggrb=1126.1MB/s
```

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Test setup: sequential reads

```
$ sudo fio \
--filename=/dev/mapper/encrypted-ram0 \
--readwrite=readwrite --bs=4k --direct=1 \
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~7x slower!

Test setup: sequential reads

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$ sudo cryptsetup benchmark -c aes-xts
# Tests are approximate using memory only (no
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#  Algorithm | Key |  Encryption |  Decryption
     aes-xts   256b  1823.1 MiB/s  1900.3 MiB/s
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desired: **~696 MB/s**, actual: **~294 MB/s**

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  - “`same_cpu_crypt`” and “`submit_from_crypt_cpus`”

We tried...

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- experimenting with dm-crypt optional flags
  - “`same_cpu_crypt`” and “`submit_from_crypt_cpus`”
- trying filesystem-level encryption
  - much slower and potentially less secure

Despair

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Ask the community

“If the numbers disturb you, then this is from lack of understanding on your side. You are probably unaware that encryption is a heavy-weight operation…“

https://www.spinics.net/lists/dm-crypt/msg07516.html

But actually…

“Using TLS is very cheap, even at the scale of Cloudflare. Modern crypto is very fast, with AES-GCM and P256 being great examples.”

https://blog.cloudflare.com/how-expensive-is-crypto-anyway/

dm-crypt: life of an encrypted BIO request

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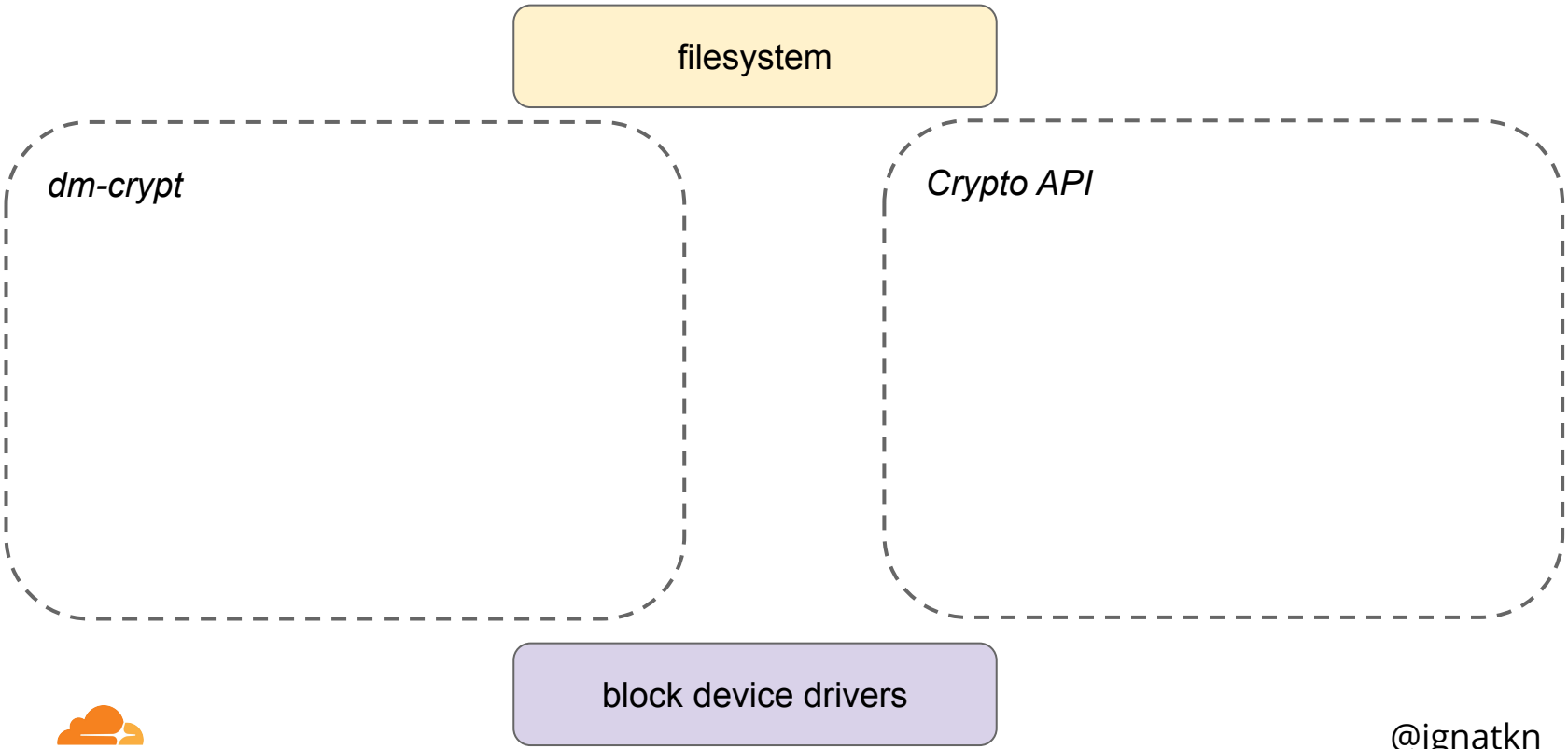

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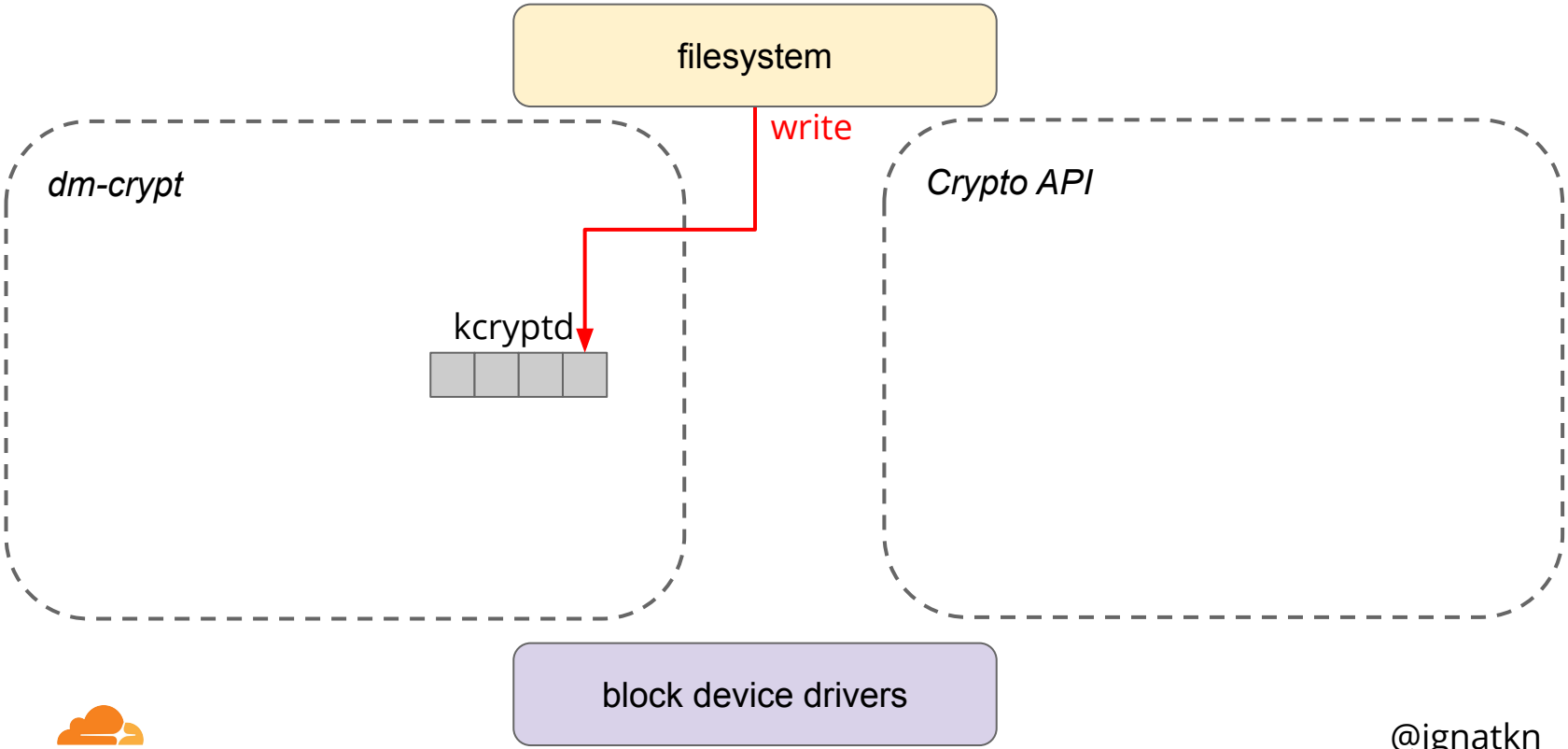

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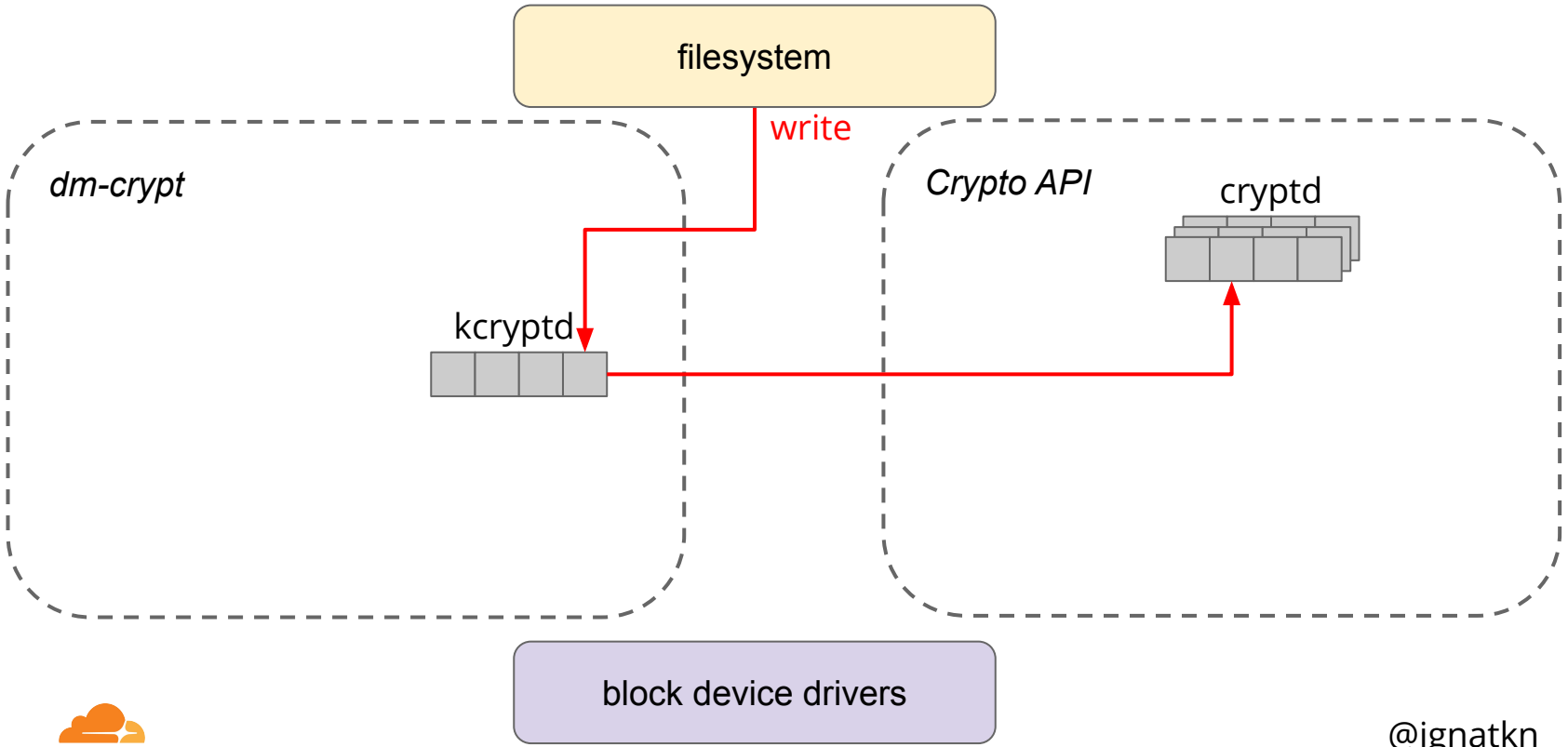

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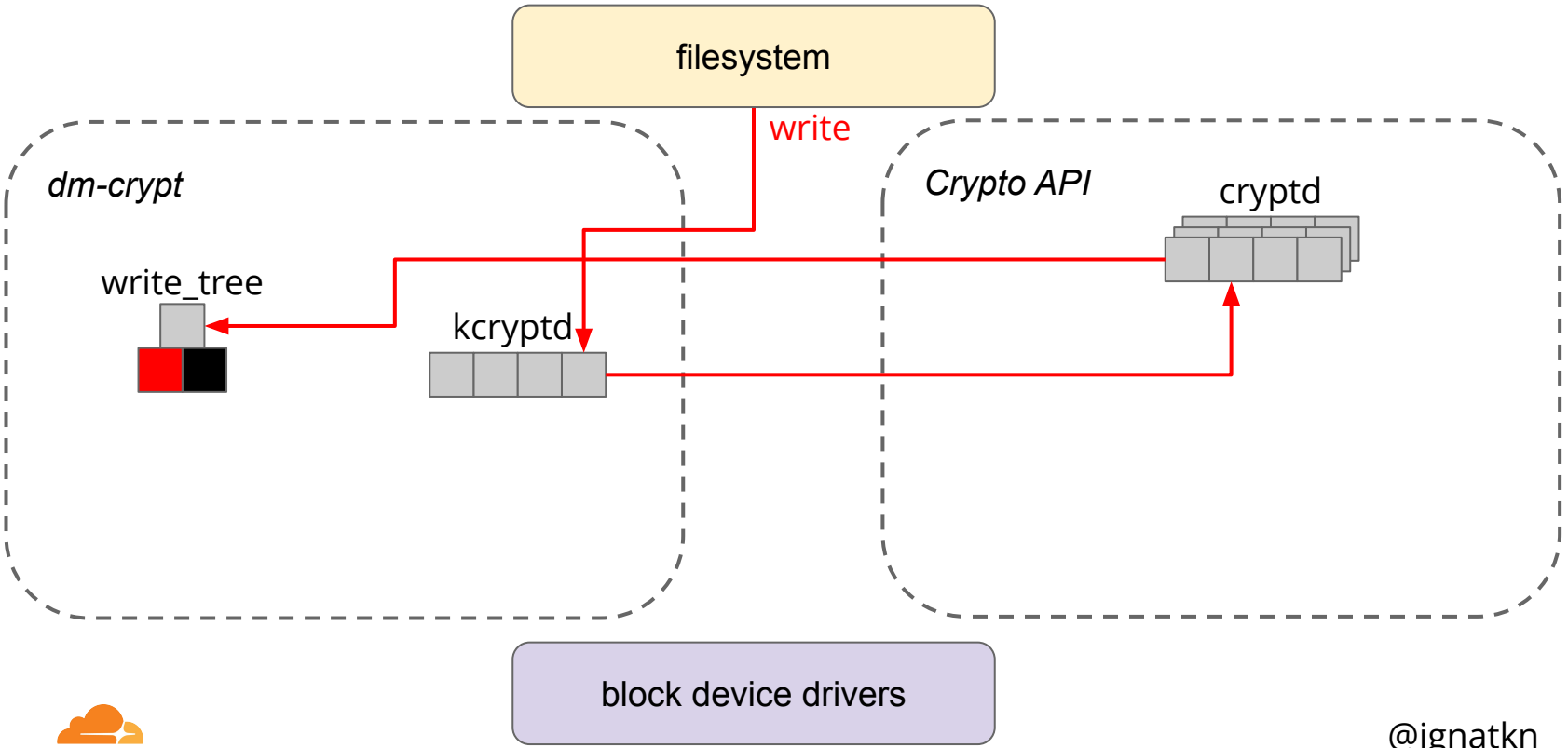

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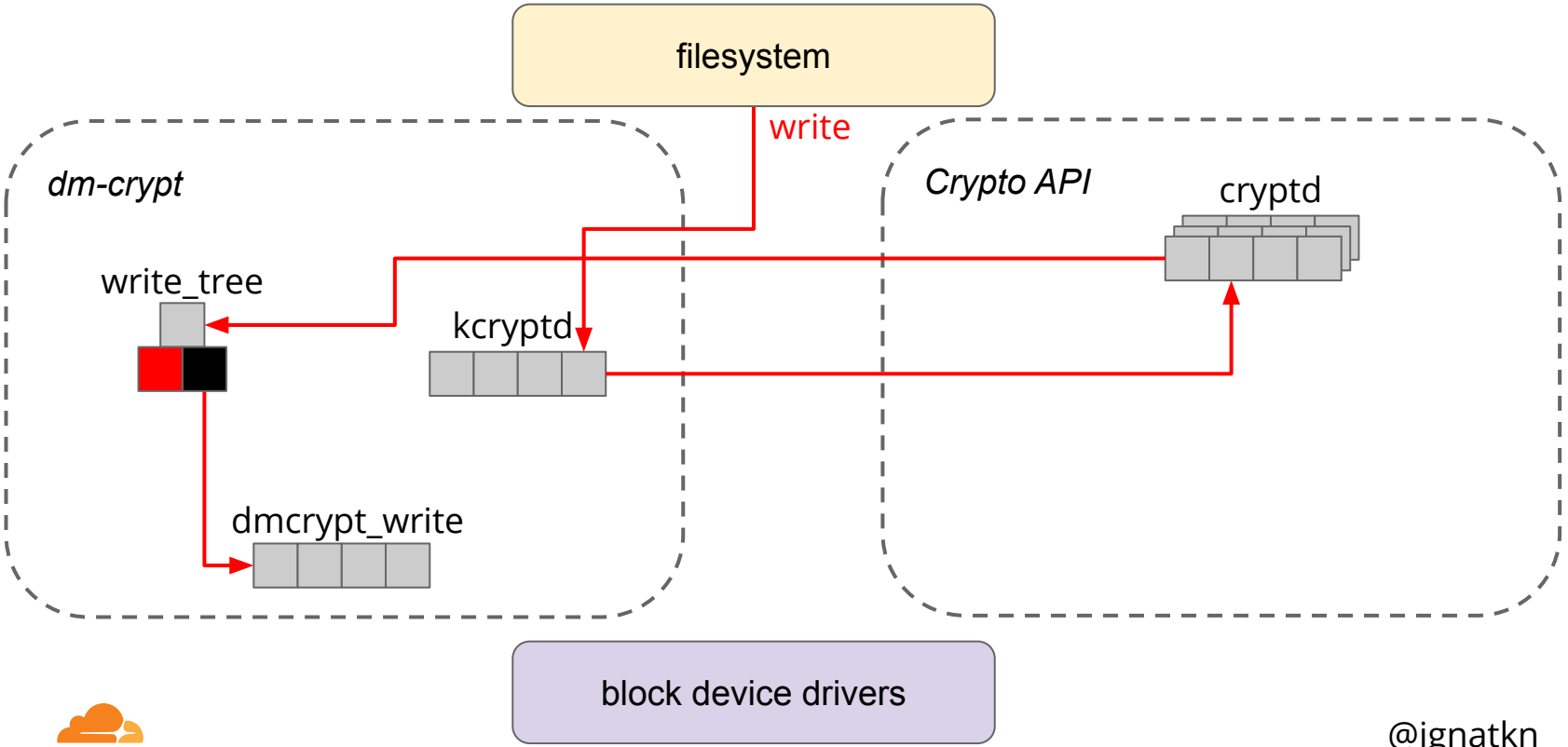

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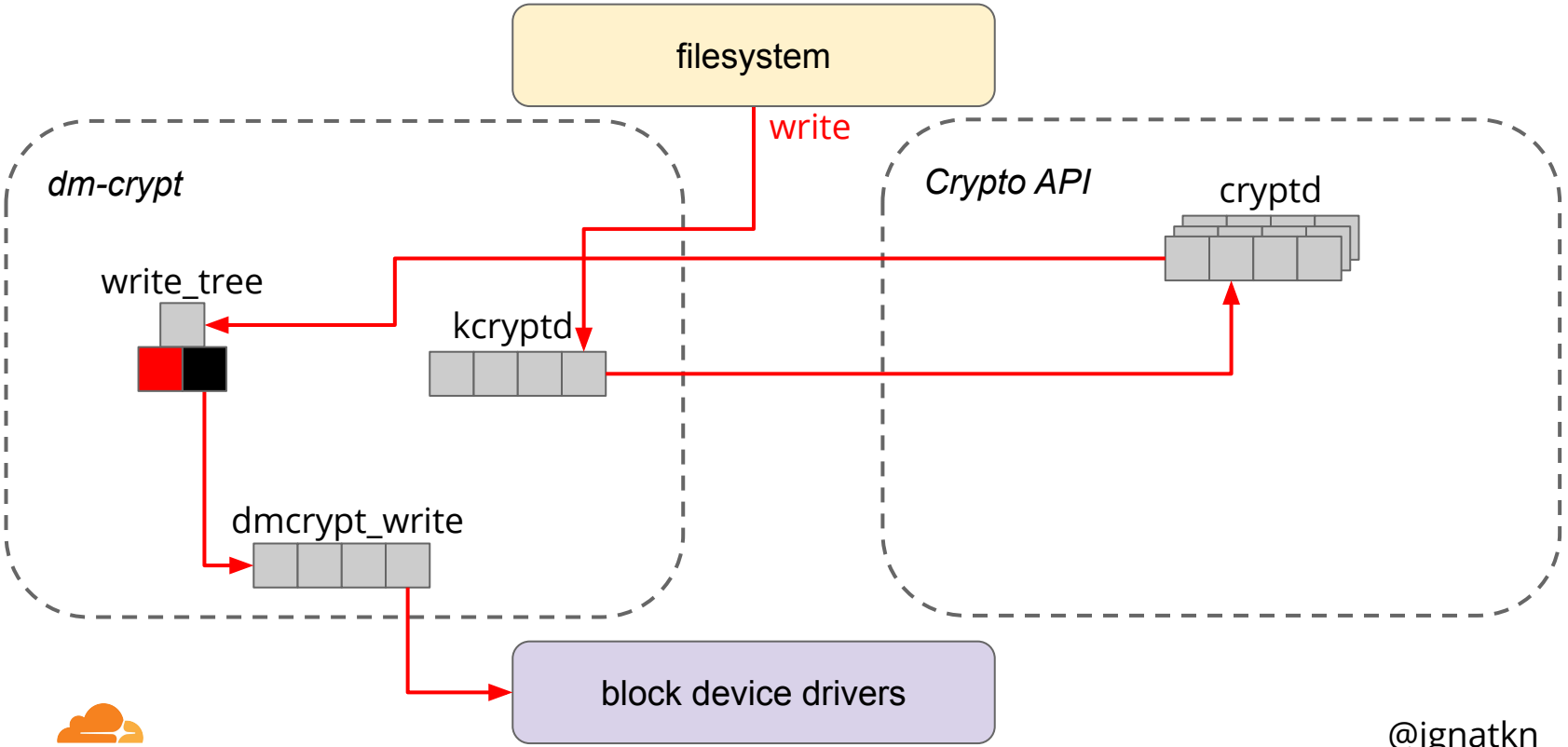

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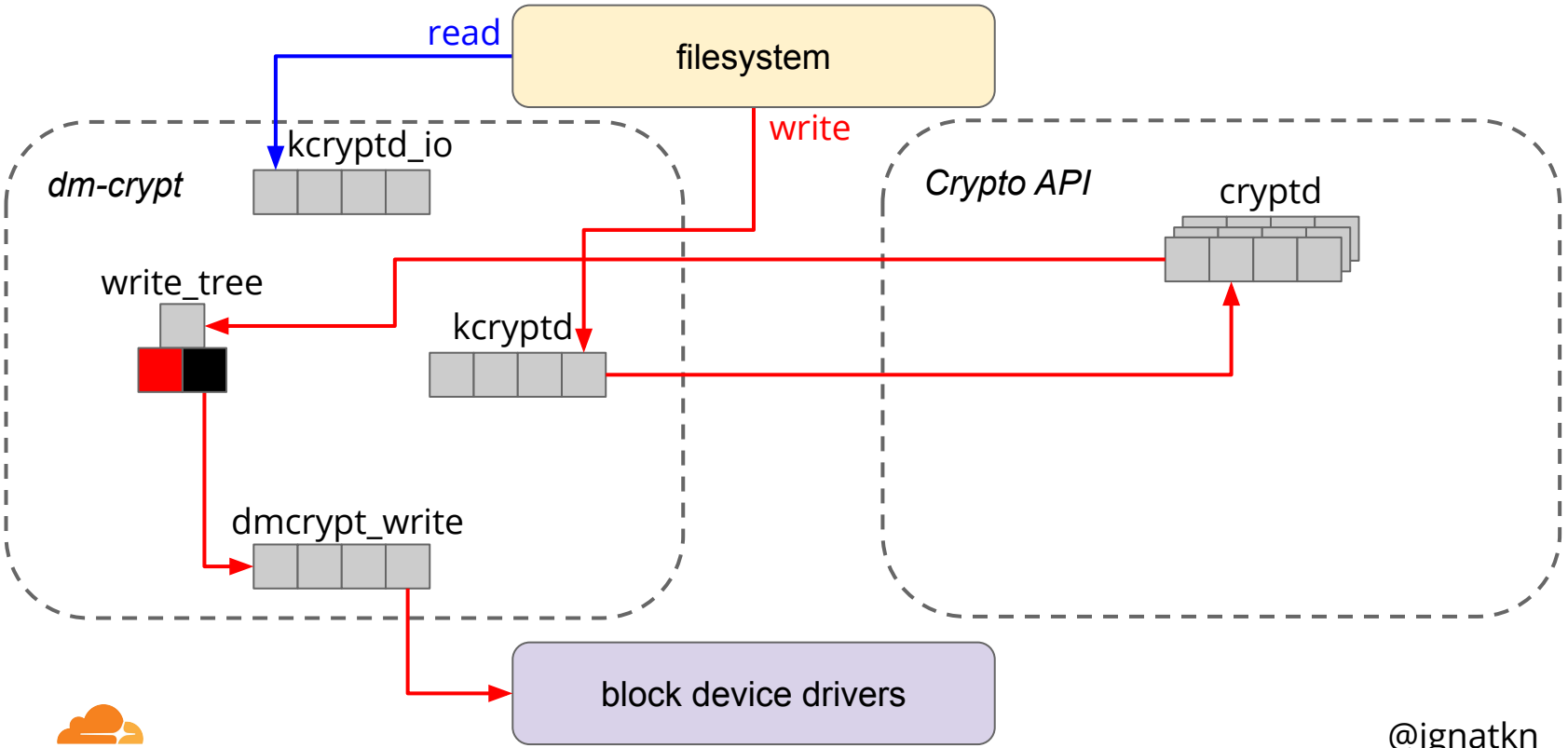

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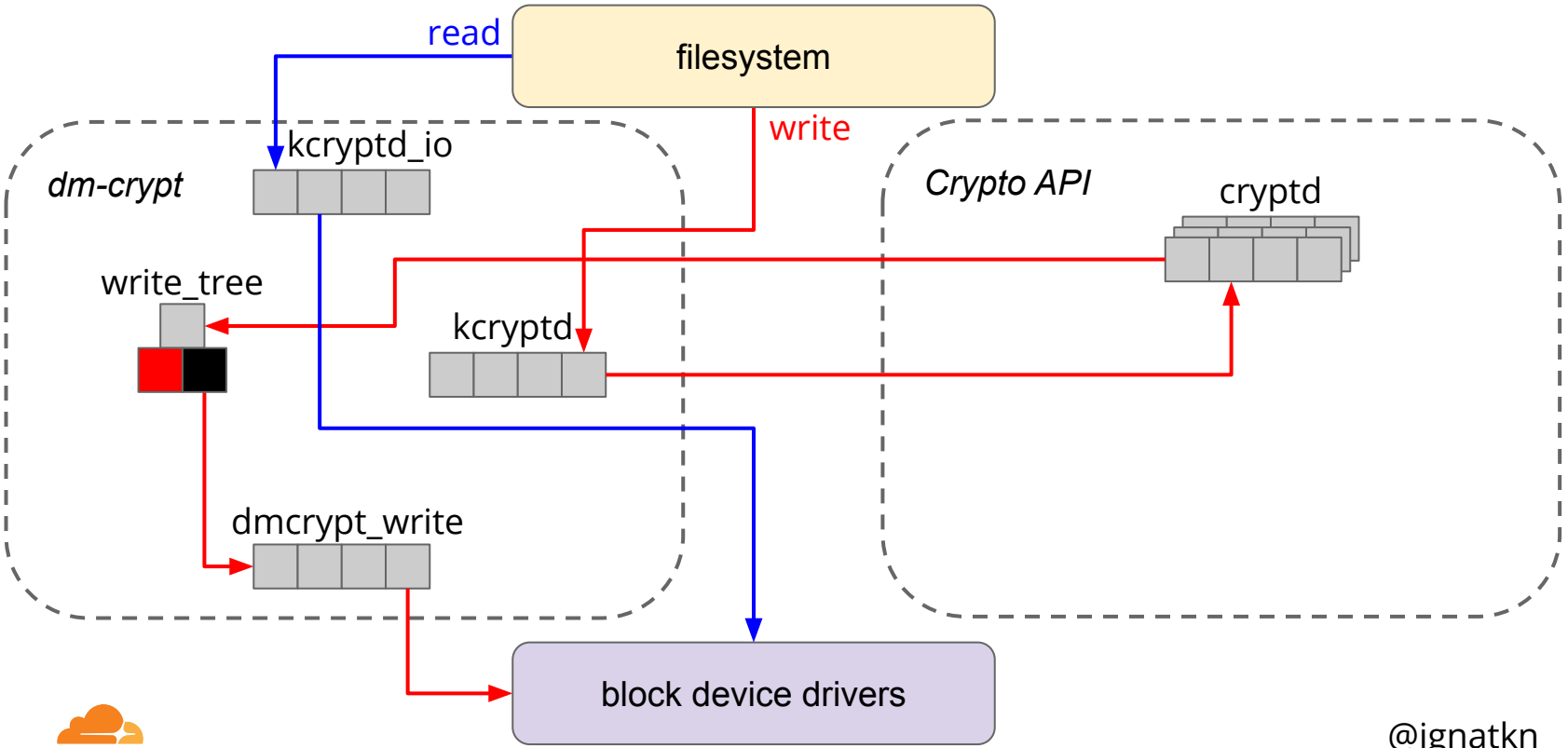

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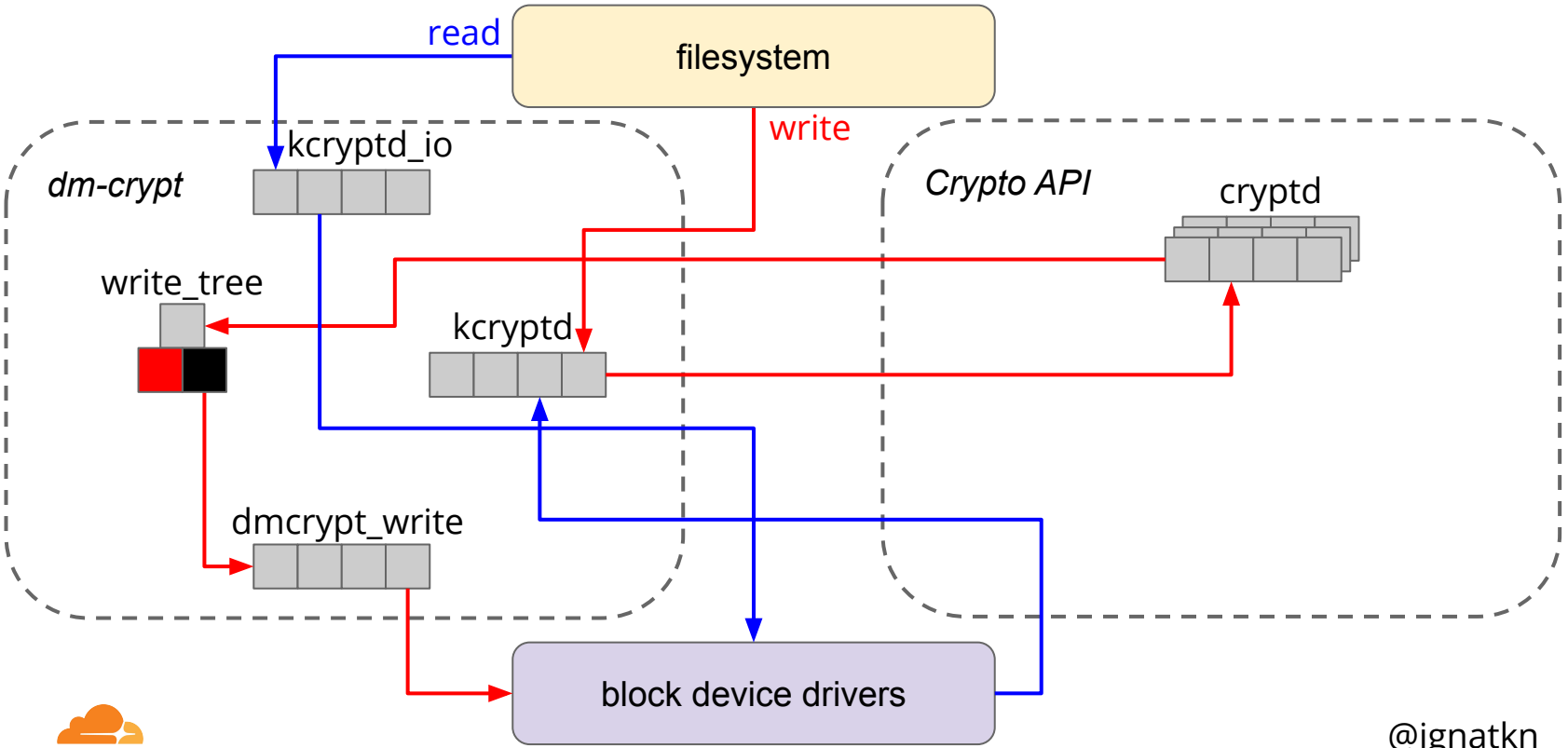

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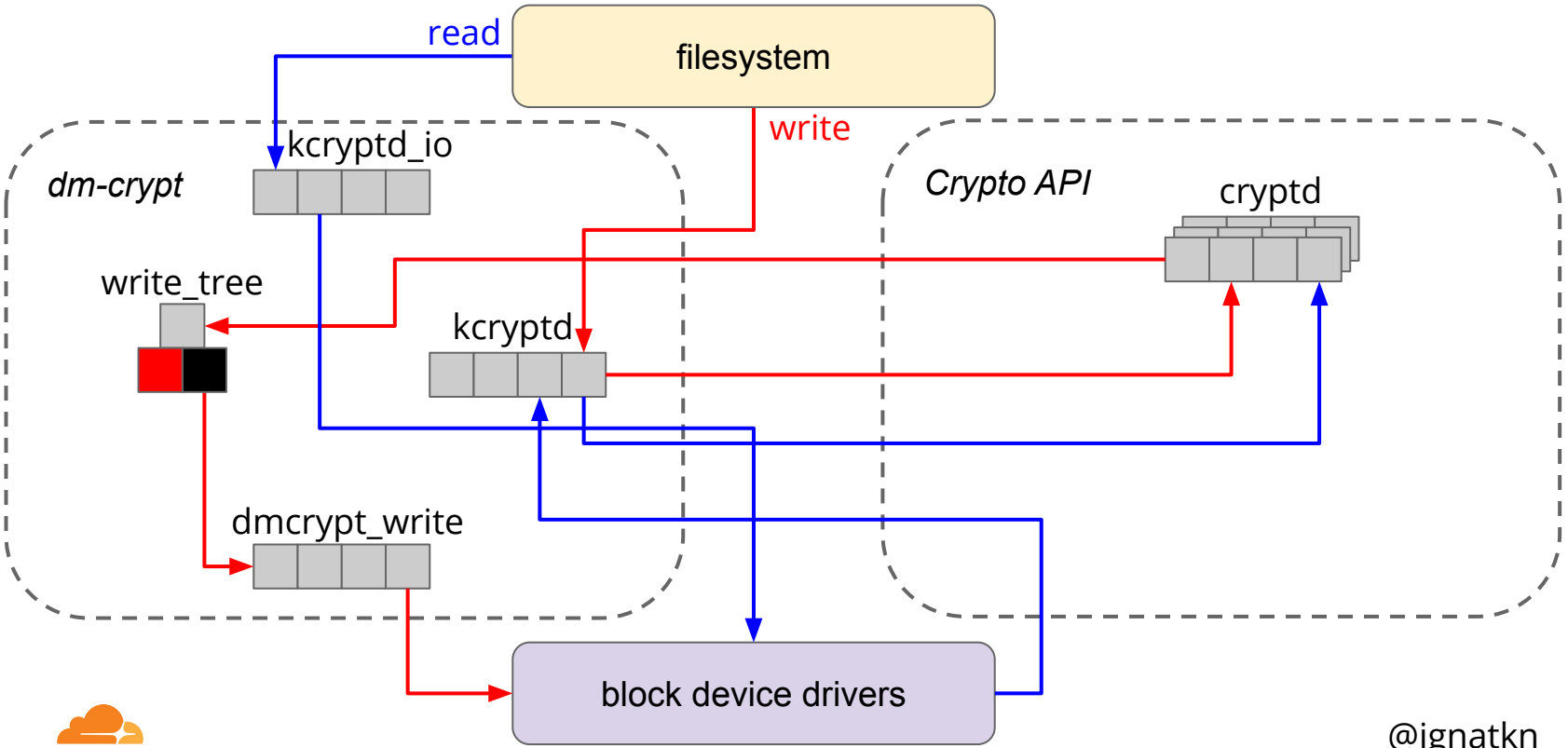

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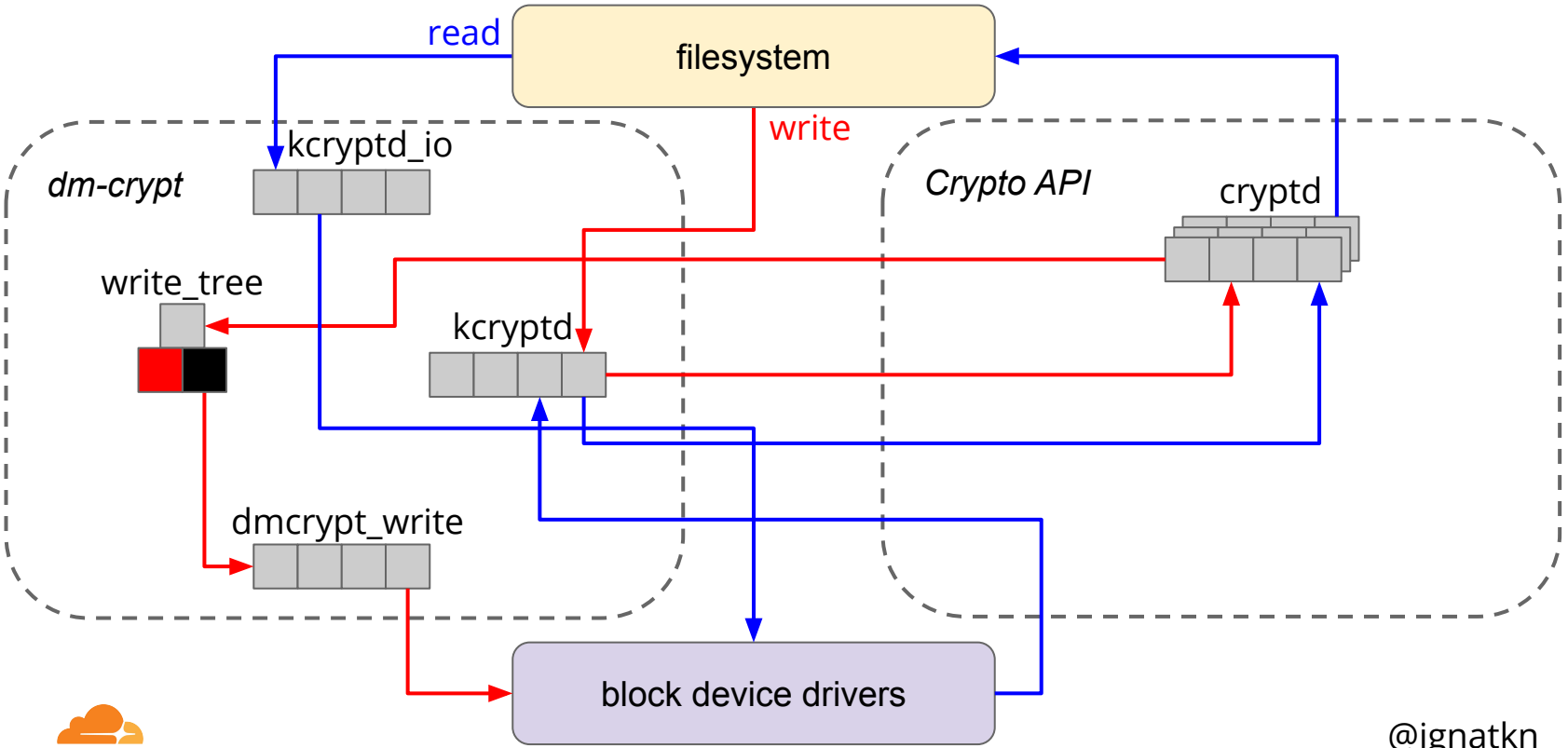

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queues vs latency

“A significant amount of tail latency is due to queueing effects”

https://www.usenix.org/conference/srecon19asia/presentation/plenz

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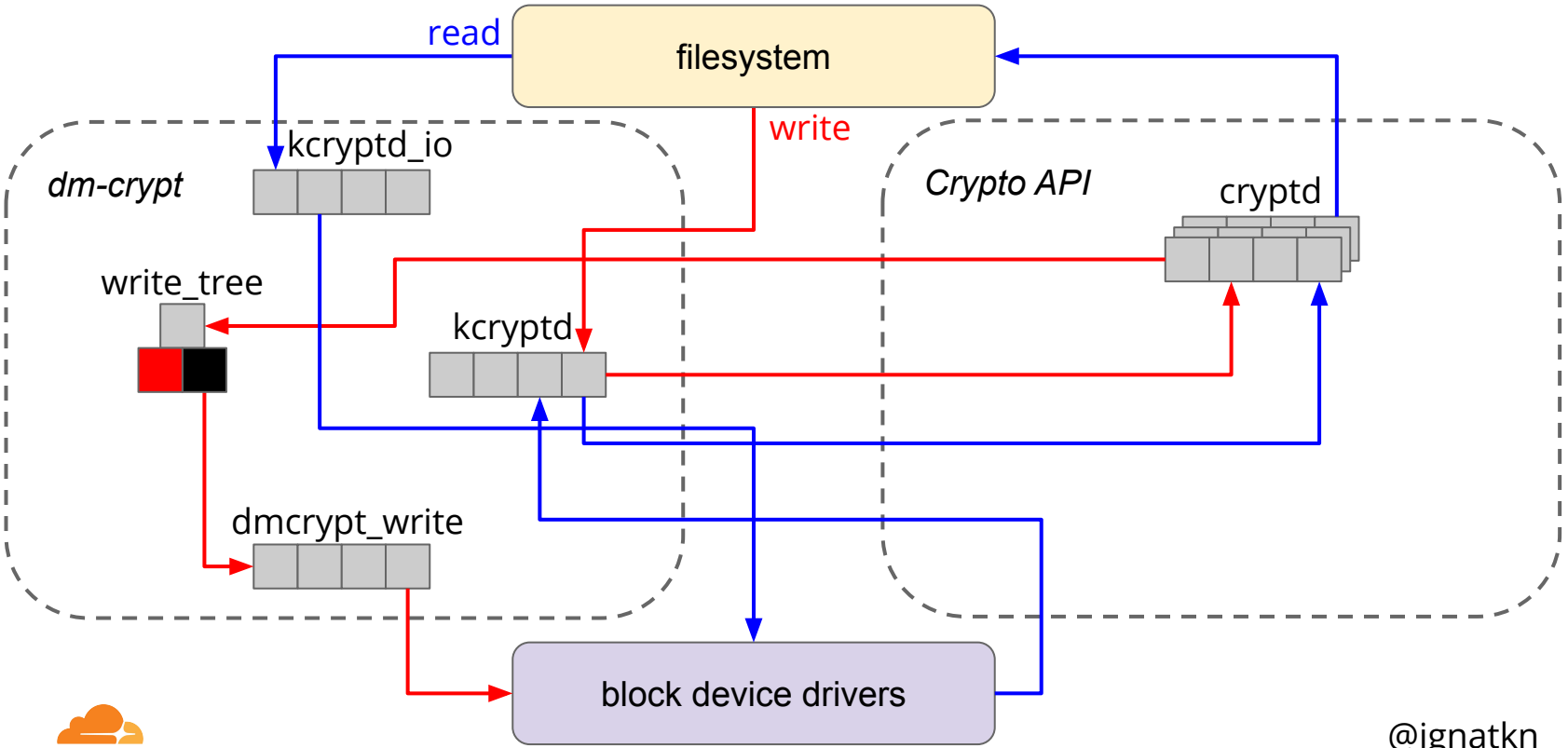

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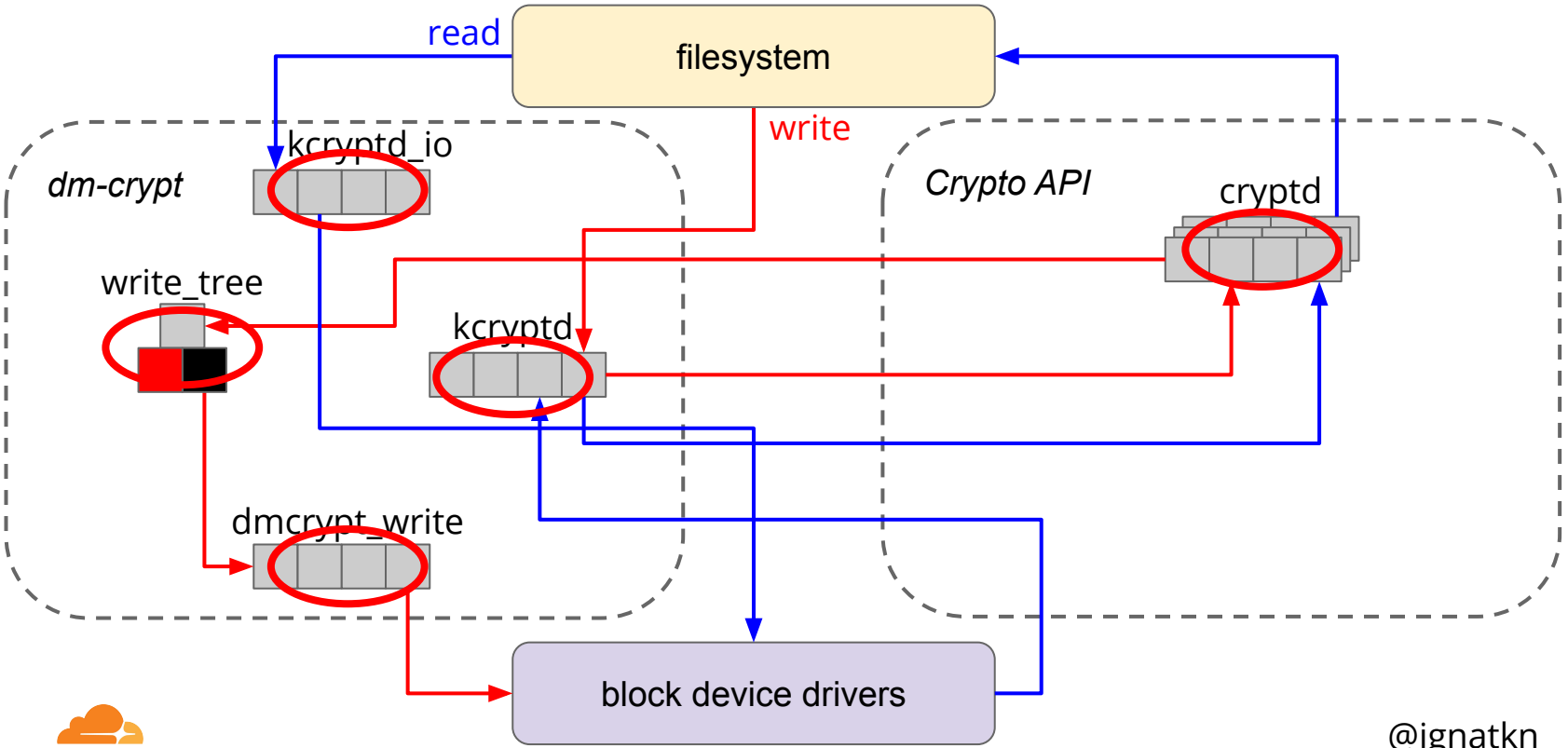

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- offload writes to thread and IO sorting (2015)
  - for spinning disks, but “may improve SSDs”
  - mentions CFQ scheduler, which is deprecated
- commits to optionally revert some queuing
  - “`same_cpu_crypt`” and “`submit_from_crypt_cpus`” option flags

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  - disk IO latency >> scheduling latency
- sorting BIOs in dm-crypt probably violates “do one thing and do it well” Unix principle
  - the task for the IO scheduler
- `kcryptd` may be redundant as modern Linux Crypto API is asynchronous by itself
  - remove offloading the offload

dm-crypt: cleanup

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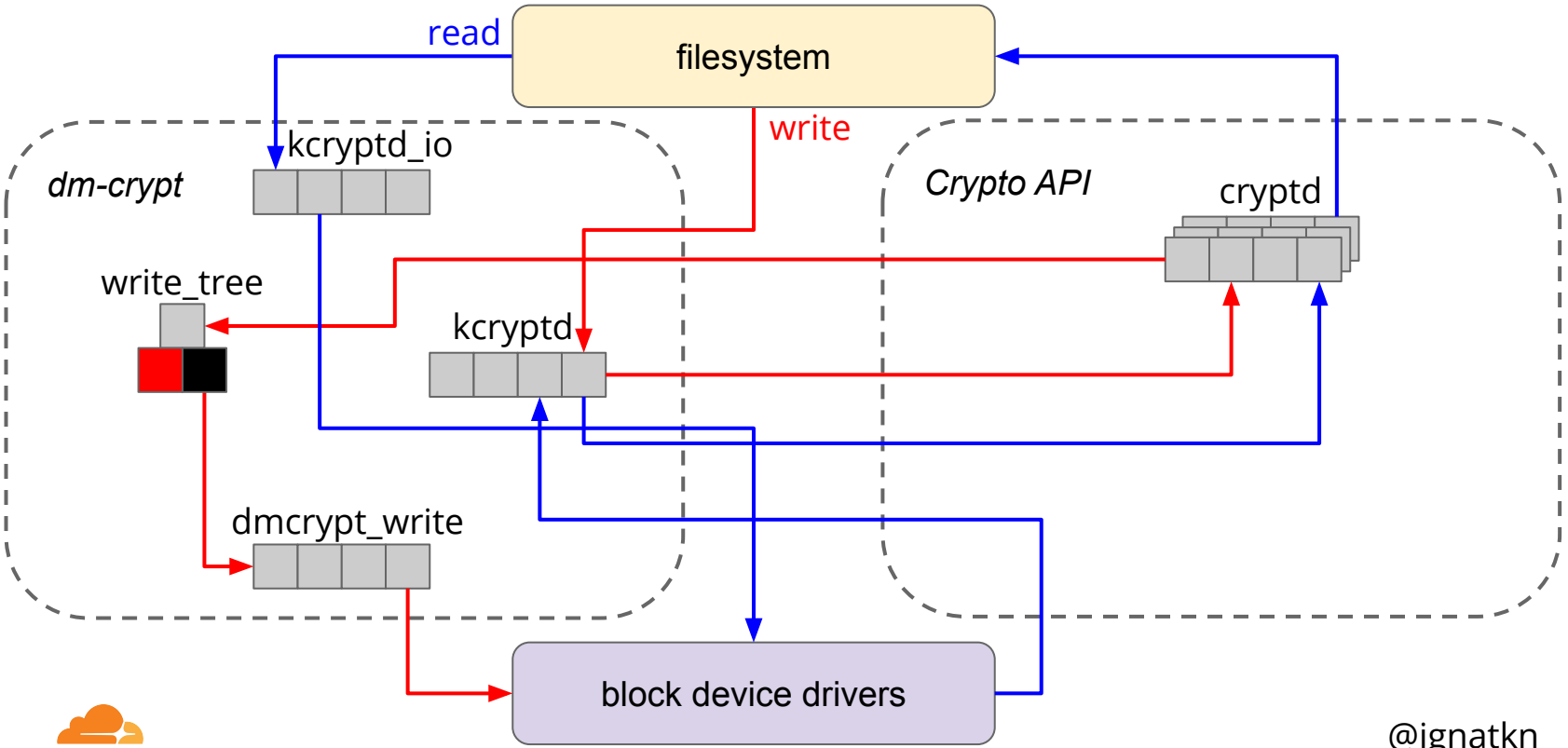

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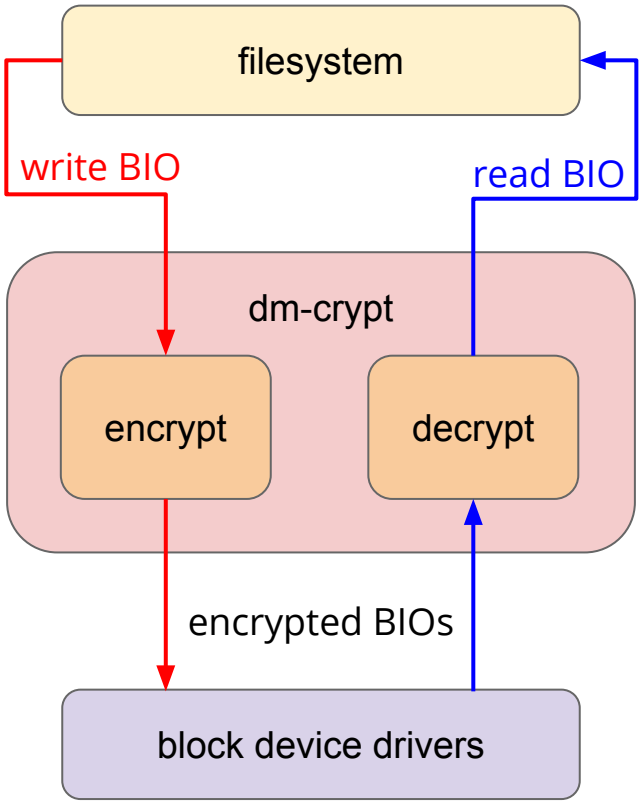

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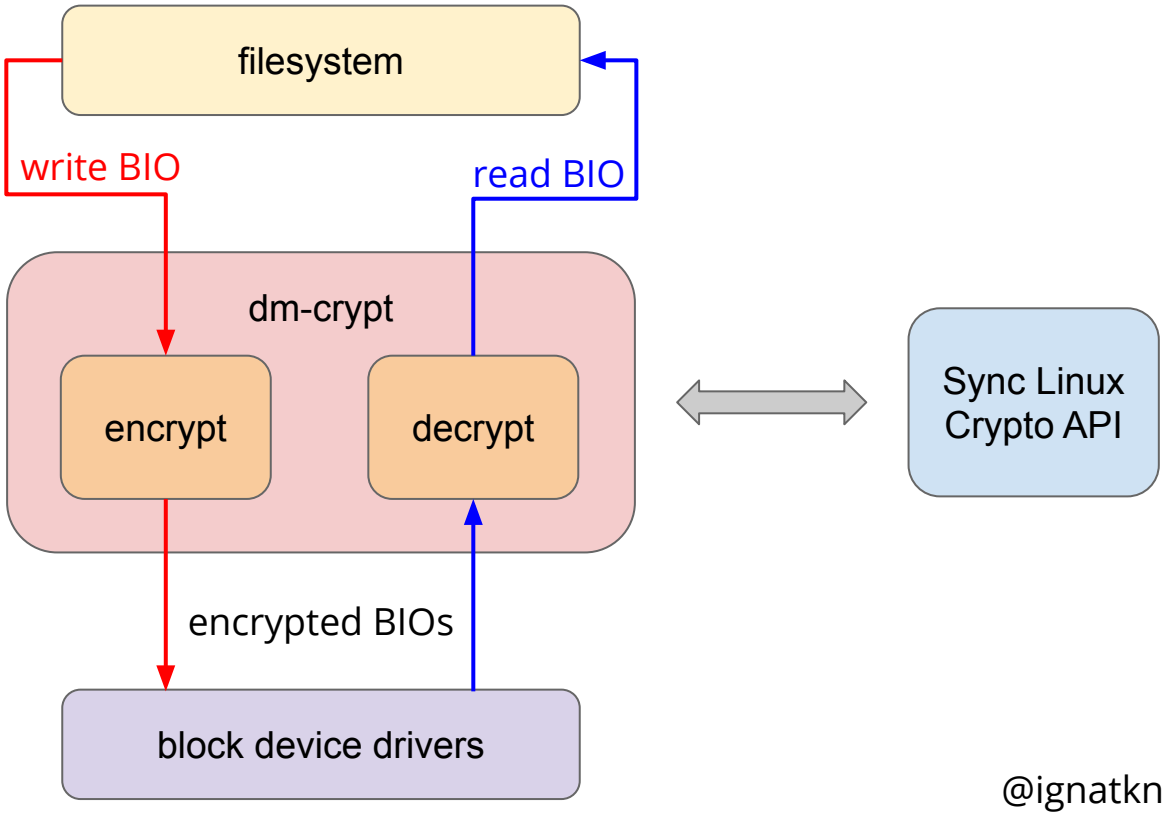

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- Linux Crypto API is a bit more complicated
  - by default specific implementation is selected dynamically based on priority
  - aes-ni synchronous implementation is marked as “internal”
  - aes-ni (FPU) is not usable in some interrupt contexts

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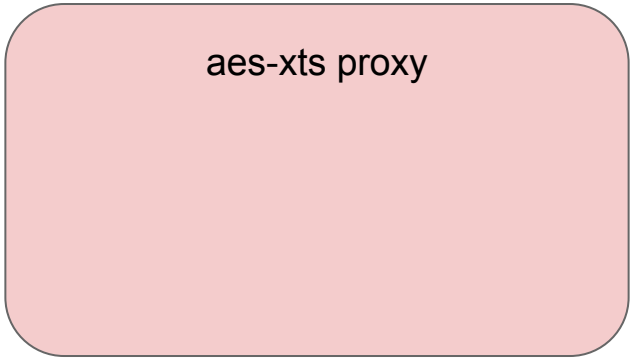
- dm-crypt module: a simple patch, which bypasses all queues/async threads based on a new runtime flag
- Linux Crypto API is a bit more complicated
  - by default specific implementation is selected dynamically based on priority
  - aes-ni synchronous implementation is marked as “internal”
  - aes-ni (FPU) is not usable in some interrupt contexts
- xtsproxy: a dedicated synchronous aes-xts module

xtsproxy crypto API module



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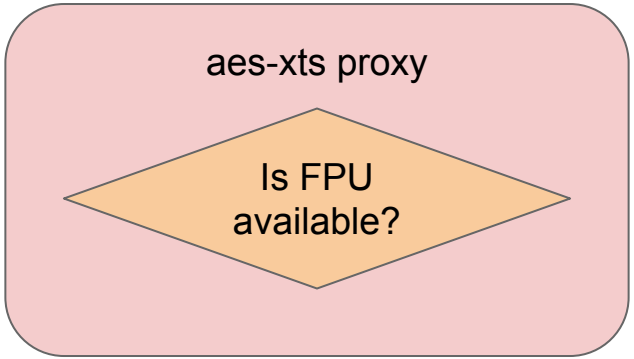

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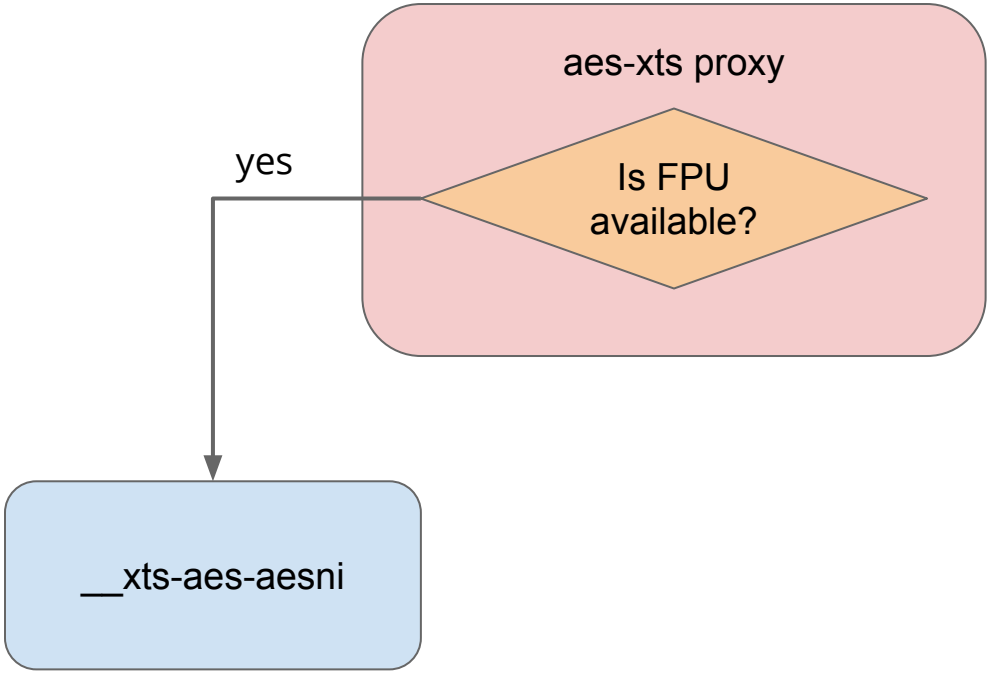

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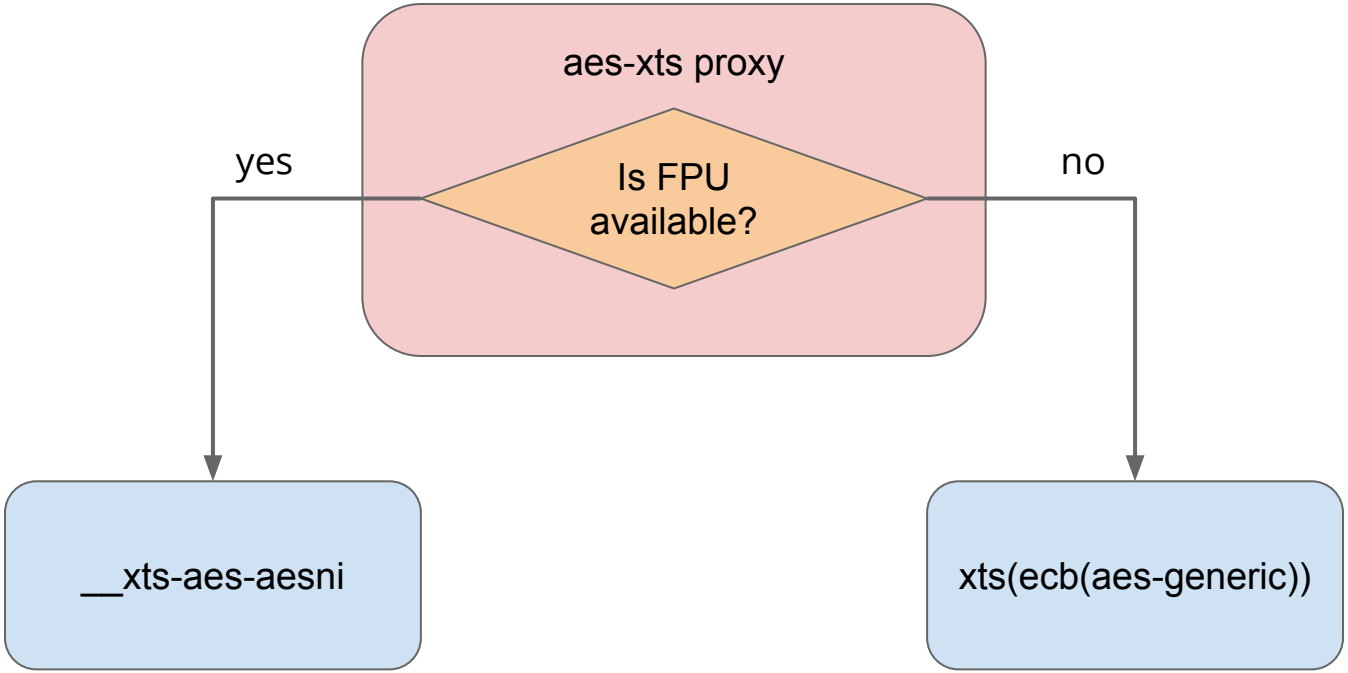

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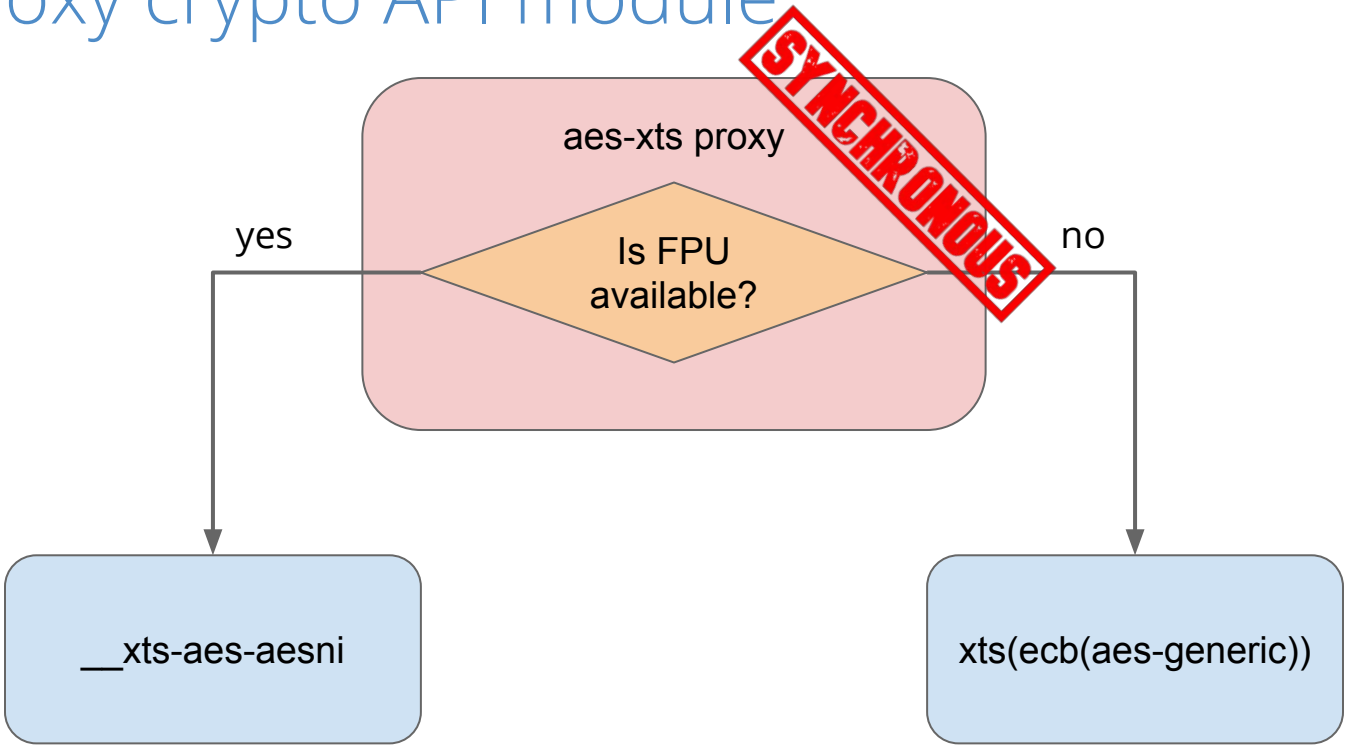

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Test setup: sequential IO

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$ sudo fio --filename=/dev/mapper/encrypted-ram0 \
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$ sudo dmsetup suspend encrypted-ram0 && sudo dmsetup \
resume encrypted-ram0
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ramdisk: read throughput

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ramdisk: write throughput

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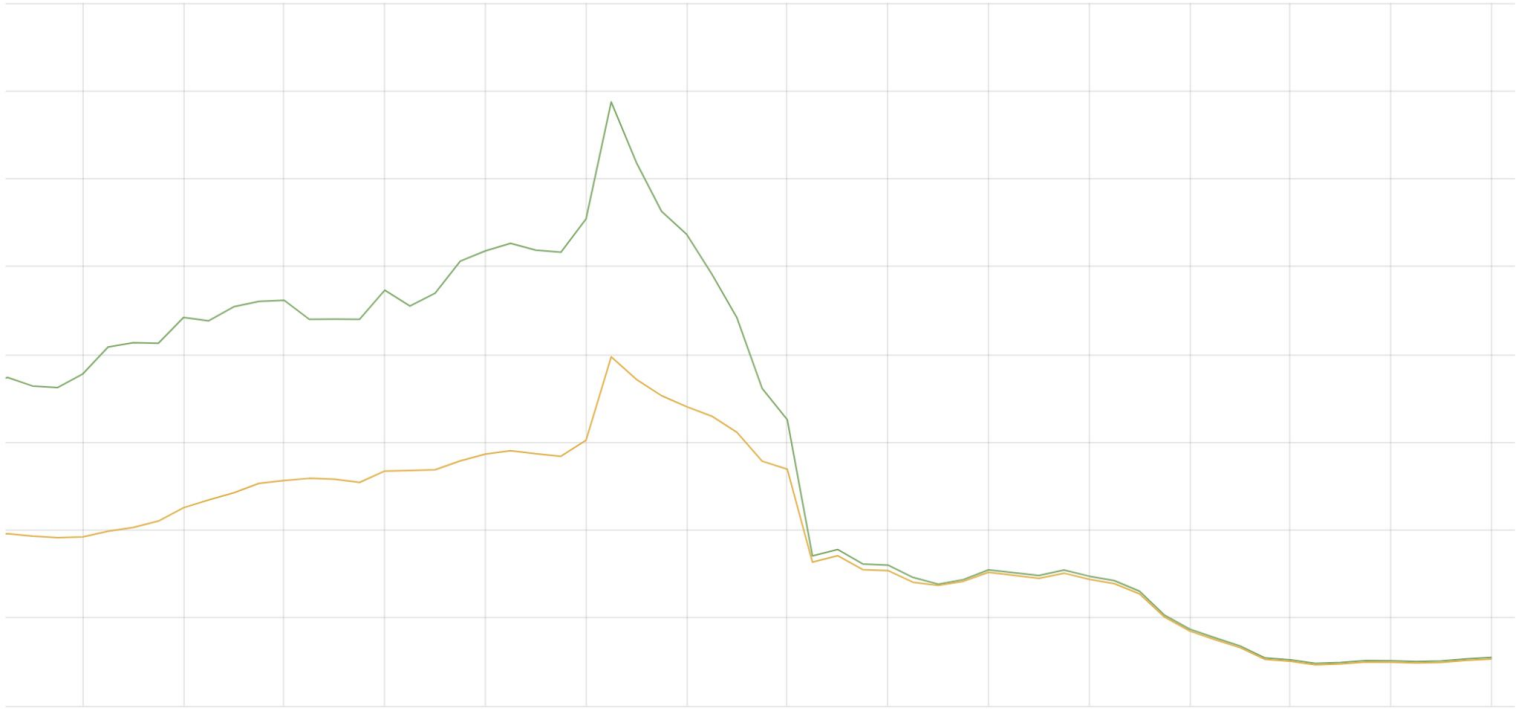
ssd: IO latency (iowait)

- ssd disk
- dm-crypt device



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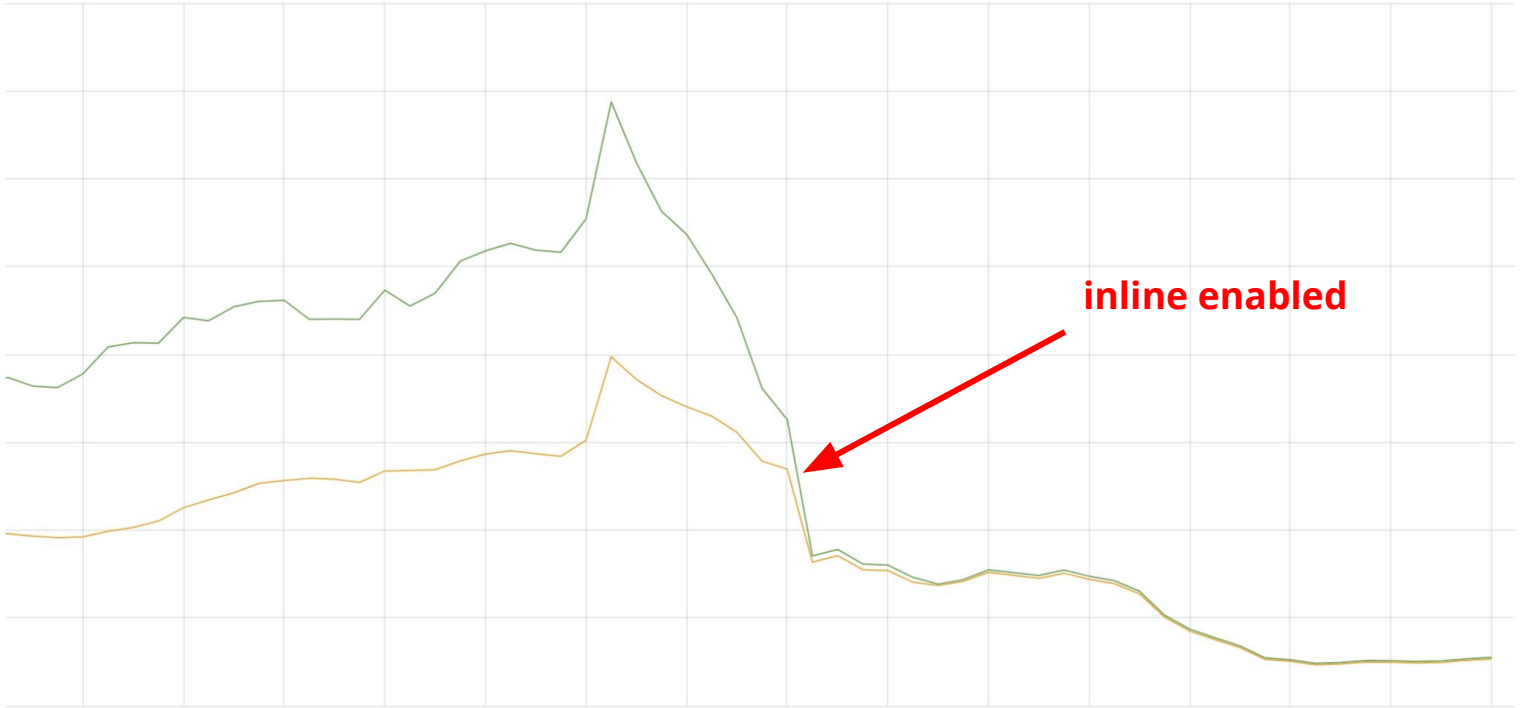

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Cloudflare cache impact

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Cloudflare cache impact

- unencrypted
- encrypted
- encrypted with patched dm-crypt

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Conclusions

- a simple patch which may improve dm-crypt performance by 200%-300%
  - fully compatible with stock Linux dm-crypt
  - can be enabled/disabled in runtime without service disruption
- modern crypto is fast and cheap
  - performance degradation is likely elsewhere
- extra queuing may be harmful on modern low latency storage

Caveats and future work

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- the patch improves performance on small block size/high IOPS workloads
  - >2MB block size shows worse performance
- the whole setup assumes hardware-accelerated crypto
  - xtsproxy supports x86 only
- your mileage may vary
  - always measure and compare before deployment
  - let us know the results

Links

- https://gitlab.com/cryptsetup/cryptsetup
- http://man7.org/linux/man-pages/man8/dmsetup.8.html
- https://blog.cloudflare.com/speeding-up-linux-disk-encryption
- https://github.com/cloudflare/linux
- Linux commit 39d42fa96ba1b7d2544db3f8ed5da8fb0d5cb877

  (available from Linux 5.9)

Questions?

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