



in  
120 minutes

SLEEP BETTER WITH

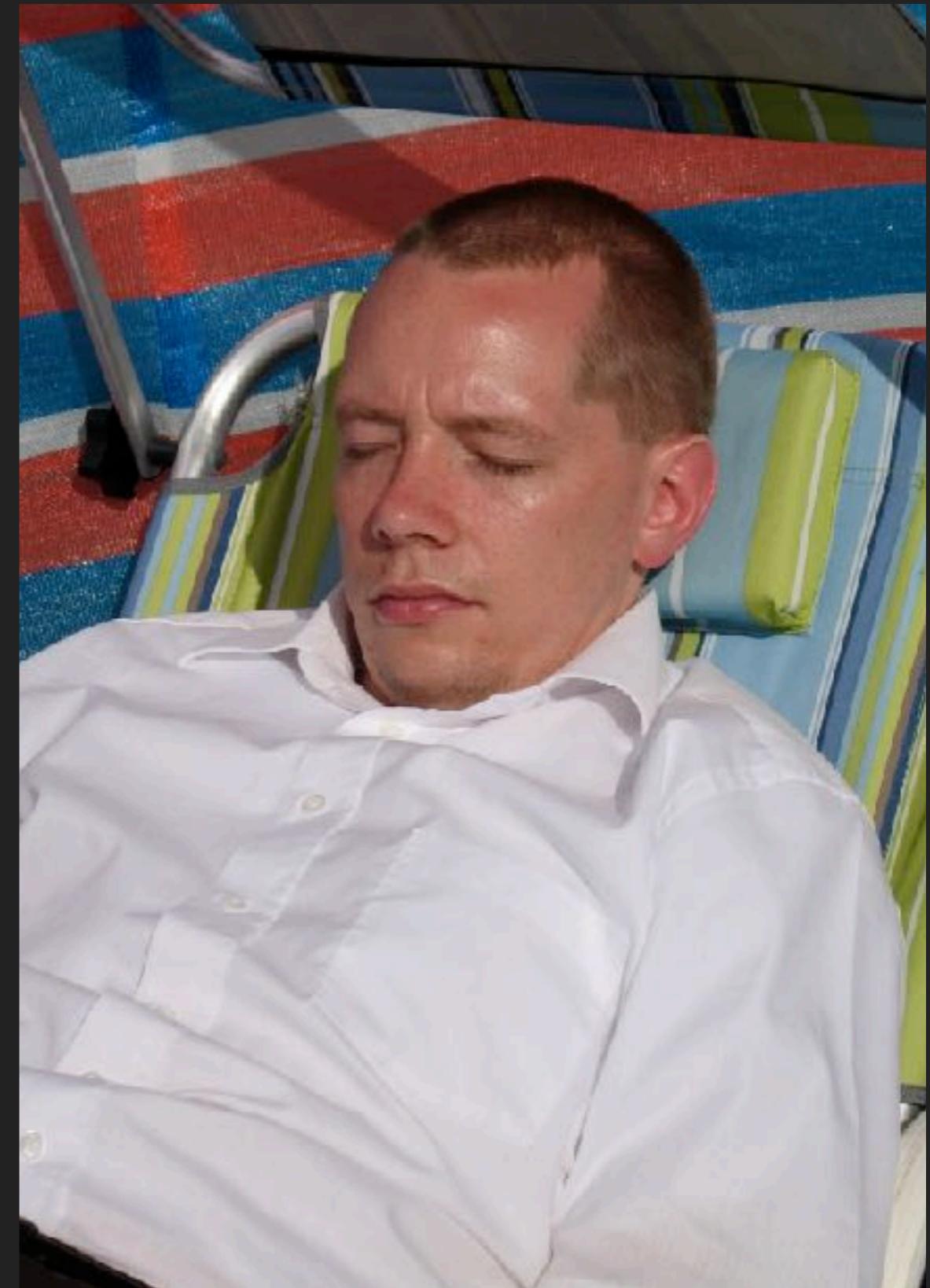
---

# CONTENT ENCRYPTION



# WHO AM I?

- ▶ Jens Neuhalfen
- ▶ Age: Forty something
- ▶ IT since: ever
- ▶ Skills: Bridge between IT and business, IT-Security Management, writing software
- ▶ <https://github.com/neuhalje>



# SUMMARY

Regulations apply - whatever you do!

Encryption is not for free!

No encryption might be way more expensive!

Encryption is a safety net (*last* line of defence)

→ Assess risks & cost, plan, implement!

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→ Assess risks & cost, plan, implement!

I AM NOT A CRYPTOGRAPHER!

I AM NOT A LAWYER!

THIS TALK MADE ME A  
CRYPTOGRAPHY AND/OR  
LEGAL EXPERT

said no-one ever

I AM NOT A LAWYER!

I AM NOT A CRYPTOGRAPHER!

# YOUR DATA

# YOUR DATA



Collect

# YOUR DATA



Collect

Process

# YOUR DATA



Collect

Process

*Store but not use*

# YOUR DATA



Collect

Store *but not use*

Delete

Process

# YOUR DATA



# YOUR DATA



# YOUR DATA

● Business value

● Liability



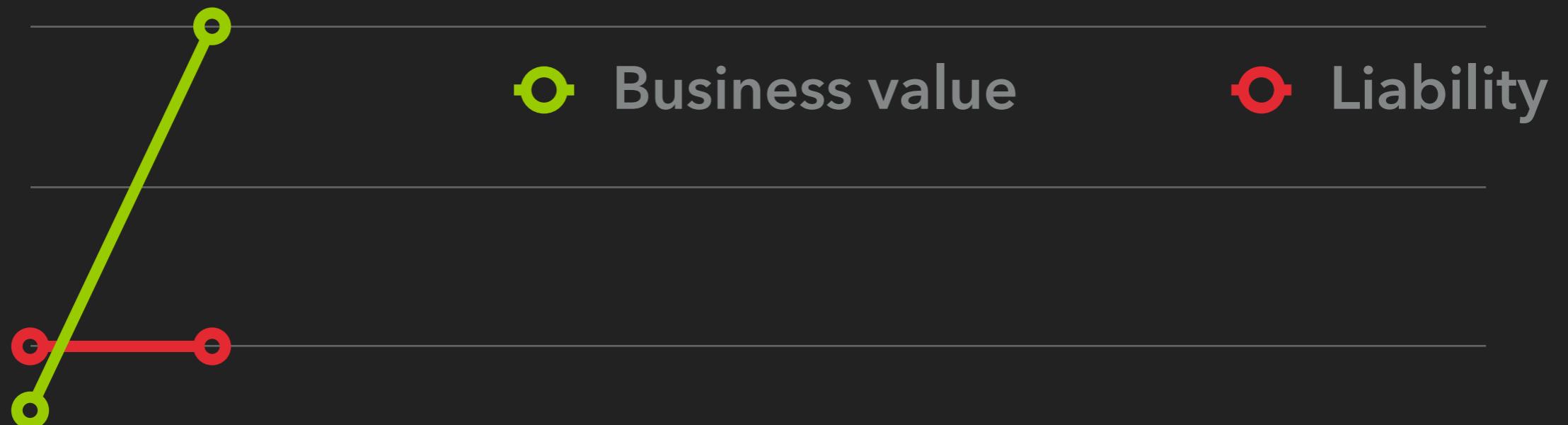
# YOUR DATA

● Business value

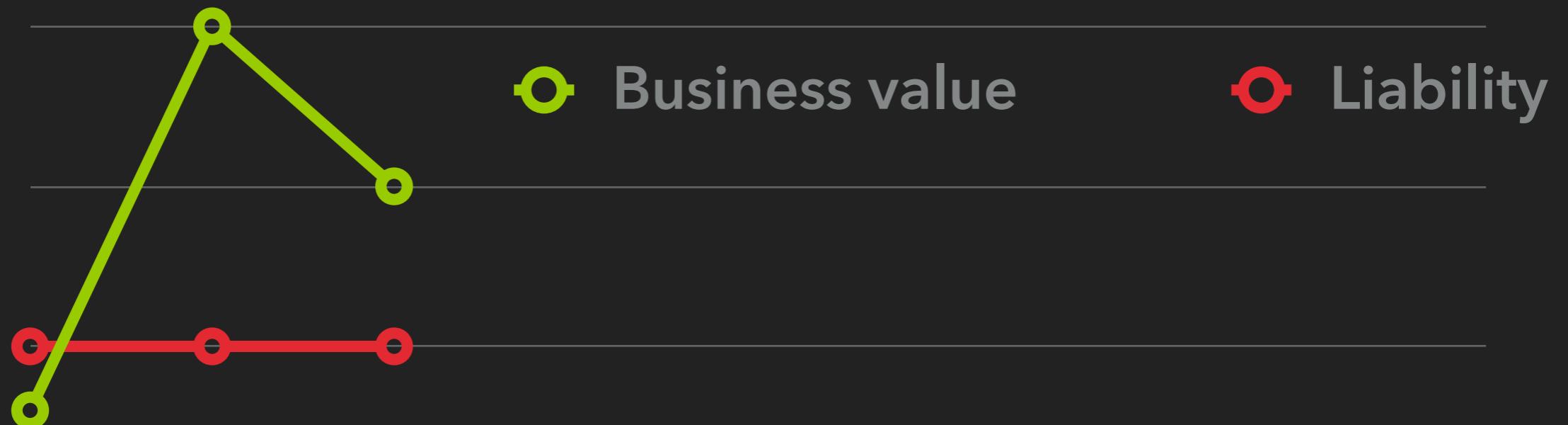
● Liability



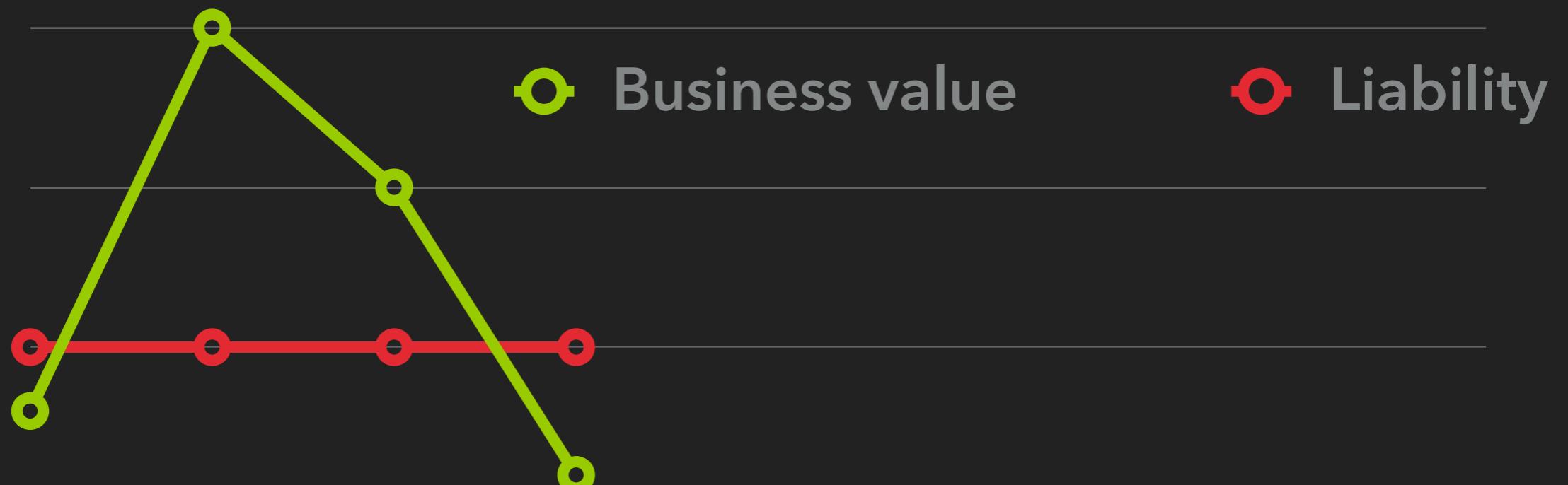
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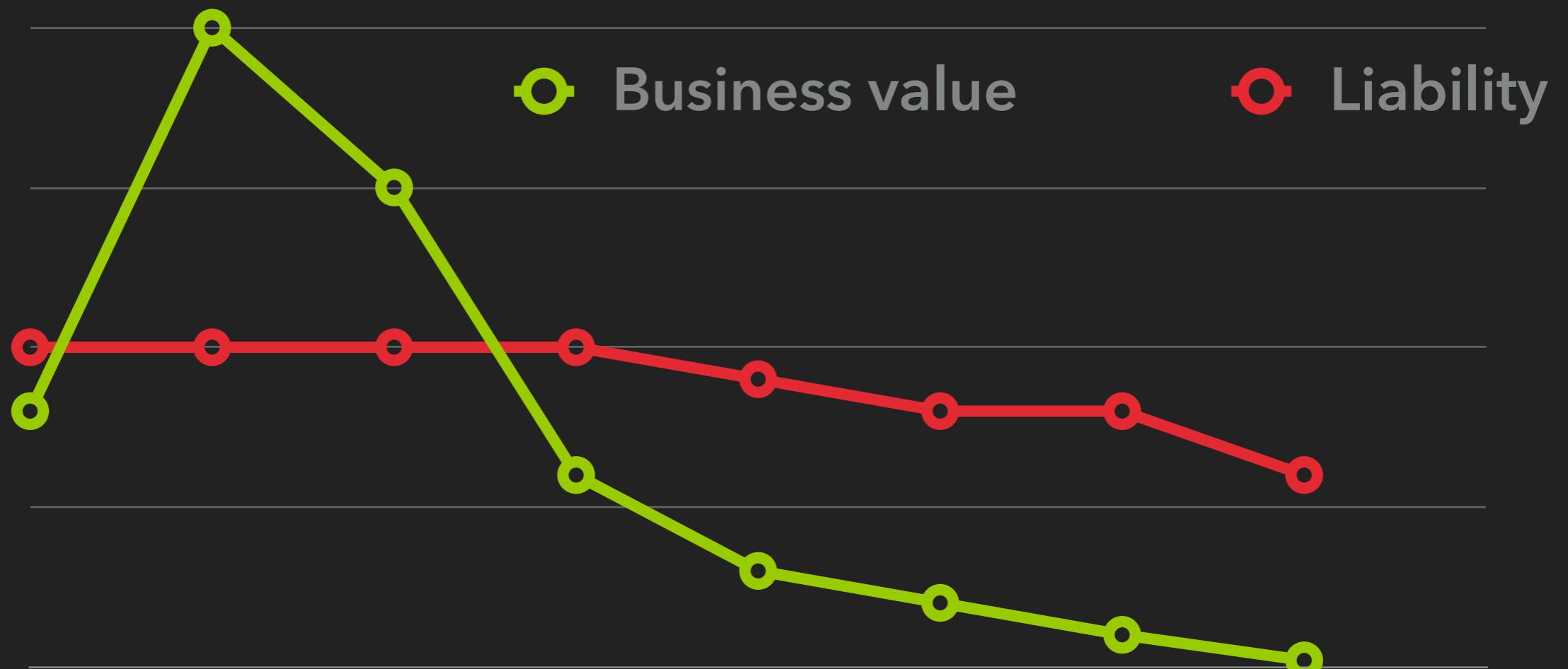
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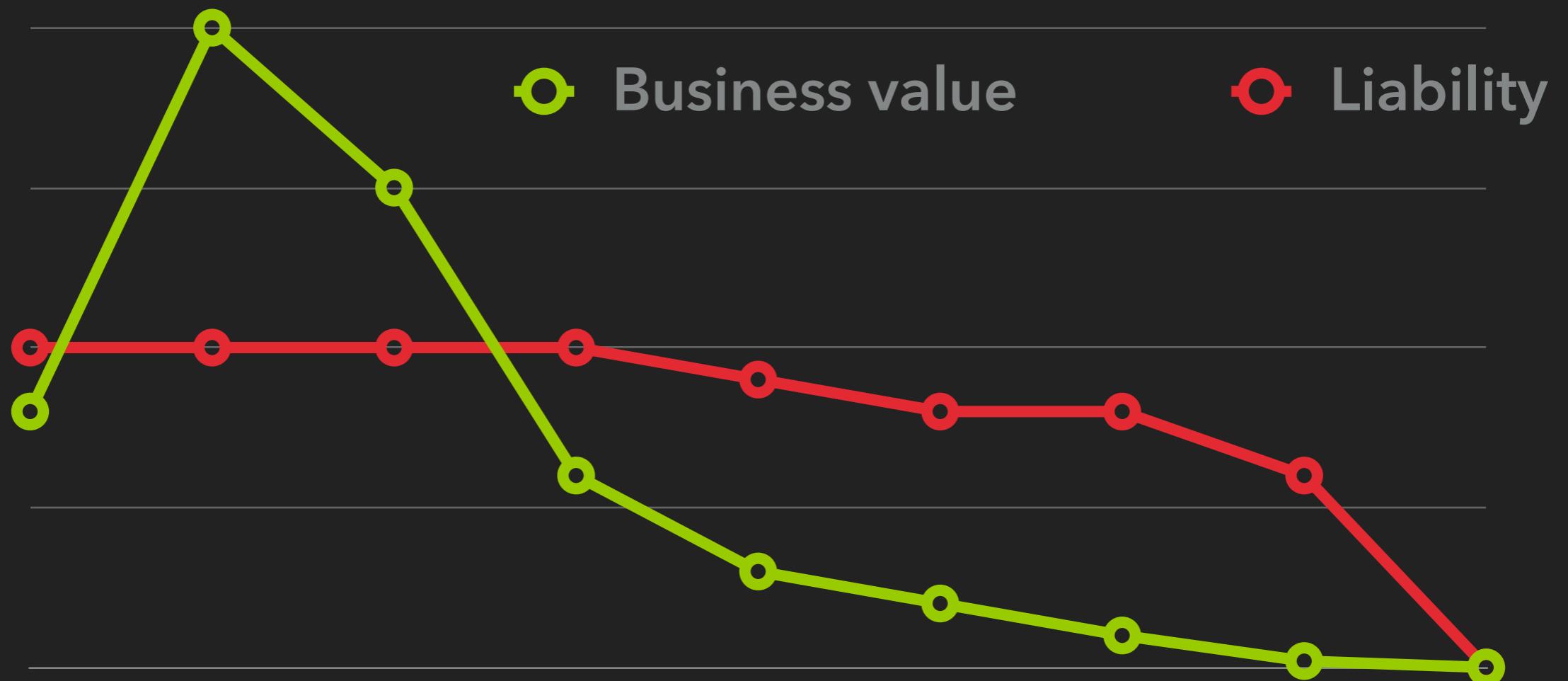
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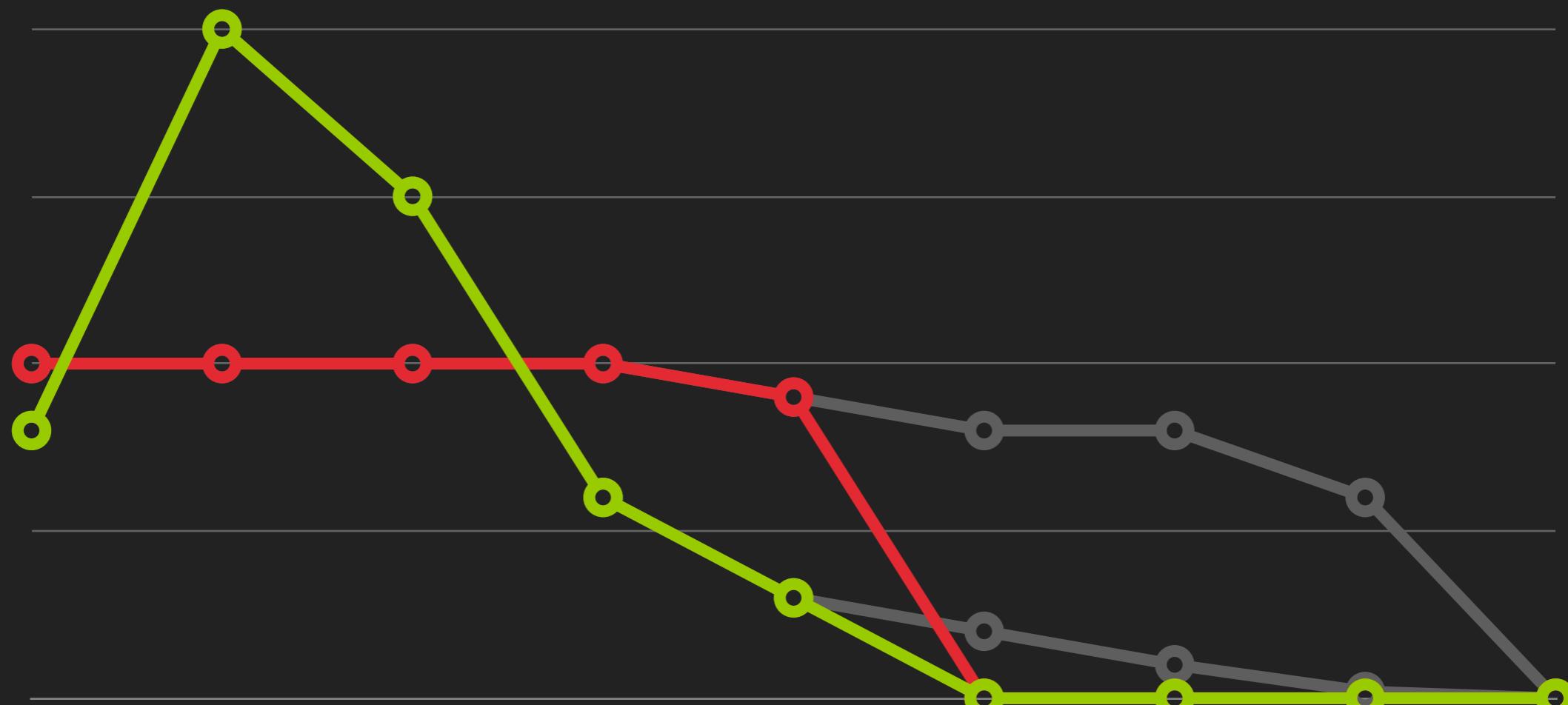
## YOUR DATA



## YOUR DATA



## YOUR DATA





DATA

WHAT IS  
CONTENT  
ENCRYPTION?

---

WHAT IS ...?

# CONTENT ENCRYPTION IS LIKE AN AIRBAG

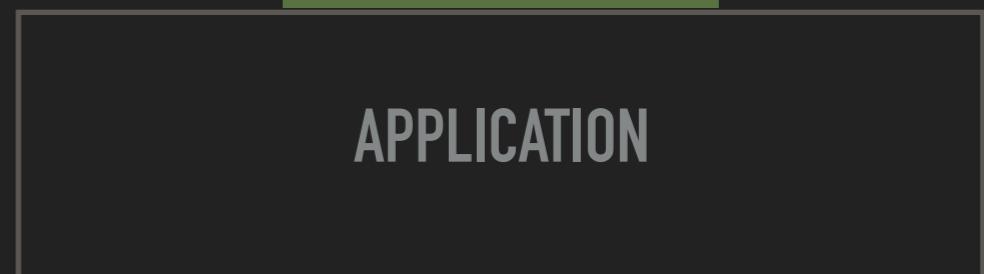
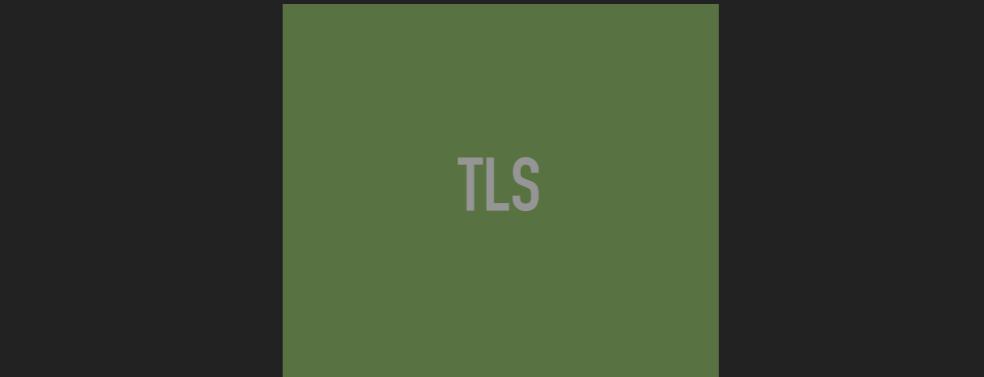
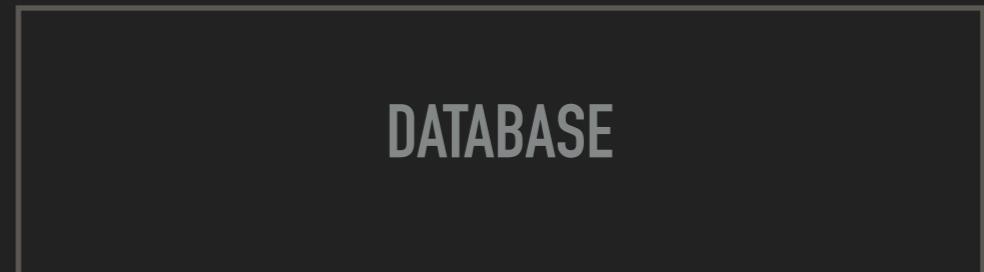
IMAGE: PINEAPPLE FEZ

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[HTTPS://COMMONS.WIKIMEDIA.ORG/WIKI/FILE:SUZUKI\\_ALTO\\_BODY2\\_-\\_AIMS.JPG](https://commons.wikimedia.org/wiki/File:Suzuki_Alto_Body2_-_AIMS.jpg)

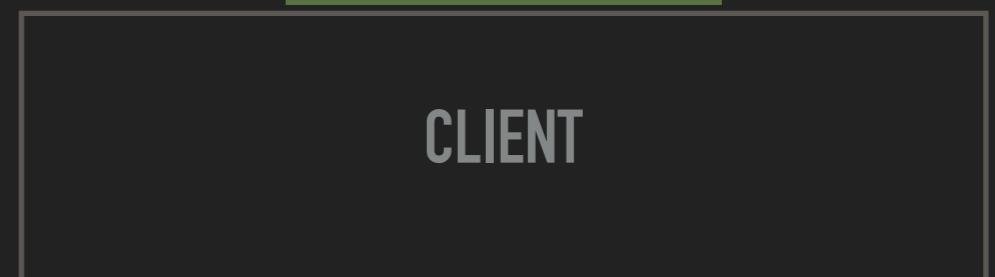
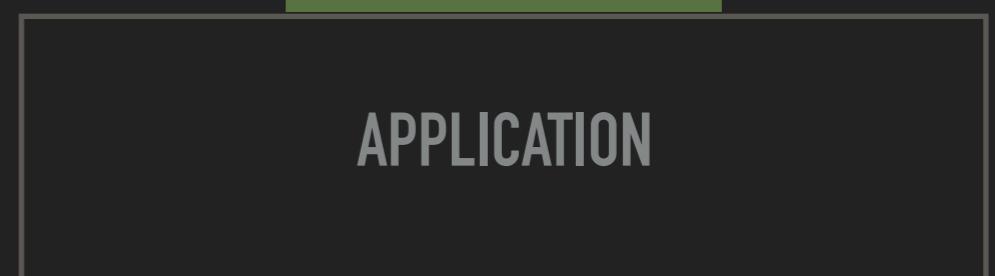
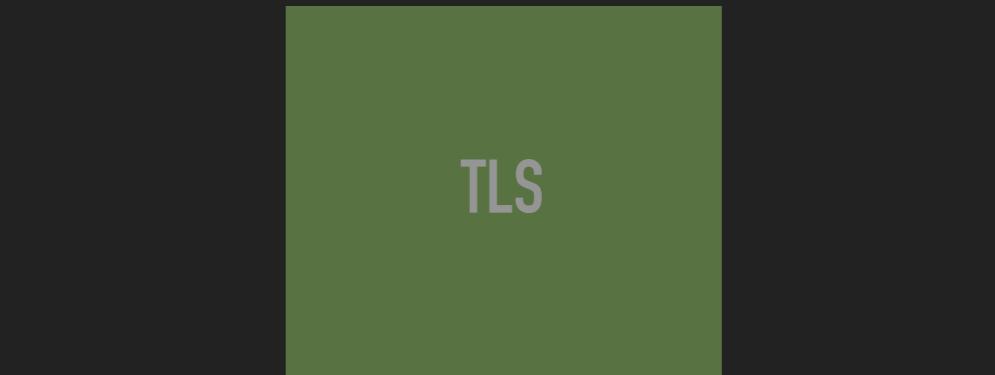
# YOUR FATHERS CRYPTO (\*)

- ▶ CLIENT sends request
- ▶ APPLICATION applies logic
- ▶ DATABASE stores result
- ▶ Data encrypted via TLS 



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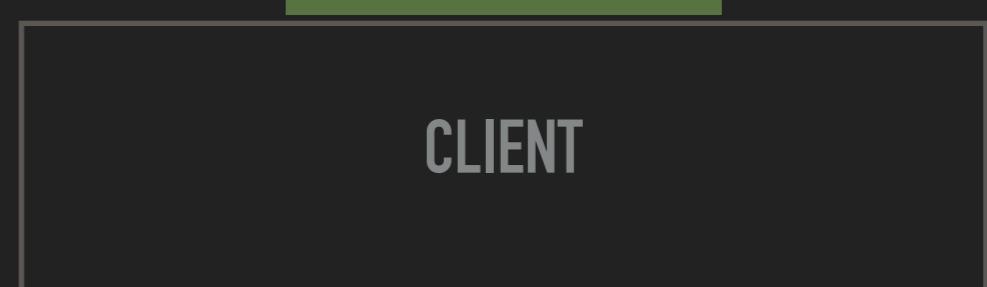
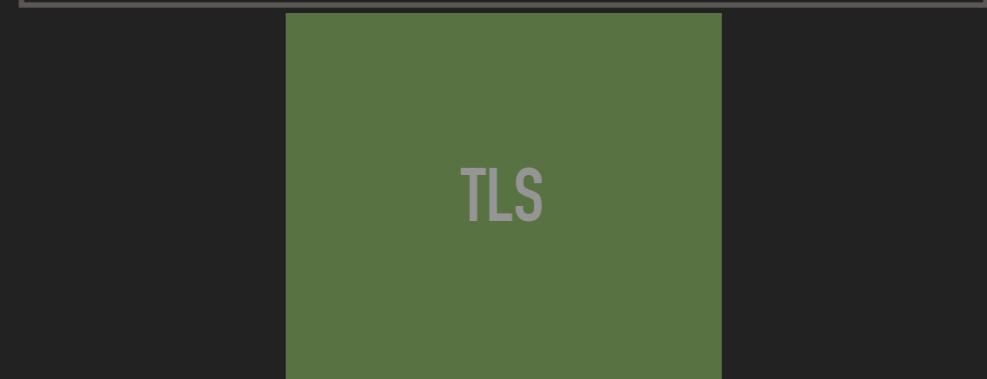
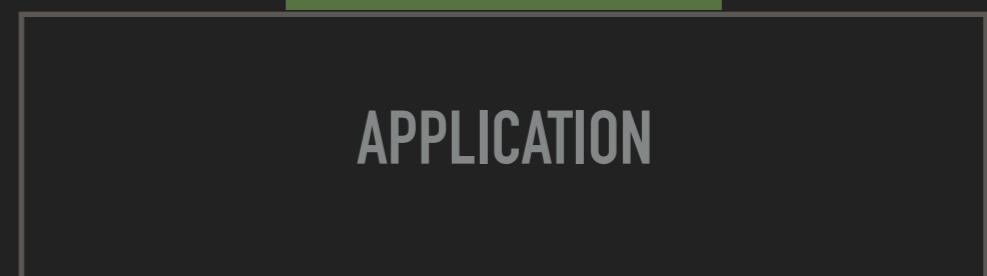


(\*) I'm going to gloss over the whole cryptography nomenclature in these first slides. Bear with me.

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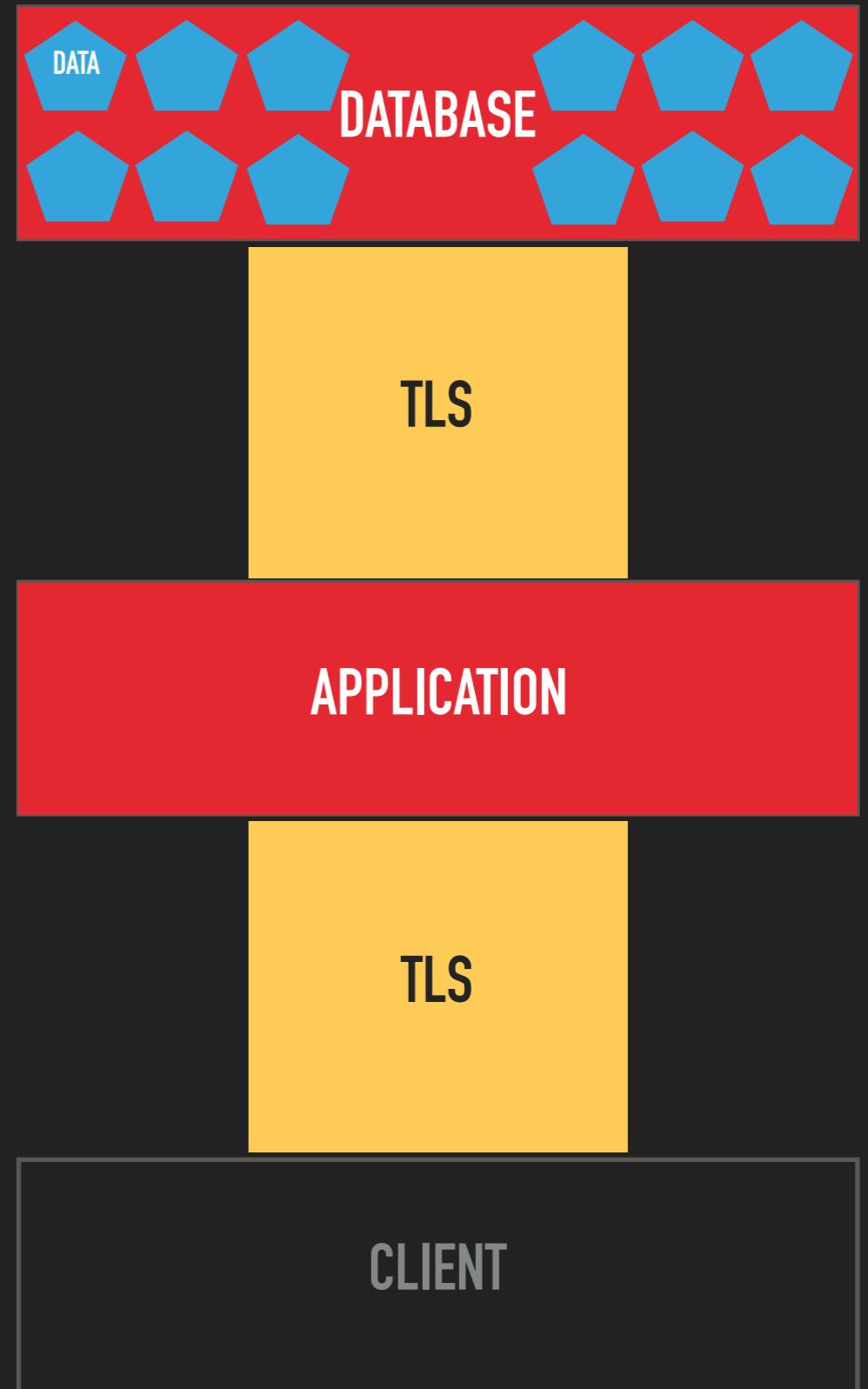
**SO, EVERYTHING IS SAFE?**



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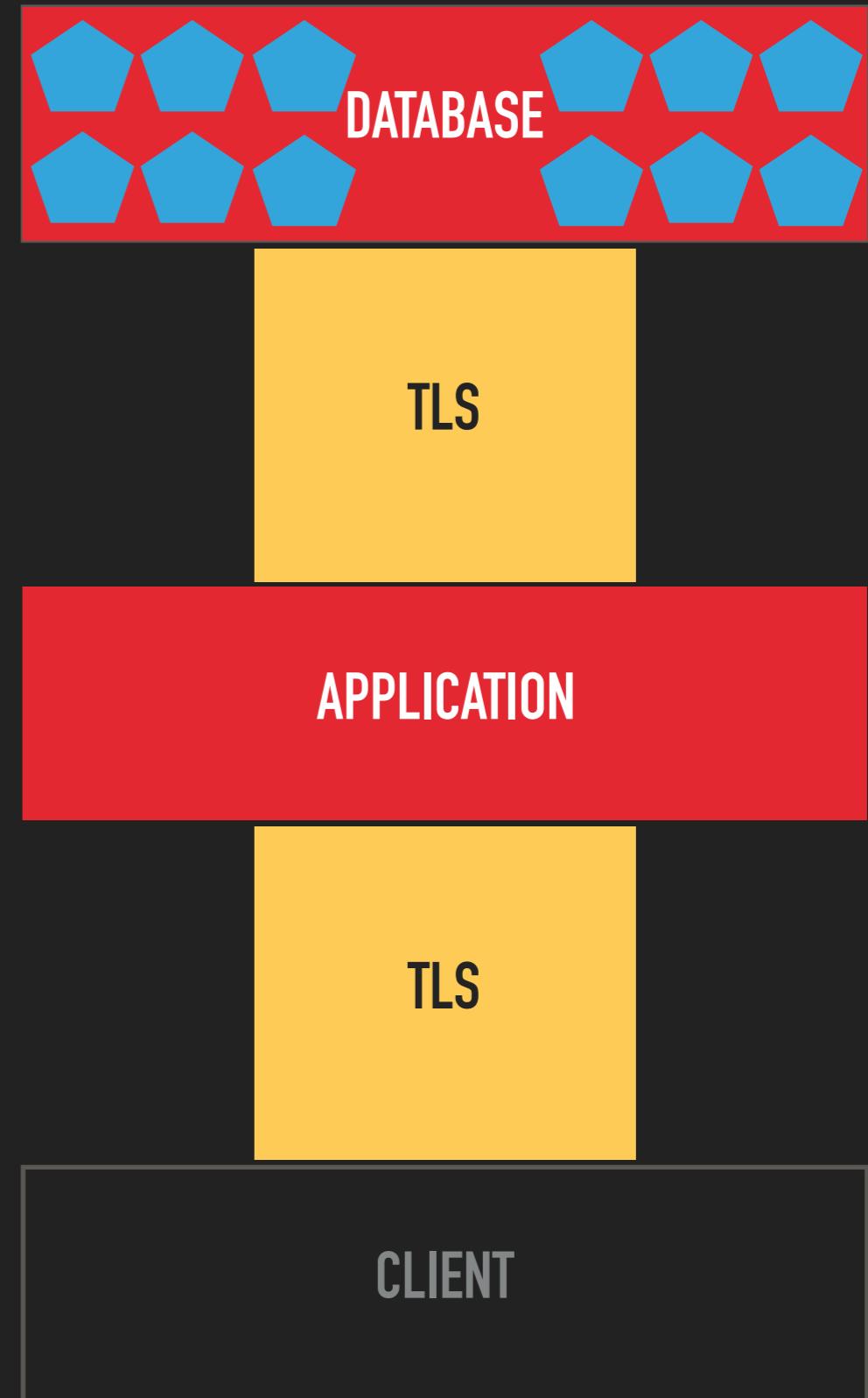
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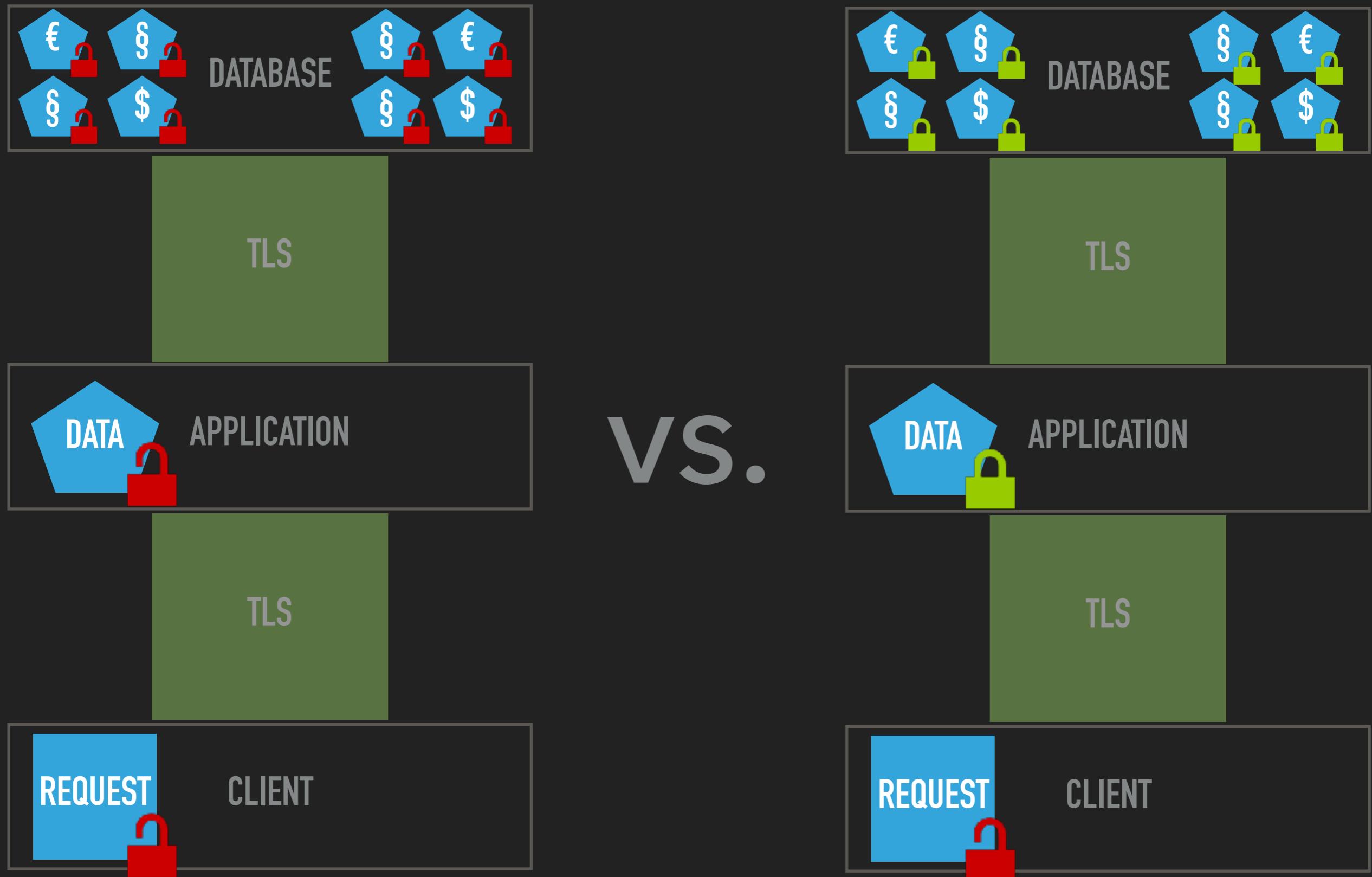
## WHAT ABOUT TLS?

- ▶ Data is at rest for ~99.99998% of the time (\*)
- ▶ Also: Heartbleed, POODLE, DROWN, Lucky13, Logjam, FREAK, ...
- ▶ Also: Backups!



## WHAT IS CONTENT ENCRYPTION?

- ▶ Encrypt\*\* data 'itself'
- ▶ E.g. encrypted\*\* data at rest
- ▶ Even: Protected\*\* data while working with it





WHY USE  

---

**CONTENT  
ENCRYPTION?**

## IT'S THE LAW

- ▶ A lot of (German) laws take data protection seriously
- ▶ Bundesdatenschutzgesetz (BDSG)
- ▶ Telemediengesetz (TMG)
- ▶ Telekommunikationsgesetz (TKG)
- ▶ Strafgesetzbuch (StGB)
- ▶ Sozialgesetzbuch (SGB)
- ▶ EUDSGV



# BUNDESDATENSCHUTZGESETZ

**Applies to: Everyone working with personal data**

► **§ 3 Weitere Begriffsbestimmungen**

(1) Personenbezogene Daten sind Einzelangaben über persönliche oder sachliche Verhältnisse einer bestimmten oder bestimmbaren natürlichen Person (Betroffener).

...

(9) Besondere Arten personenbezogener Daten sind Angaben über die rassische und ethnische Herkunft, politische Meinungen, religiöse oder philosophische Überzeugungen, Gewerkschaftzugehörigkeit, Gesundheit oder Sexualleben.

► **§ 42a Informationspflicht bei unrechtmäßiger Kenntniserlangung von Daten**

Stellt [eine verarbeitende Stelle] fest, dass bei ihr gespeicherte

1. besondere Arten personenbezogener Daten (§ 3 Absatz 9),
2. personenbezogene Daten, die einem Berufsgeheimnis unterliegen,
3. [...] strafbare Handlungen oder Ordnungswidrigkeiten [...]
4. personenbezogene Daten zu Bank- oder Kreditkartenkonten

unrechtmäßig übermittelt [...], und drohen schwerwiegende Beeinträchtigungen für die Rechte oder schutzwürdigen Interessen der Betroffenen [...]

**[Meldung an Aufsichtsbehörde und Betroffenen, ggfs. halbseitige Anzeige]**



# BDG

# TELEMEDIENGESETZ

**Applies to: Everyone providing websites for profit**

## ► § 13 Pflichten des Diensteanbieters

(7) Diensteanbieter haben [...] durch technische und organisatorische Vorkehrungen sicherzustellen, dass

1. [Zugriff auf] technischen Einrichtungen möglich ist und

2. diese

a) **gegen Verletzungen des Schutzes personenbezogener Daten ...**

Vorkehrungen nach Satz 1 müssen den Stand der Technik berücksichtigen. **Eine Maßnahme nach Satz 1 ist insbesondere die Anwendung eines als sicher anerkannten Verschlüsselungsverfahrens.**

## ► § 16 Bußgeldvorschriften

...

(3) Die Ordnungswidrigkeit kann mit einer **Geldbuße bis zu fünfzigtausend Euro** geahndet werden.



**TMG**

# TELEKOMMUNIKATIONSGESETZ

**Applies to: Everyone providing communication services (\*)**



## ► § 109a Daten- und Informationssicherheit

(1) [...] im Fall einer Verletzung [...] unverzüglich [...] BNetzA & BfDI [...] zu benachrichtigen.

Ist anzunehmen [...] schutzwürdigen Interessen beeinträchtigt werden, hat der Anbieter [...] zusätzlich die Betroffenen unverzüglich von dieser Verletzung zu benachrichtigen. In Fällen, [...] durch geeignete technische Vorkehrungen gesichert, insbesondere [...]

Verschlüsselungsverfahrens gespeichert wurden, ist eine Benachrichtigung nicht erforderlich.

# TKG

I AM NOT A LAWYER!

# STRAFGESETZBUCH

**Applies to: Everyone - here to Doctors, Lawyers,  
Health insurance,..**



## ► § 203 Verletzung von Privatgeheimnissen

(1) Wer unbefugt ein fremdes Geheimnis, namentlich ein zum persönlichen Lebensbereich gehörendes Geheimnis oder ein Betriebs- oder Geschäftsgeheimnis, offenbart, das ihm als [Berufsgeheimnisträger] anvertraut worden oder sonst bekanntgeworden ist, wird mit Freiheitsstrafe bis zu einem Jahr oder mit Geldstrafe bestraft.

# STGB

# SOZIALGESETZBUCH

**Applies to: Everyone working with social data**

- ▶ You know when it applies!



**SGB**

## EU DATENSCHUTZGRUNDVERORDNUNG

Applies to: You (starting May 2018)

- ▶ Art. 32 DSGVO Sicherheit der Verarbeitung

Unter Berücksichtigung des Stands der Technik, der Implementierungskosten [...] diese Maßnahmen schließen unter anderem Folgendes ein:

- A. die **Pseudonymisierung und Verschlüsselung** personenbezogener Daten;
  - B. die Fähigkeit, die **Vertraulichkeit, Integrität, Verfügbarkeit** und Belastbarkeit der Systeme und Dienste im Zusammenhang mit der Verarbeitung auf Dauer sicherzustellen;
  - C. ...
- ▶ Erwägungsgrund 83



# DSGVO

## IT'S COMPLIANCE

- ▶ Company rules require encryption
- ▶ PCI DSS
- ▶ ISO 27001
- ▶ ...



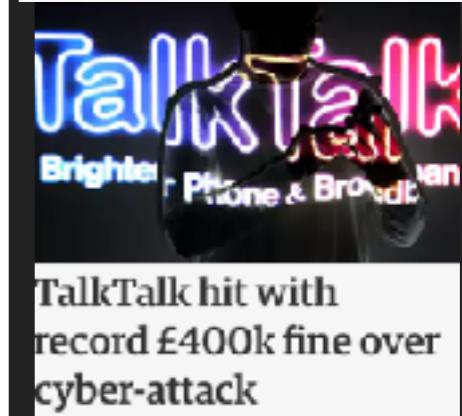
NOT  
CONVINCED  
YET?

**ASK THE  
COMPETITION!**

# ASK THE COMPETITION PT. 1



TalkTalk profits halve after cyber-attack



<https://www.bloomberg.com/quote/TALK:LN>

<https://www.theguardian.com/business/2016/may/12/talktalk-profits-halve-hack-cyber-attack>

<https://www.theguardian.com/business/2016/feb/02/talktalk-cyberattack-costs-customers-leave>

## ASK THE COMPETITION PT. 2

### Adultery Website AshleyMadison Seeks IPO as Demand Booms

Kristen Schweizer

18 April 2015, 13:27 CEST

before

after

A data dump, 9.7 gigabytes in size, was posted on Tuesday to the dark web using an Onion address accessible only through the Tor browser. The files appear to include account details and log-ins for some 32 million users of the social networking site, touted as the premier site for married individuals seeking partners for affairs. Seven years worth of credit card and other payment transaction details are also part of the dump.

In August 2015, after its customer records were leaked by hackers, a \$576 million class-action lawsuit was filed against the company.<sup>[48]</sup>

<https://www.bloomberg.com/news/articles/2015-04-15/adultery-website-ashleymadison-seeks-ipo-as-demand-booms>

<https://www.wired.com/2015/08/happened-hackers-posted-stolen-ashley-madison-data/>

[https://en.wikipedia.org/wiki/Ashley\\_Madison](https://en.wikipedia.org/wiki/Ashley_Madison)

## ASK THE COMPETITION PT. 3

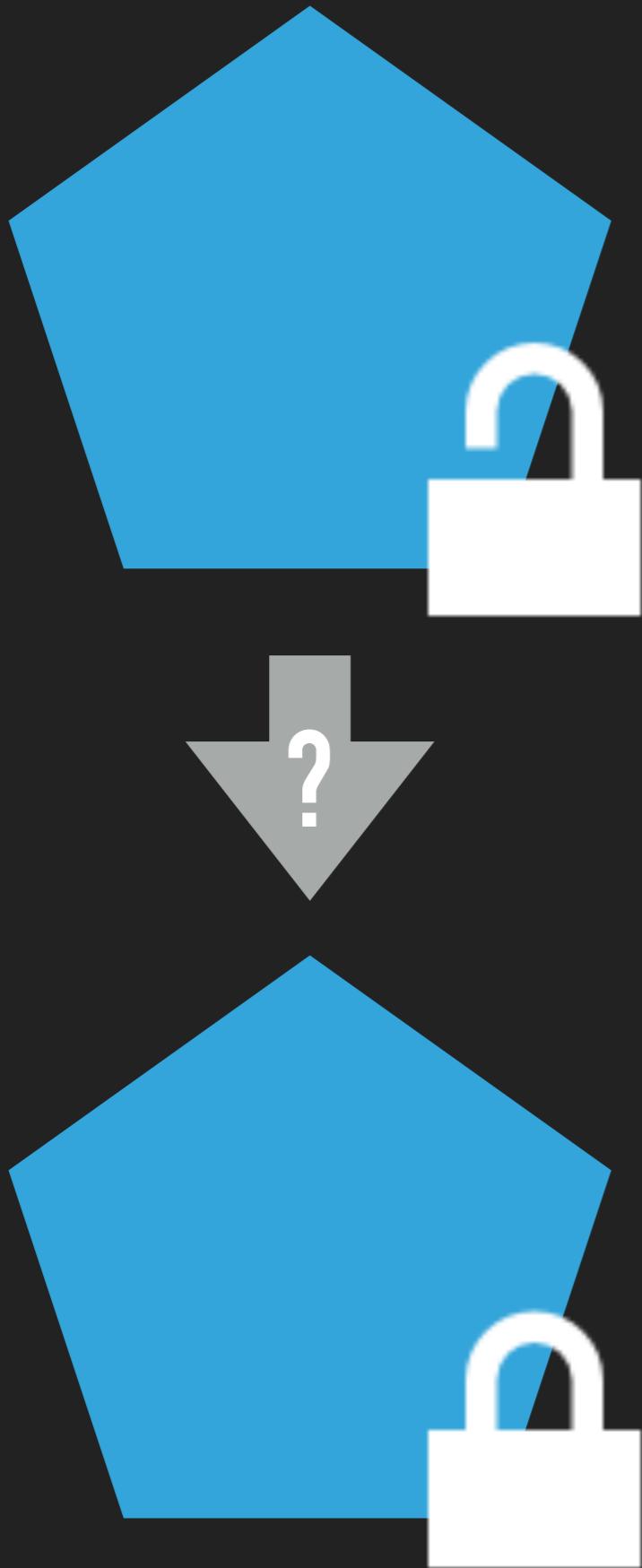
### Breached Organizations Lose Millions in Market Value, Finds New Report

*“For a typical FTSE 100 firm the impact of 1.8 per cent equates to a permanent loss of market capitalization of £120 million,” explains the report – which amounts close to \$150 million USD.*

*“Lost shareholder value across European markets could rise by as much as a factor of 10 when the new regulations take effect in May 2018,” Rogoyski told Infosecurity Magazine.*

<https://www.tripwire.com/state-of-security/latest-security-news/breached-organizations-lose-millions-market-value-finds-new-report/>

<http://breachlevelindex.com/>



# HOW TO DESIGN CONTENT ENCRYPTION

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# 0 - REGULATIONS & INITIAL RISK ASSESSMENT

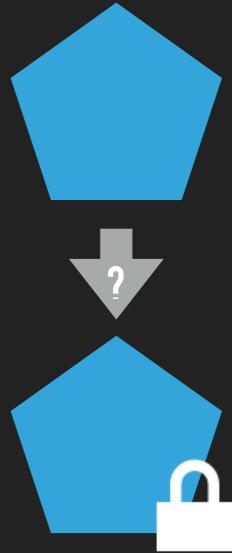
## 1 - DATA CLASSIFICATION

## 2 - DATA TREATMENT PLAN

## 3 - IMPLEMENTATION PLAN



## 0 - REGULATIONS & INITIAL RISK ASSESSMENT

- 
1. List all relevant **laws, regulations, etc.** with a legal expert
  2. List all **data items** ("Adress", "Bank Account", ...)
  3. Estimate **initial risks** (damage & probability) for CIA violations with management and legal expert

# 1 - DATA CLASSIFICATION

Classify all data items with respect to regulations

Item	Regulation	
<b>Customer</b>		
- Name	BDSG	Pers. bez. Datum
- Bank Account	BDSG	bes. PbD
...	...	...
<b>Marketing E-Mail</b>		
- Recipient	BDSG	Pers. bez. Datum
- Text	???	???
- Protocol	???	???



THIS DEPENDS ON YOUR SPECIFIC APPLICATION/SCENARIO!

I AM NOT A LAWYER!

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- Protocol	???	???

**Classification depends on context!**

THIS DEPENDS ON YOUR SPECIFIC APPLICATION/SCENARIO!

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## 2 - DATA TREATMENT PLAN

Create a data treatment plan, and for each data item

- describe how (\*) this data must be
- ... **stored**
- ... **transmitted**
- ... **logged**
- ... **backed up**
- and when it must be **deleted!**

(\*) how: plain, masked ("XXXXX 123"), pseudonymised, anonymised, encrypted, hashed.

**Also:** consider integrity protection.



Item	Store	Transmit	Log	Backup	Delete
<b>Customer</b>					
- Name	Plain	Encrypted	Pseud.	Encrypted	BDSG
- Bank	Encrypted	Encrypted	Masked	Encrypted	BDSG
...	...	...			
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- Recipient	Plain	Encrypted	Pseud.	Encrypted	BDSG
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**Also:** consider integrity protection.

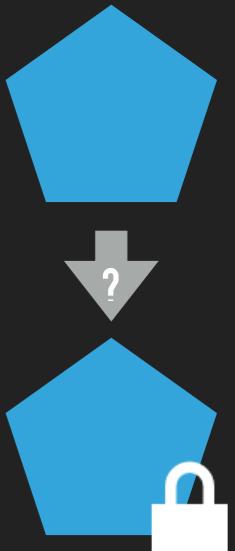
THIS DEPENDS ON YOUR SPECIFIC APPLICATION/SCENARIO!

I AM NOT A LAWYER!

## 3 - IMPLEMENTATION PLAN

Update the requirements

- Merge Use Cases & data treatment plan
- Add cryptographic use cases



# RECAP

0 - Regulations & initial risk assessment



1 - Data classification

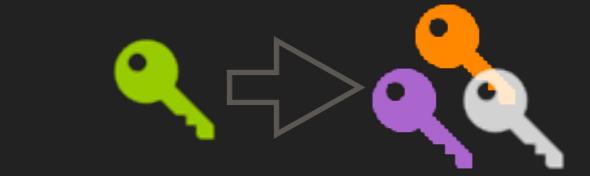


2 - Data treatment plan



3 - Implementation Plan





DES	BLOWFISH	AES
MD5	SHA-1	SHA-256
RSA-1024	RSA-2048	?? POST QUANTUM ??

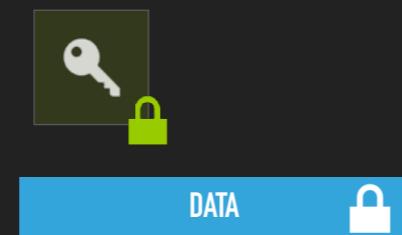
- Data treatment ...
- Use existing ...
- ...



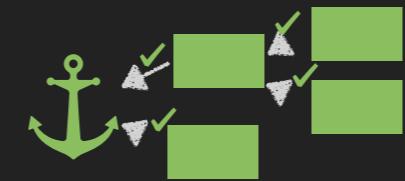
## CONTENT ENCRYPTION

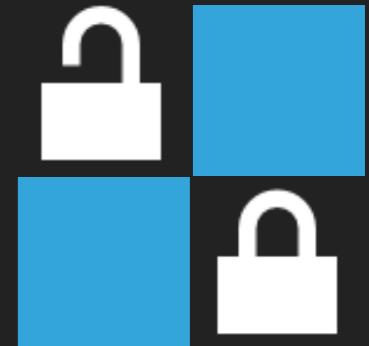
# PATTERNS

```
int getRandomNumber()
{
    return 4; // chosen by fair dice roll.
              // guaranteed to be random.
}
```



\*\*\*\*\*

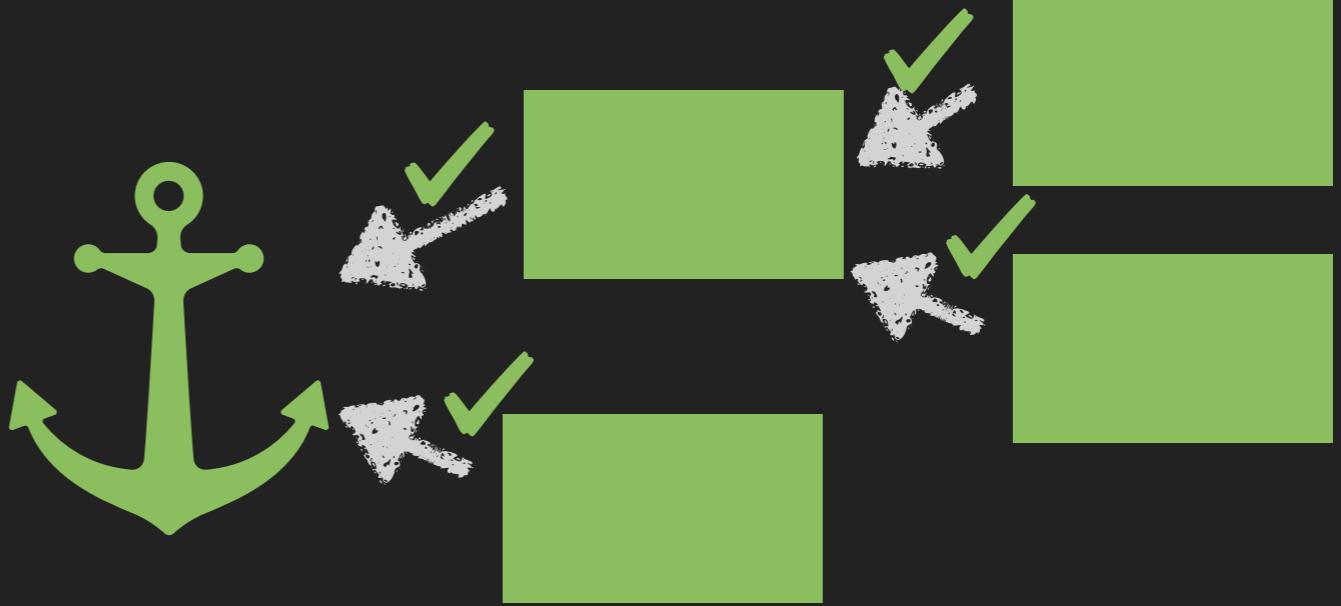
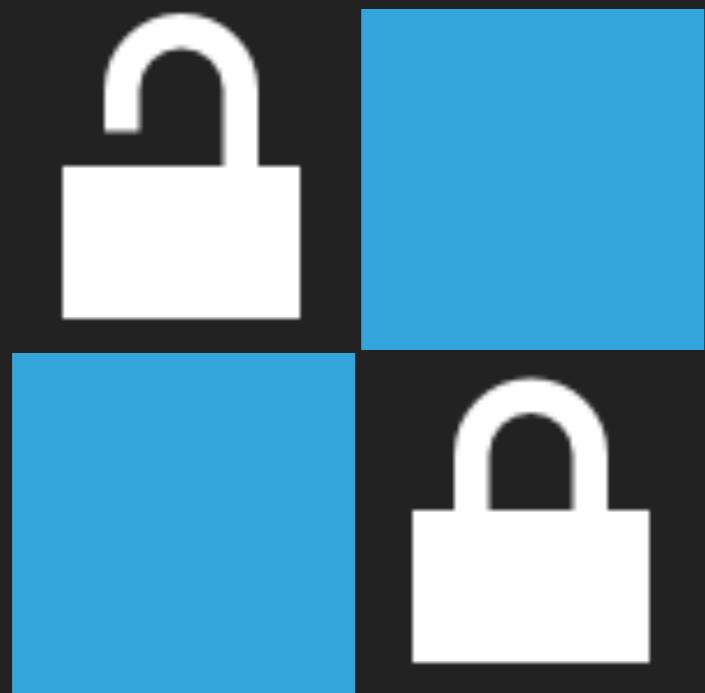




# **MOST IMPORTANT ADVICE: GET AN EXPERT OR AT LEAST READ AND UNDERSTAND THE DOCUMENTATION!**

Like all power tools: Better RTFM than to lose an eye!

- ▶ At least be able to explain: “Hash vs. encryption”,  
“Integrity vs. encryption”, “Stream vs. block”, “Mode of  
operation”, “IV”, “Nonce”, “Padding”, “Key derivation”
- ▶ Identify and name your trust anchors



# PATTERNS

---

# TRUST ANCHORS

## TRUST ANCHORS

**Problem:** You do not know when to start trusting / stop discussing

**Solution:** Define your trust anchors

Reasoning about the security of a system is impossible without

- ▶ knowing what you want to protect against ([threat model](#))
- ▶ knowing what you can ultimately rely upon ([trust anchor](#))

\* *Threat modeling not discussed here but it is really important!*

## TRUST ANCHORS



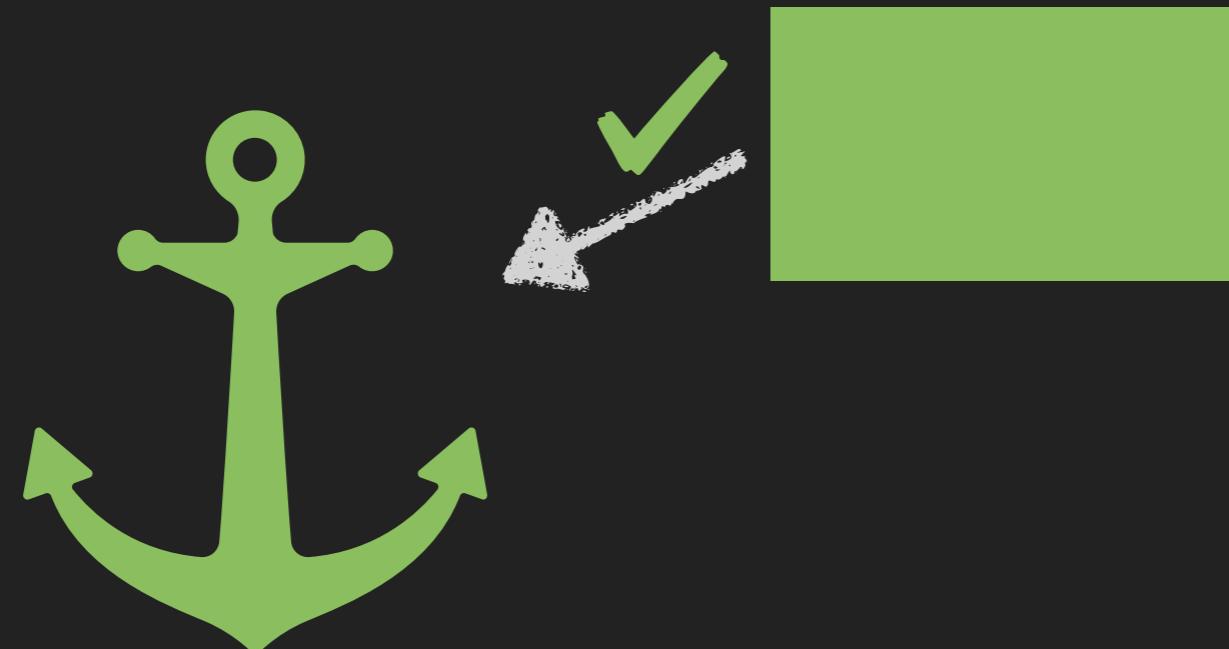
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## TRUST ANCHORS



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2. You reason that something else is also trusted by relying on the trust anchor(s)

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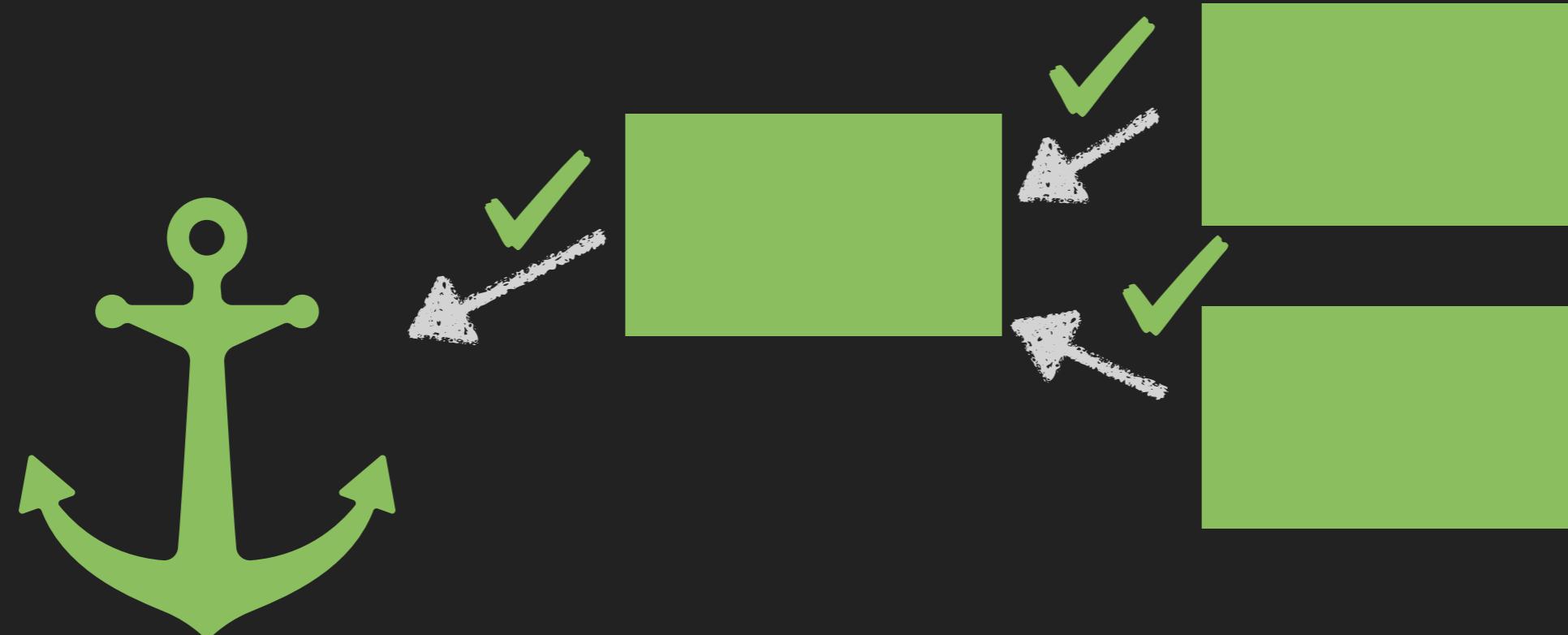
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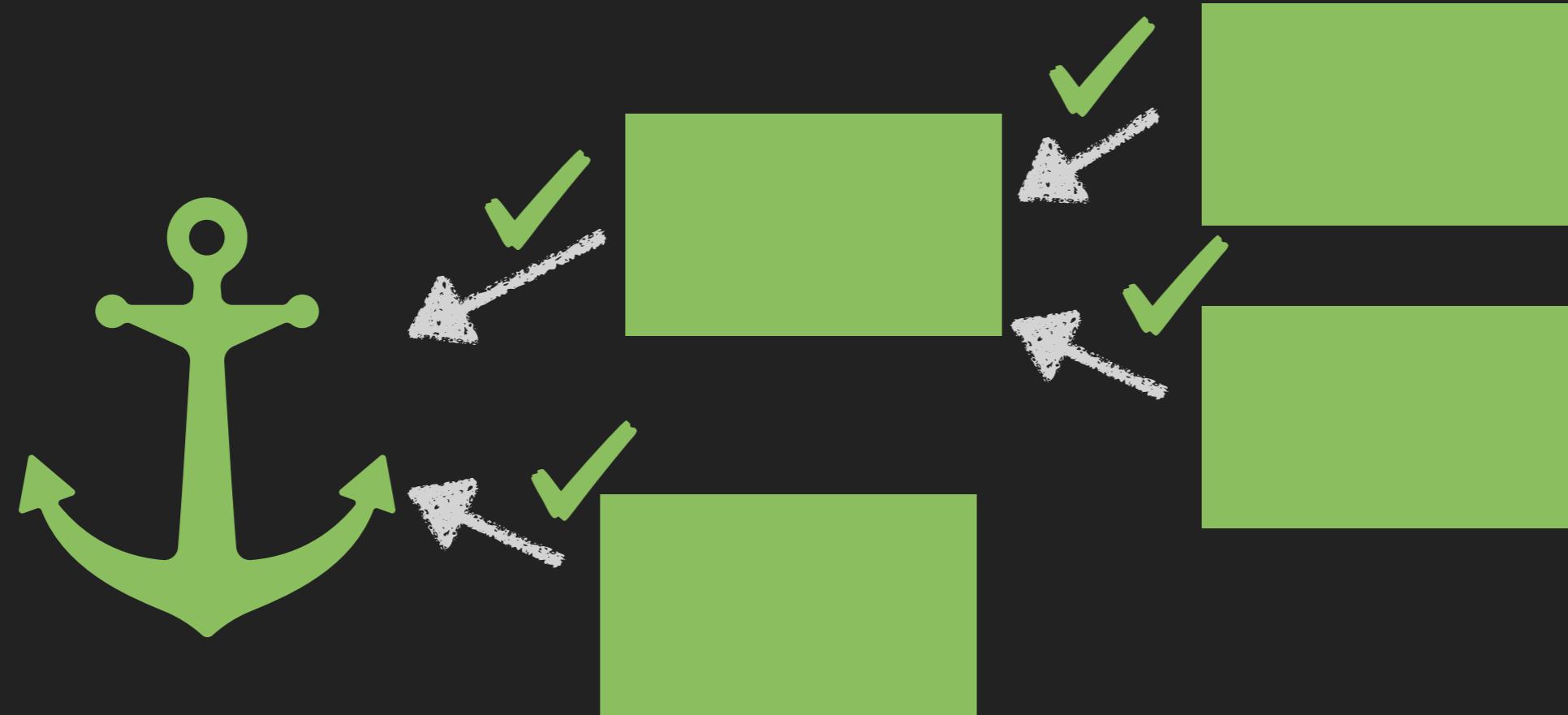
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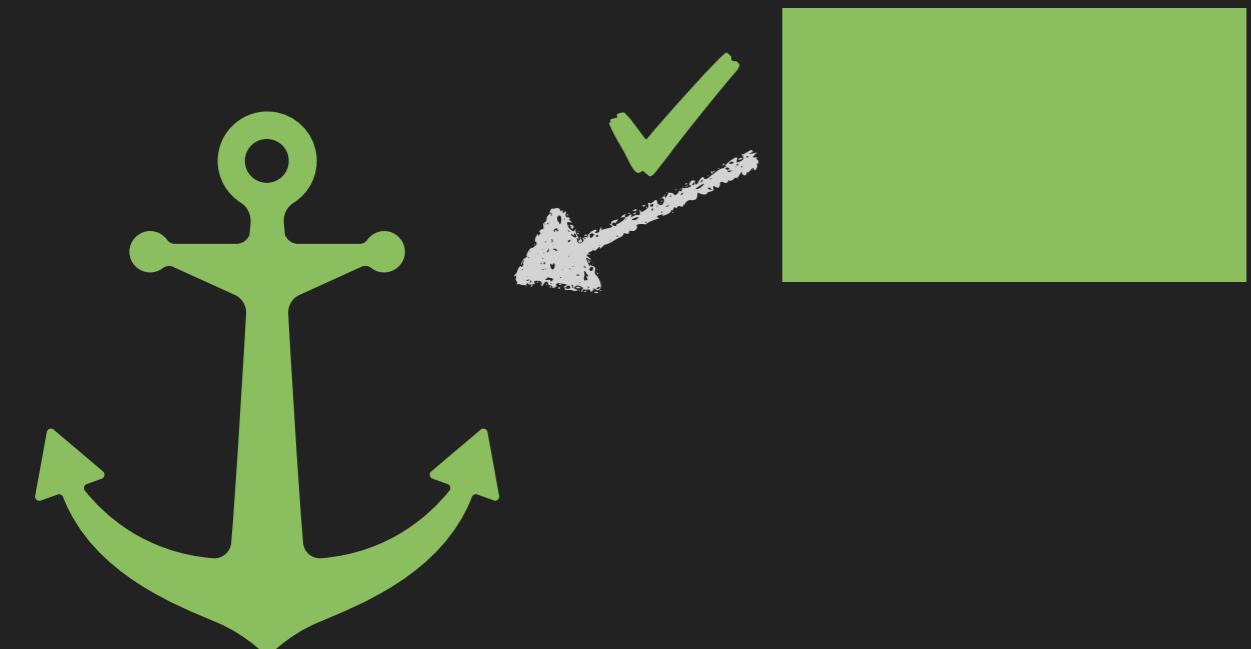
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## TRUST ANCHORS: EXAMPLE



1. I trust my cloud provider

## TRUST ANCHORS: EXAMPLE



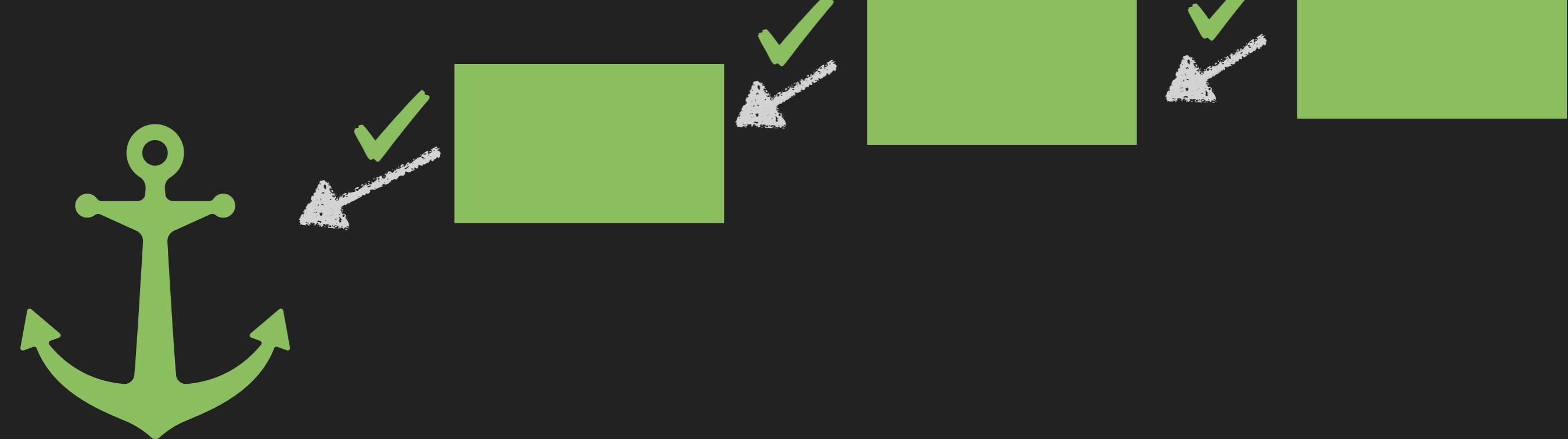
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2. I trust that my cloud provider has a secure key storage

## TRUST ANCHORS: EXAMPLE



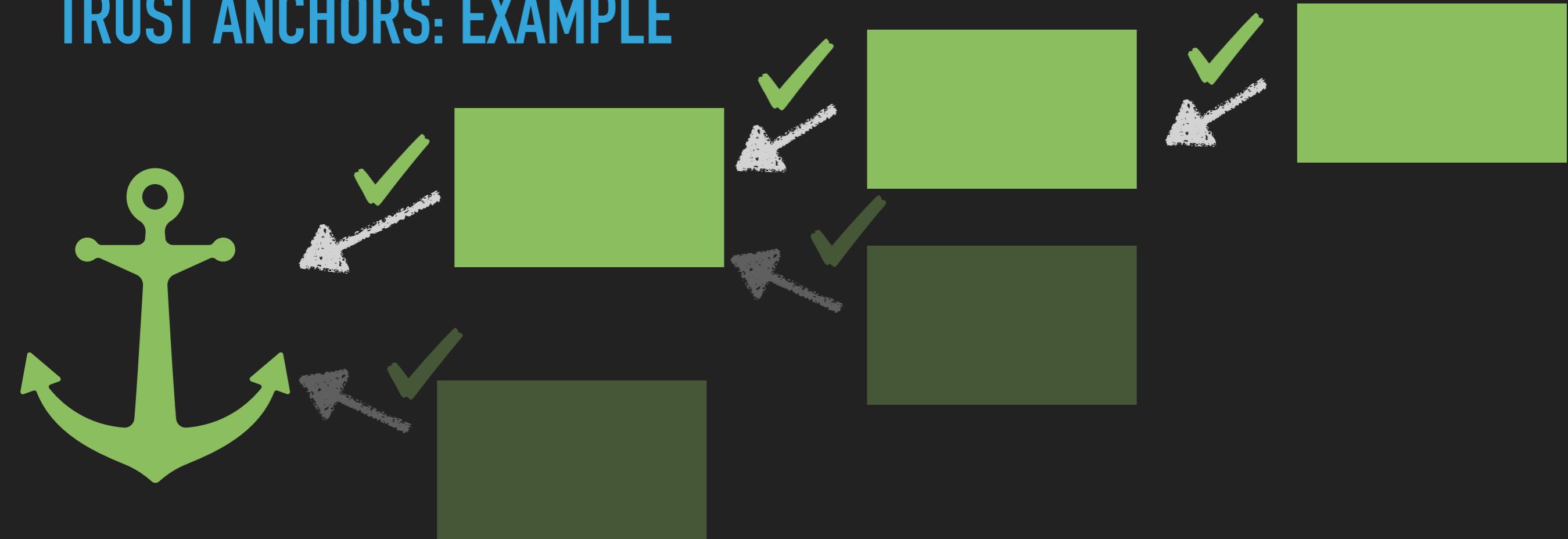
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2. I trust that my cloud provider has a secure key storage
3. Data encrypted with keys stored in the keyring is secure

## TRUST ANCHORS: EXAMPLE



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4. Therefore I can store sensitive data in my cloud

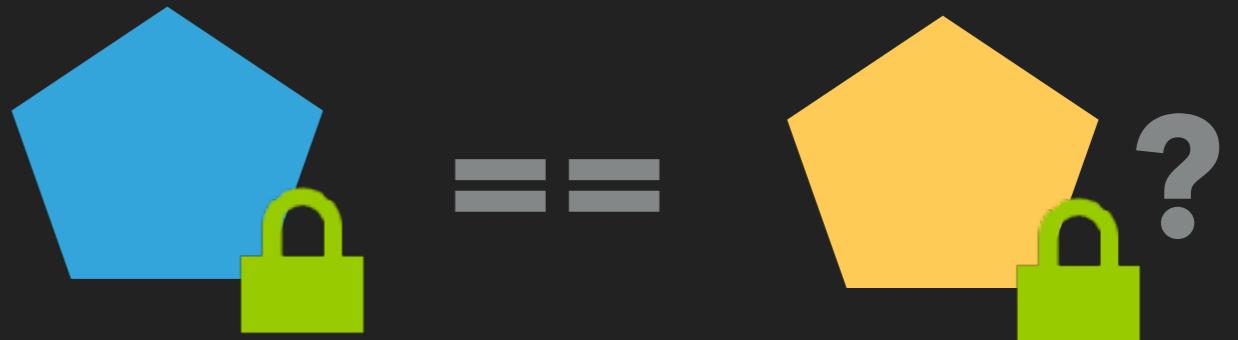
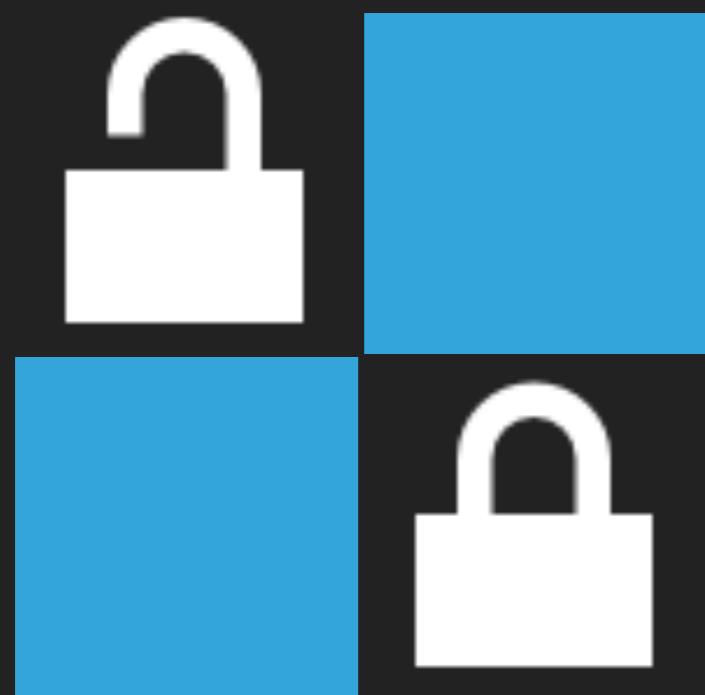
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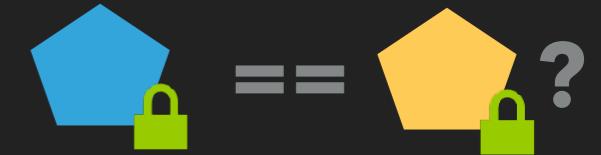
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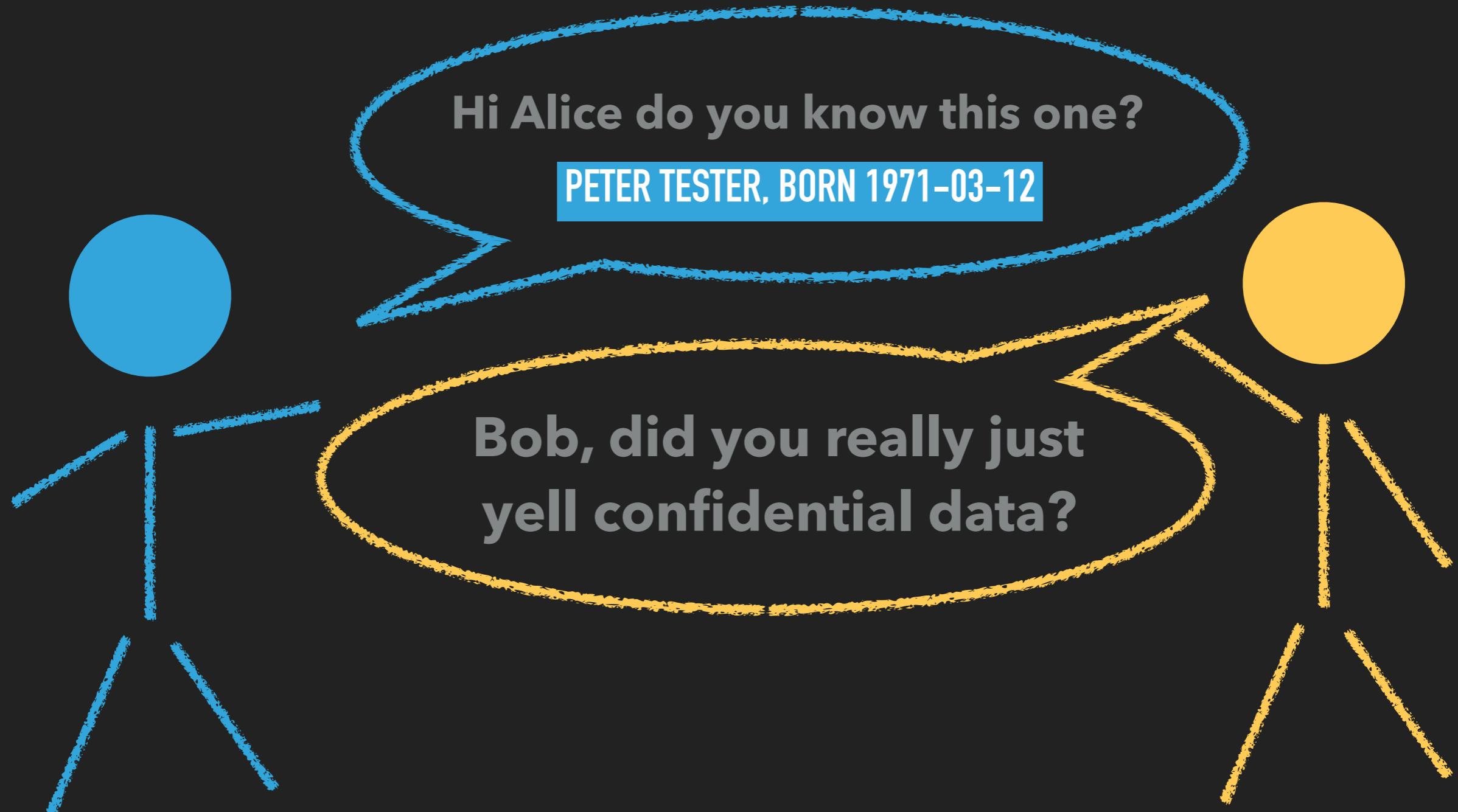


# PATTERNS COMPARING

## COMPARE DATA



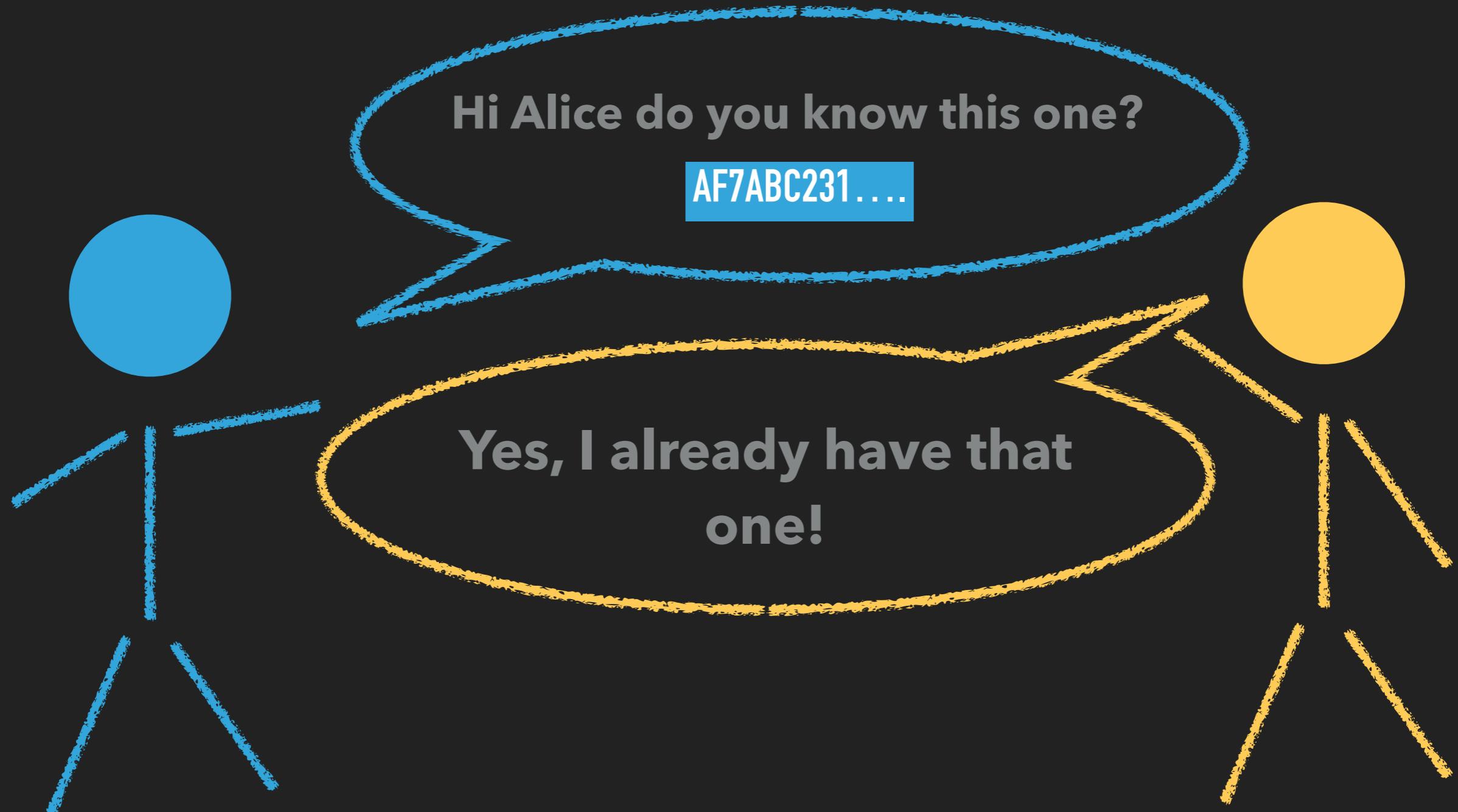
**Problem:** Securely compare two data items



## COMPARE DATA



**Problem:** Securely compare two data items



NO CONFIDENTIAL DATA EXCHANGED.

## COMPARE DATA



**Problem:** Securely compare two data items

**Solution:** Normalise & hash data, compare hashes

LOREM IPSUM ...   ==   LOREM IPSUM ...

## COMPARE DATA



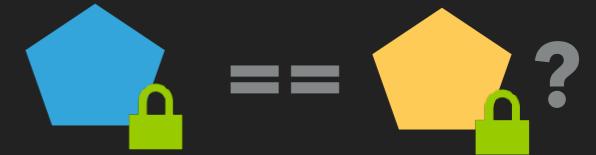
**Problem:** Securely compare two data items

**Solution:** Normalise & hash data, compare hashes

**LOREM IPSUM ... == LOREM IPSUM ...**

=> **sha256( LOREM IPSUM ... ) == sha256( LOREM IPSUM ... )**

## COMPARE DATA



**Problem:** Securely compare two data items

**Solution:** Normalise & hash data, compare hashes

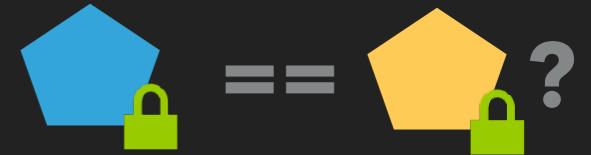
=>  
★

LOREM IPSUM ... == LOREM IPSUM ...

sha256( LOREM IPSUM ... ) == sha256( LOREM IPSUM ... )

- ★ Collisions [A != B but sha256(A) == sha256(B)] are mathematically possible, but practically not relevant

## COMPARE DATA



**Problem:** Securely compare two data items

**Solution:** Normalise & hash data, compare hashes

=>  
★

LOREM IPSUM ... == LOREM IPSUM ...

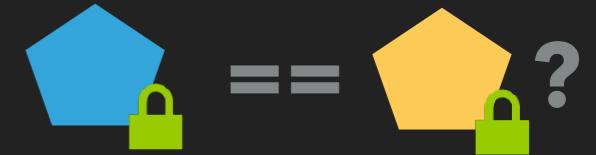
sha256( LOREM IPSUM ... ) == sha256( LOREM IPSUM ... )

<=>

4C53E9C9... == 4C53E9C9...

- ★ Collisions [A != B but sha256(A) == sha256(B)] are mathematically possible, but practically not relevant

## COMPARE DATA



**Problem:** Securely compare two data items

**Solution:** Normalise & hash data, compare hashes

### 1 - Normalize

E.g. **J. EDGAR HOOVER** → **HOOVER, JOHN EDGAR** →\* **H160, J500 E326**

### 2 - Hash

Use  $\text{hash}(\text{salt} + \text{data})$  to prevent precomputing attacks. Use multiple iterations of hashing.

- ▶ *public salt* => treat hash as *pseudonymised*
- ▶ *secret salt* => treat hash as *anonymised*

\* Soundex - but choose whatever normalisation works for you



PATTERNS

---

TRANSPARENT  
ENCRYPTION

# TRANSPARENT ENCRYPTION



What?

**Transparent encryption  
is also transparent to the attacker**

?!?!  
?!?!

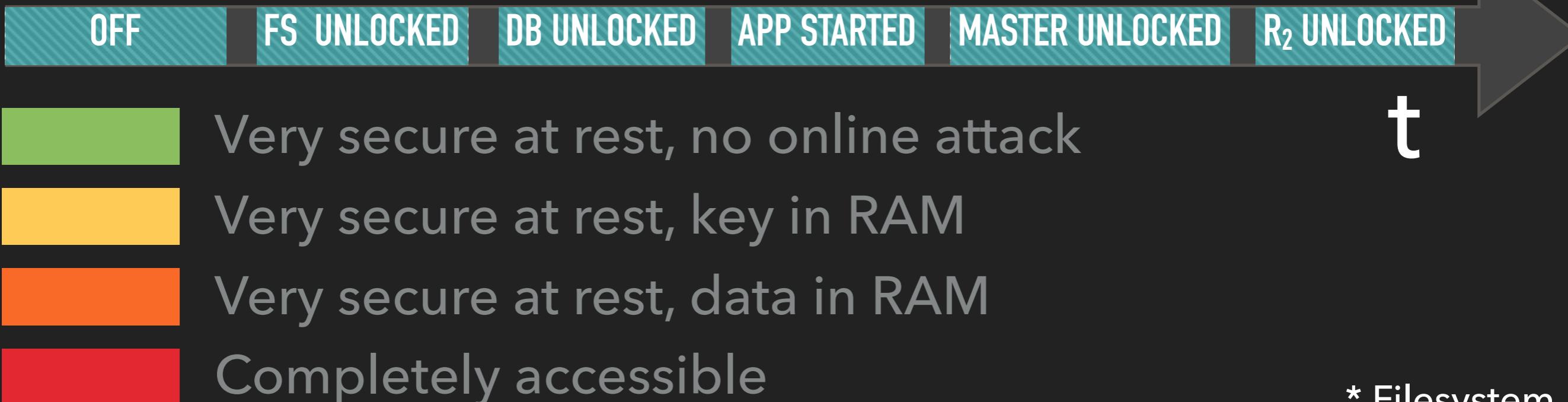


- ▶ Full disk encryption
- ▶ File system encryption
- ▶ Transparent database encryption

Help against stolen hard disks.

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)

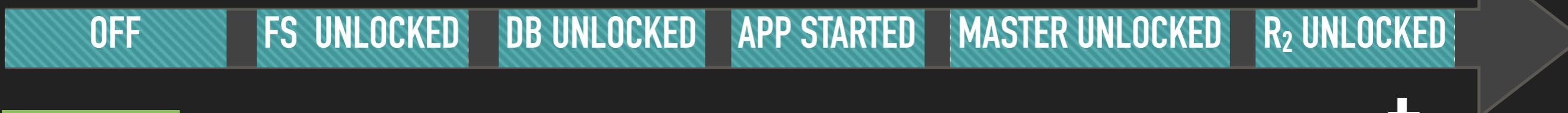
Attack



# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



FS\* 



 Very secure at rest, no online attack 

 Very secure at rest, key in RAM

 Very secure at rest, data in RAM

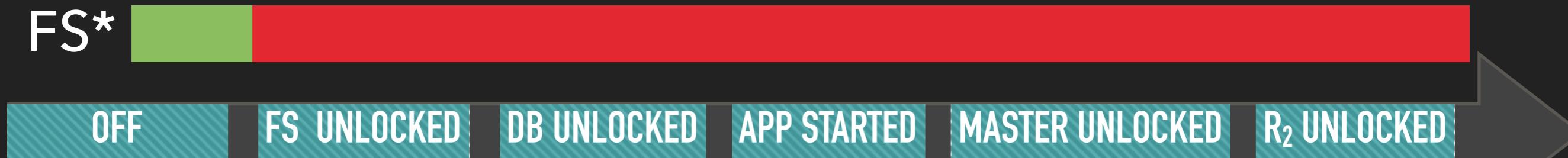
 Completely accessible

\* Filesystem

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



FS\*



Very secure at rest, no online attack t

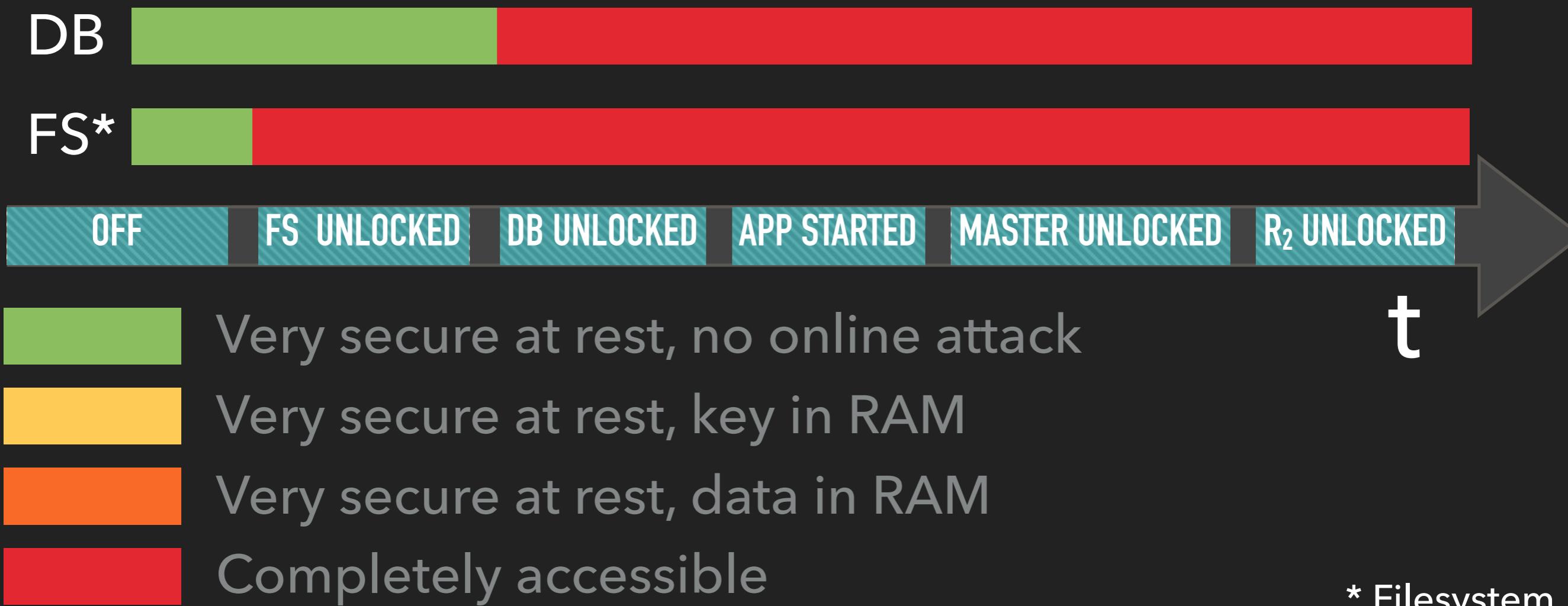
Very secure at rest, key in RAM

Very secure at rest, data in RAM

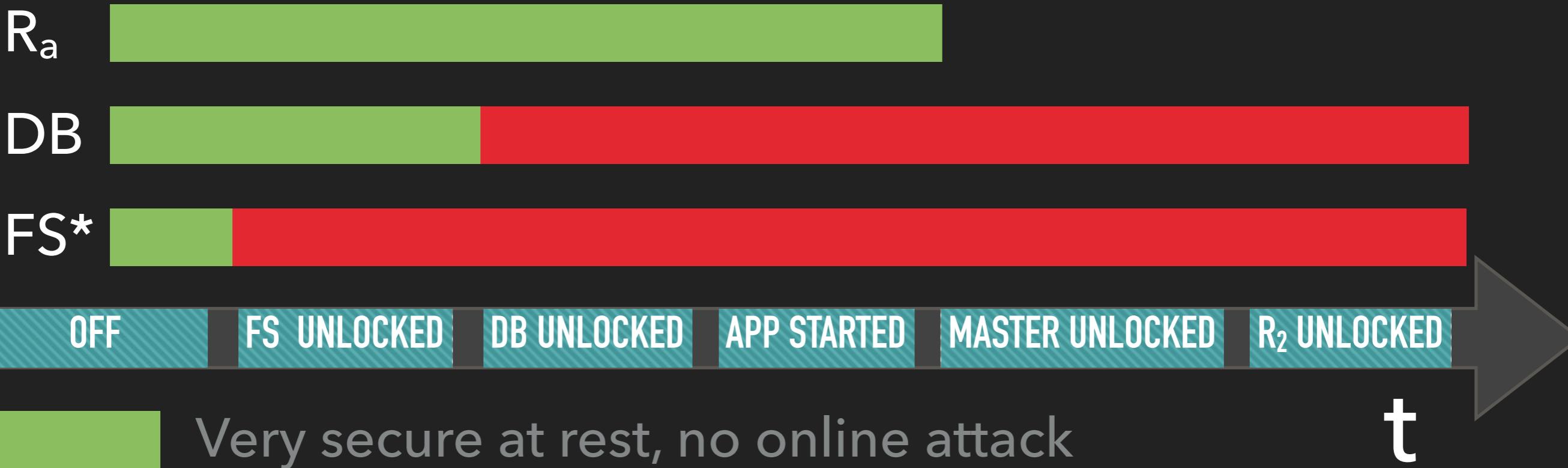
Completely accessible

\* Filesystem

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



Very secure at rest, no online attack t

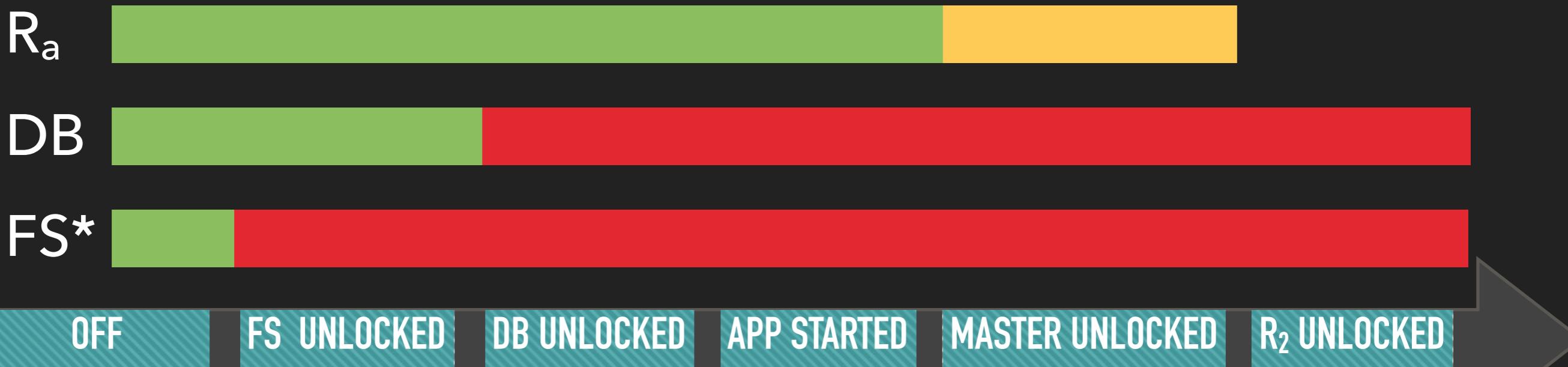
Very secure at rest, key in RAM

Very secure at rest, data in RAM

Completely accessible

\* Filesystem

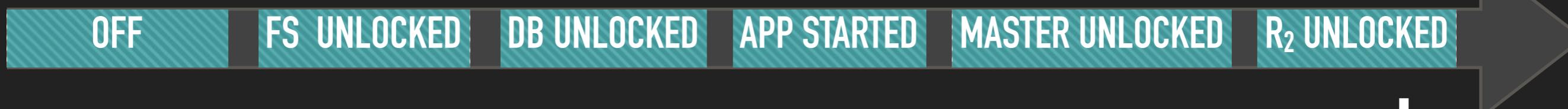
# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



- Very secure at rest, no online attack t
- Very secure at rest, key in RAM
- Very secure at rest, data in RAM
- Completely accessible

\* Filesystem

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



Very secure at rest, no online attack t

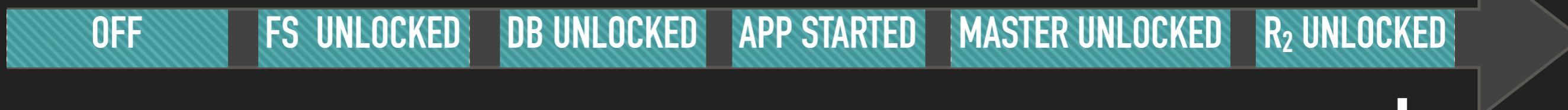
Very secure at rest, key in RAM

Very secure at rest, data in RAM

Completely accessible

\* Filesystem

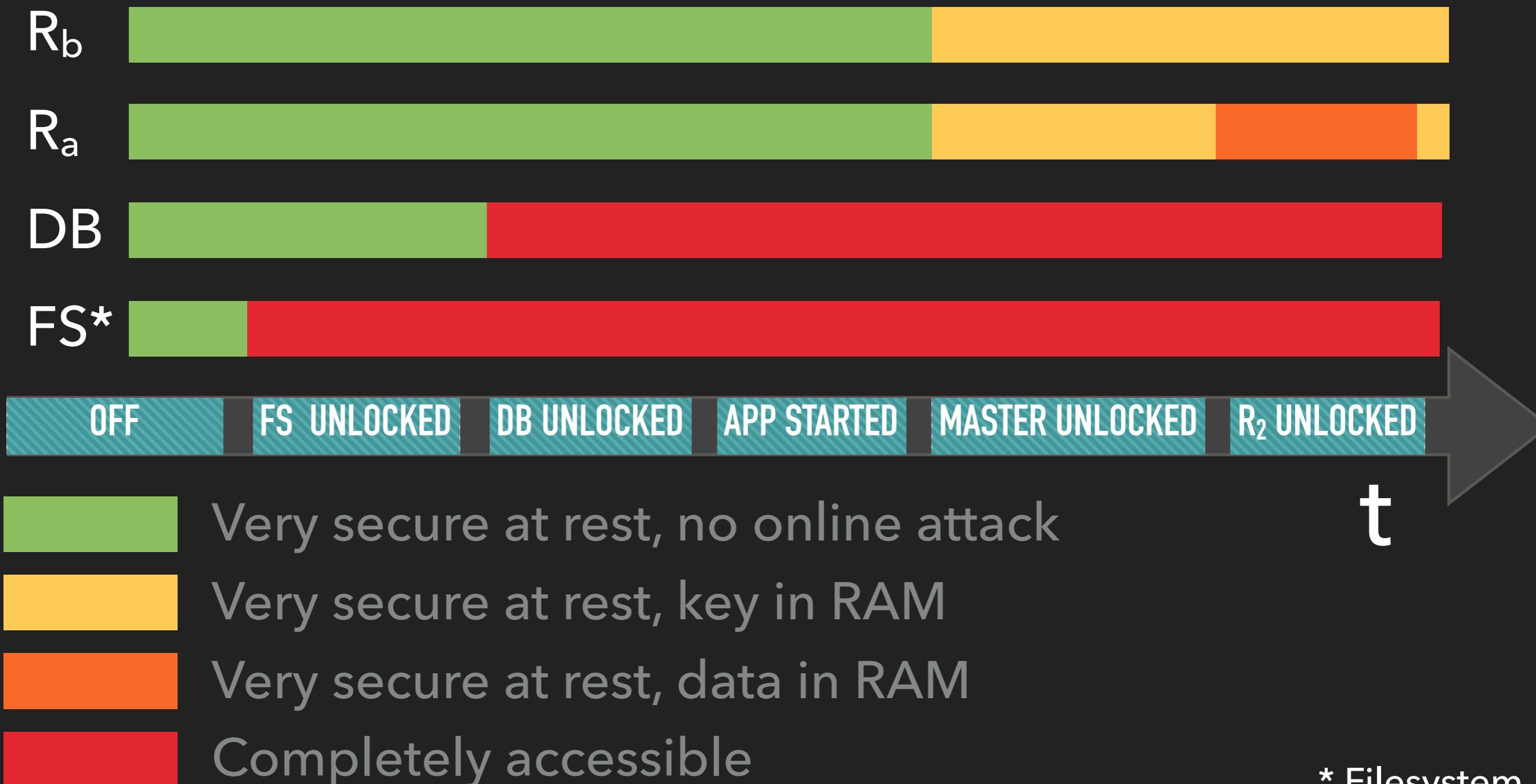
# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



- Very secure at rest, no online attack t
- Very secure at rest, key in RAM
- Very secure at rest, data in RAM
- Completely accessible

\* Filesystem

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)

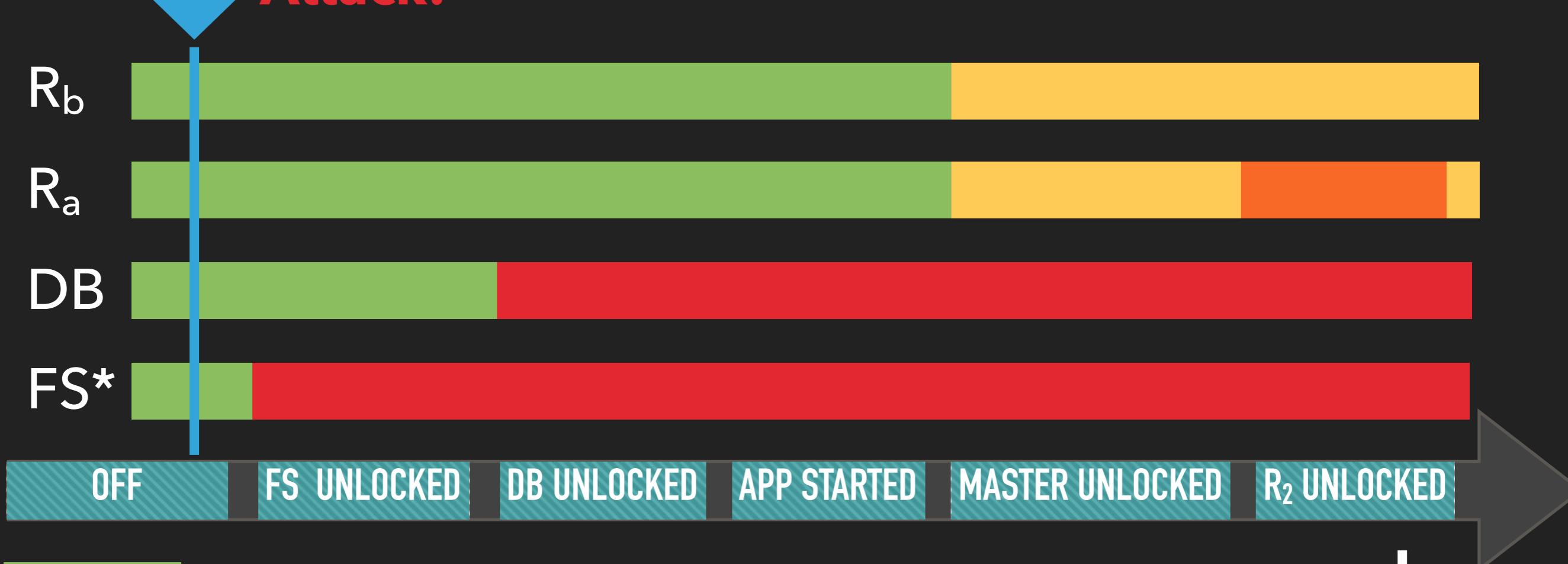


\* Filesystem

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



**Attack!**



Very secure at rest, no online attack

t

Very secure at rest, key in RAM

Very secure at rest, data in RAM

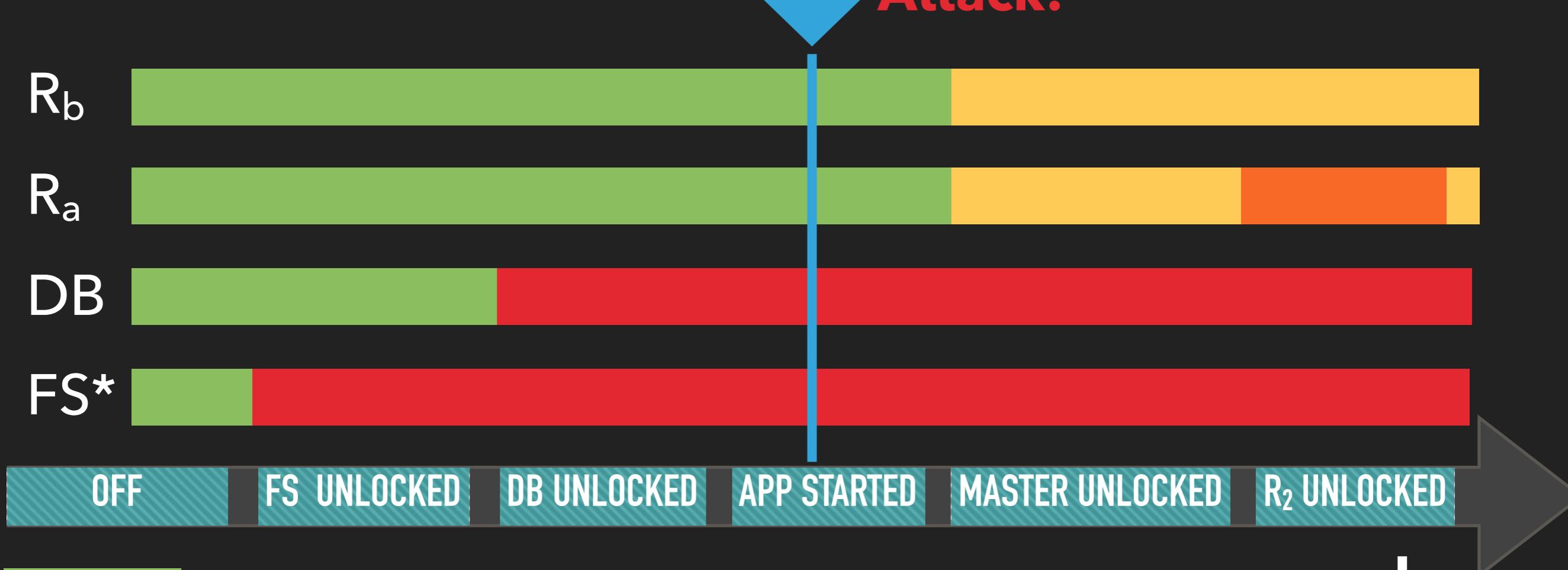
Completely accessible

\* Filesystem

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



Attack!



Very secure at rest, no online attack t

Very secure at rest, key in RAM

Very secure at rest, data in RAM

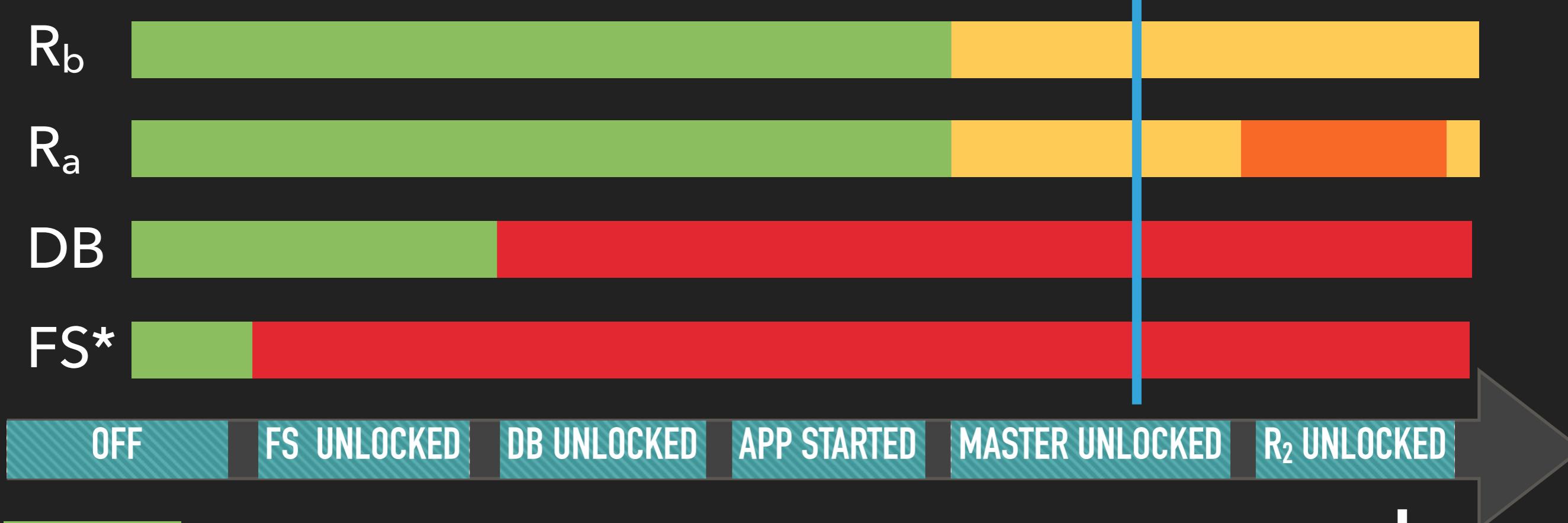
Completely accessible

\* Filesystem

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



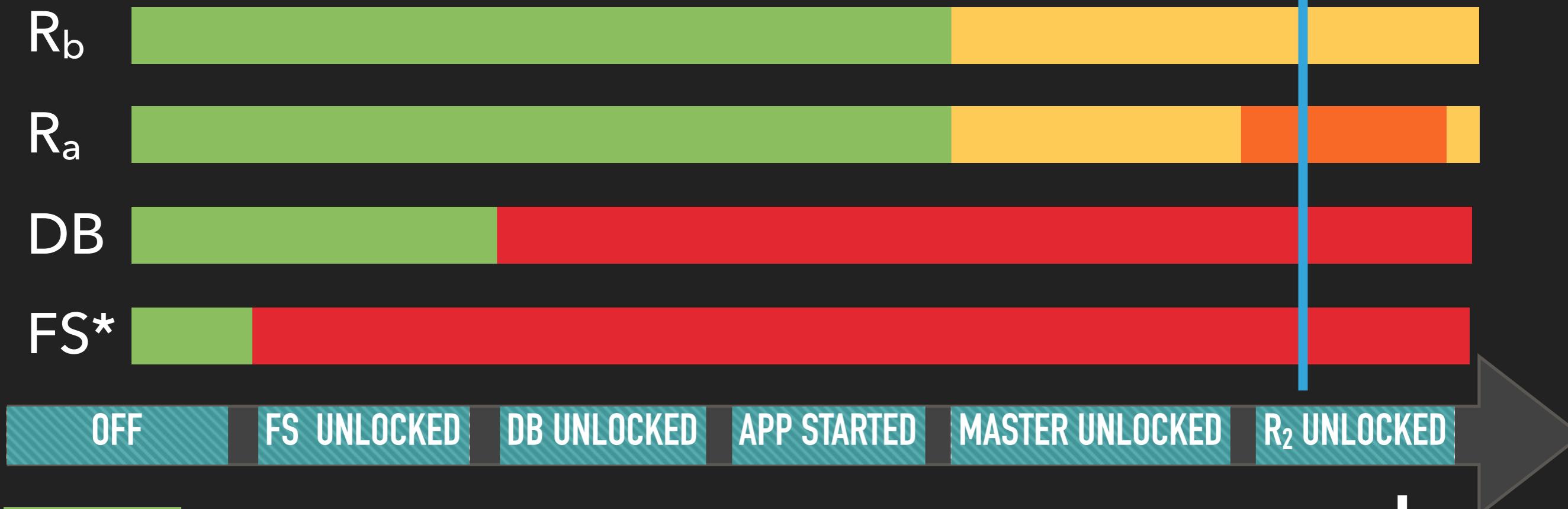
Attack!



- Very secure at rest, no online attack t
- Very secure at rest, key in RAM
- Very secure at rest, data in RAM
- Completely accessible

\* Filesystem

# TRANSPARENT ENCRYPTION (ATTACKS VIA APPLICATION)



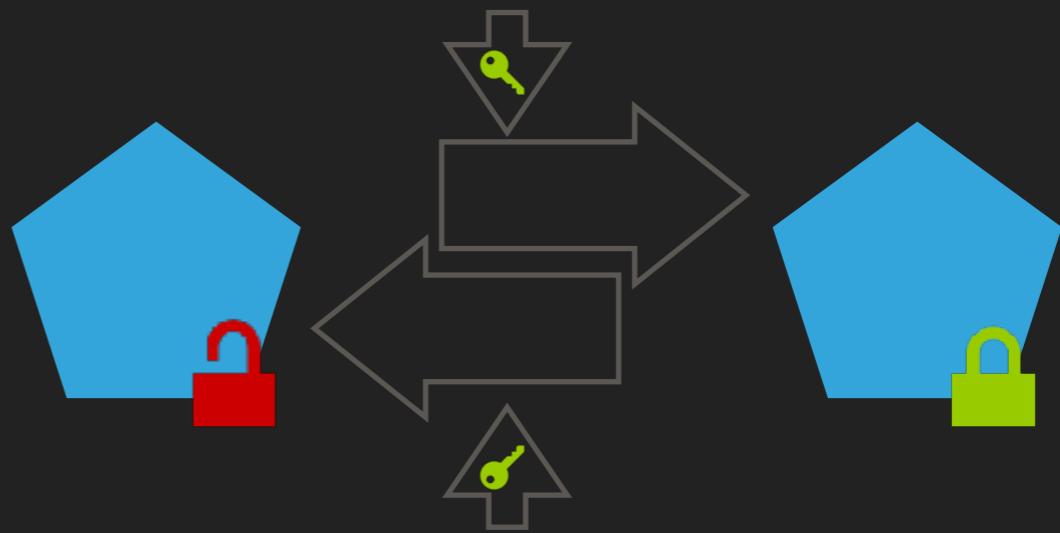
Very secure at rest, no online attack t

Very secure at rest, key in RAM

Very secure at rest, data in RAM

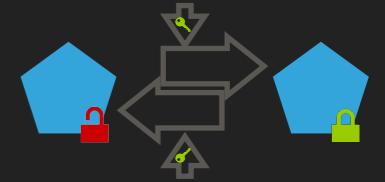
Completely accessible

\* Filesystem



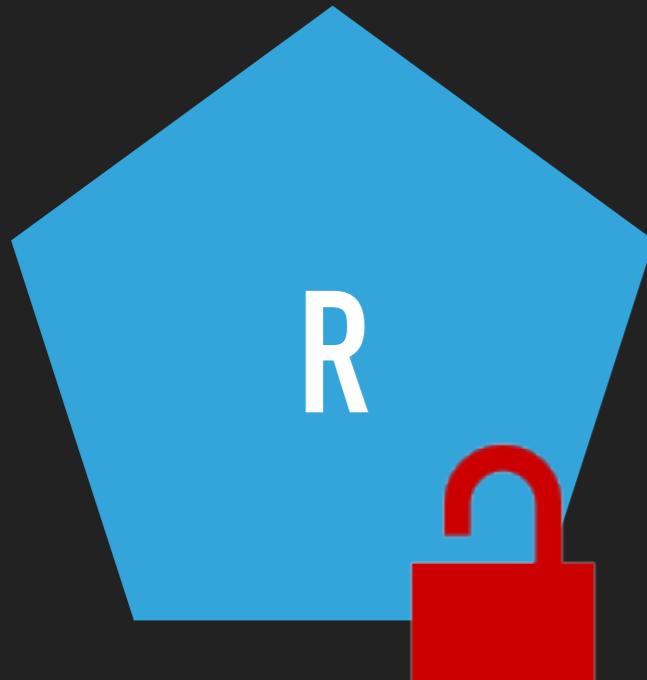
# PATTERNS STORING

# SECURE MULTIPLE DATA RECORDS



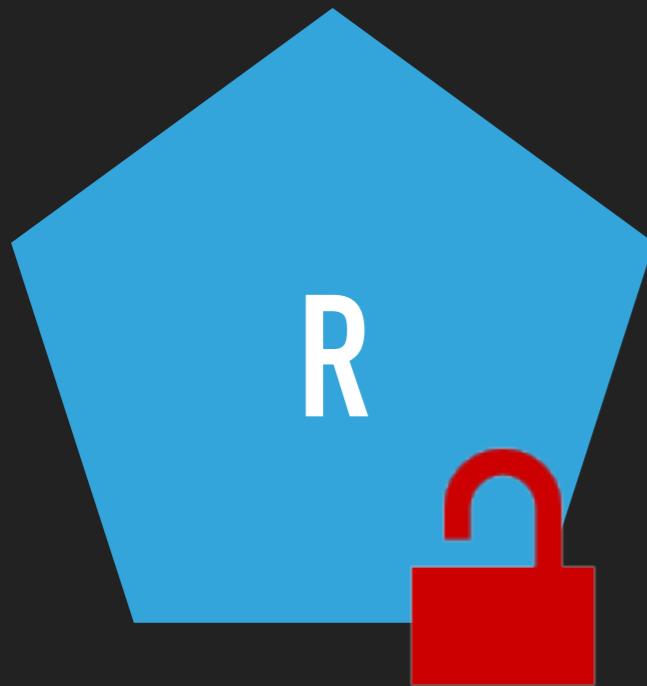
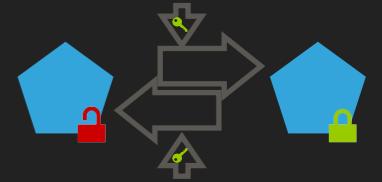
**Problem:** Multiple records are read and written by the same application.

**Solution:** Use symmetric encryption to protect the records.



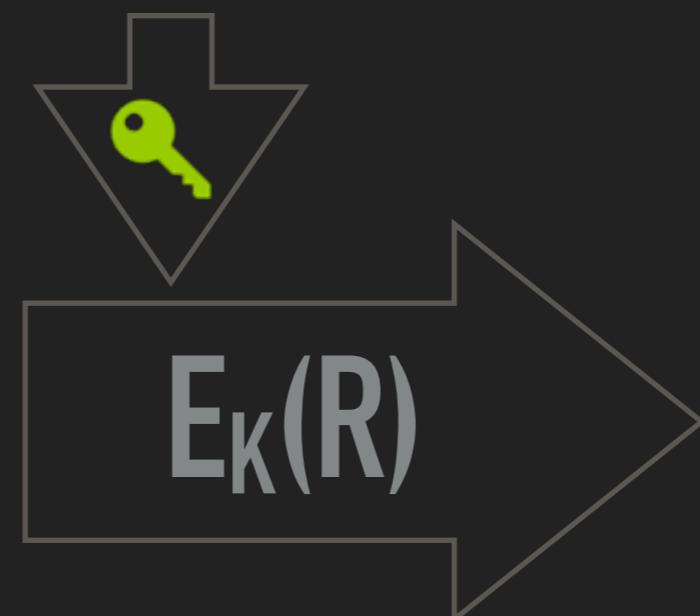
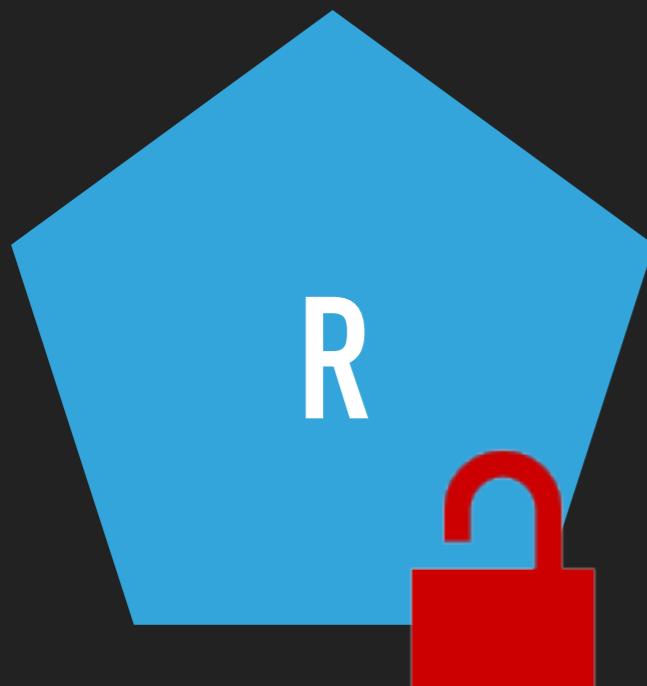
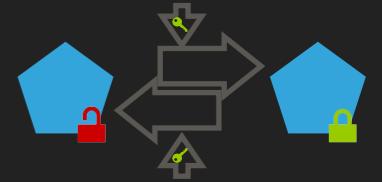
Reading and writing plaintext record 'R' 

# SECURE MULTIPLE DATA RECORDS



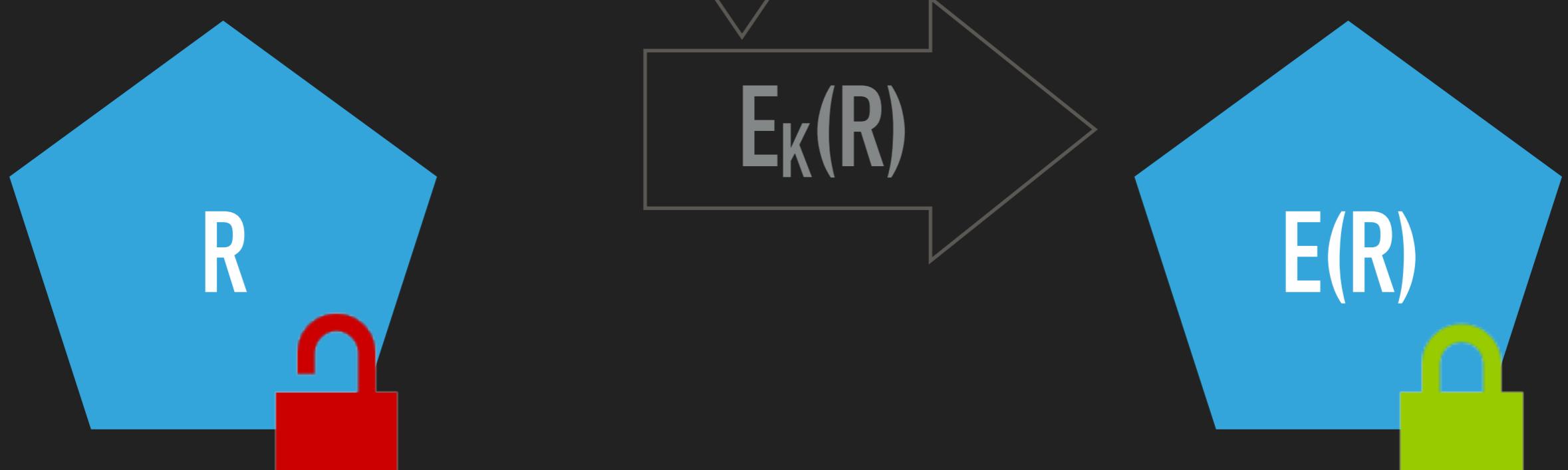
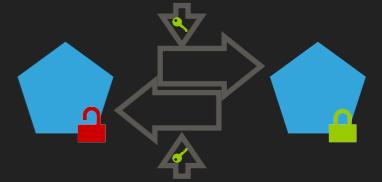
En-/decrypt Data 'R' (record) with key 'K'. 

# SECURE MULTIPLE DATA RECORDS



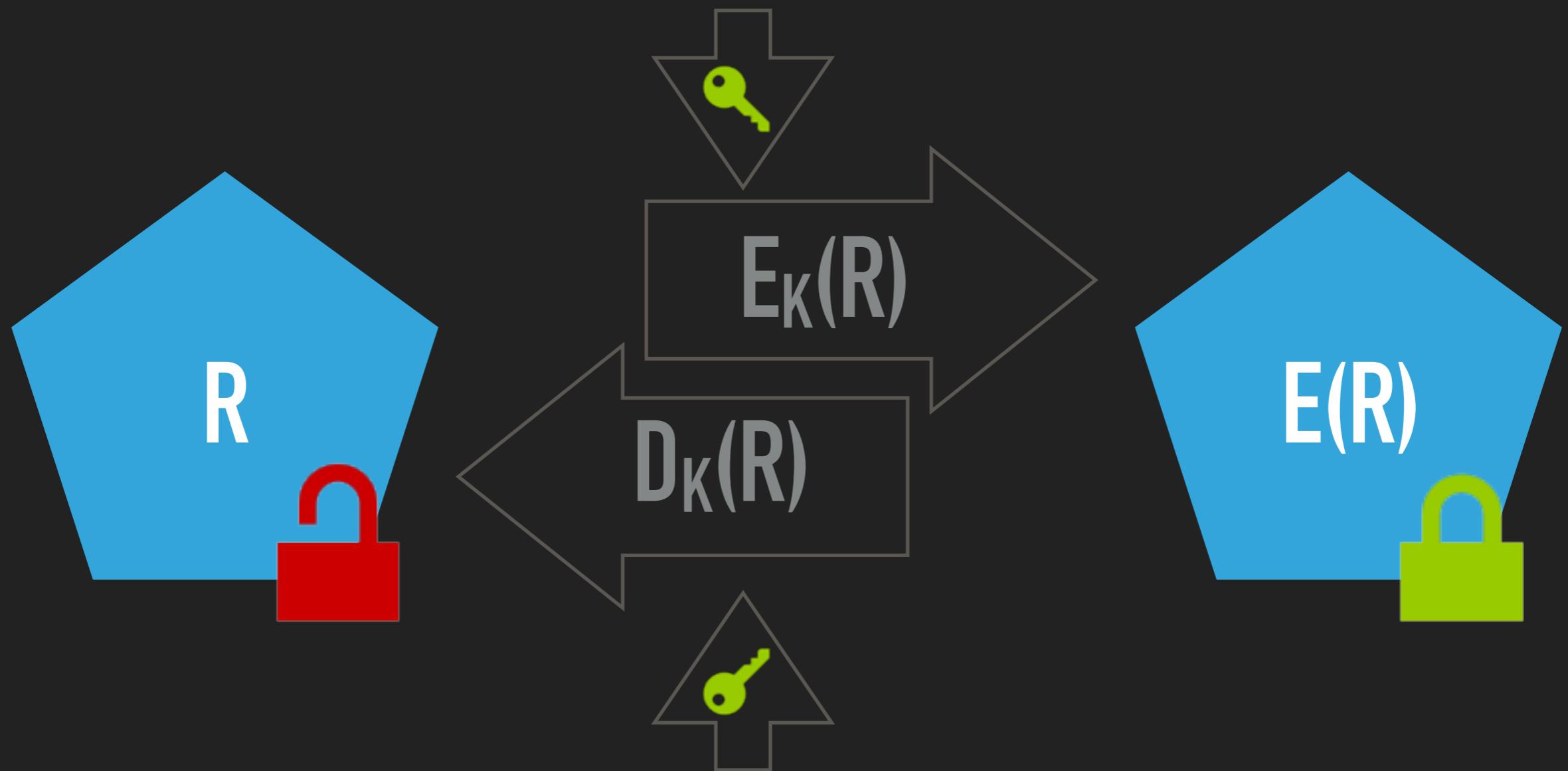
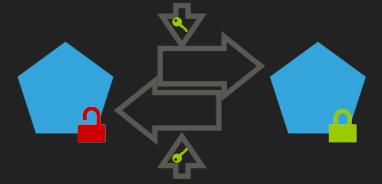
En-/decrypt Data 'R' (record) with key 'K'. 

# SECURE MULTIPLE DATA RECORDS



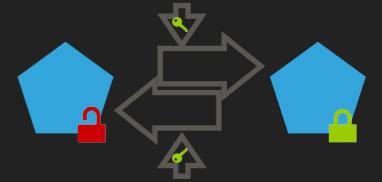
En-/decrypt Data 'R' (record) with key 'K'. 

# SECURE MULTIPLE DATA RECORDS

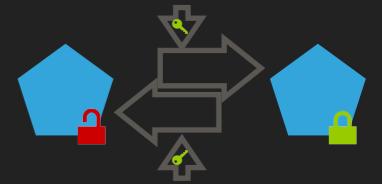


En-/decrypt Data 'R' (record) with key 'K'. 🔑

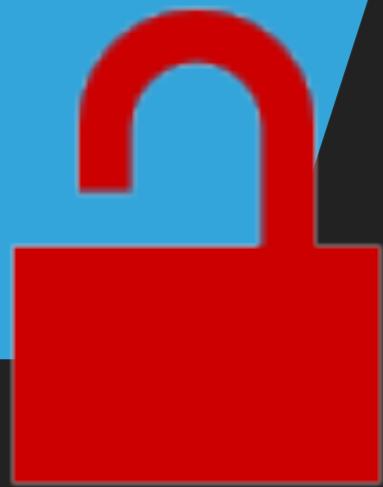
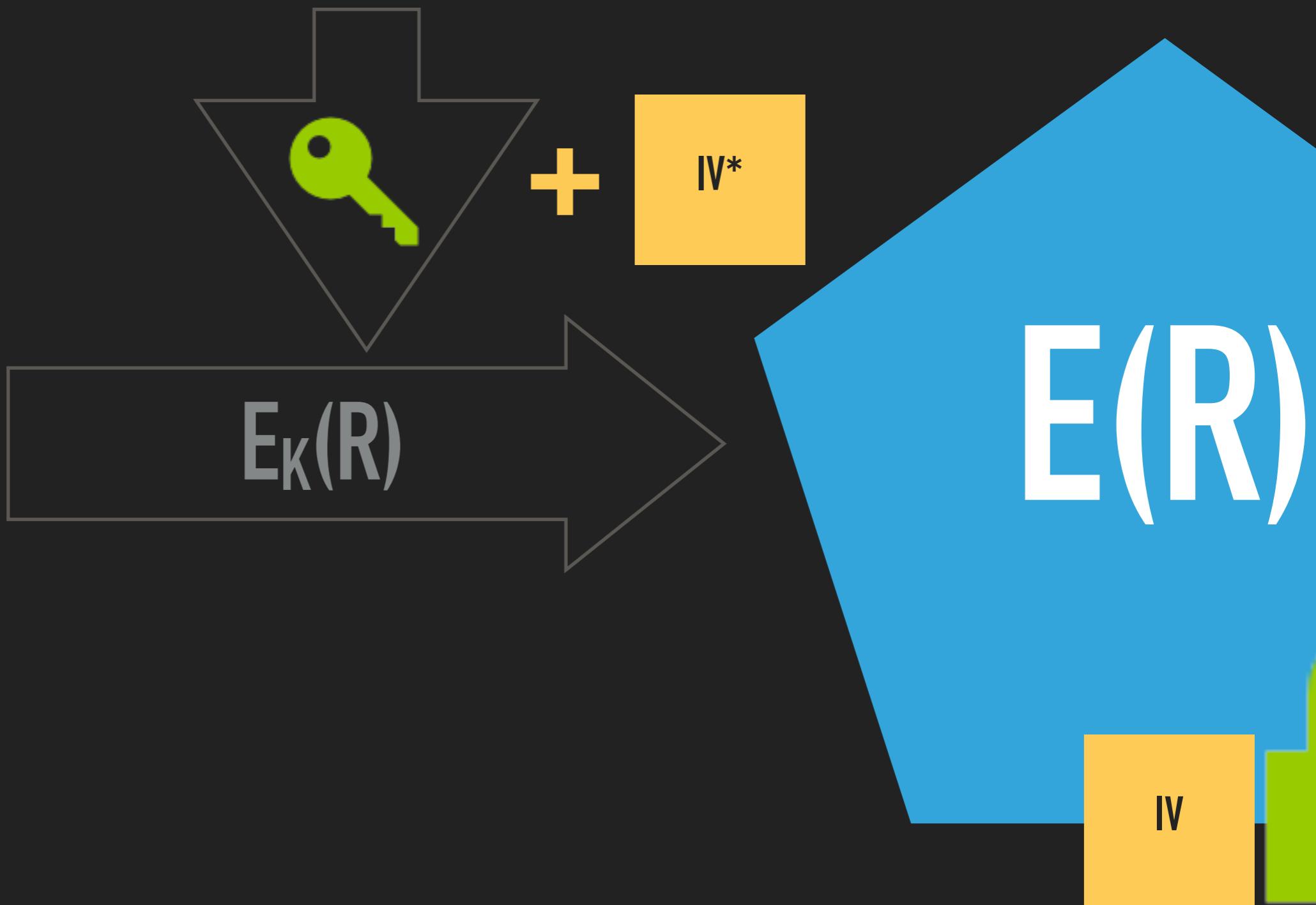
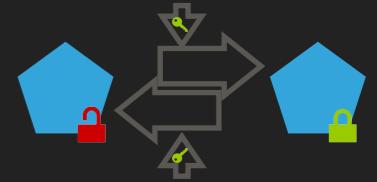
# SECURE SMALL KEY(S)

 $E_K(R)$  $E(R)$

# SECURE SMALL KEY(S)

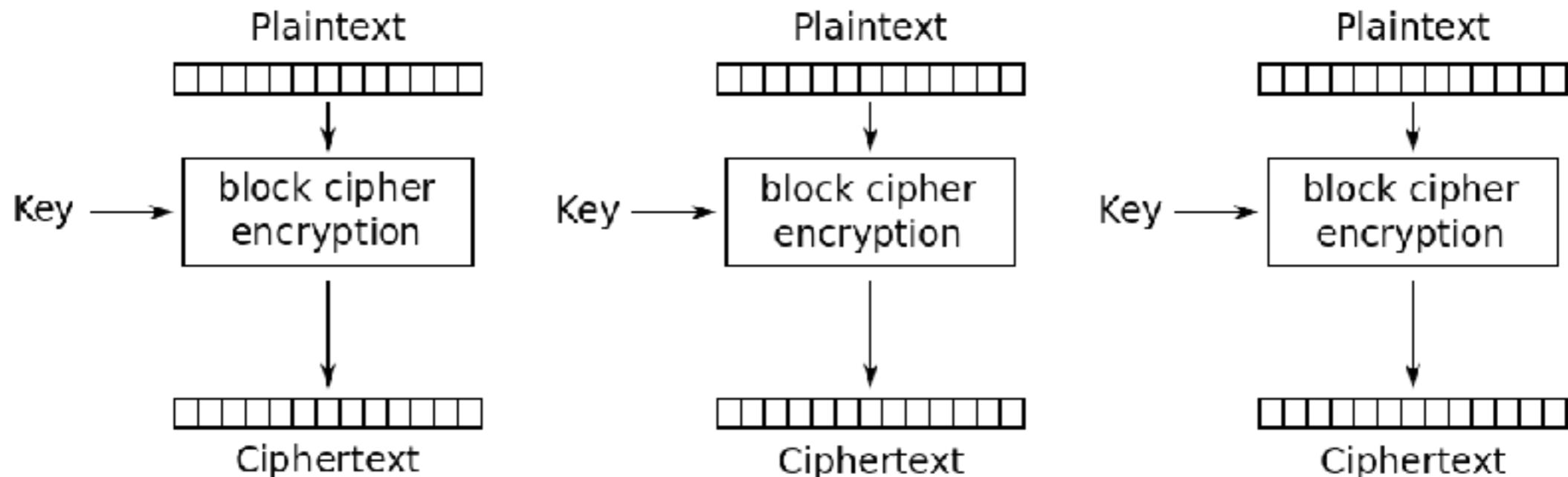


# SECURE SMALL KEY(S)

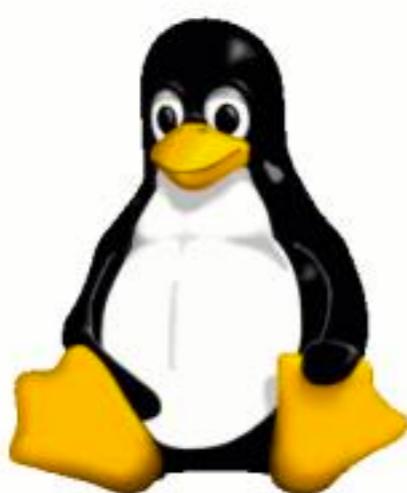


(\*) IV - Initialisation Vector. Used in many cryptographic operations. Like a salt. Must be random, might be public.

# BLOCK CIPHERS AND THE IV



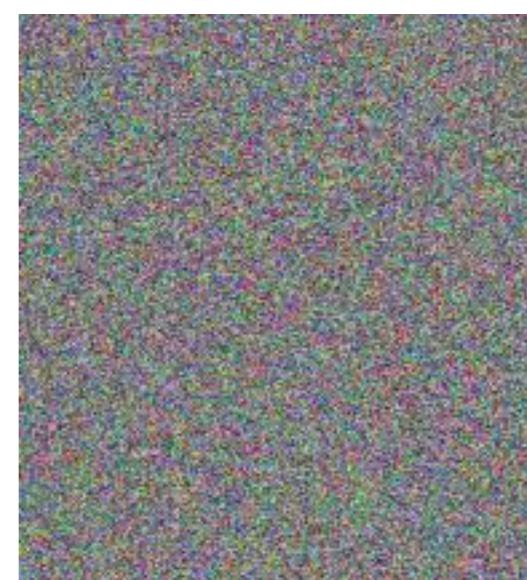
Electronic Codebook (ECB) mode encryption



Original

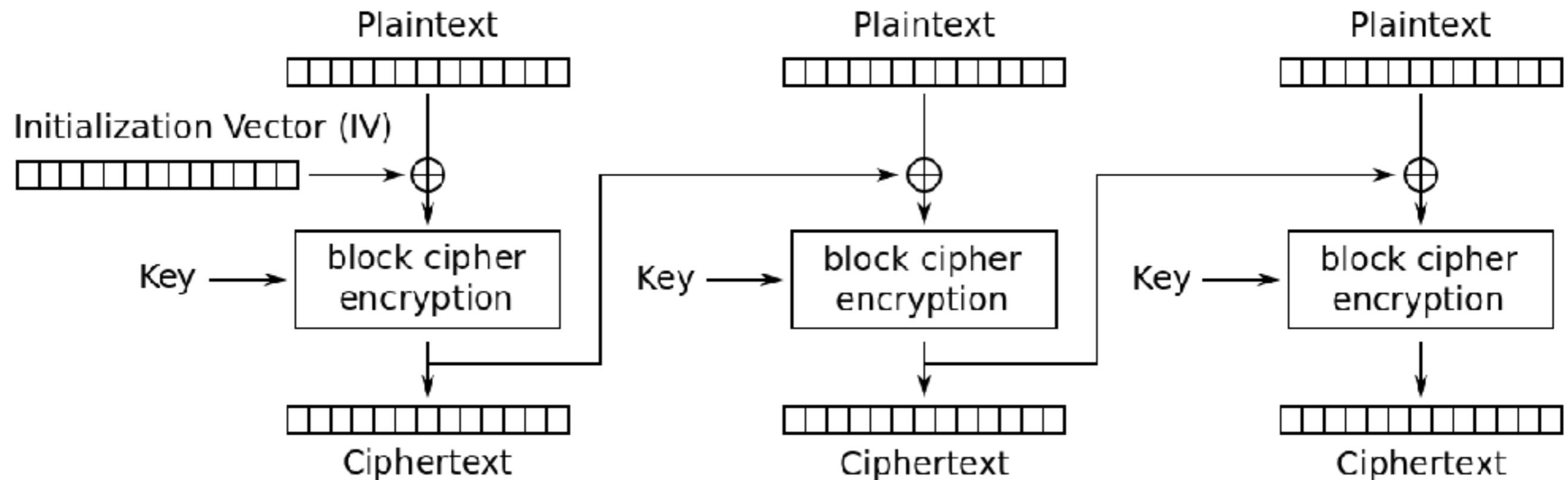


ECB



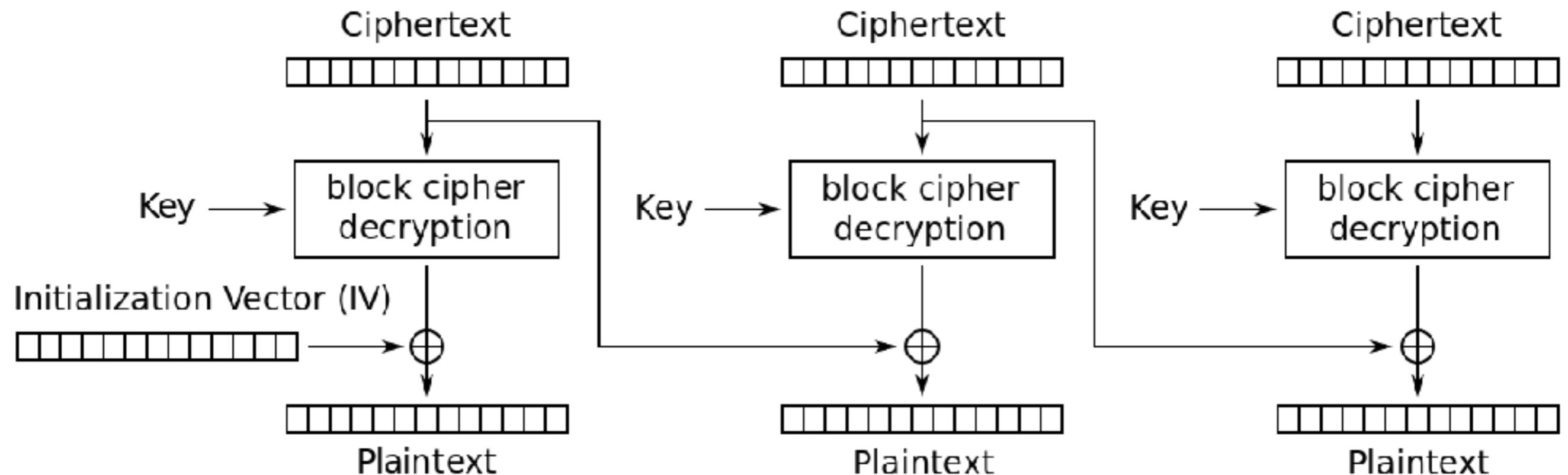
CBC (or other)

## BLOCK CIPHERS AND THE IV



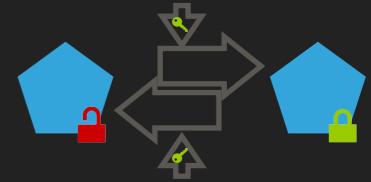
Cipher Block Chaining (CBC) mode encryption

## BLOCK CIPHERS AND THE IV



Cipher Block Chaining (CBC) mode decryption

# SOLUTIONS FOR SECURING KEY(S)



## Master key in different storage

E.g. records in DB, master key on filesystem.

Baseline. Easy. Protects (only) against DB theft (e.g. SQL injection)

## Encrypt master key

Use baked in 'obfuscation key' to encrypt master key. Better:  
Store master key in OS keyring.

Easy. Some protection against FS access (e.g. remote file inclusion)

## Derive per-record key

Unique per record key derived from master key.  
*Bonus: Protect integrity. Bind to record.*

Mostly easy. Protects against some cipher text attacks. Use [AEAD!](#)

## Crypto Host

All crypto operations on a dedicated host. (Master)key never leaves Crypto Host.

Depends on architecture. Helps w. key distribution. Makes key theft difficult.

## HSM

Use Hardware Security Module as Crypto Host.

Expensive & difficult.  
"Crypto Host on steroids".



\*\*\*\*\*



## PATTERNS

---

# KEY DERIVATION 1: PASSWORD TO KEY

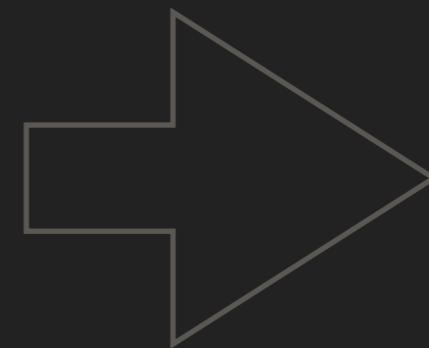
## FROM PASSWORD TO KEY

\*\*\*\*\*



\*\*\*\*\*

password



128 bit key

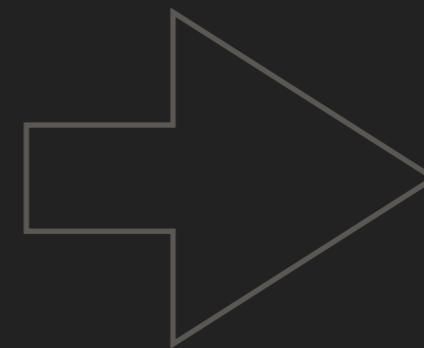
## FROM PASSWORD TO KEY

\*\*\*\*\*



\*\*\*\*\*

password



128 bit key

- ▶ A *random* password has ~ 6 bits per character (\*)
- ▶ A 128 bit key needs  $\geq 21$  character passwords

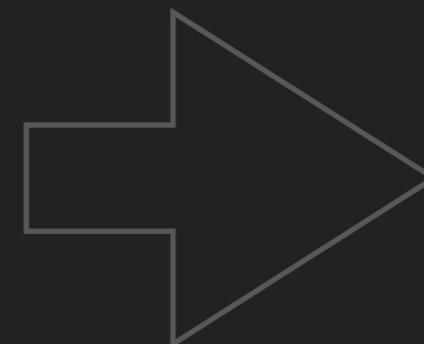
## FROM PASSWORD TO KEY

\*\*\*\*\*



\*\*\*\*\*

password



128 bit key

- ▶ A *random* password has ~ 6 bits per character (\*)
- ▶ A 128 bit key needs  $\geq 21$  character passwords

**Secure passwords are *very long***

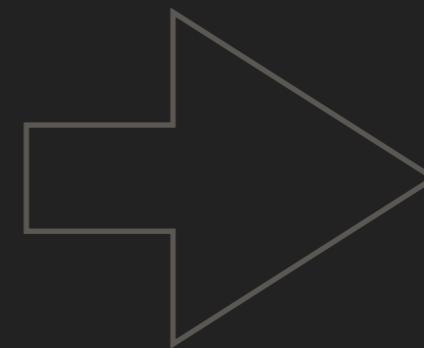
## FROM PASSWORD TO KEY

\*\*\*\*\*



\*\*\*\*\*

password



128 bit key

- ▶ aw92SDAVglkqusabvgw38 ✓
- ▶ 128 bit
- ▶ 3o8uGsdA ✗
- ▶ 8 chars, 48 bit (cracked in hours to days)

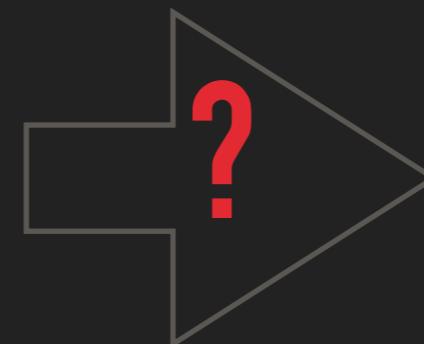
# FROM PASSWORD TO KEY

\*\*\*\*\*



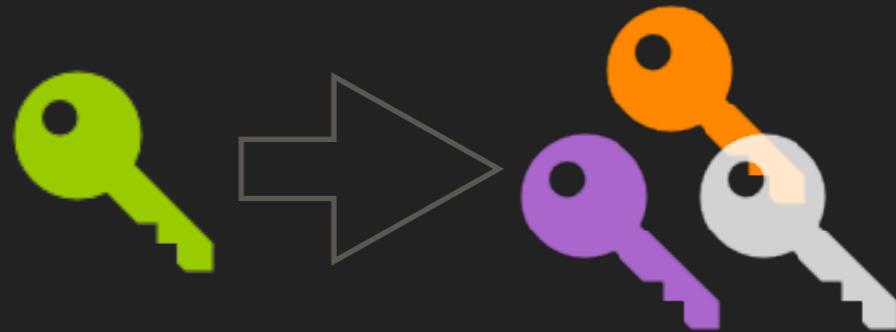
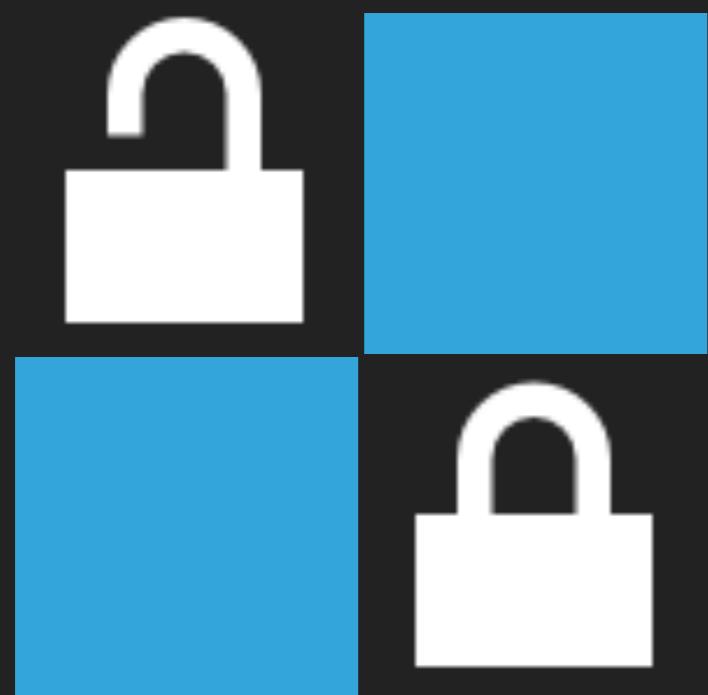
\*\*\*\*\*

password



128 bit key

- ▶ Key derivation functions (KDF) convert passwords to keys
- ▶ For good (21+ chars) passwords use HKDF ([RFC5869](#))
- ▶ Else: use a KDF with brute force protection (\*)
  - ▶ SCRYPT ([RFC7914](#))
  - ▶ PBKDF2 ([RFC2898](#))

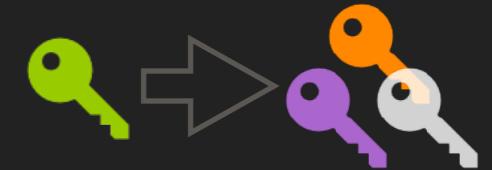


## PATTERNS

---

# KEY DERIVATION 2: FROM 1 TO N

## DERIVE PER RECORD KEYS



**Problem:** Use different keys for different records, only store master key.

**Solution:** Use key derivation to derive per-record keys.

Master Key +  $r_1.id + r_1.ver \rightarrow$  Record Key

Master Key +  $r_2.id + r_2.ver \rightarrow$  Record Key

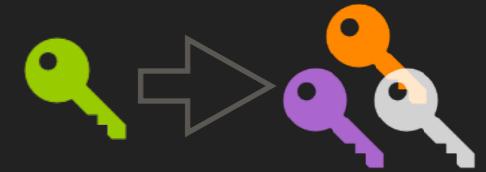
...

Master Key +  $r_n.id + r_n.ver \rightarrow$  Record Key

**IMPORTANT: NEVER USE THE SAME KEY/IV TO ENCRYPT DIFFERENT DATA**

MAKE SURE THAT THE MASTER KEY HAS ENOUGH ENTROPY FOR DERIVED KEY AND DERIVED IV

## DERIVE PER RECORD KEYS



**Problem:** Use different keys for different records, only store master key.

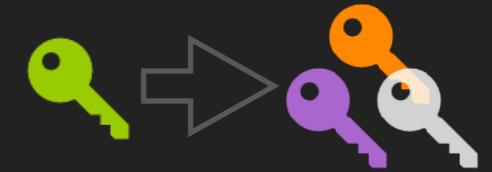
**Solution:** Use key derivation to derive per-record keys.



**IMPORTANT: NEVER USE THE SAME KEY/IV TO ENCRYPT DIFFERENT DATA**

MAKE SURE THAT THE MASTER KEY HAS ENOUGH ENTROPY FOR DERIVED KEY AND DERIVED IV

# SOLUTIONS FOR DERIVING KEY(S)



```
// Input:  
// Master_key and  
// (DB) record_id target record DB id  
// Output:  
// AES-Key and  
// salt for encrypting target record
```

```
// AES-Key and salt for target record. "||" concatenates  
// AES-CBC uses 128 bit IV. AES-GCM uses a 96 bit IV  
byte[ 32 ] keyAndIV = derive_key( master_key ||  
                           record_id || record_version, 256 bit )
```

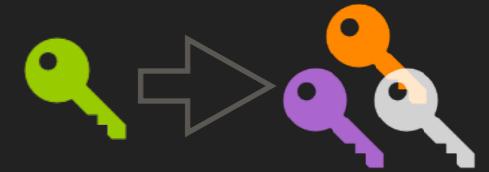
```
byte[ 16 ] derived_iv    = keyAndIV[ 0..15 ]  
byte[ 16 ] derived_key   = keyAndIV[ 16..31 ]
```

- ▶ `derive_key` needs an additional *installation specific* salt of  $\geq 128$  bit. PBKDF2 with HMAC sha256 is an example of `derive_key`, as is scrypt or [argon2](#).
- ▶ Use same process for decryption.
- ▶ No need to store the generated IV value.

**IMPORTANT: NEVER USE THE SAME KEY/IV TO ENCRYPT DIFFERENT DATA**

**MAKE SURE THAT THE MASTER KEY HAS ENOUGH ENTROPY FOR DERIVED KEY AND DERIVED SALT**

# NEVER REUSE KEYS!

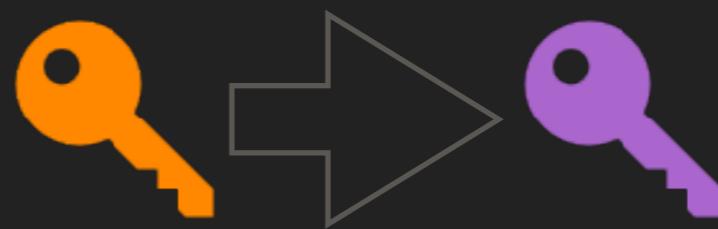


- ▶ Encrypting different data with the same key and IV can lead to complete loss of confidentiality / integrity (\*)
- ▶ **When updating encrypted records a new IV must be used** (better: a new key and IV)
- ▶ This can be achieved by incrementing a record-version on each encryption and using it in the key derivation.

(\*) This is because of the way CTR/GCM/CBC/... work. See e.g Appendix B of [NIST Sp. Pub. 800-38A](#)

**IMPORTANT: NEVER USE THE SAME KEY/IV TO ENCRYPT DIFFERENT DATA**

**MAKE SURE THAT THE MASTER KEY HAS ENOUGH ENTROPY FOR DERIVED KEY AND DERIVED SALT**

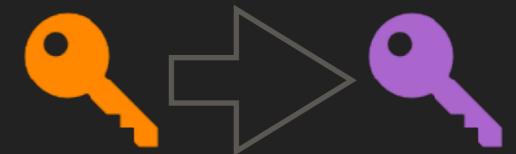


# PATTERNS

---

# KEY REFRESH

## KEY REFRESH



**Problem:** Keys must only be used for a limited amount of data

**Solution:** Design for constant key rollover

Record-ID	Version	Masterkey ID (Data...)	
B9E10DEE-C97E-...	1	<b>B874920B-E801...</b>	...
FDE0C6E3-8BF0-...	1	<b>9A6580FC-1248...</b>	...
...	3	<b>9A6580FC-1248...</b>	...



DES BLOWFISH AES

MD5 SHA-1 SHA-256

RSA-1024 RSA-2048 ?? POST QUANTUM ??

## PATTERNS

---

# ALGORITHM ROLLOVER

# ALGORITHM ROLLOVER

DES	BLOWFISH	AES
MD5	SHA-1	SHA-256
RSA-1024	RSA-2048	?? POST QUANTUM ??

**Problem:** Algorithms must be changed and data migrated

**Solution:** Design for online data migration

Record-ID	...	Masterkey ID (Data...)	...
B9E10DEE-C97E-...	...	B874920B-E801-...	...
FDE0C6E3-8BF0-...	...	9A6580FC-1248...	...
...	...	9A6580FC-1248...	...

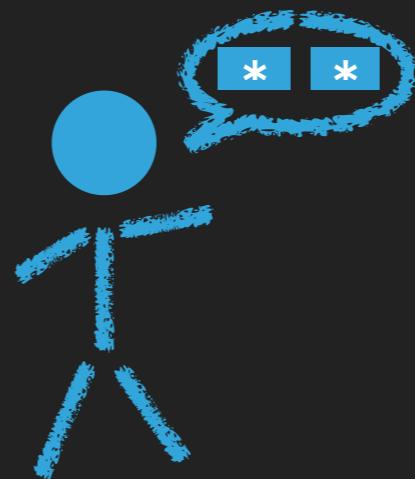
# ALGORITHM ROLLOVER

DES	BLOWFISH	AES
MD5	SHA-1	SHA-256
RSA-1024	RSA-2048	?? POST QUANTUM ??

**Problem:** Algorithms must be changed and data migrated

**Solution:** Design for online data migration

Record-ID	Algorithms	Masterkey ID (Data...)	
B9E10DEE-C97E-...	▶ <b>PBKDF2(...)</b> ▶ <b>AES128–GCM</b>	B874920B-E801-...	...
FDE0C6E3-8BF0-...	▶ <b>SCRYPT(...)</b> ▶ <b>AES256–CBC</b> ▶ <b>PKCS#5</b>	9A6580FC-1248-...	...
...	...	9A6580FC-1248...	...



PATTERNS

---

PASSWORD  
VERIFICATION

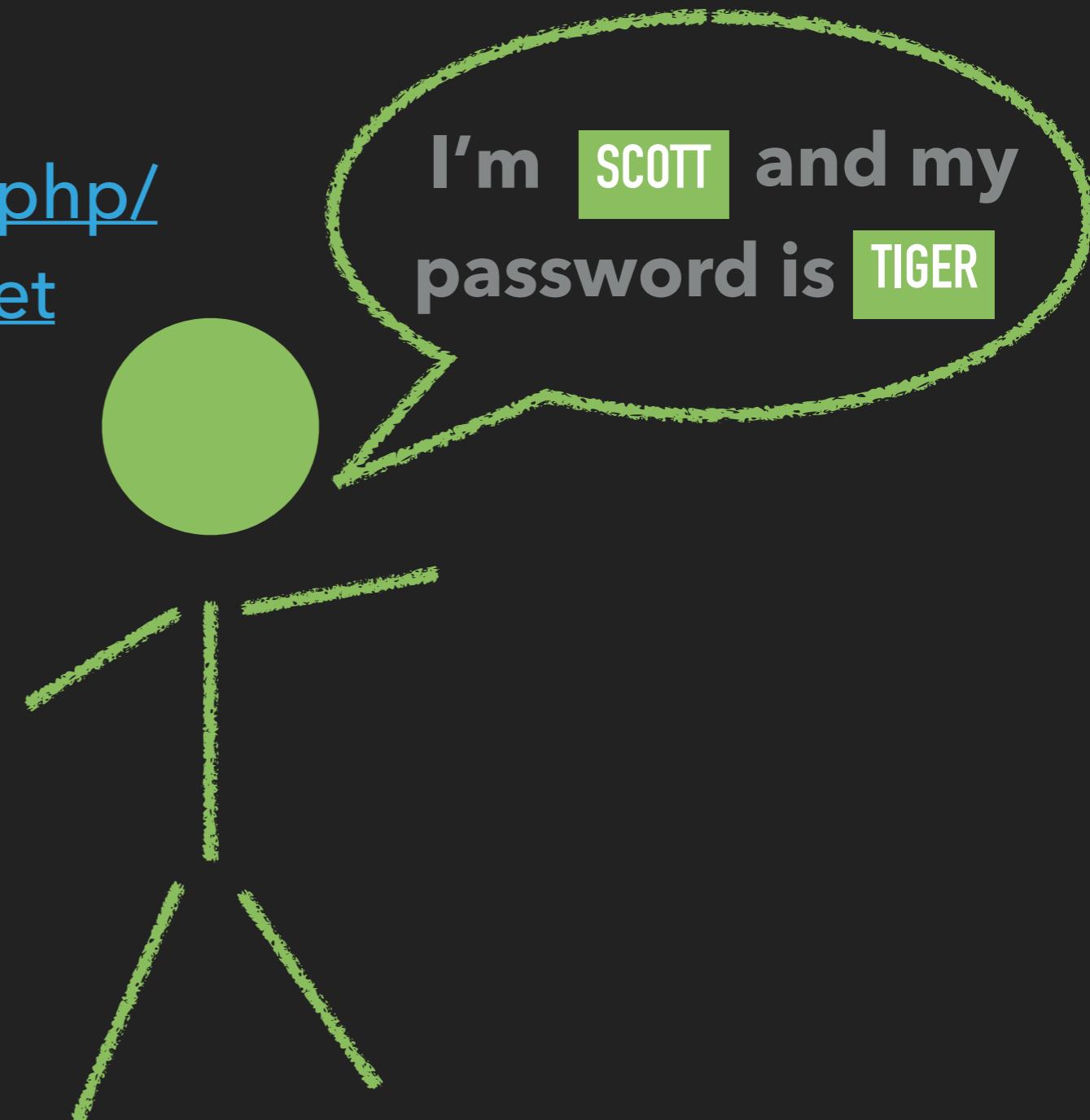
## USER LOGIN

**Problem:** Login a user

**Solution:** Not in scope here

[https://www.owasp.org/index.php/  
Password\\_Storage\\_Cheat\\_Sheet](https://www.owasp.org/index.php/Password_Storage_Cheat_Sheet)

Also: OAUTH, Kerberos, ...

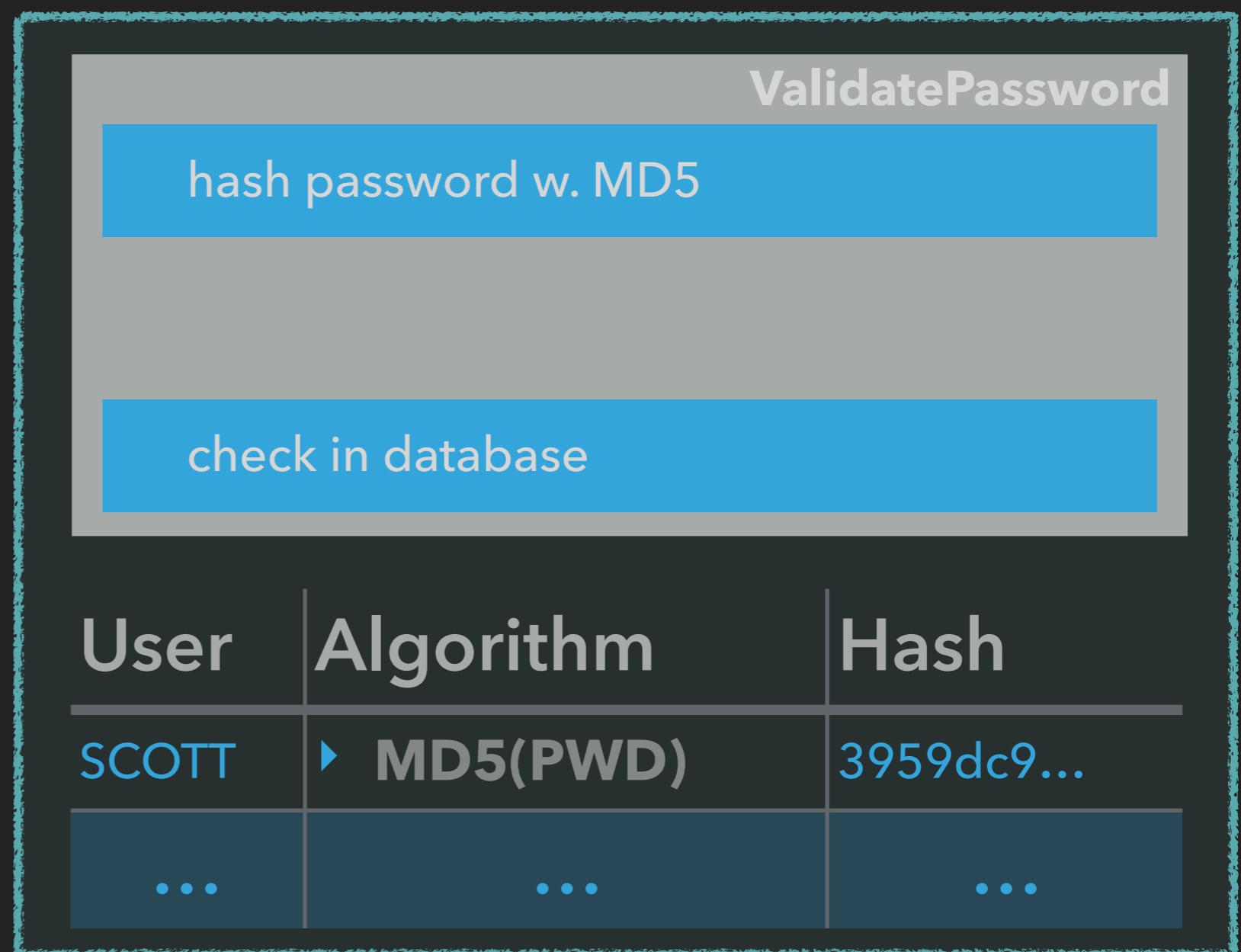
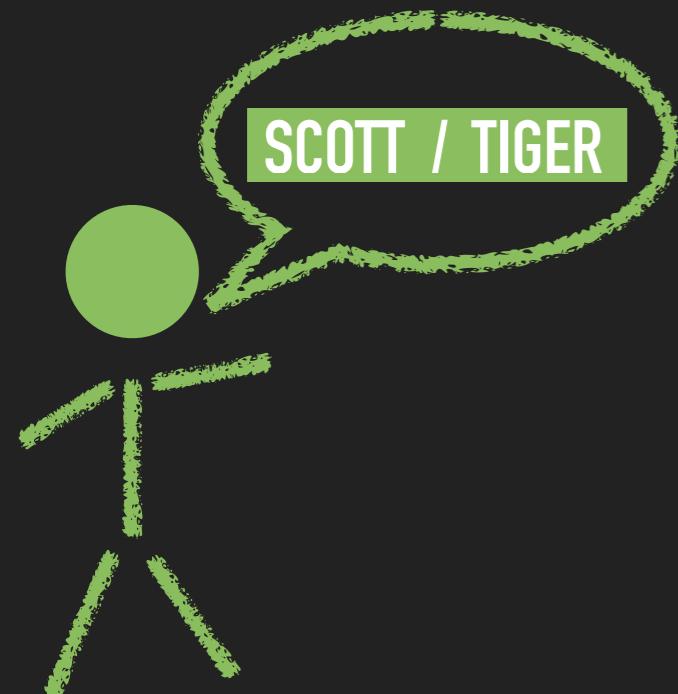


# USER LOGIN: MIGRATE PASSWORDS



**Problem:** Migrate password hashes to new algorithms

**Solution:** Chain hashing functions

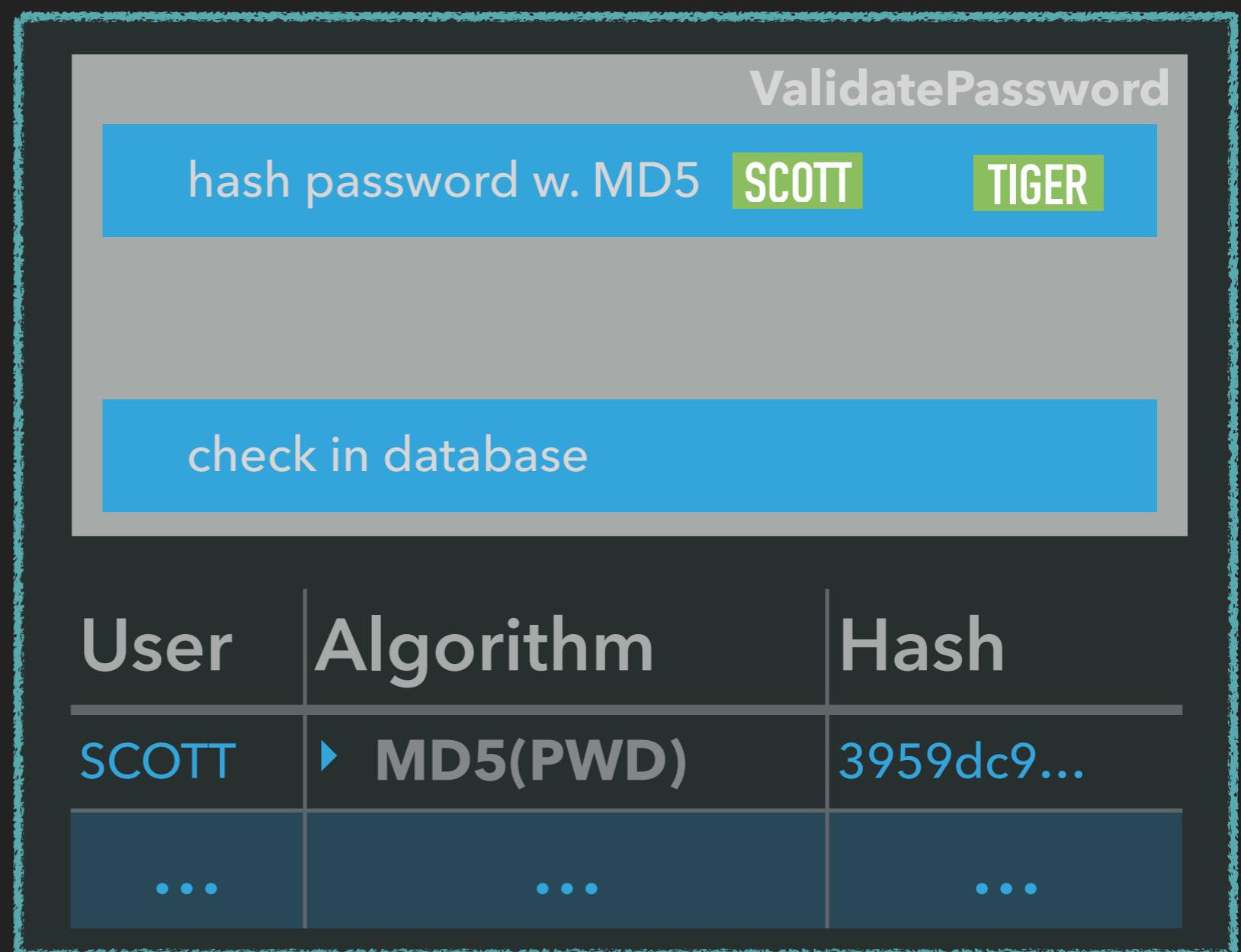
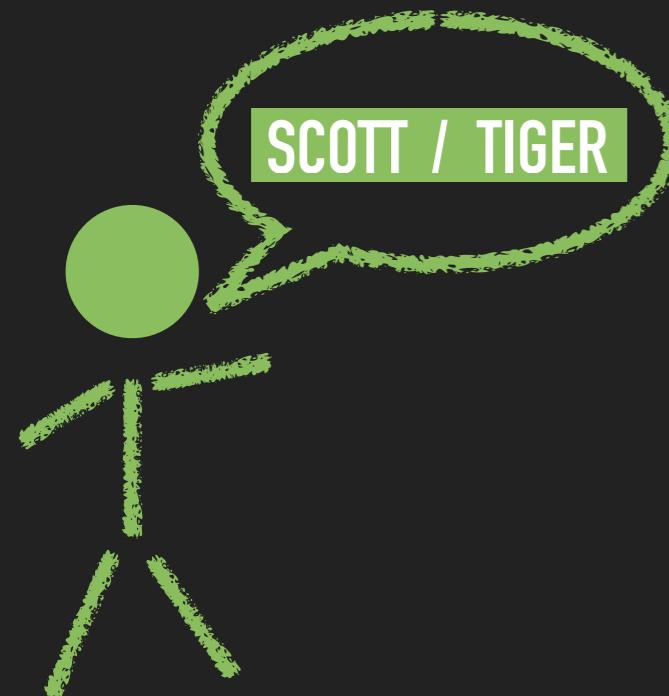


# USER LOGIN: MIGRATE PASSWORDS



**Problem:** Migrate password hashes to new algorithms

**Solution:** Chain hashing functions

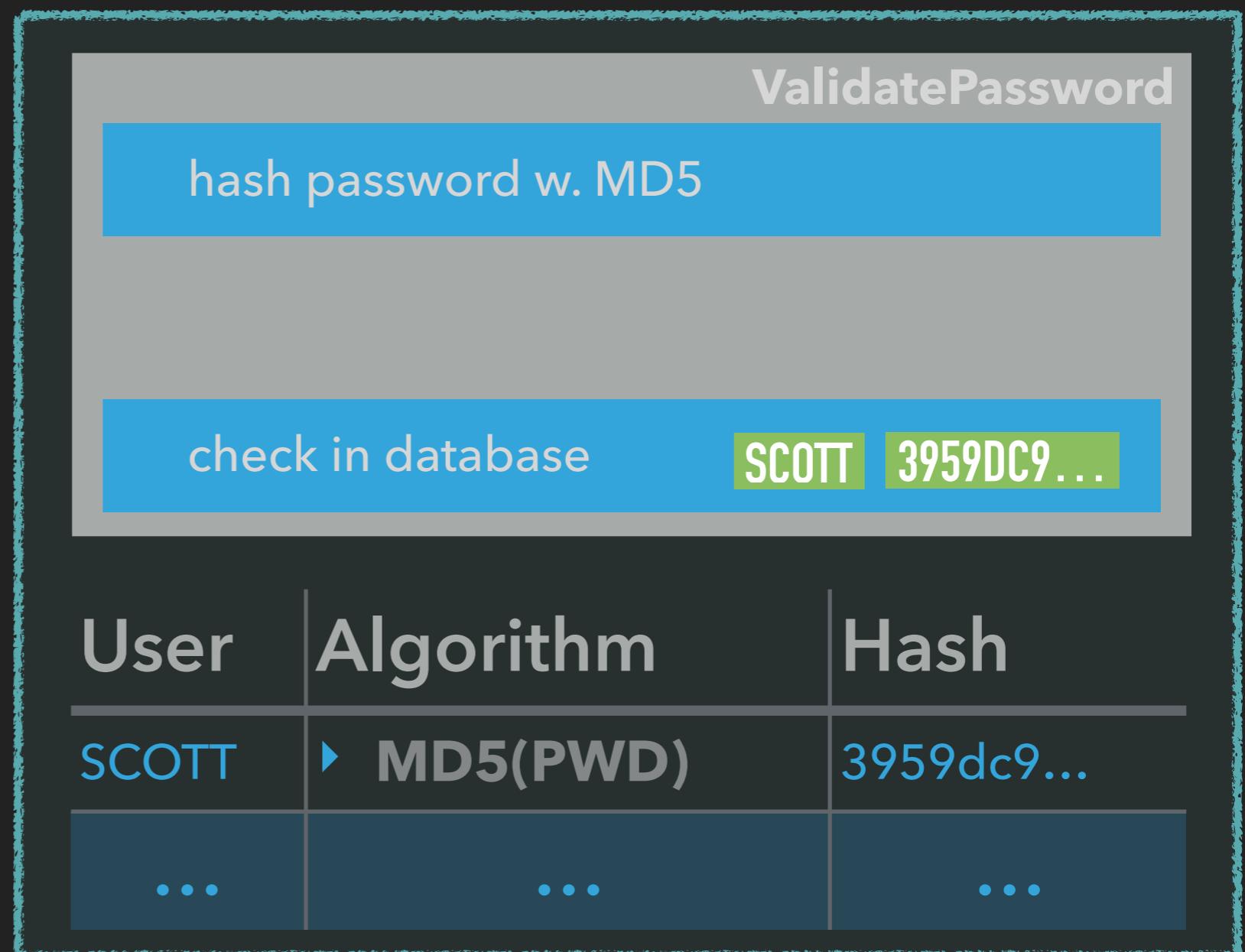
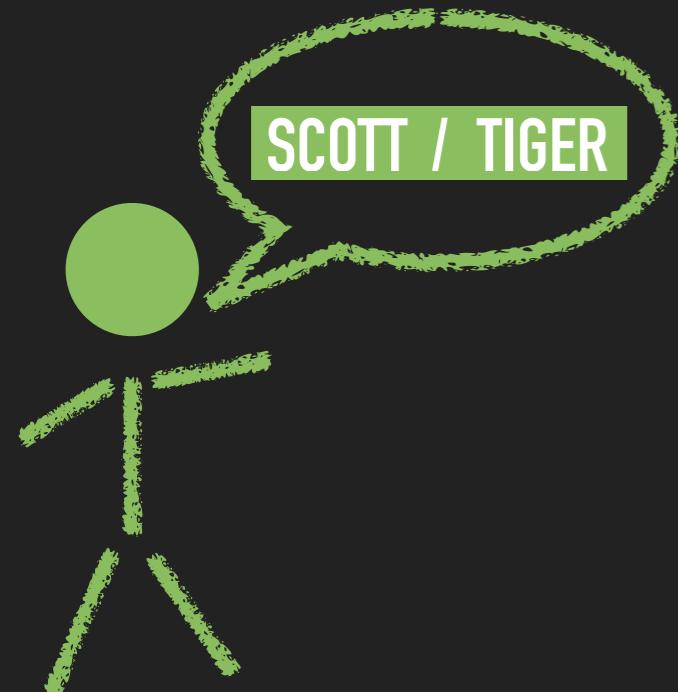


# USER LOGIN: MIGRATE PASSWORDS



**Problem:** Migrate password hashes to new algorithms

**Solution:** Chain hashing functions

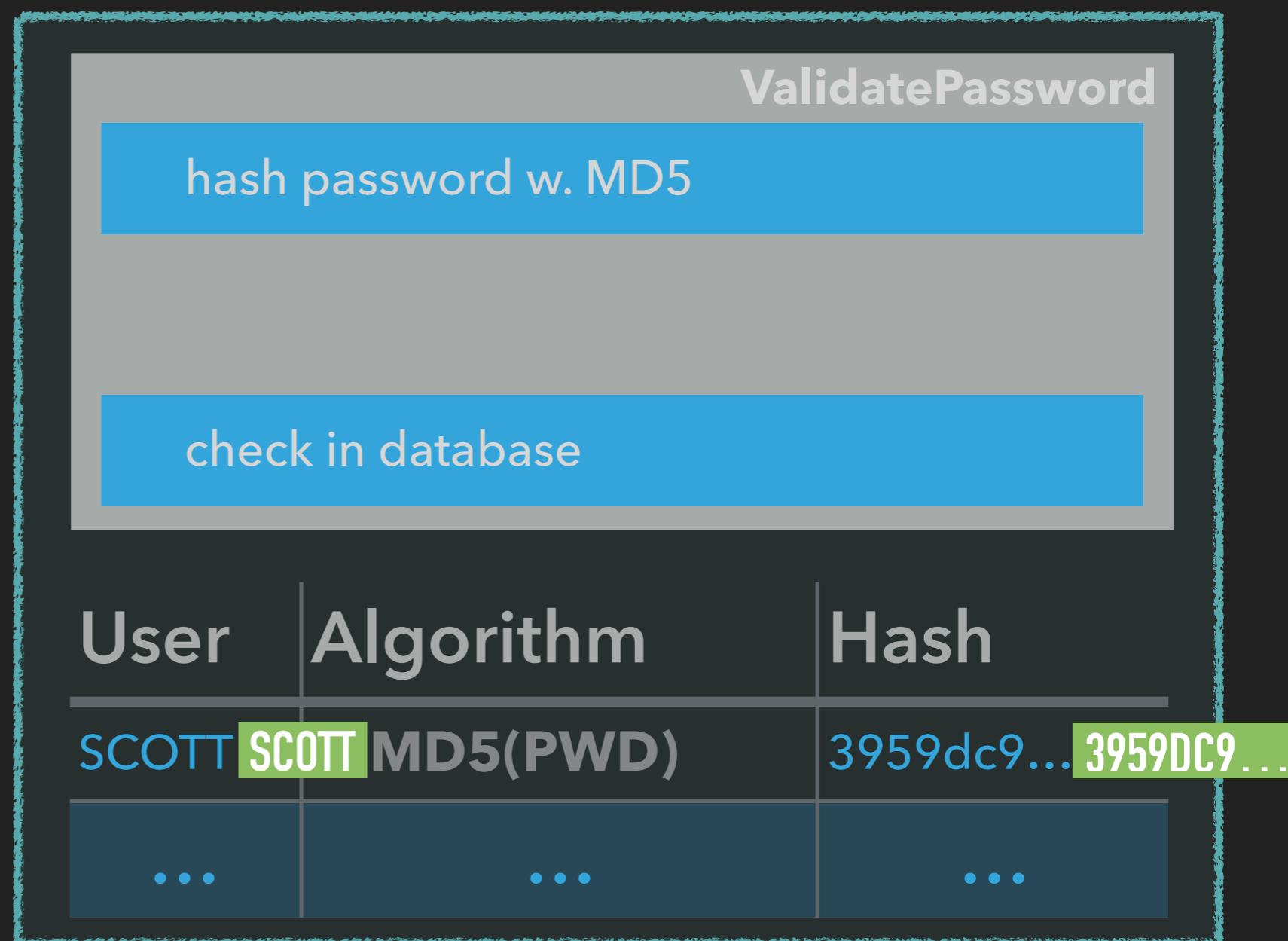
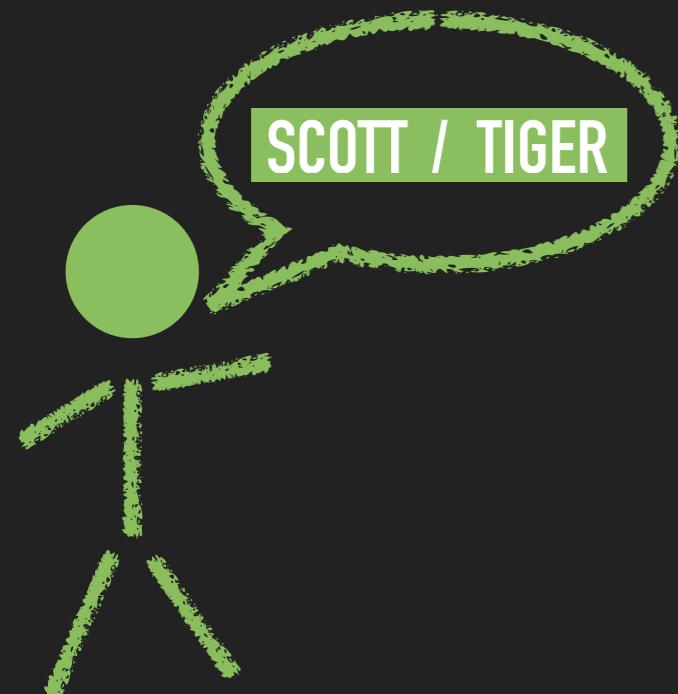


# USER LOGIN: MIGRATE PASSWORDS



**Problem:** Migrate password hashes to new algorithms

**Solution:** Chain hashing functions

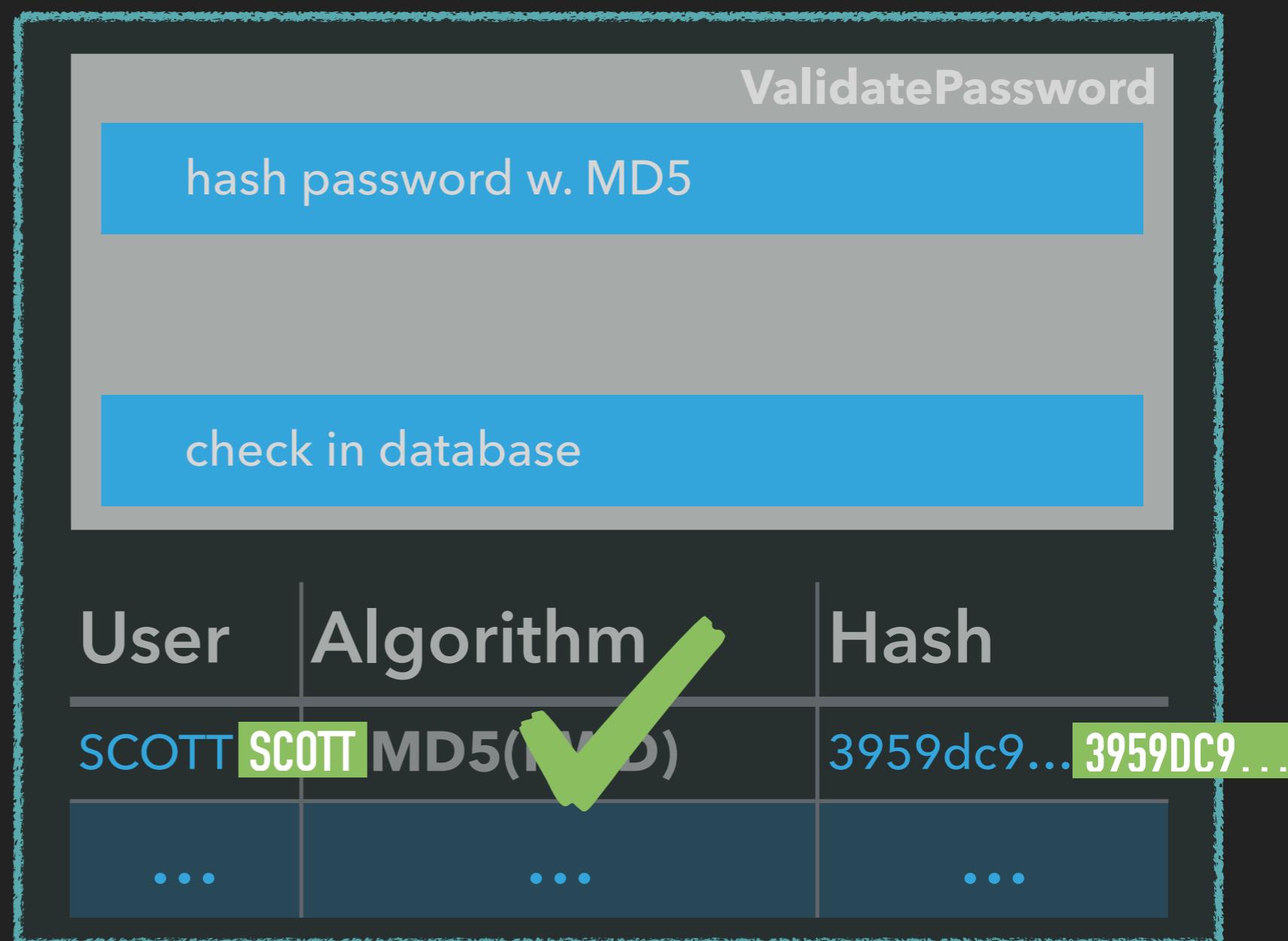
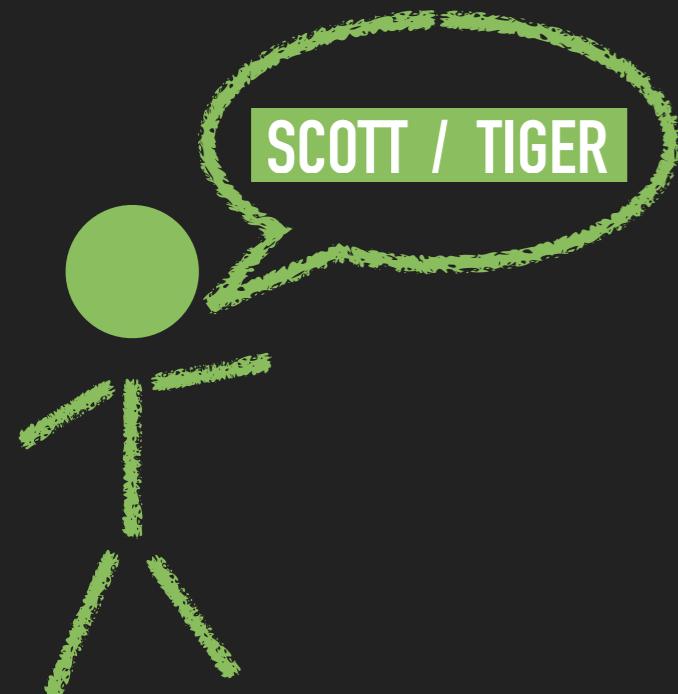


# USER LOGIN: MIGRATE PASSWORDS

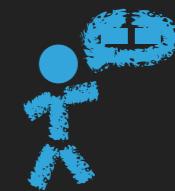


**Problem:** Migrate password hashes to new algorithms

**Solution:** Chain hashing functions

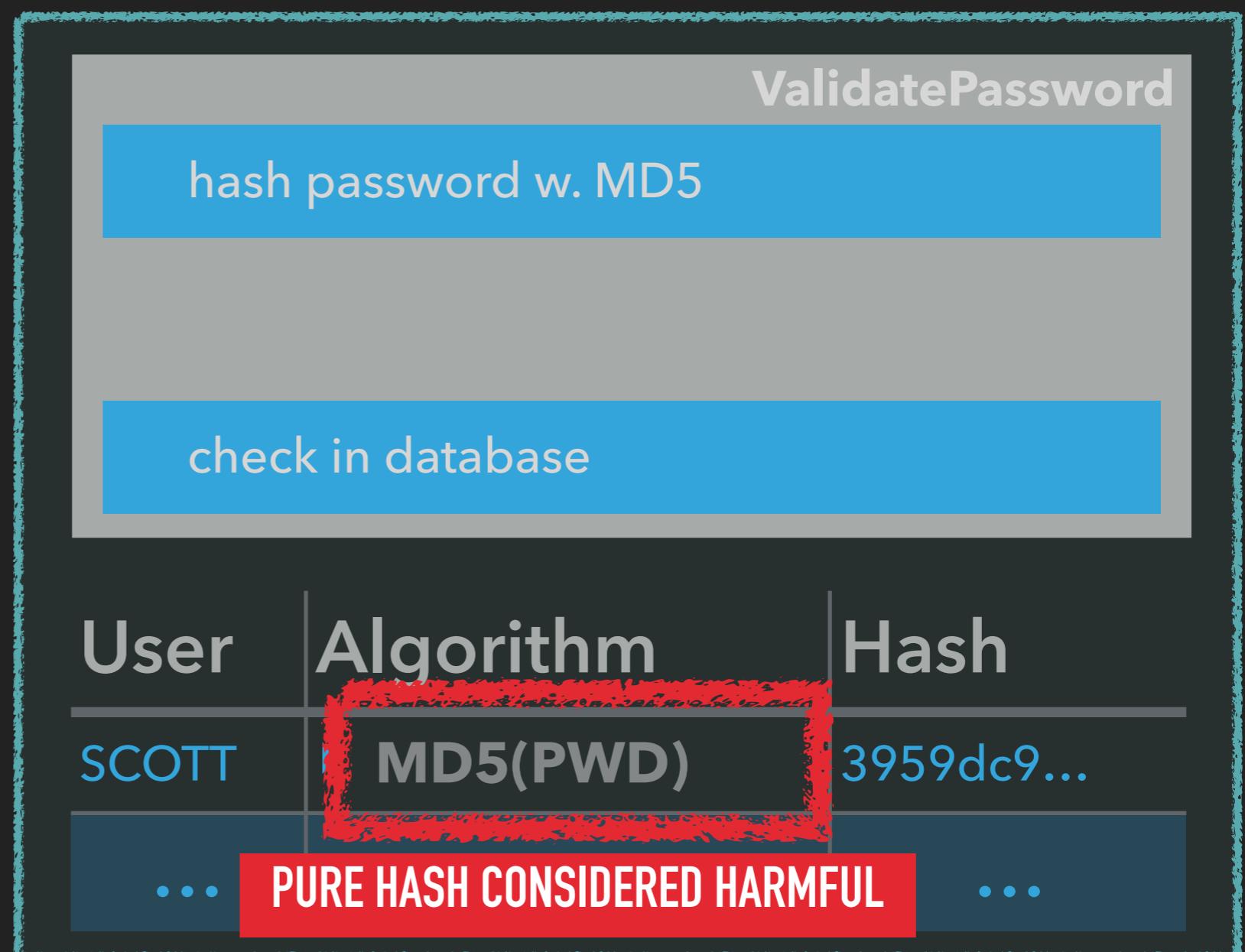
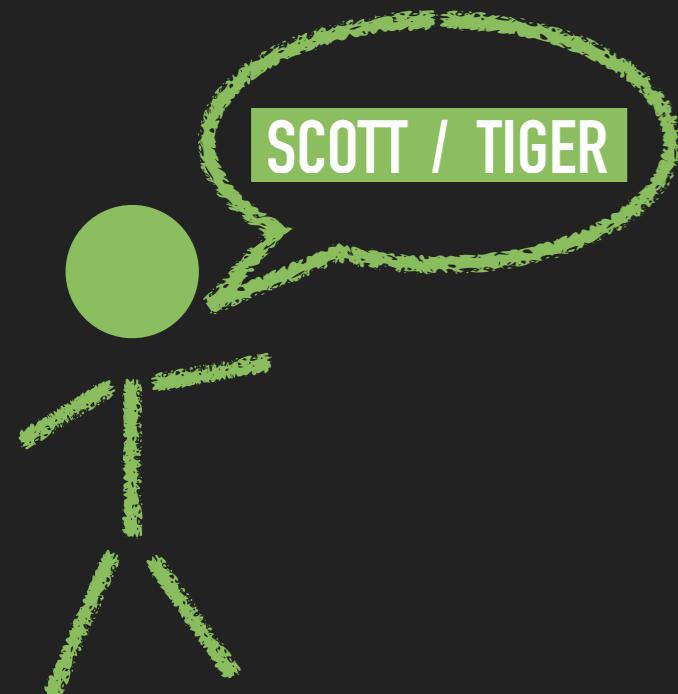


# USER LOGIN: MIGRATE PASSWORDS



**Problem:** Migrate password hashes to new algorithms

**Solution:** Chain hashing functions



User	Algorithm	Hash
SCOTT	MD5(MD5)	3959dc9...
... PURE HASH CONSIDERED HARMFUL ...		

**Even consumer grade graphic cards calculates giga-hashes ( $2^{30}$ ) per second.**

- <https://www.troyhunt.com/our-password-hashing-has-no-clothes/>
- <https://gist.github.com/epixoip/a83d38f412b4737e99bbef804a270c40>
- <http://cynosureprime.blogspot.de/2017/08/320-million-hashes-exposed.html>
- [https://www.owasp.org/index.php/Password\\_Storage\\_Cheat\\_Sheet](https://www.owasp.org/index.php/Password_Storage_Cheat_Sheet)

User	Algorithm	Hash
SCOTT	MD5(✓)	3959dc9...
... PURE HASH CONSIDERED HARMFUL ...		

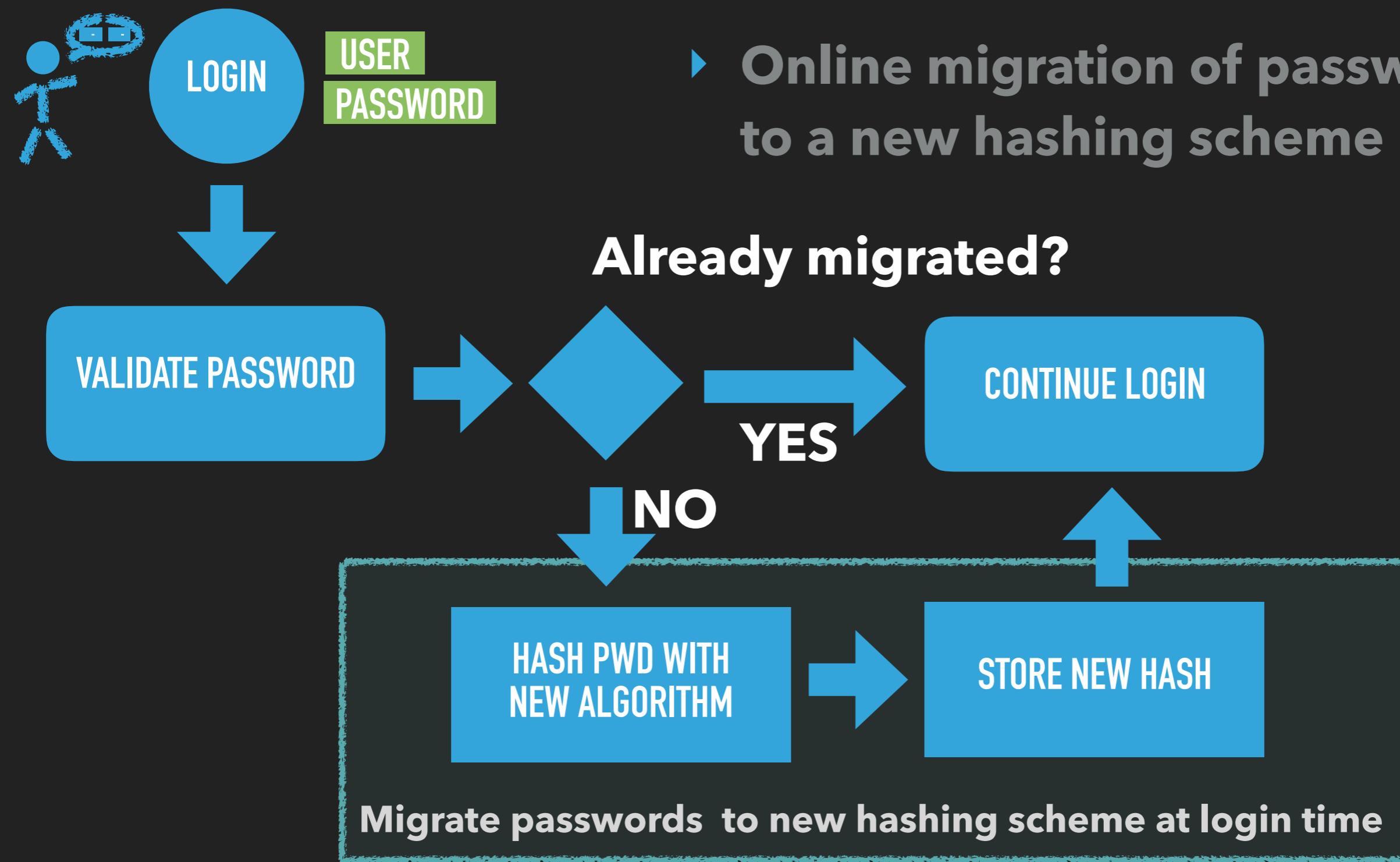
**Even consumer grade graphic cards calculates giga-hashes ( $2^{30}$ ) per second.**

**HASHES - EVEN SALTED - OFFER NO PROTECTION**

**SWITCH TO BRUTE-FORCE PROOF SCHEMES**

- <https://www.troyhunt.com/our-password-hashing-has-no-clothes/>
- <https://gist.github.com/epixoip/a83d38f412b4737e99bbef804a270c40>
- <http://cynosureprime.blogspot.de/2017/08/320-million-hashes-exposed.html>
- [https://www.owasp.org/index.php/Password\\_Storage\\_Cheat\\_Sheet](https://www.owasp.org/index.php/Password_Storage_Cheat_Sheet)

# USER LOGIN: MIGRATE PASSWORDS



# USER LOGIN: MIGRATE PASSWORDS



User	Algorithm	Hash	Last Login
SCOTT	PBKDF2(PWD)	3959dc9...	Now
PETER	MD5(PWD)	...	2 years ago
...	MD5(PWD)	...	4 months ago
...	MD5(PWD)	...	...
...	MD5(PWD)	...	...
...	MD5(PWD)	...	...

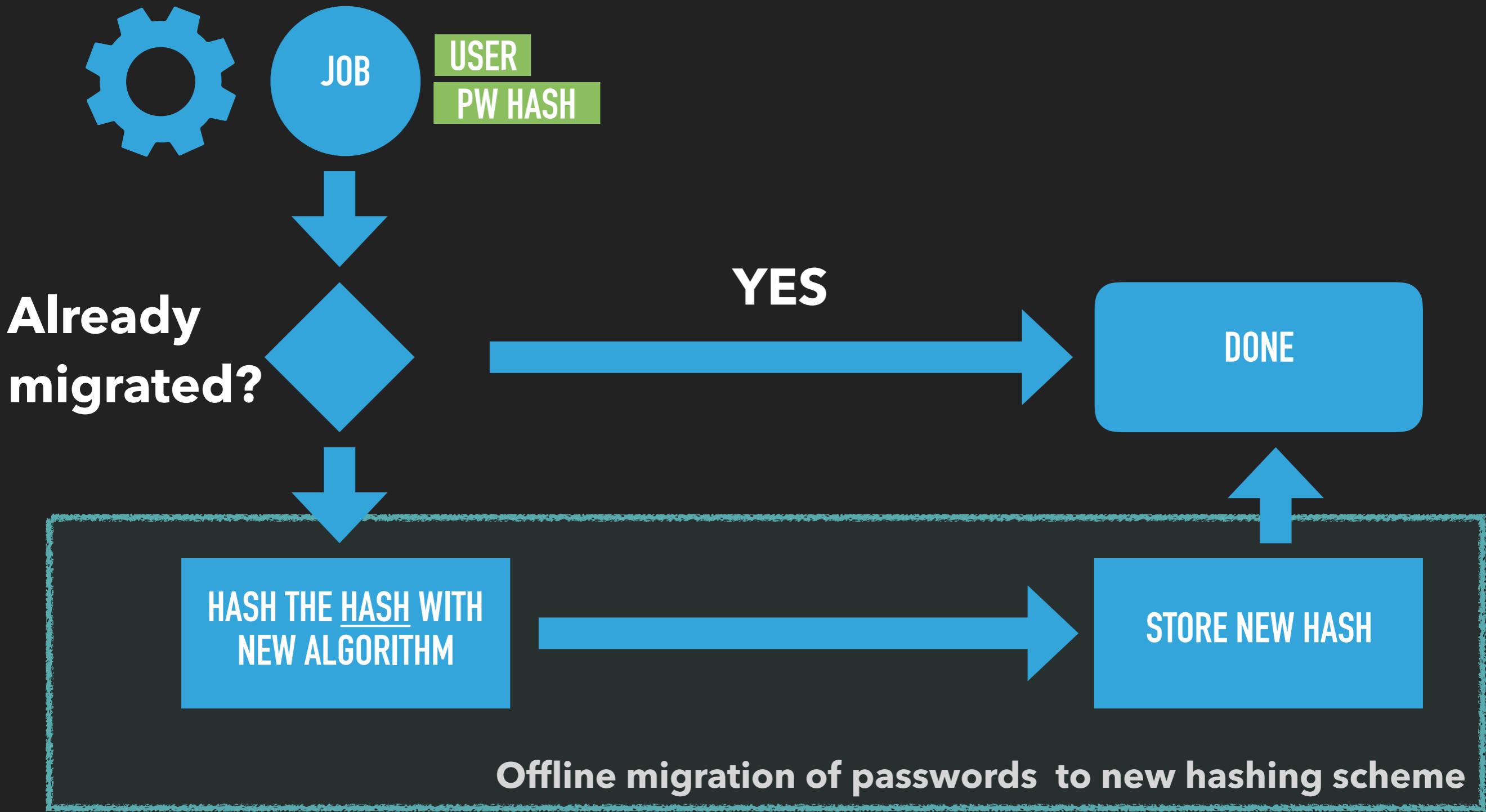
# USER LOGIN: MIGRATE PASSWORDS



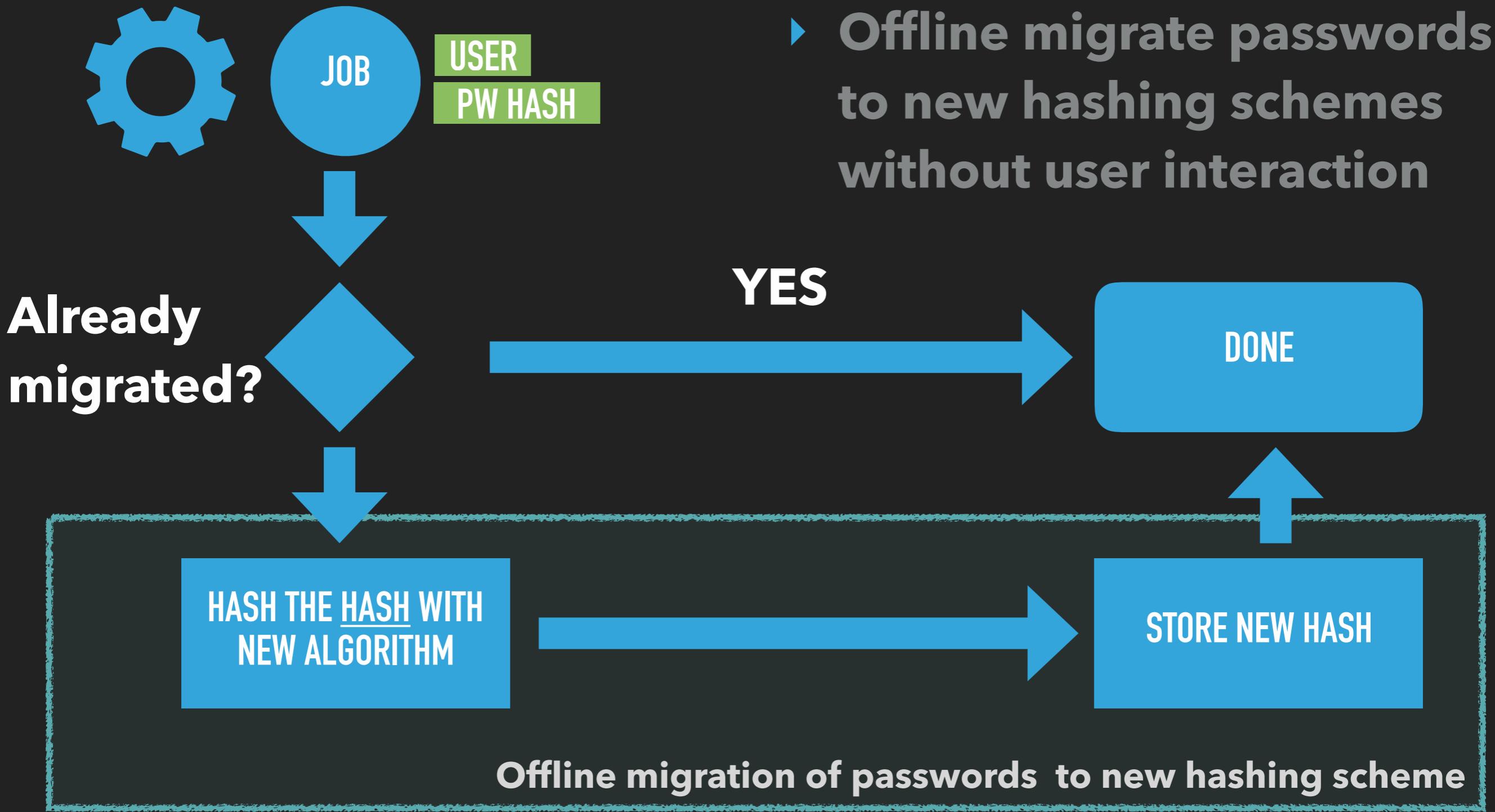
User	Algorithm	Hash	Last Login
SCOTT	PBKDF2(PWD)	3959dc9...	Now
PETER	MD5(PWD)	...	2 years ago
...	MD5(PWD)	...	4 months ago
...	MD5(PWD)	...	...
...	MD5(PWD)	...	...
...	MD5(PWD)	...	...

- ▶ How to migrate passwords of users that do not login frequently?

# USER LOGIN: MIGRATE PASSWORDS



# USER LOGIN: MIGRATE PASSWORDS



# USER LOGIN: MIGRATE PASSWORDS



User	Algorithm	Hash	Last Login
SCOTT	PBKDF2(PWD)	3959dc9...	Now
PETER	PBKDF2(MD5(PWD))	...	2 years ago
...	PBKDF2(MD5(PWD))	...	4 months ago
...	PBKDF2(MD5(PWD))	...	...
...	PBKDF2(MD5(PWD))	...	...
...	PBKDF2(MD5(PWD))	...	...



# PATTERNS

---

# INTEGRITY

# DATA INTEGRITY & ASSOCIATION

0X123456... ✓

**Problem:** Sensitive data can be manipulated.

User	Salary	...
Alice	3,141€	...
Eve	2,718 €	...
...	...	...

## DATA INTEGRITY & ASSOCIATION

0X123456... ✓

**Problem:** Sensitive data can be manipulated.

User	Salary	...
Alice	3,141€	...
Eve	10,000 €	...
...	EVE GETS AN INSTANT PROMOTION	...

## DATA INTEGRITY & ASSOCIATION

0x123456... ✓

**Problem:** Sensitive data can be manipulated.

**Solution:** Use cryptographic checksums with a secret.

User	Salary	Checksum*
Alice	3,141€	0x4711...
Eve	2,718 €	0xabcd...
...	...	...

\* Checksum with a secret: hmac, AEAD, public key signatures

## DATA INTEGRITY & ASSOCIATION

0x123456... ✓

**Problem:** Sensitive data can be manipulated.

**Solution:** Use cryptographic checksums with a secret.

User	Salary	Checksum*
Alice	3,141€	0x4711...
Eve	10,000 €	0xabcd...

THE CHECKSUMS DON'T MATCH, PROMOTION IS DECLINED

\* Checksum with a secret: hmac, AEAD, public key signatures

## DATA INTEGRITY & ASSOCIATION

0x123456... ✓

**Problem:** Protected data can be “replayed”.

User	Salary	Checksum*
Alice	3,141€	0x4711...
Eve	2,718 €	0xabcd...
...	...	...

## DATA INTEGRITY & ASSOCIATION

0X123456... ✓

**Problem:** Protected data can be “replayed”.

User	Salary	Checksum*
Alice	3,141€	0x4711...
Eve	3,141€	0x4711...
...	EVE GETS AN INSTANT PROMOTION	...

## DATA INTEGRITY & ASSOCIATION

0x123456... ✓

**Problem:** Protected data can be “replayed”.

**Solution:** Cryptographically bind data to context.

User	Salary	Checksum*
Alice	3,141€	0xabcd...
Eve	2,718€	0x9876...
...	...	...

\* including the username in the hash/hmac

## DATA INTEGRITY & ASSOCIATION

0x123456... ✓

**Problem:** Protected data can be “replayed”.

**Solution:** Cryptographically bind data to context.

User	Salary	Checksum*
Alice	3,141€	0xabcd...
Eve	3,141€	0xabcd...

```
graph LR; AliceUser[User Alice] -- "green arrow" --> AliceSalary[Salary 3,141€]; AliceUser -- "blue arrow" --> AliceChecksum["Checksum* 0xabcd..."]; EveUser[User Eve] -- "red double arrow" --> EveSalary[Salary 3,141€]; EveUser -- "red double arrow" --> EveChecksum["Checksum* 0xabcd..."];
```

THE CHECKSUMS DON'T MATCH, PROMOTION IS DECLINED

\* including the username in the hash/hmac

## DATA INTEGRITY & ASSOCIATION

0X123456... ✓

**Problem:** Protected data can be “replayed”.

**Solution:** Cryptographically bind data to context.

User	Password Hash *	...
Alice	0X123456...	...
Eve	0XABCDEF...	...
...	...	...

\* including the username in the hash/hmac

## DATA INTEGRITY & ASSOCIATION

0X123456...

**Problem:** Protected data can be “replayed”.

**Solution:** Cryptographically bind data to context.

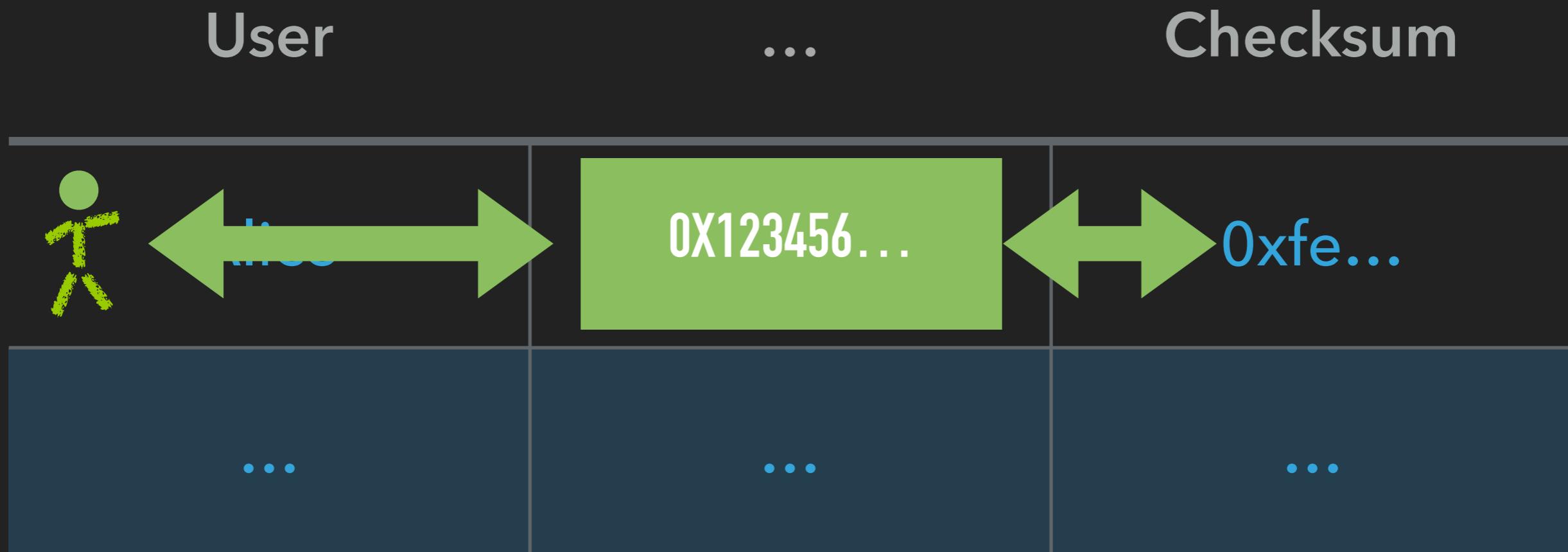
User	Password Hash *	...
Alice	OXABCDEF...	...
Eve	OXABCDEF...	...

**INTEGRITY PROTECTION BINDS USER TO SECRET**

\* including the username in the hash/hmac

# DATA INTEGRITY & ASSOCIATION

0X123456... ✓



- ▶ Add integrity checks to the data (HMAC, AEAD encryption, signatures)
- ▶ Include an association (here: "User") in the integrity check



PATTERNS

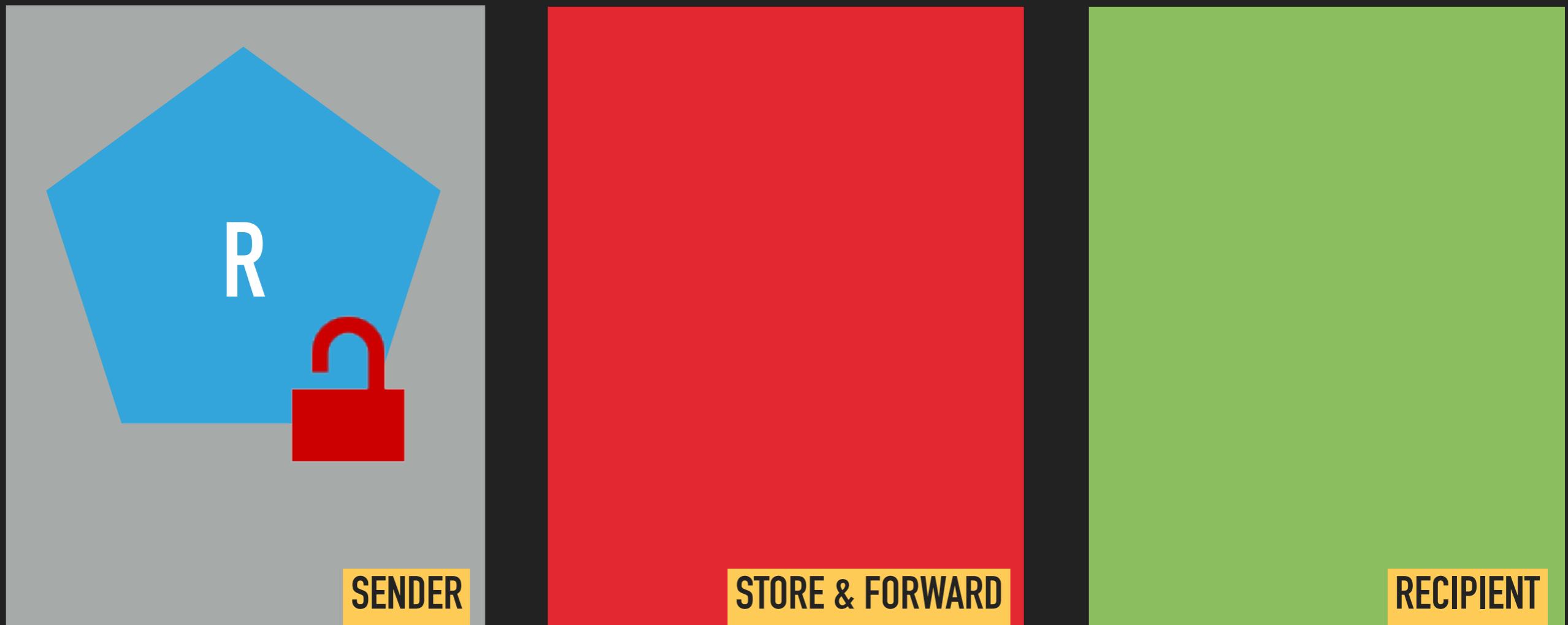
---

MOVING

## MOVE DATA BETWEEN PARTIES

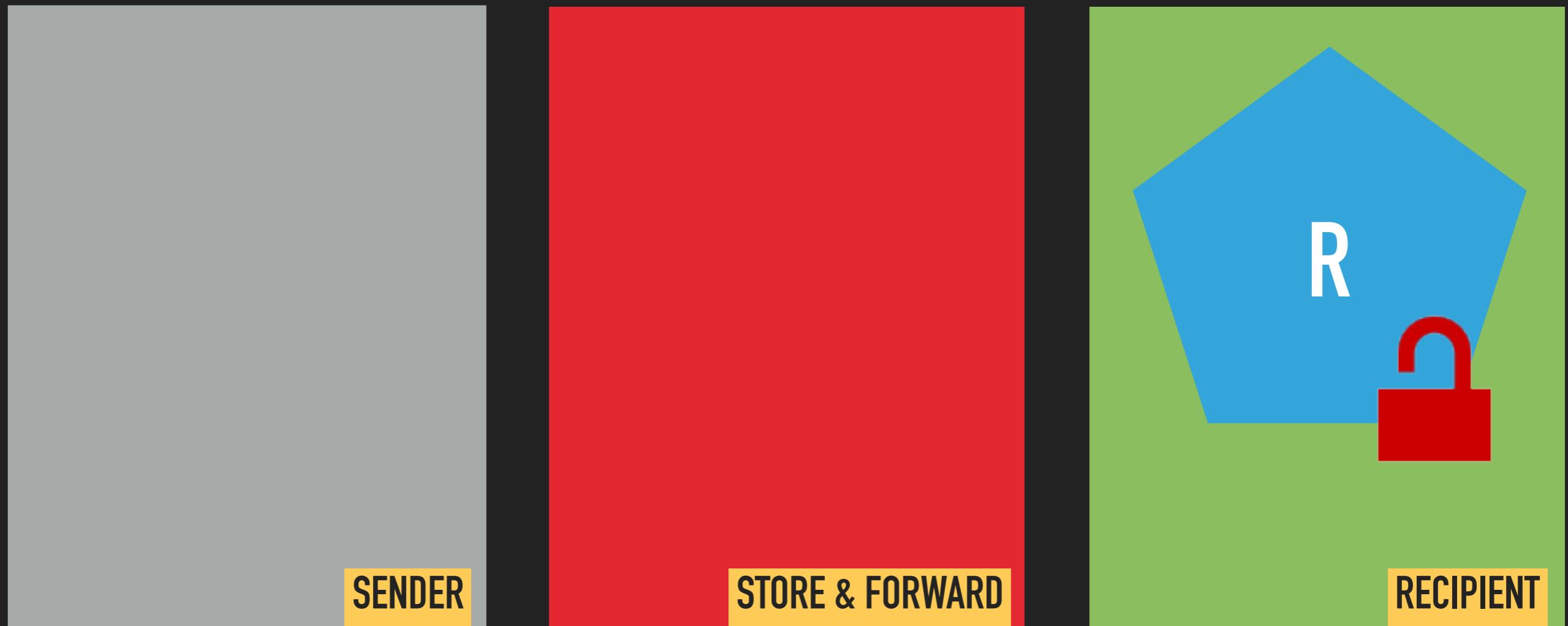


**Problem:** Data is exchanged between parties.



## MOVE DATA BETWEEN PARTIES

**Problem:** Data is exchanged between parties.

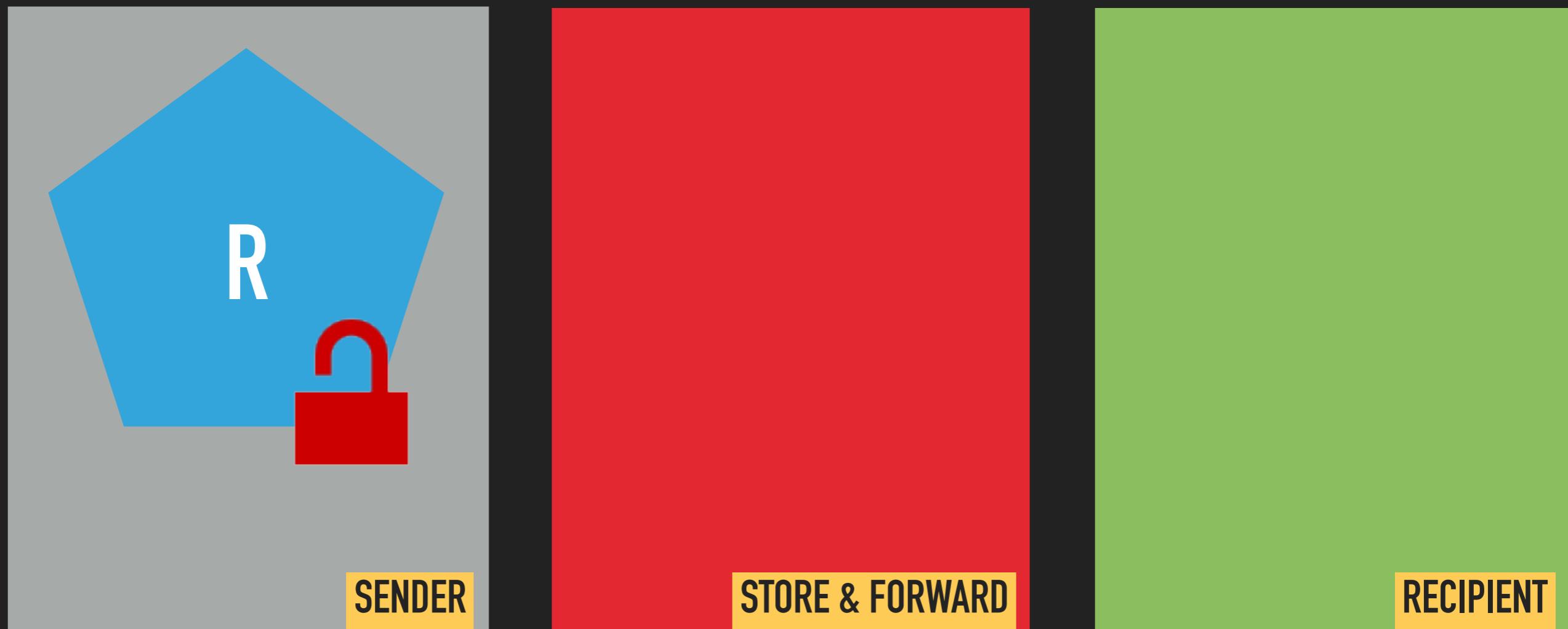


## MOVE DATA BETWEEN PARTIES



**Problem:** Data is exchanged between parties.

**Solution:** Use public key cryptography to protect data.



Encrypt with public key

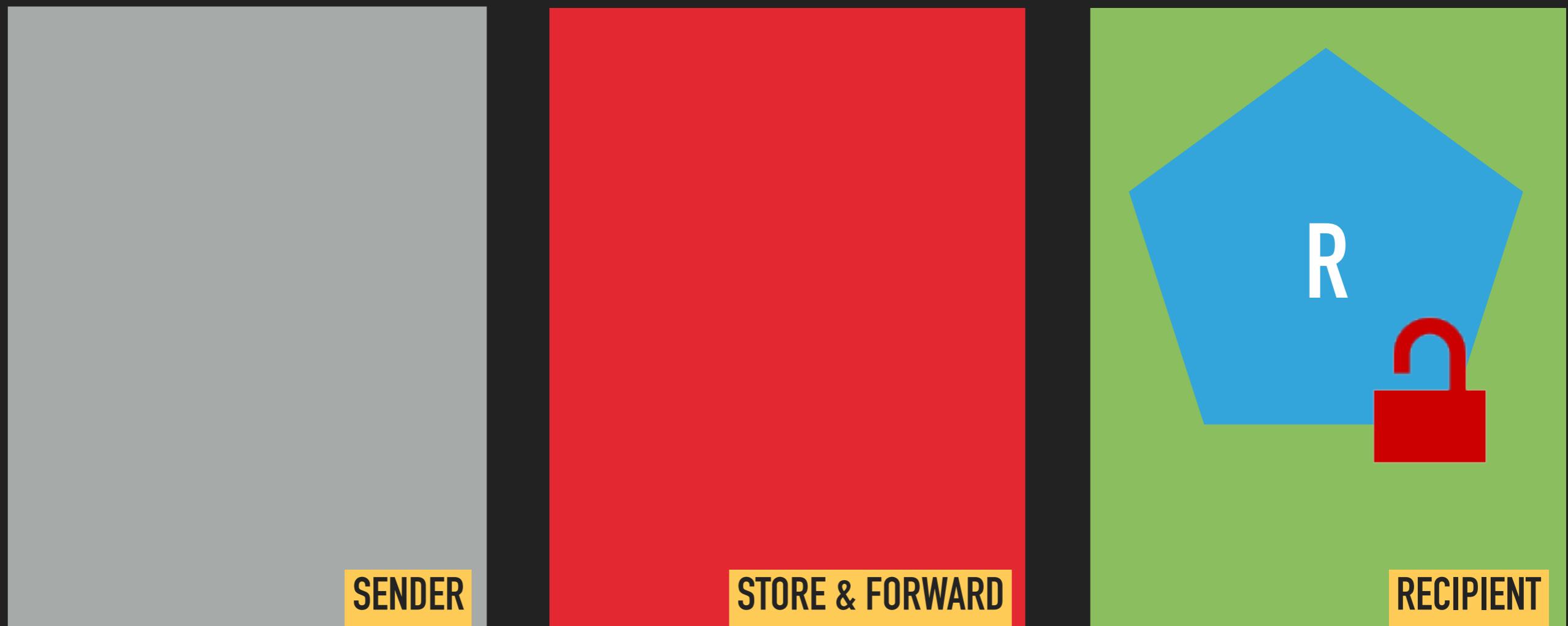
Decrypt with private key

## MOVE DATA BETWEEN PARTIES



**Problem:** Data is exchanged between parties.

**Solution:** Use public key cryptography to protect data.



Encrypt with public key

Decrypt with private key

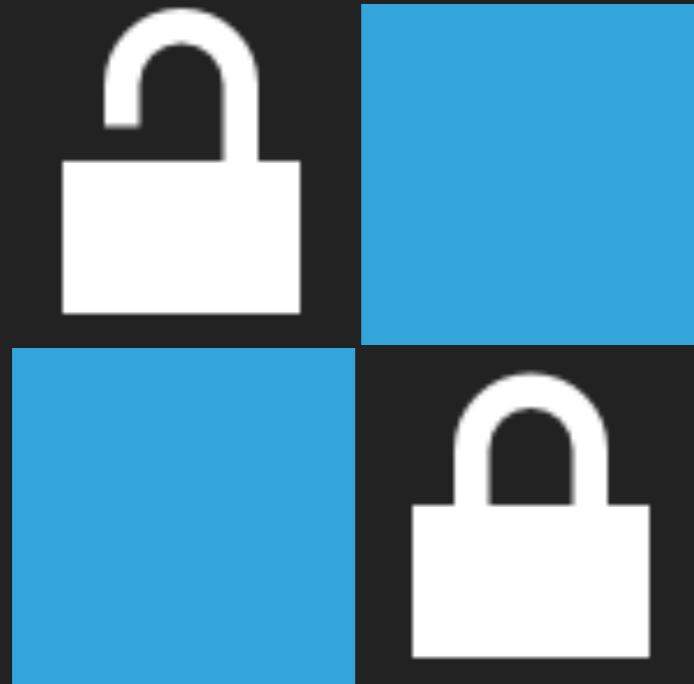
# MOVE DATA BETWEEN PARTIES



```
KeyringConfig keyringConfig = KeyringConfigs
    .withKeyRingsFromFiles(
        "/.../pubring.gpg",
        "/.../secring.gpg",
        withPassword(secKeyRingPassword));
try (
    final InputStream cipherTextStream = Files.newInputStream(sourceFile);

    final OutputStream fileOutput = Files.newOutputStream(destFile);
    final BufferedOutputStream bufferedOut = ...

    final InputStream plaintextStream = BouncyGPG
        .decryptAndVerifyStream()
        .withConfig(keyringConfig)
        .andRequireSignatureFromAllKeys("sender@example.com")
        .fromEncryptedInputStream(cipherTextStream)
) {
    Streams.pipeAll(plaintextStream, bufferedOut);
}
```



```
int getRandomNumber()
{
    return 4; // chosen by fair dice roll.
              // guaranteed to be random.
}
```

<https://xkcd.com/221/>

## PATTERNS

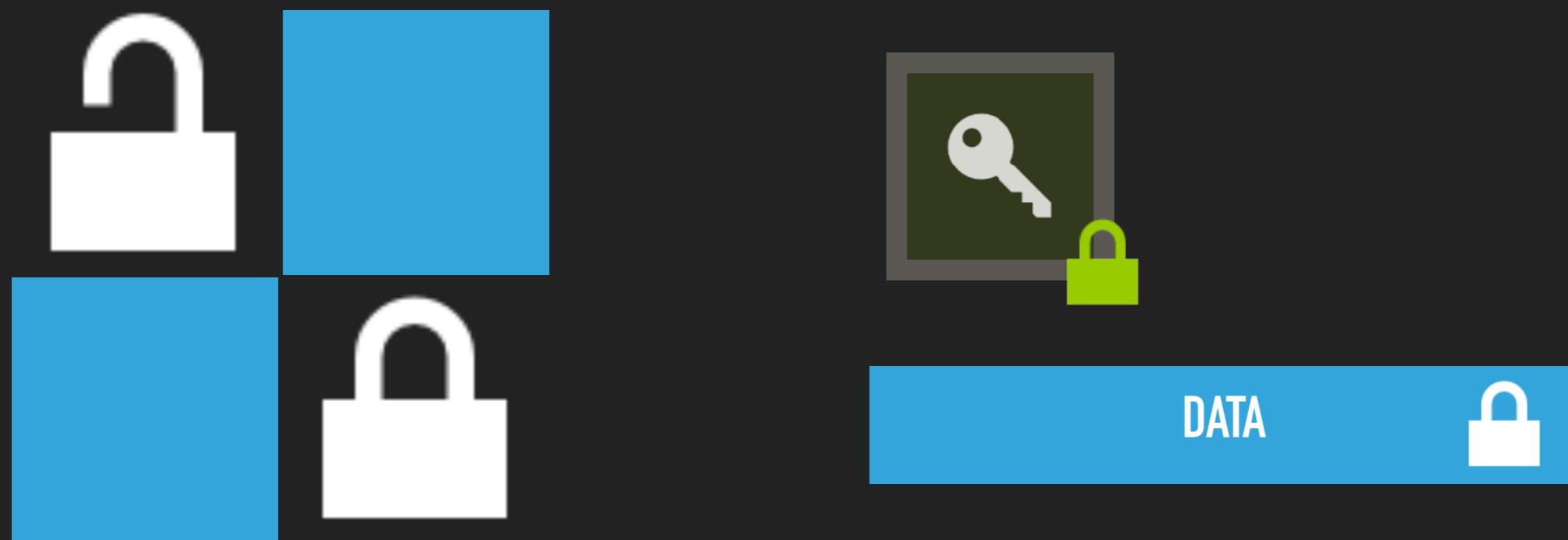
---

# ENTROPY

# ENTROPY

- ▶ Bad entropy compromises keys
- ▶ Computers are very bad at making things up! (not always)
- ▶ Entropy therefore often is limited (esp. after booting!)
- ▶ Use what the API provides (SecureRandom)
- ▶ RTFM

```
int getRandomNumber()
{
    return 4; // chosen by fair dice roll.
              // guaranteed to be random.
}
```



PATTERNS

---

ACCESS  
CONTROL

## ACCESS CONTROL

**Problem:** Make sure that data can only be accessed by some users

**Solution:** Use cryptographic access controls

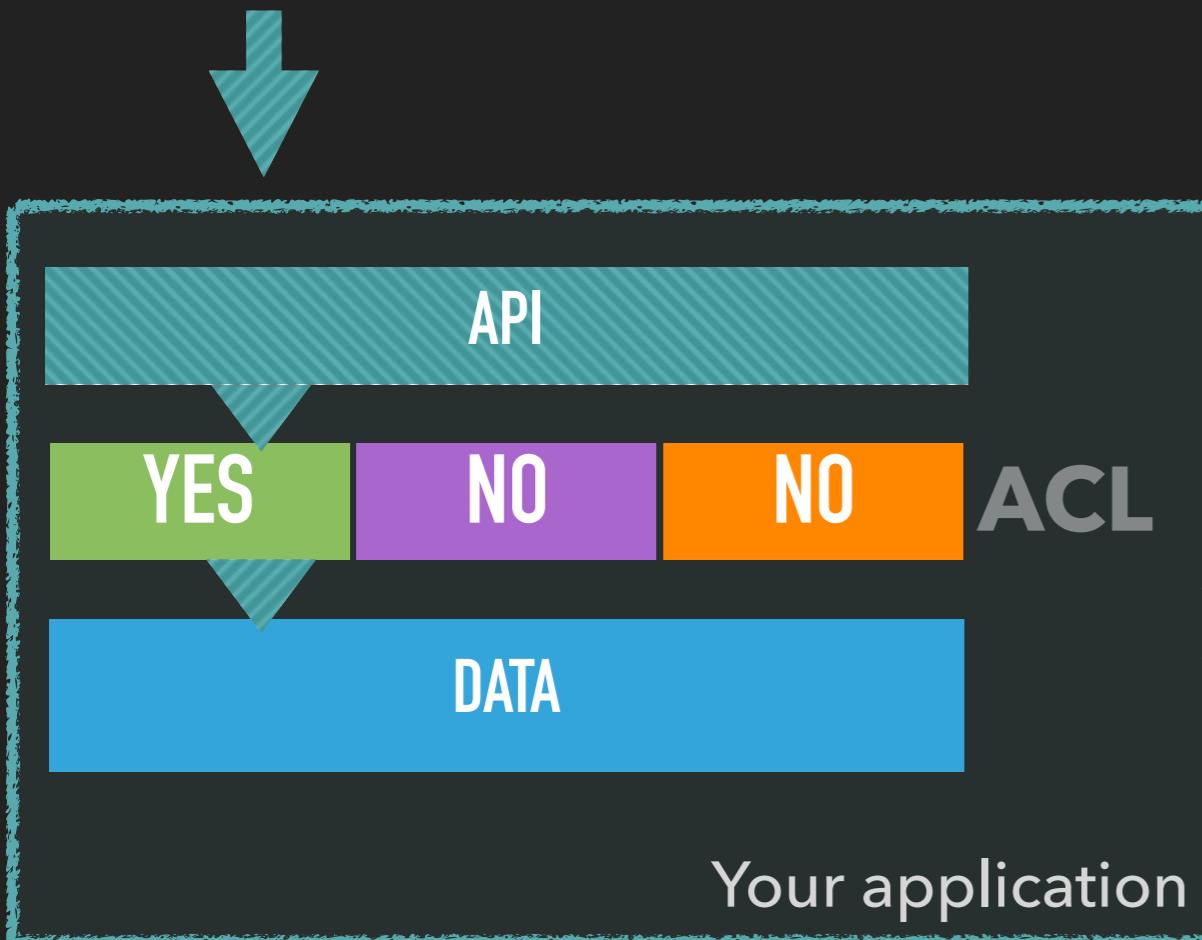
Applies primarily to

- ▶ Personal data (e.g. health data, personell records, ...)
- ▶ Top Secret data (e.g. company secrets)
- ▶ When “provable” access control is required

# ACCESS CONTROL



DATA

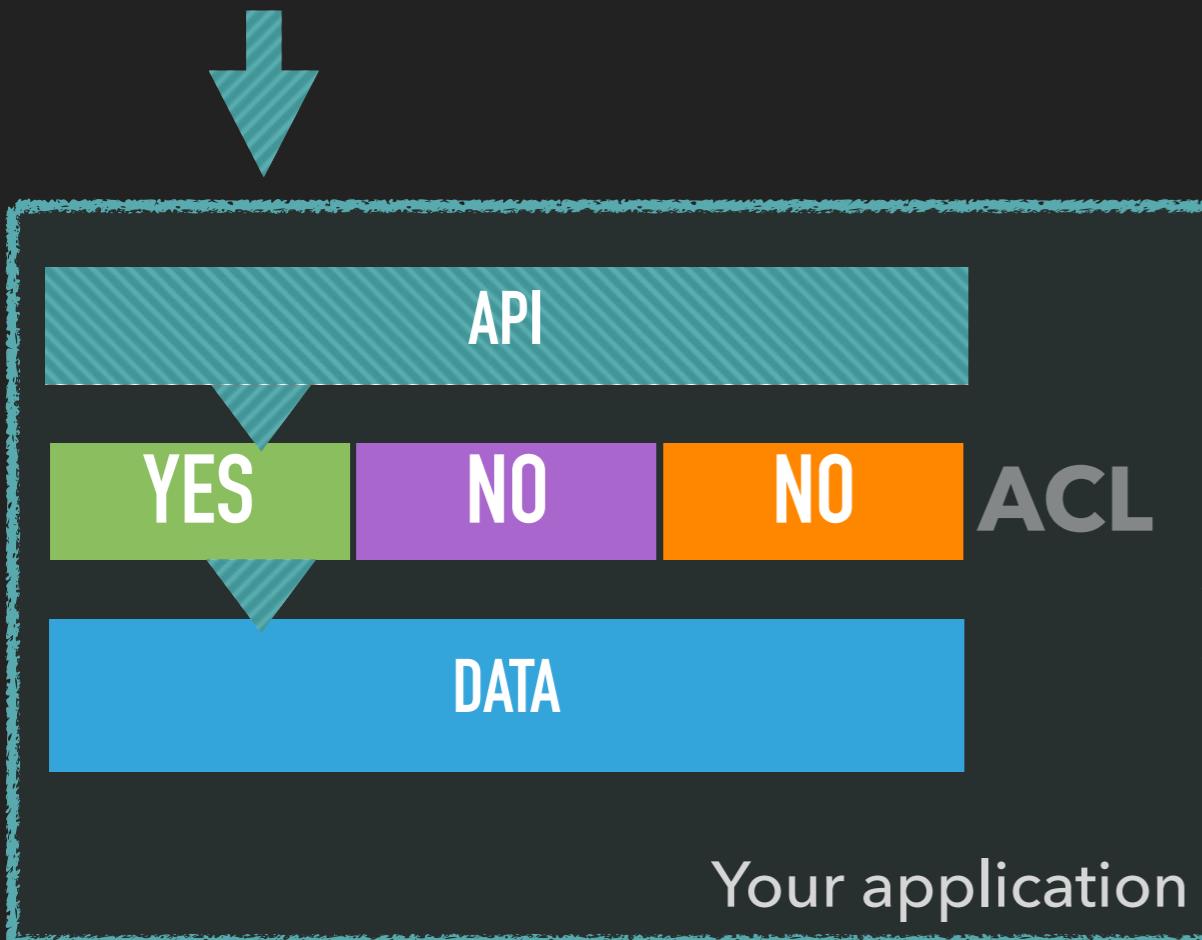


1. Alice tries to read data

# ACCESS CONTROL

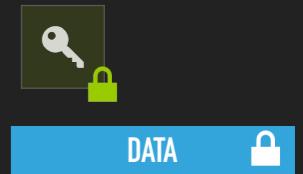


DATA

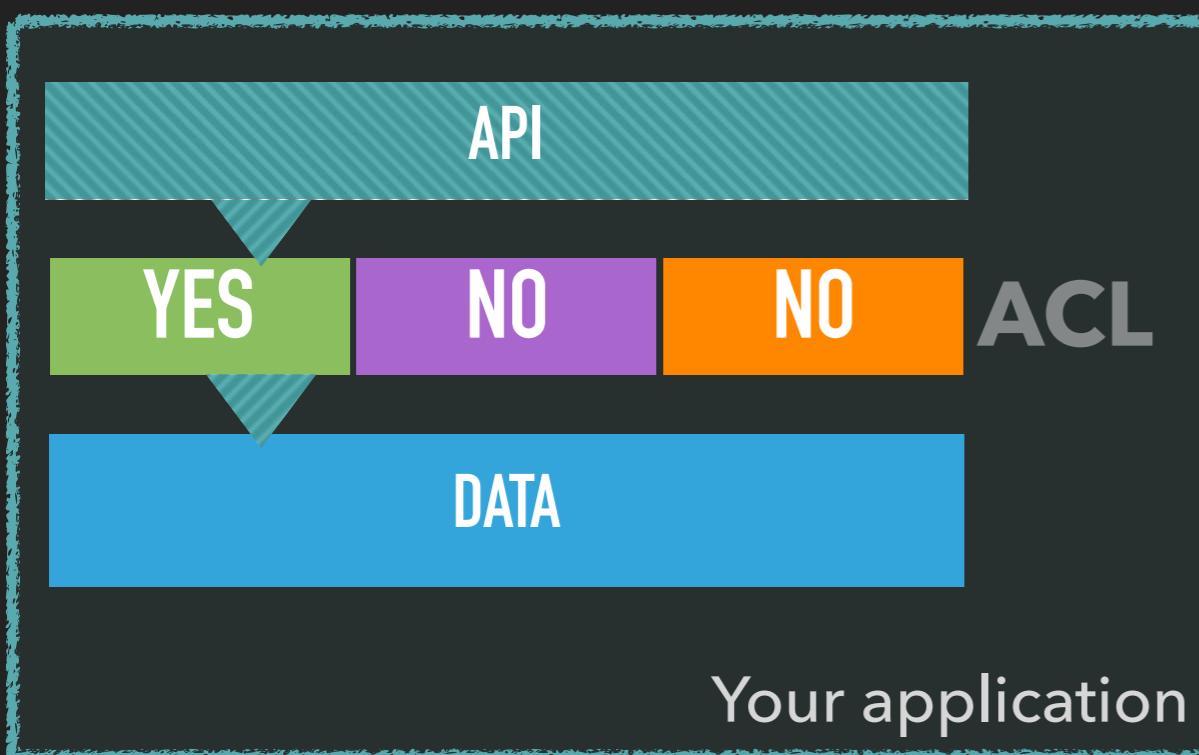


1. Alice tries to read data

# ACCESS CONTROL



Alice    Bob    Eve

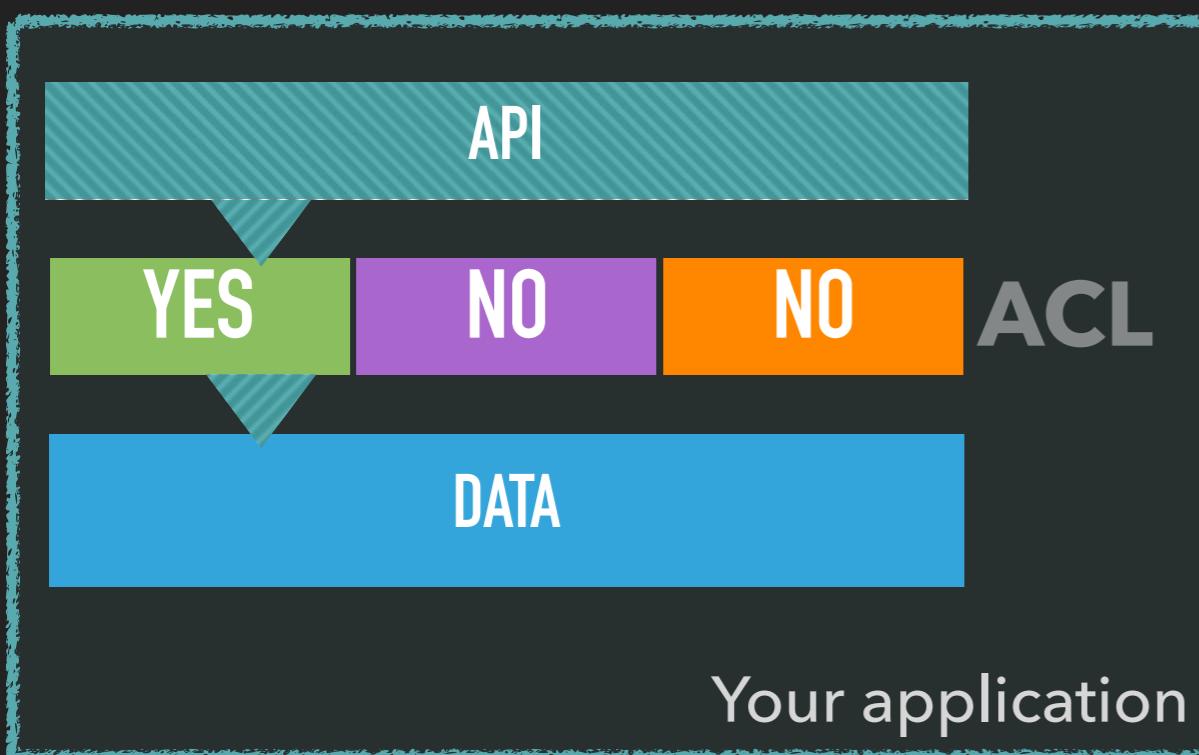


1. Alice tries to read data
2. Application validates ACL

# ACCESS CONTROL



Alice    Bob    Eve

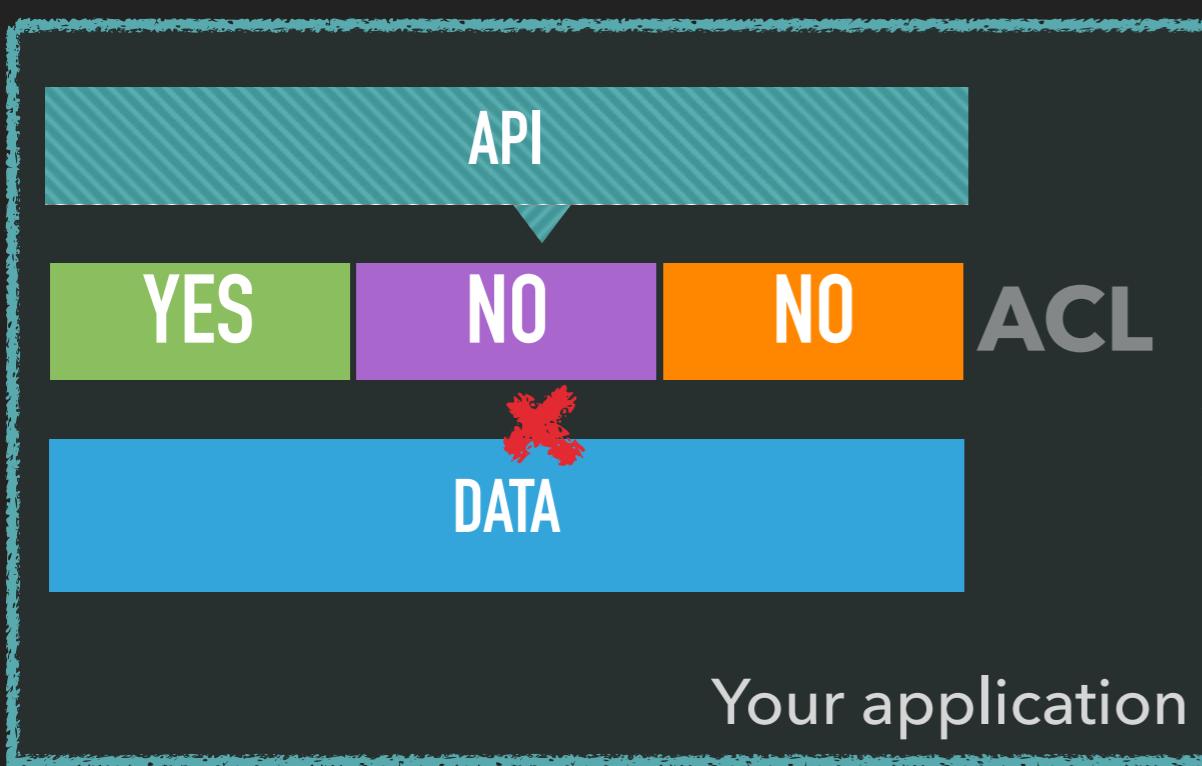


1. Alice tries to read data
2. Application validates ACL
3. Alice is granted access

# ACCESS CONTROL



Alice    Bob    Eve

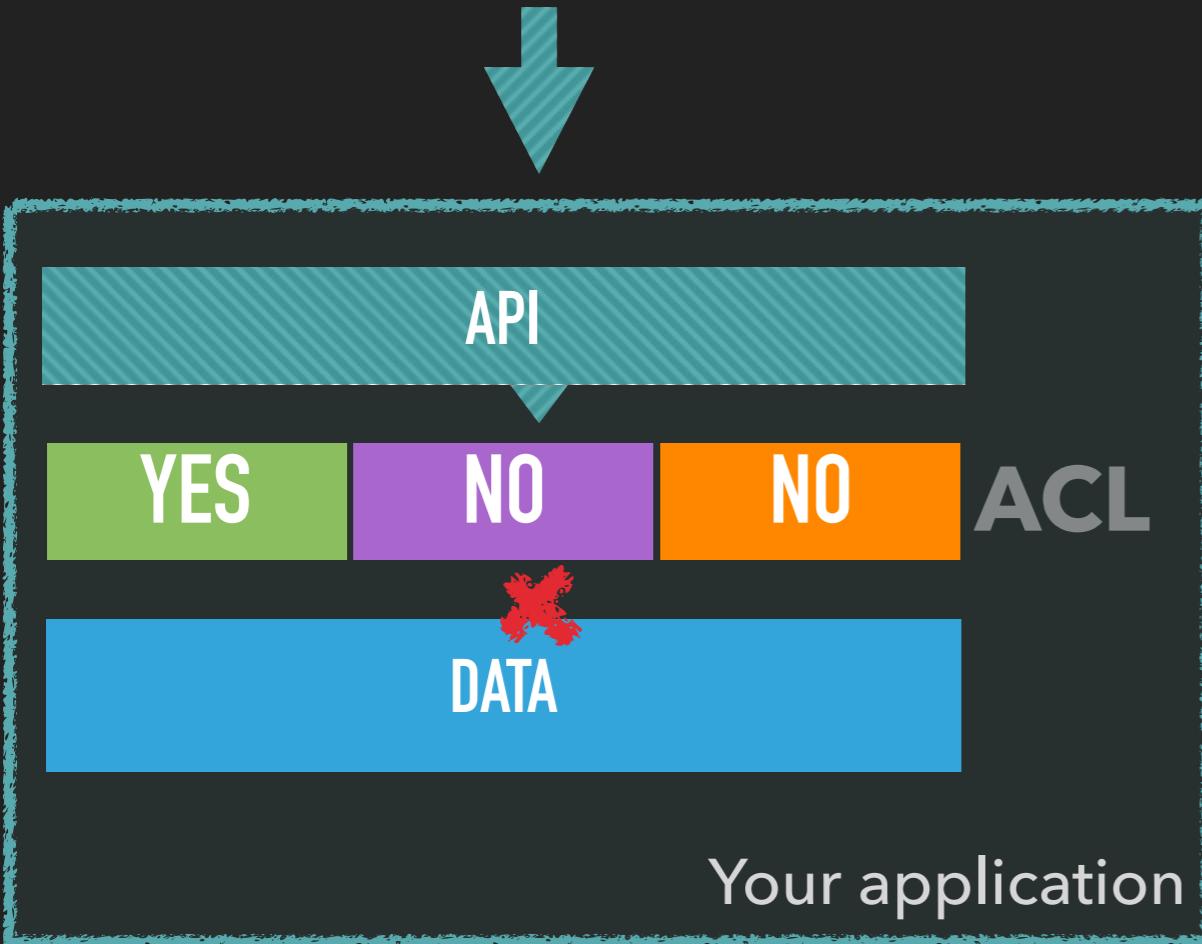


1. Bob tries to read data

# ACCESS CONTROL

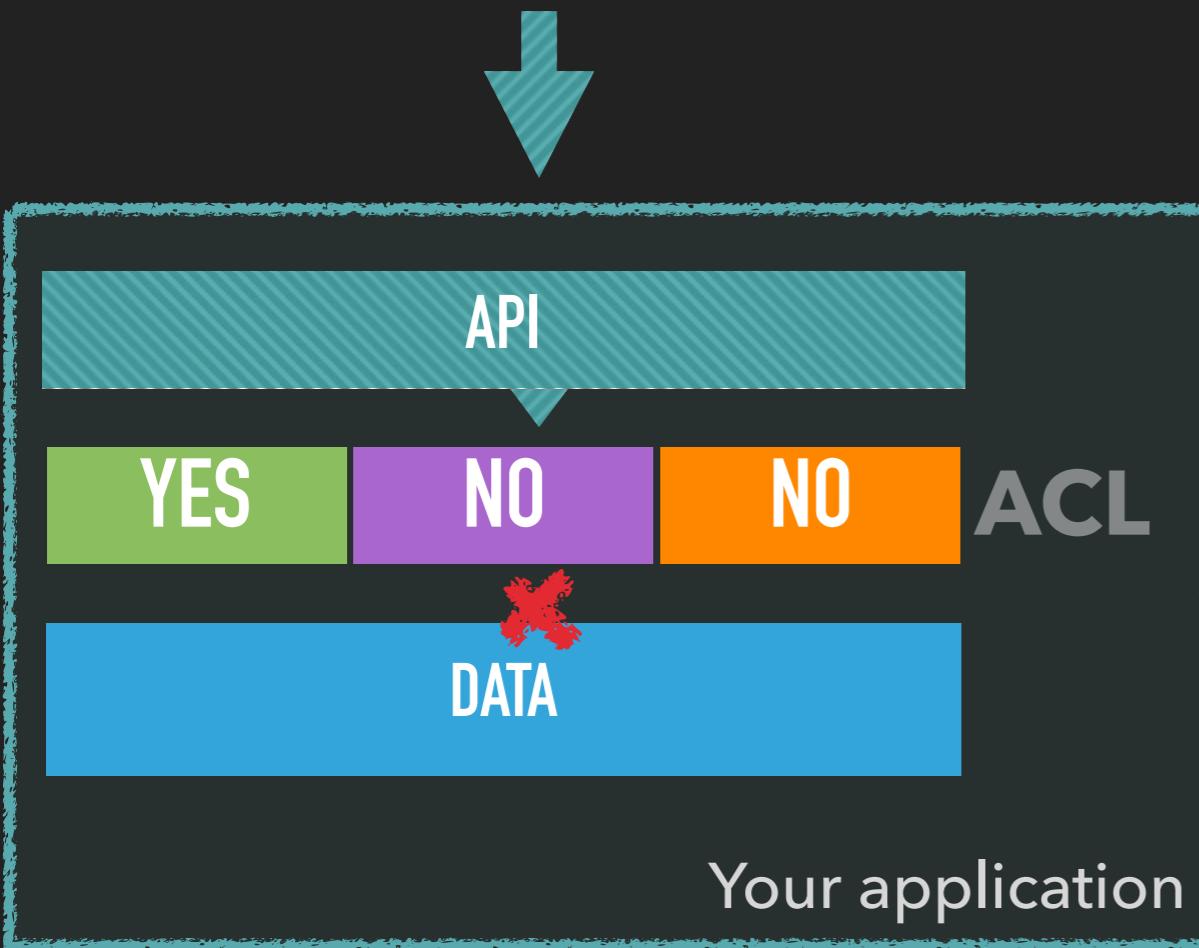


Alice    Bob    Eve



1. Bob tries to read data

# ACCESS CONTROL

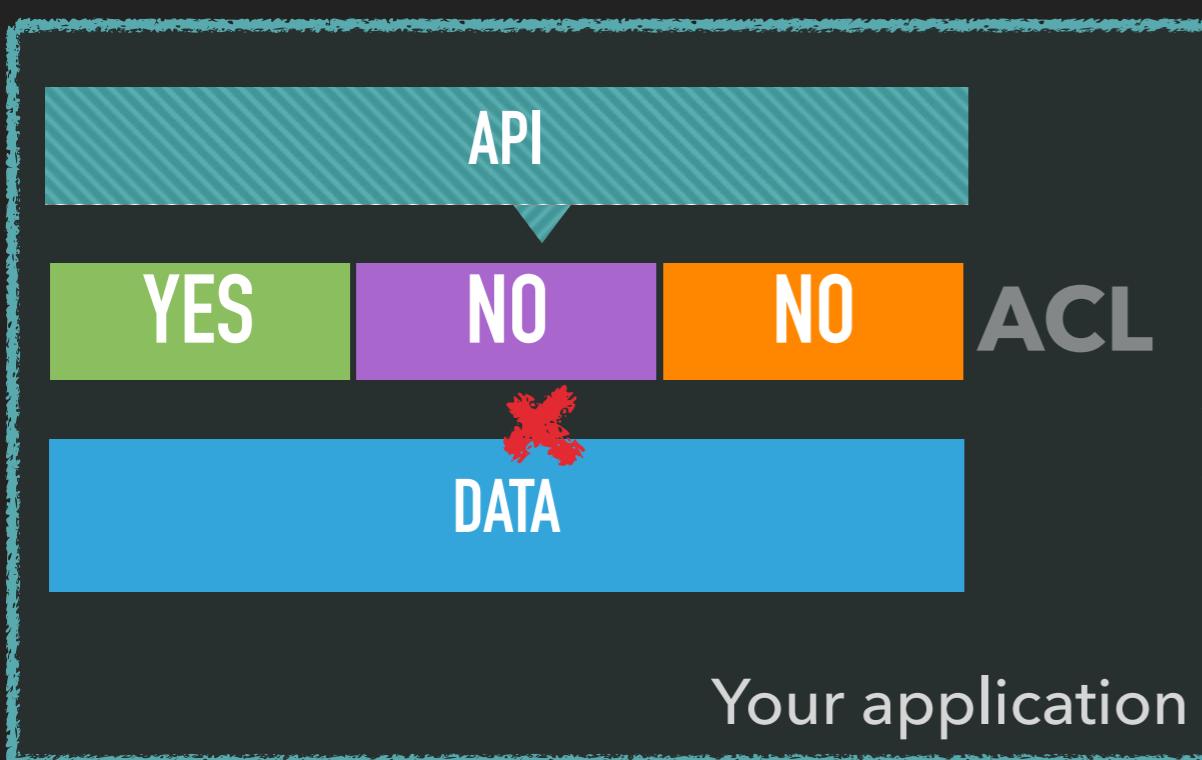


1. Bob tries to read data
2. Application validates ACL

# ACCESS CONTROL

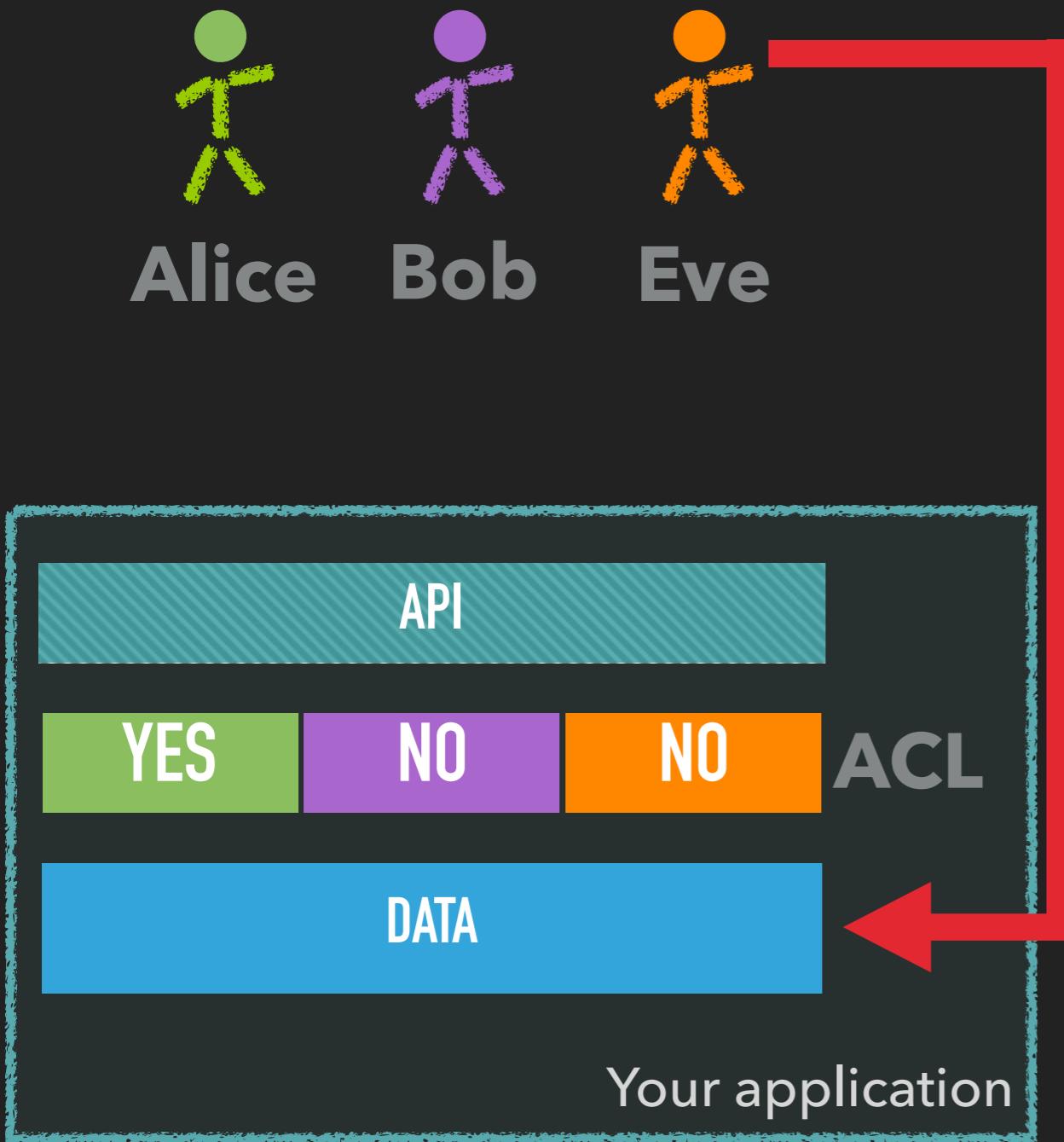


Alice    Bob    Eve



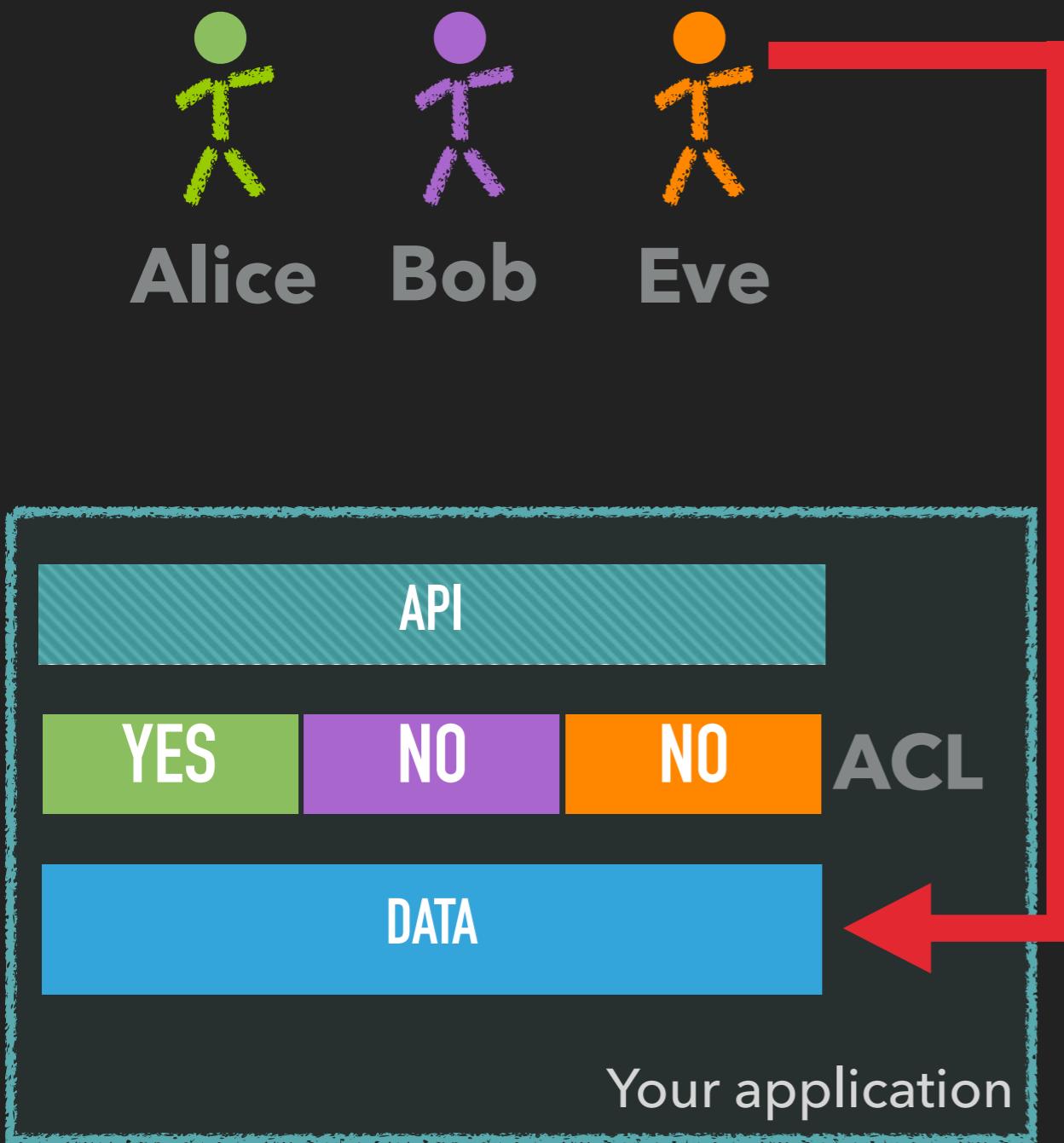
1. Bob tries to read data
2. Application validates ACL
3. Access is denied

# ACCESS CONTROL



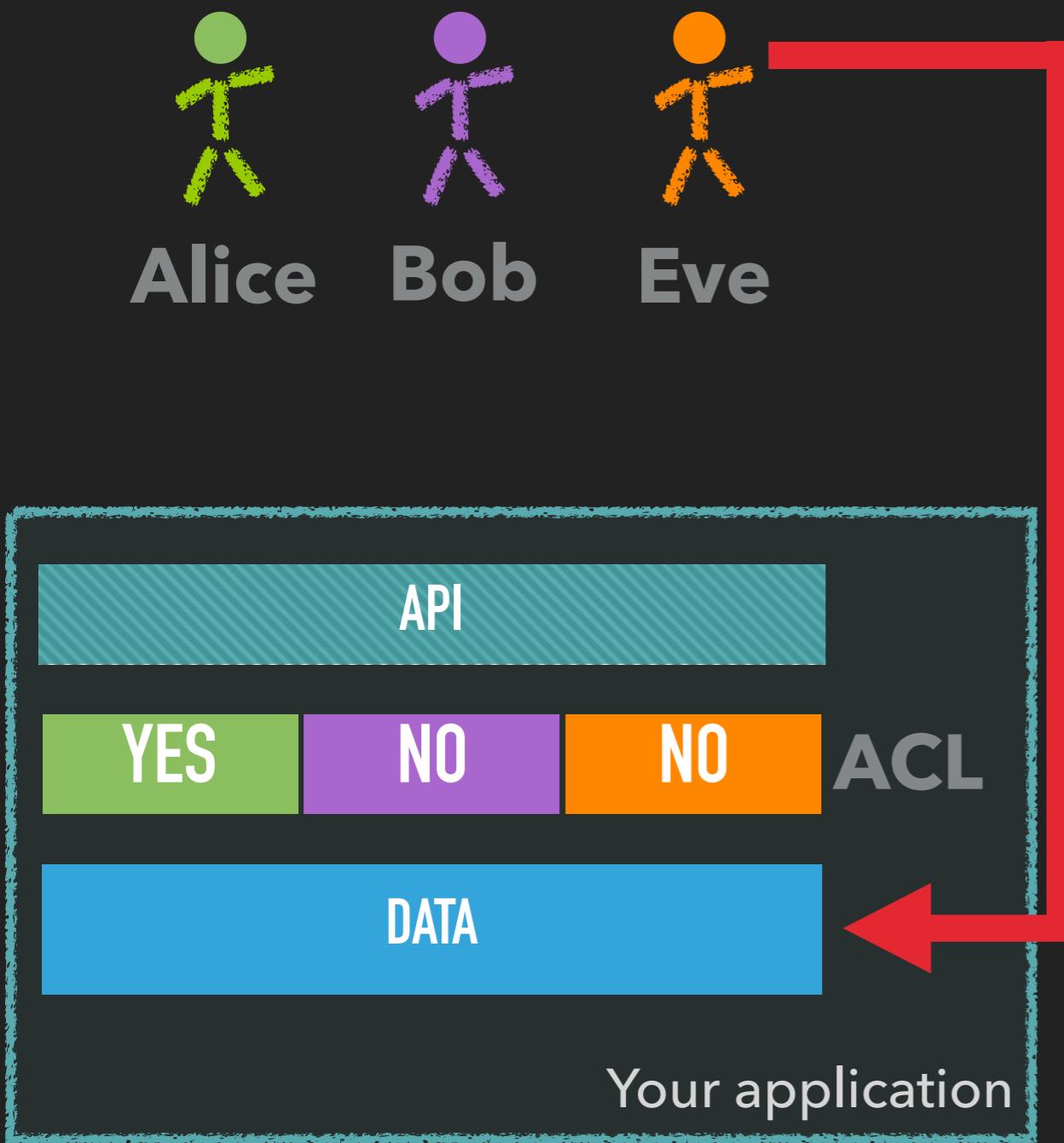
1. Eve exploits application

# ACCESS CONTROL



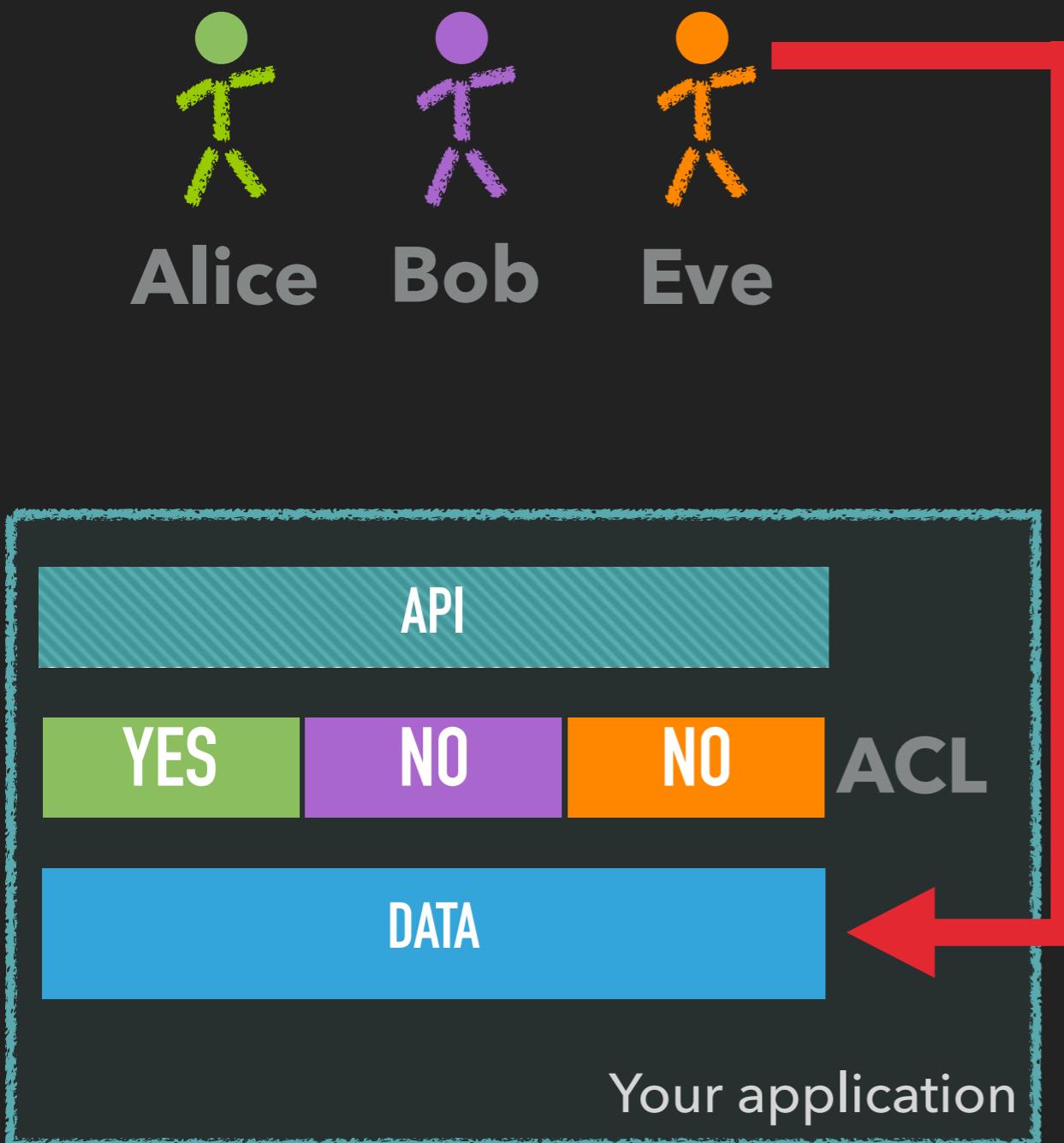
1. Eve exploits application

# ACCESS CONTROL



1. Eve exploits application
2. Application ????

# ACCESS CONTROL

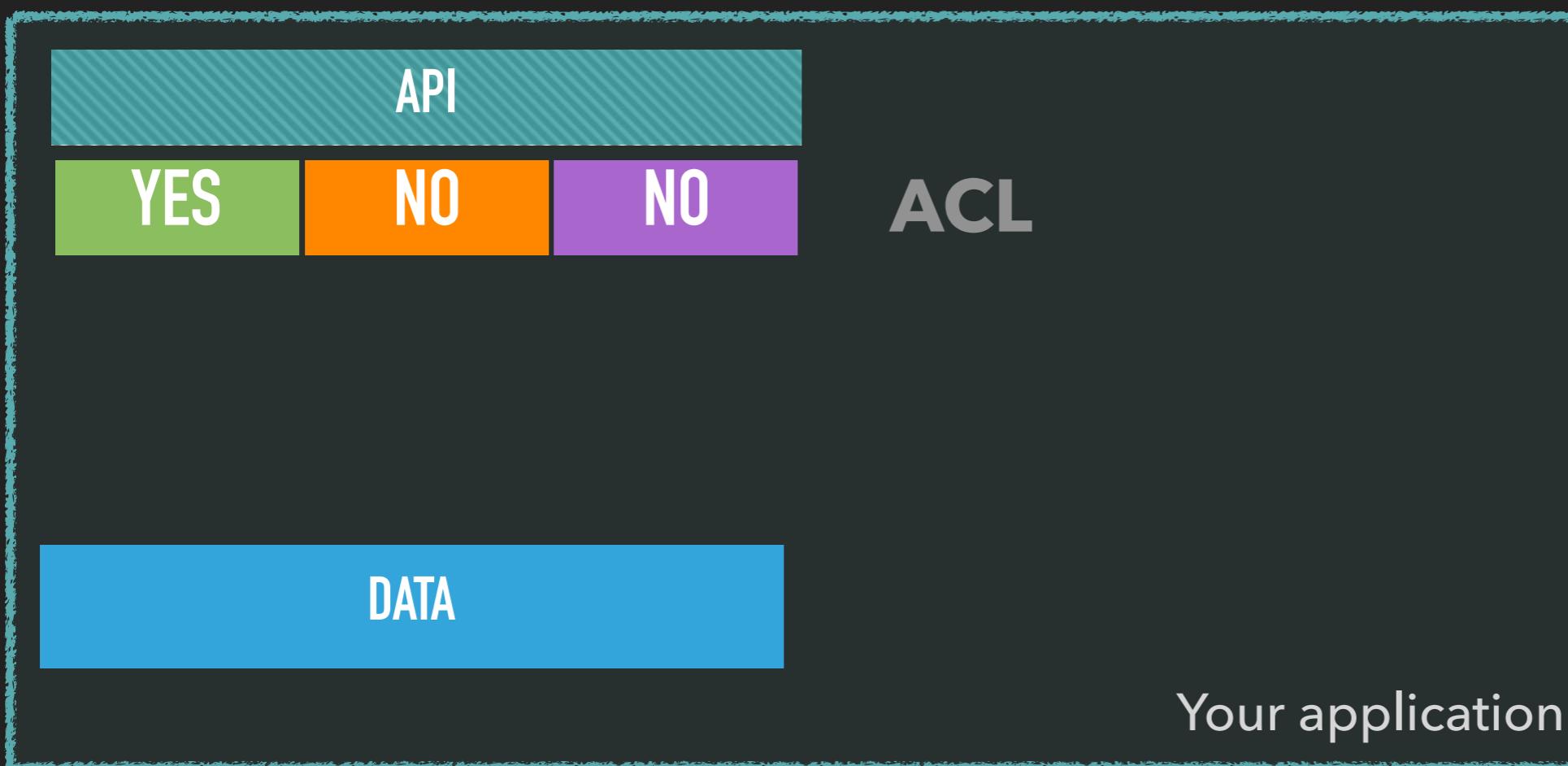


1. Eve exploits application
2. Application ????
3. Eve has access to data

# ACCESS CONTROL



Alice    Bob    Eve



# ACCESS CONTROL



Alice    Bob    Eve

API

YES

NO

NO

ACL

DATA



encrypted with

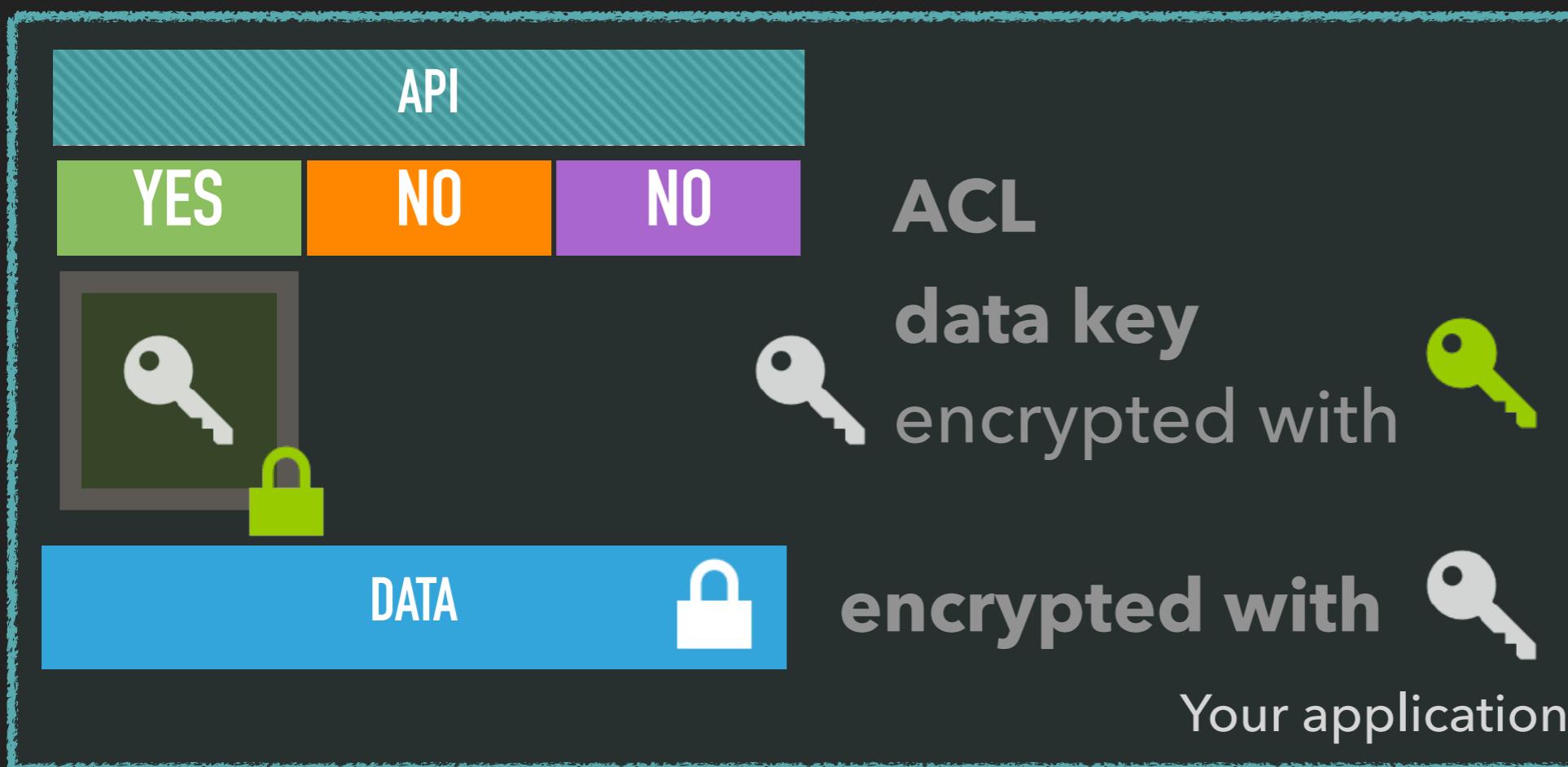


Your application

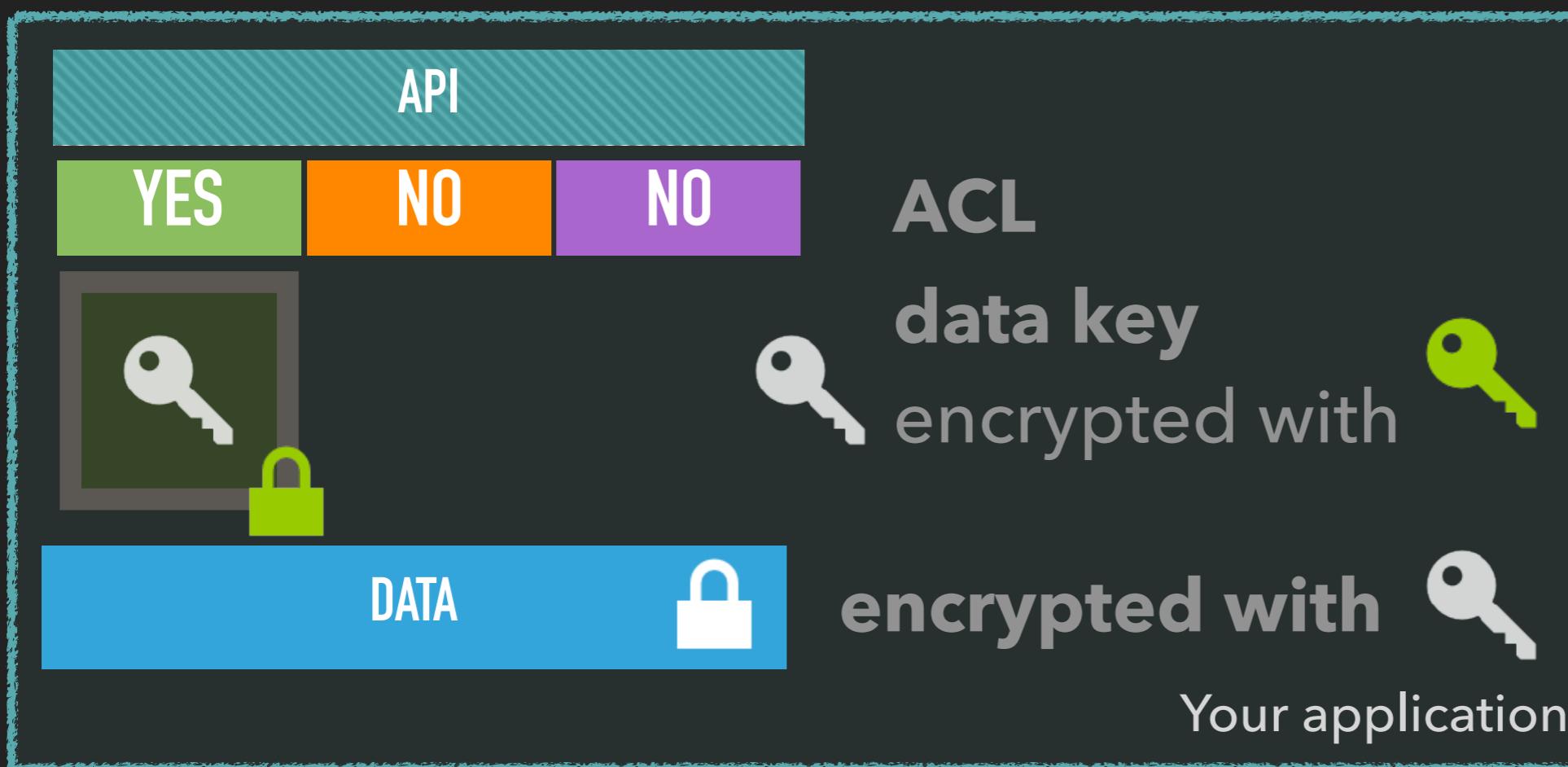
# ACCESS CONTROL



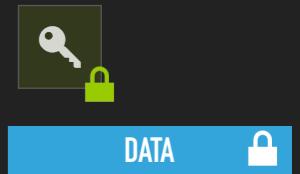
Alice    Bob    Eve



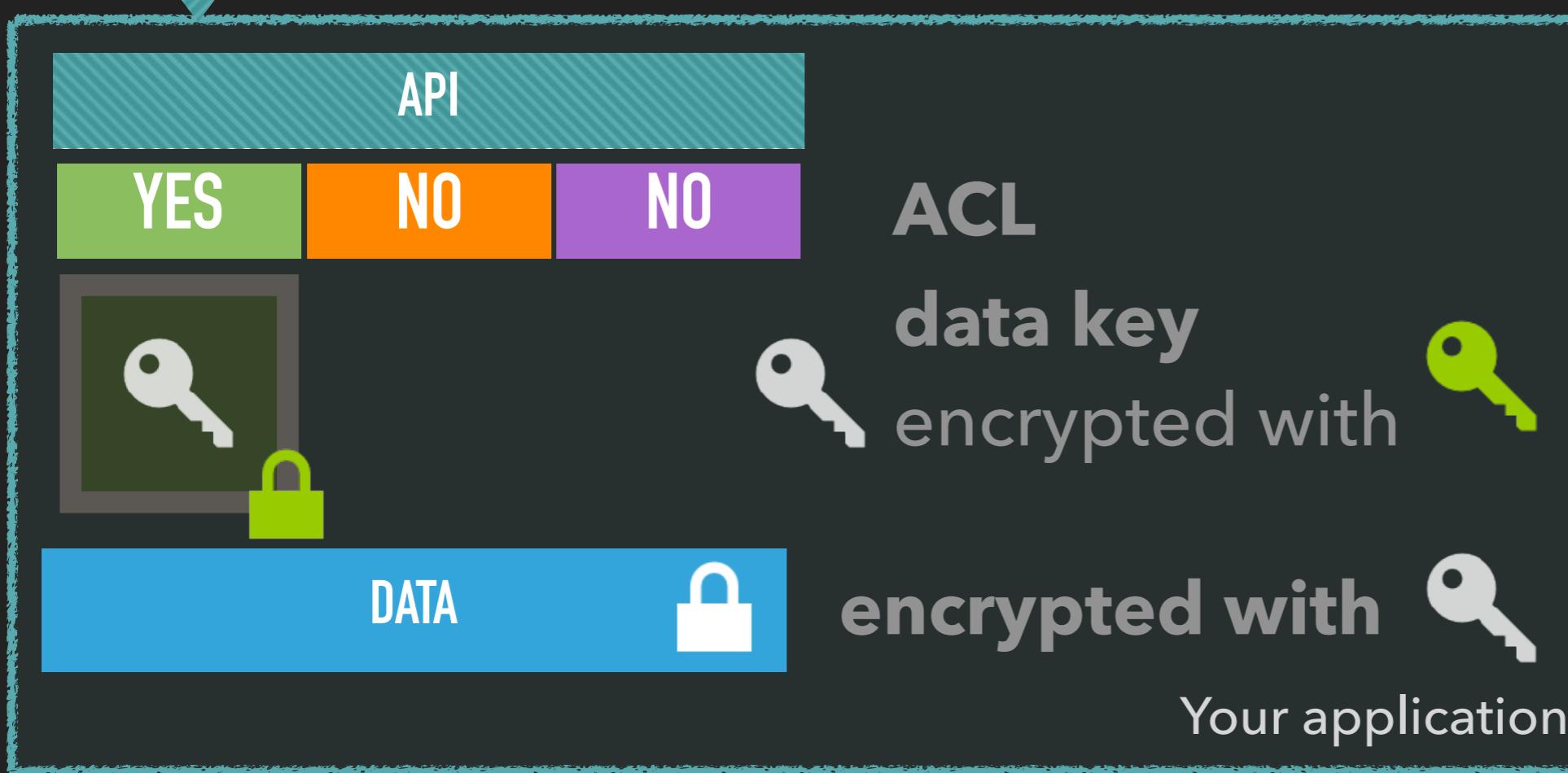
# ACCESS CONTROL



# ACCESS CONTROL

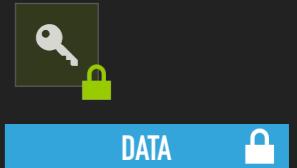


Alice    Bob    Eve

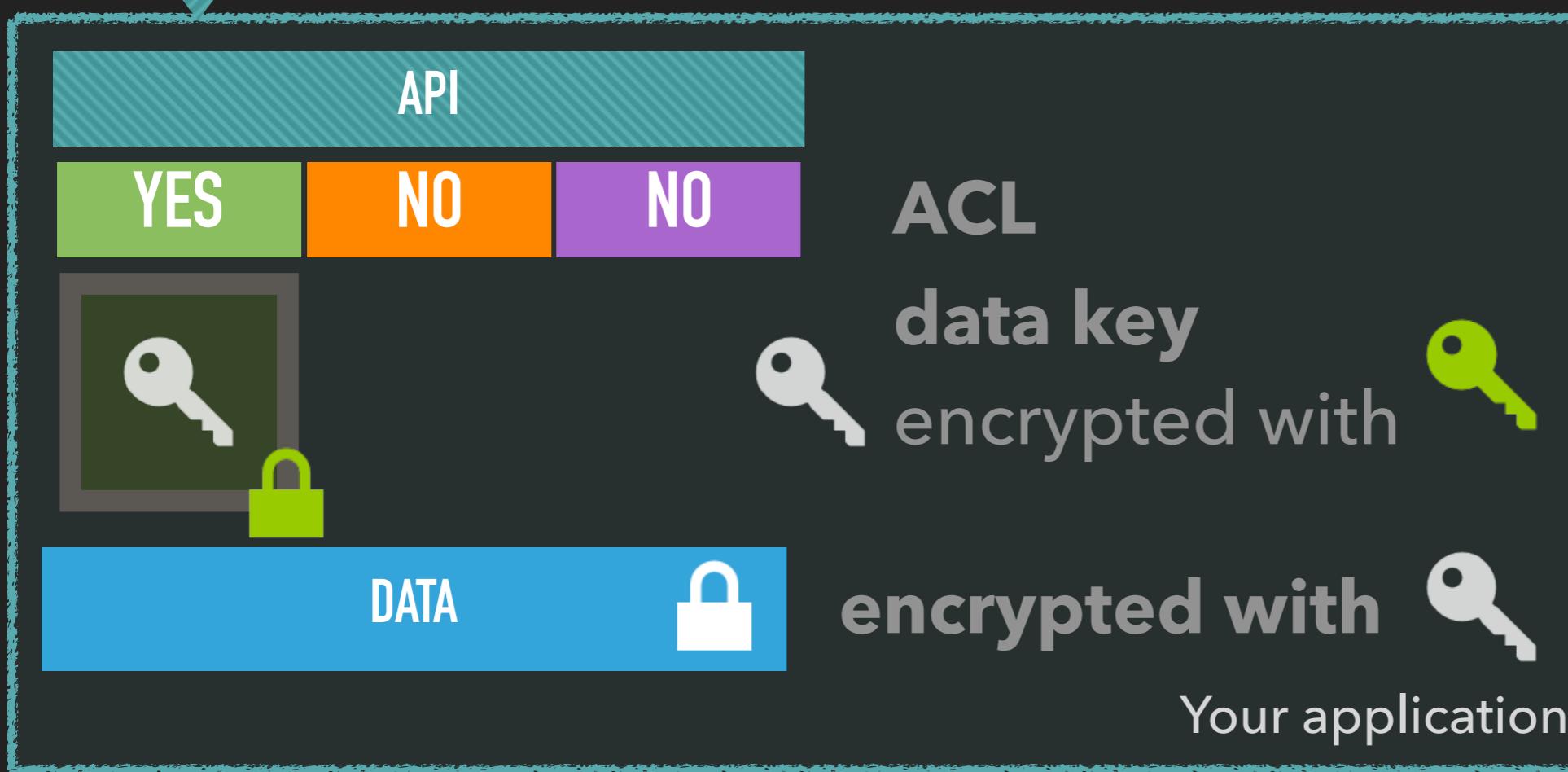
Three stick figure icons representing users: Alice (green), Bob (purple), and Eve (orange), each holding a magnifying glass over their respective names.

# ACCESS CONTROL

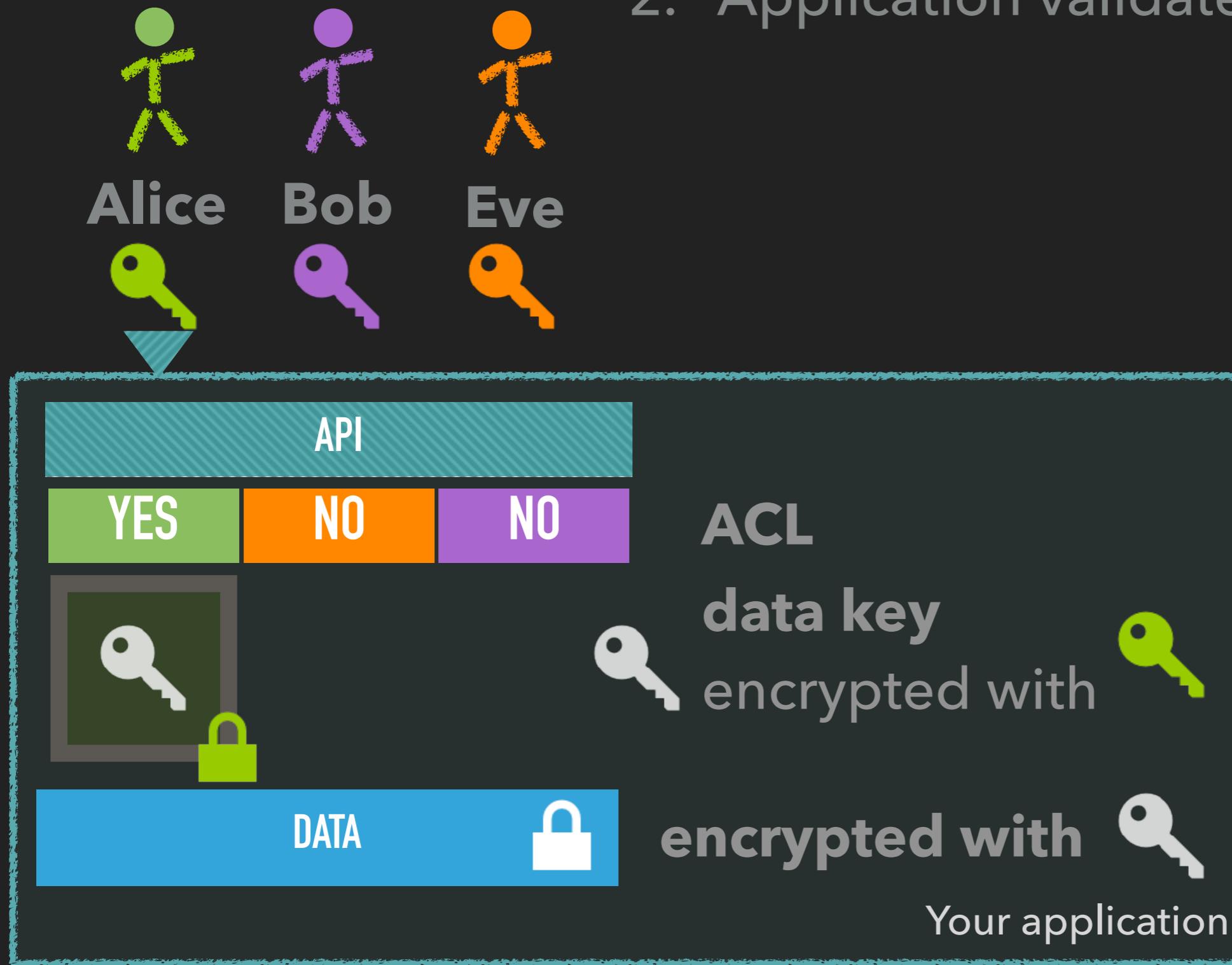
1. Alice tries to read data



Alice    Bob    Eve  
Three key icons corresponding to the stick figures: a green key, a purple key, and an orange key.



# ACCESS CONTROL



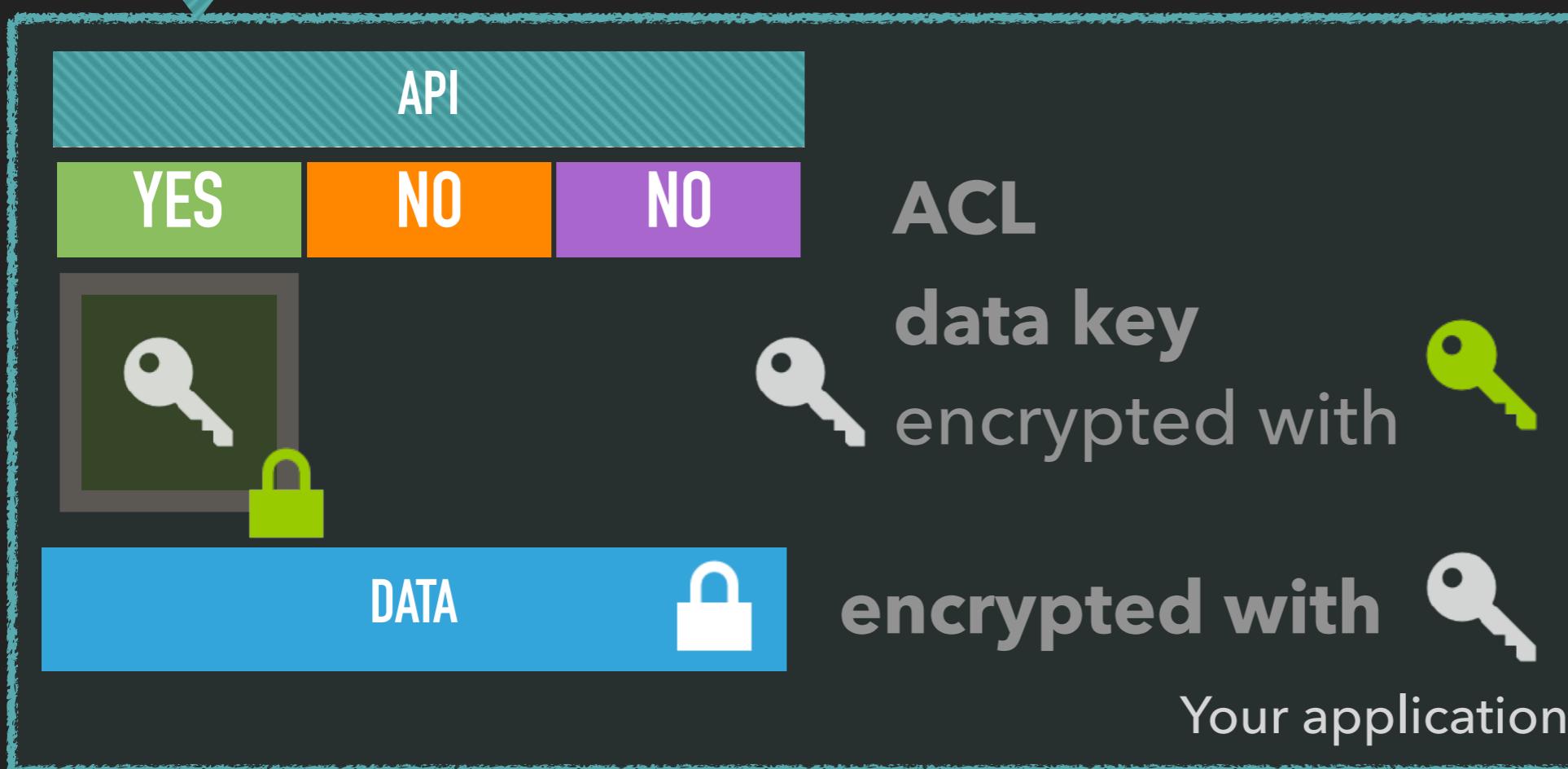
# ACCESS CONTROL



Alice    Bob    Eve

Below each stick figure is a magnifying glass icon. The green magnifying glass is held by the green stick figure, the purple by the purple one, and the orange by the orange one. They are all pointing downwards towards a central document icon.

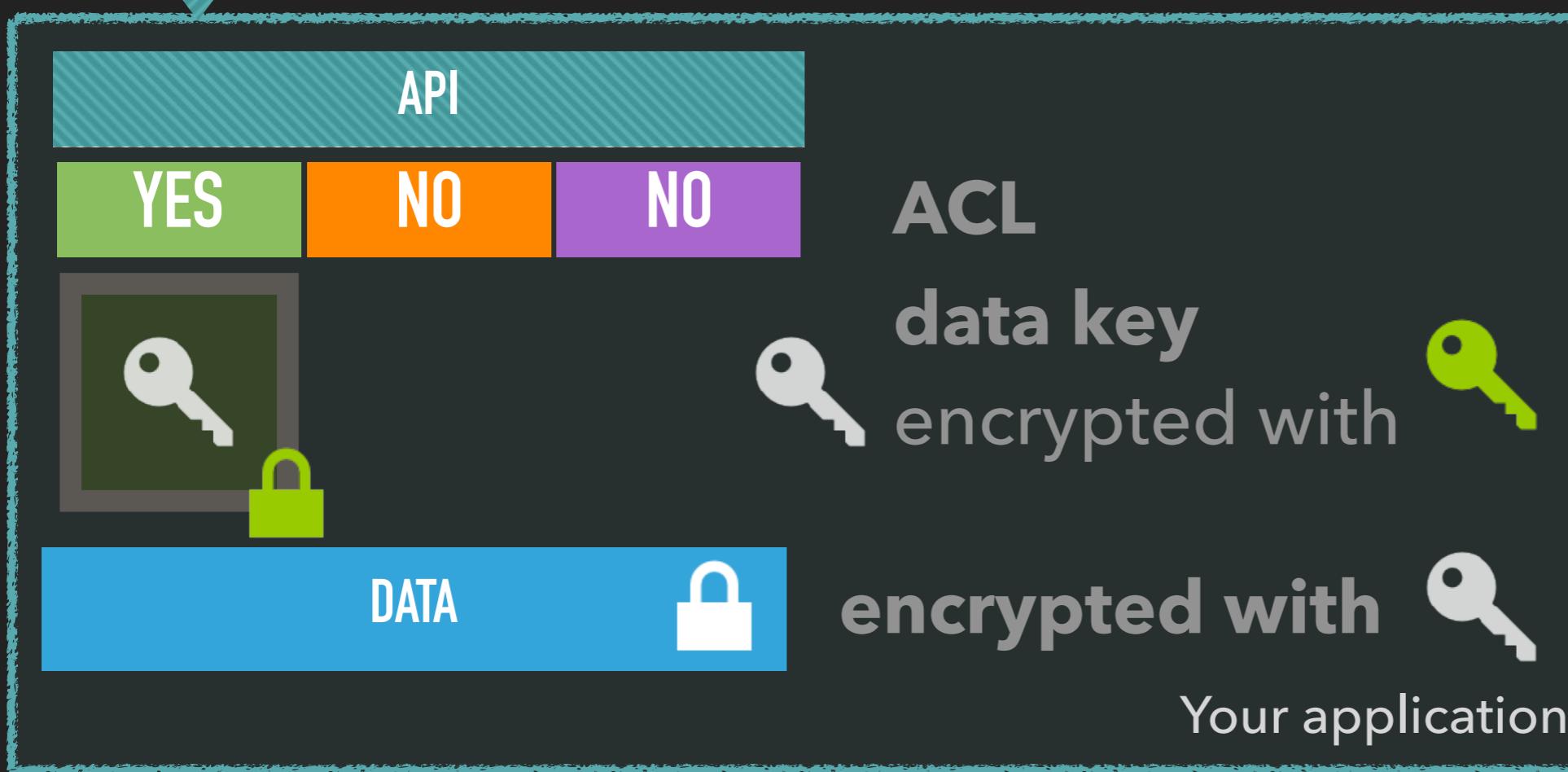
1. Alice tries to read data
2. Application validates ACL
3. Alice is granted access



# ACCESS CONTROL



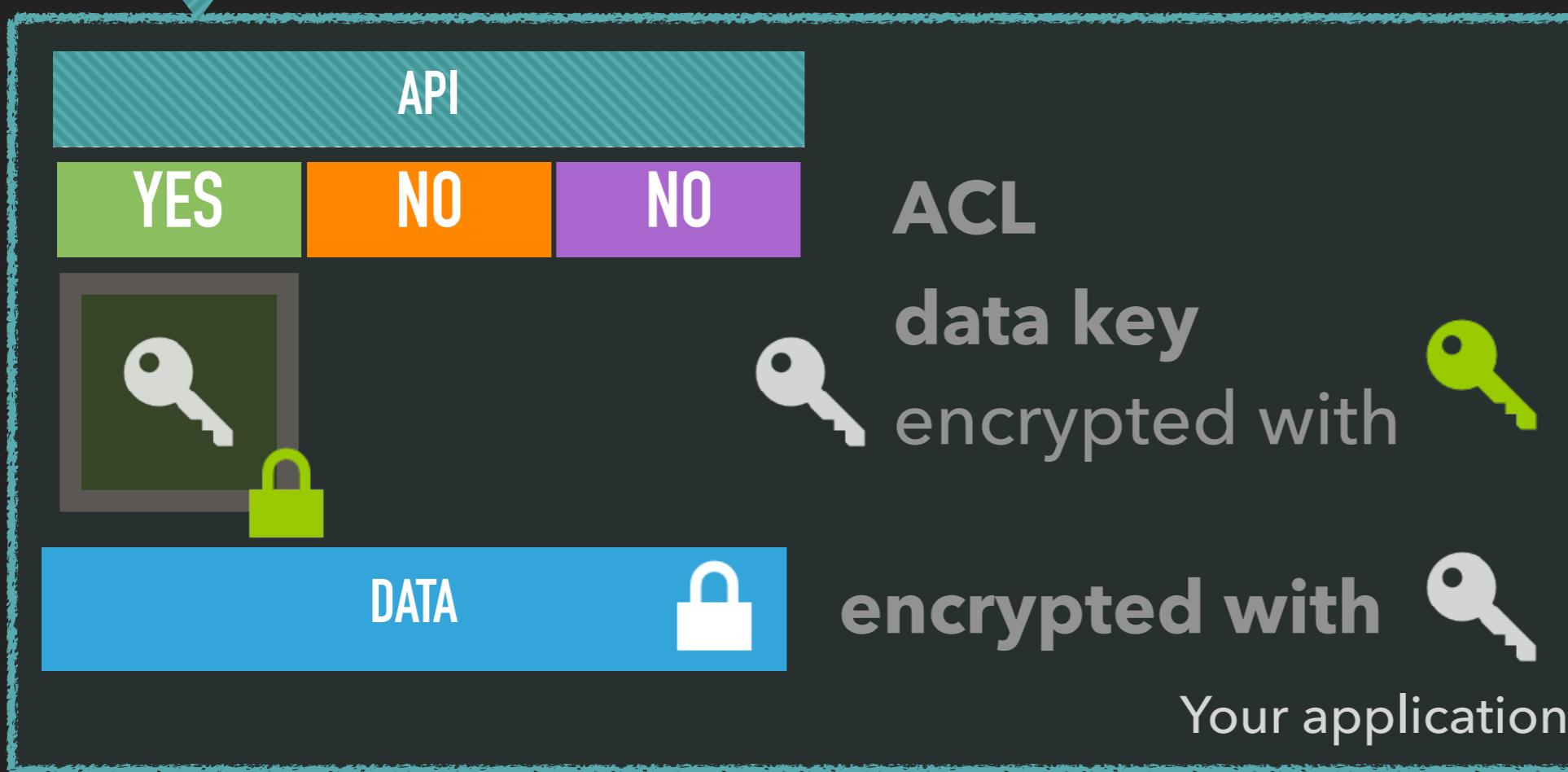
1. Alice tries to read data
2. Application validates ACL
3. Alice is granted access
4. Alice decrypts the “data key”



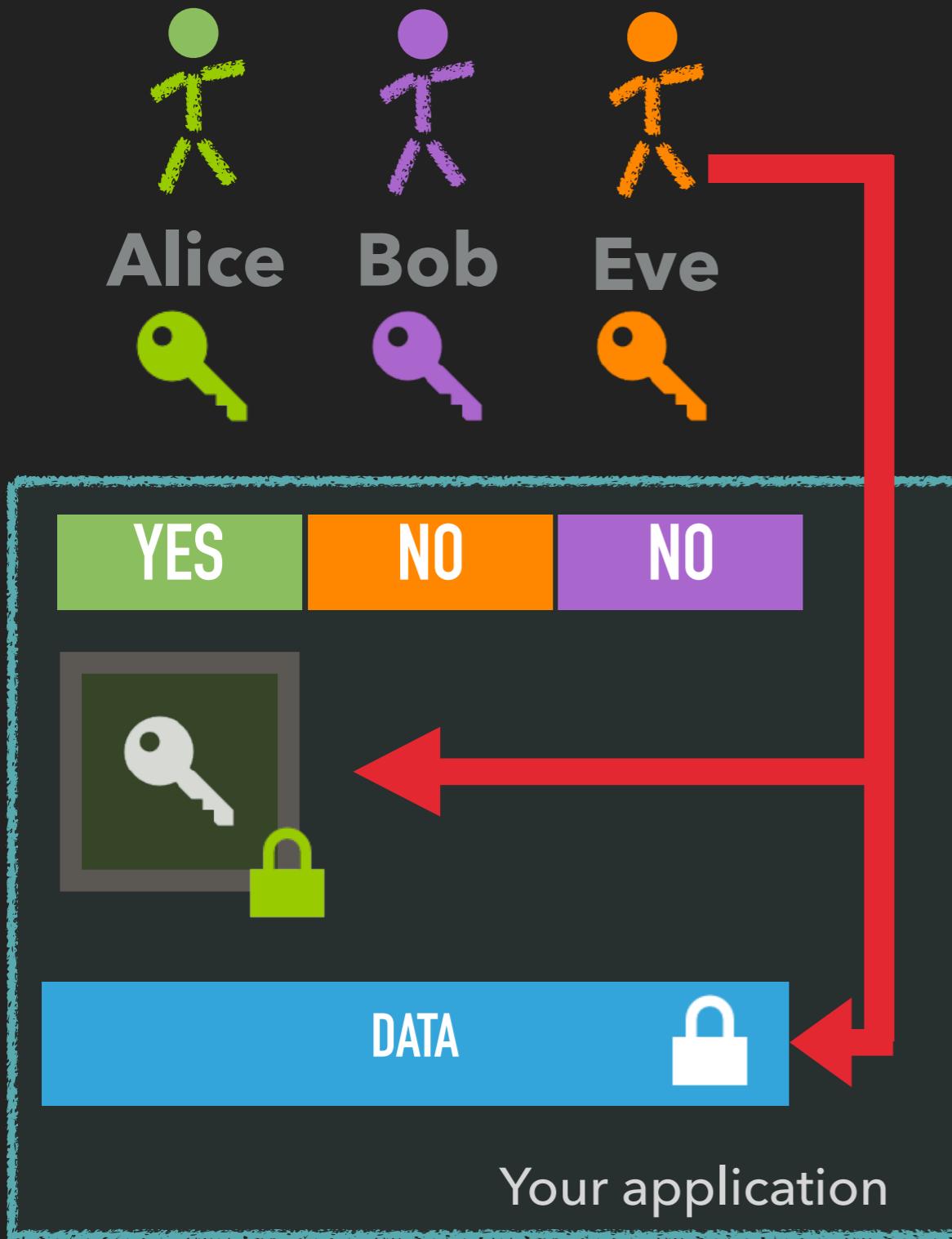
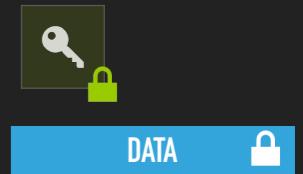
# ACCESS CONTROL



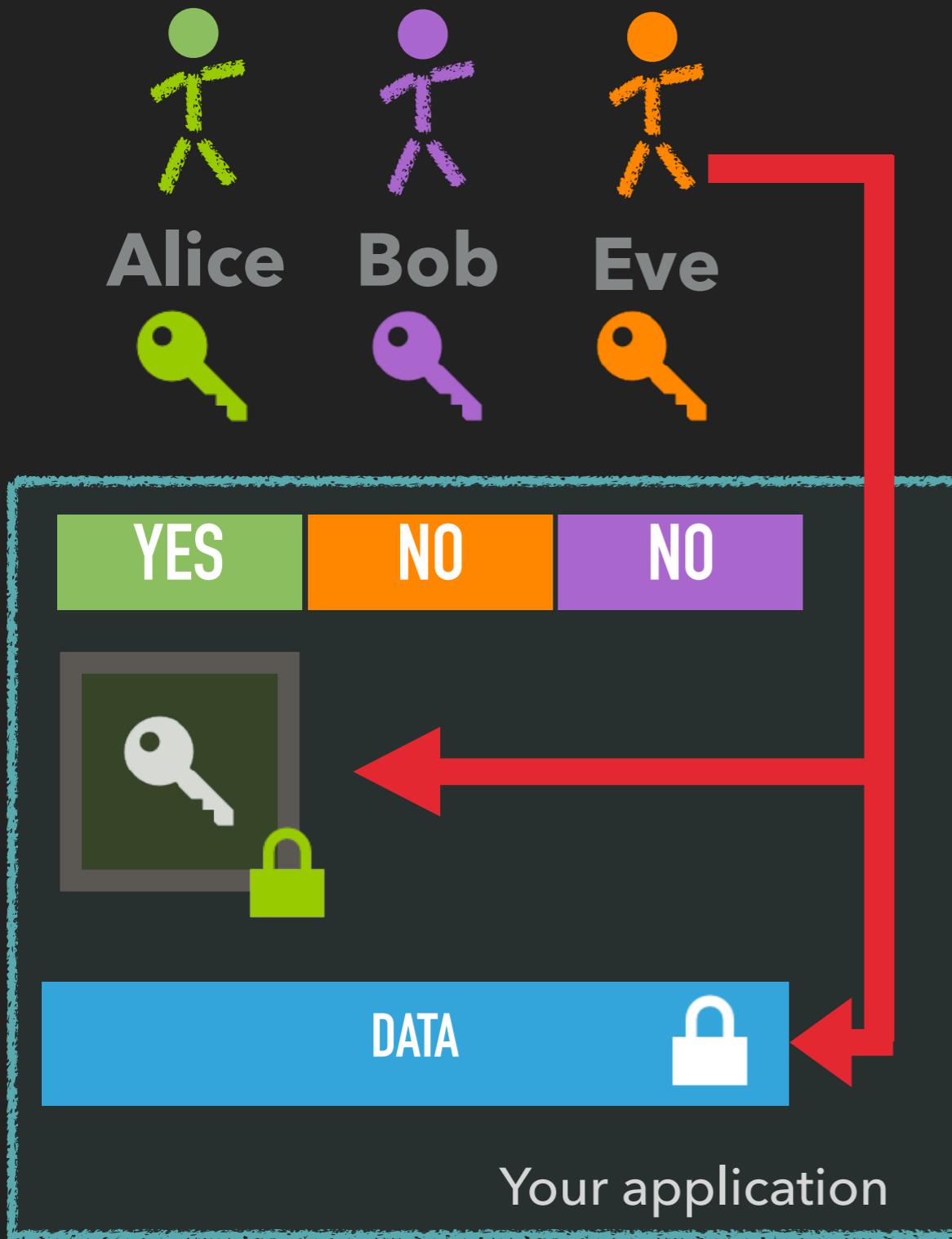
1. Alice tries to read data
2. Application validates ACL
3. Alice is granted access
4. Alice decrypts the “data key”
5. Alice decrypts data



# ACCESS CONTROL

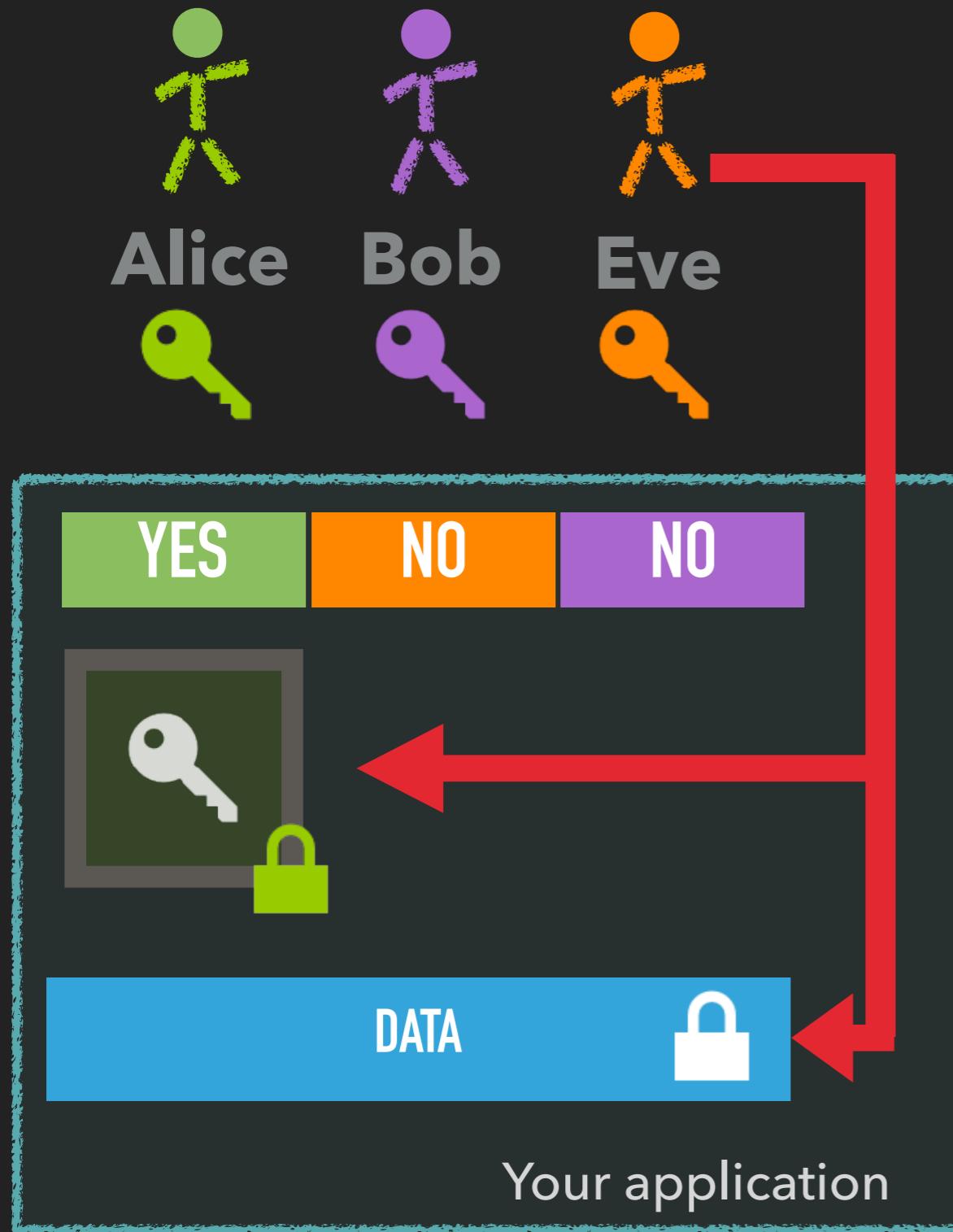
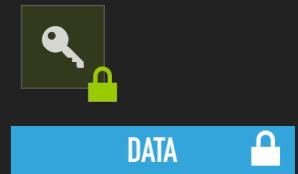


# ACCESS CONTROL



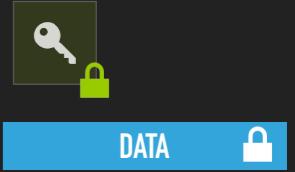
1. Eve exploits application
2. Eve gets encrypted data key  
OR  
Eve gets encrypted data  
Eve cannot decrypt the data!

# ACCESS CONTROL



1. Eve exploits application
2. Eve gets encrypted data key  
OR  
Eve gets encrypted data  
Eve cannot decrypt the data!

# ACCESS CONTROL



1. Alice enters her password

# ACCESS CONTROL



(1)

Alice

\*\*\*\*\*

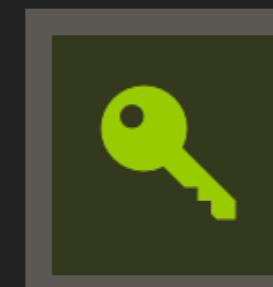
1. Alice enters her password

# ACCESS CONTROL



Alice

\*\*\*\*\*



\*\*\*\*\*

1. Alice enters her password
2. Application decrypts her strong long-term key

**Alice' long term secret key**  
encrypted with her  
password.

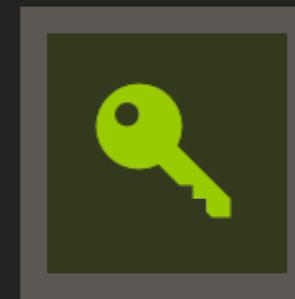
# ACCESS CONTROL



(1)

**Alice**

\*\*\*\*\*



(2)

\*\*\*\*\*



(3)

**Alice**

1. Alice enters her password
2. Application decrypts her strong long-term key
3. Alice now has her long-term key

**Alice' long term secret key**  
encrypted with her  
password.



- Data treatment ...
- Use existing ...
- ...

# PATTERNS

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# CRYPTO CHECKLIST

# CRYPTO CHECKLIST

- Data treatment ...
- Use existing ...
- ...

- Data treatment plan created and consequences accepted by management
- Trust anchors identified and named
- Sensitive operations (crypt,sign,...) require client authentication (applies to services too!)
- Existing (e.g. [RFC 4880](#)) protocols & formats used wherever possible
- Nonces used only once. Random salt used where possible
- Cryptographic concept written down & challenged in review
- (Master-)Key offsite backup established
- Key refresh after a few GiB of encrypted data implemented and tested
- Algorithm rollover implemented and tested
- Entropy source with enough entropy used
- Test cases include restore of old data (key/algorithm rollover)

# SUMMARY

Regulations apply - whatever you do!

Encryption is not for free!

No encryption might be way more expensive!

Encryption is a safety net (*last* line of defence)

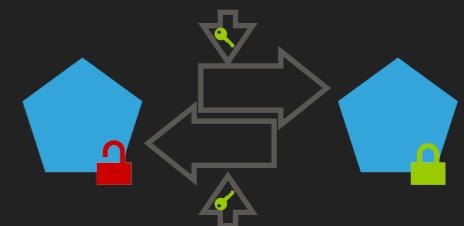
→ Assess risks & cost, plan, implement!

# SUMMARY

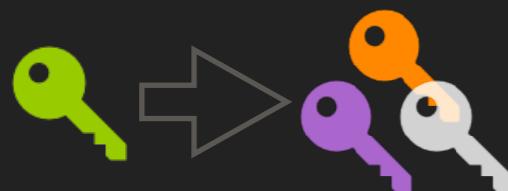
Comparing data



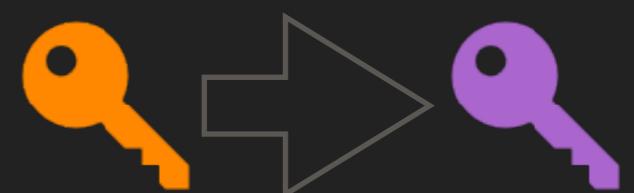
Transparent encryption



Storing data



Key derivation



Key refresh

DES	BLOWFISH	AES
MD5	SHA-1	SHA-256
RSA-1024	RSA-2048	?? POST QUANTUM ??

Algorithm rollover

# SUMMARY

0X123456...



## Integrity

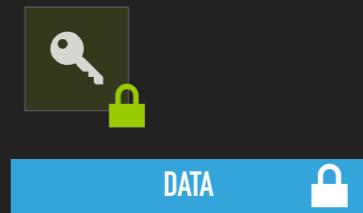
```
int getRandomNumber()
{
    return 4; // chosen by fair dice roll.
              // guaranteed to be random.
}
```

## Entropy

## Access Control

- Data treatment ...
- Use existing ...
- ...

## Crypto Checklist

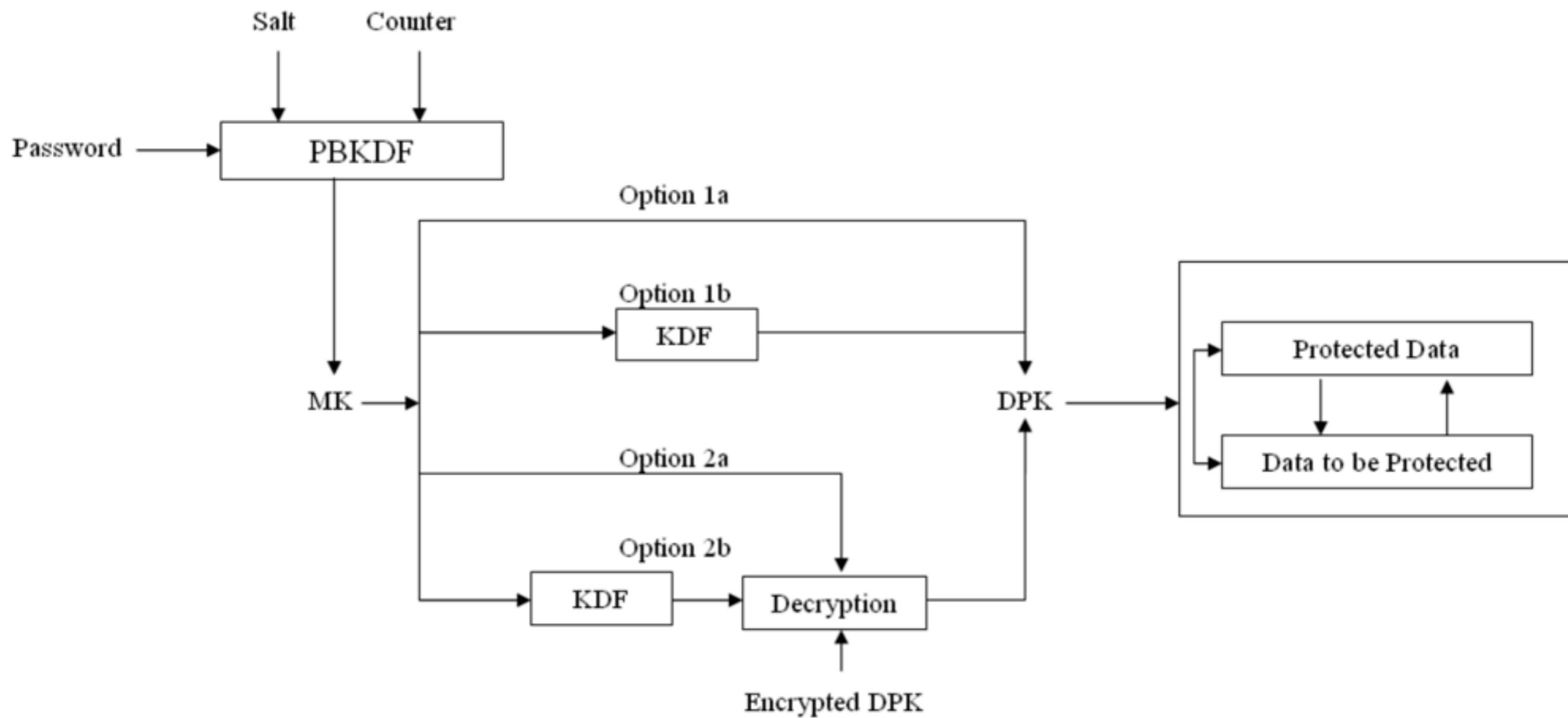


# Q & A



[https://github.com/neuhalje/presentation\\_content-encryption](https://github.com/neuhalje/presentation_content-encryption)

# BACKUP



*Option 1a:* The MK or a segment of the MK is used as DPK.

*Option 1b:* The DPK is derived from the MK using an **approved** key derivation function.

*Option 2a:* The MK is used to recover the DPK through an **approved** authenticated encryption or an **approved** key protection/recovery method.

*Option 2b:* The key to recover the DPK through an **approved** authenticated encryption or an **approved** key protection/recovery method is derived from the MK using an **approved** key derivation function.

# §

LEGAL

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(PSEUDO|  
ANONYM)ISED?

# (PSEUDO|ANONYM)ISED?

## ANONYMISIERUNG

„das Verändern personenbezogener Daten derart, dass die Einzelangaben über persönliche oder sachliche Verhältnisse nicht mehr oder nur mit einem unverhältnismäßig großen Aufwand an Zeit, Kosten und Arbeitskraft einer bestimmten oder bestimmbaren natürlichen Person zugeordnet werden können.“ § 3 Abs. 6 BDSG



§

## PSEUDONYMISIERUNG

„das Ersetzen des Namens und anderer Identifikationsmerkmale durch ein Kennzeichen zu dem Zweck, die Bestimmung des Betroffenen auszuschließen oder wesentlich zu erschweren.“ § 3 Abs. 6a BDSG

## VERSCHLÜSSELUNG

„Technisch versteht man unter Verschlüsselung den Vorgang, bei dem ein klar lesbarer Text (Klartext) oder auch Informationen anderer Art wie Ton- oder Bildaufzeichnungen mit Hilfe eines Verschlüsselungsverfahrens (Kryptosystem) in eine „unleserliche“, das heißt nicht einfach interpretierbare Zeichenfolge (Geheimtext) umgewandelt wird. Als entscheidend wichtige Parameter der Verschlüsselung werden hierbei ein oder auch mehrere Schlüssel verwendet. Man unterscheidet deshalb zwischen symmetrischer und asymmetrischer Verschlüsselung. Bei der symmetrischen Verschlüsselung wird zum Ver- und Entschlüsseln der gleiche Schlüssel verwendet; bei der asymmetrischen Verschlüsselung sind dies immer verschiedene Schlüssel, die aber zueinander passen müssen. Das Gesetz lässt allerdings offen, welche Art der Verschlüsselung Verwendung finden soll.“ BDSG-Kommentar von Simitis (§ 9, Rn. 166)

~BACKUP