Proactive Threshold Wallets With Offline Devices

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KZen

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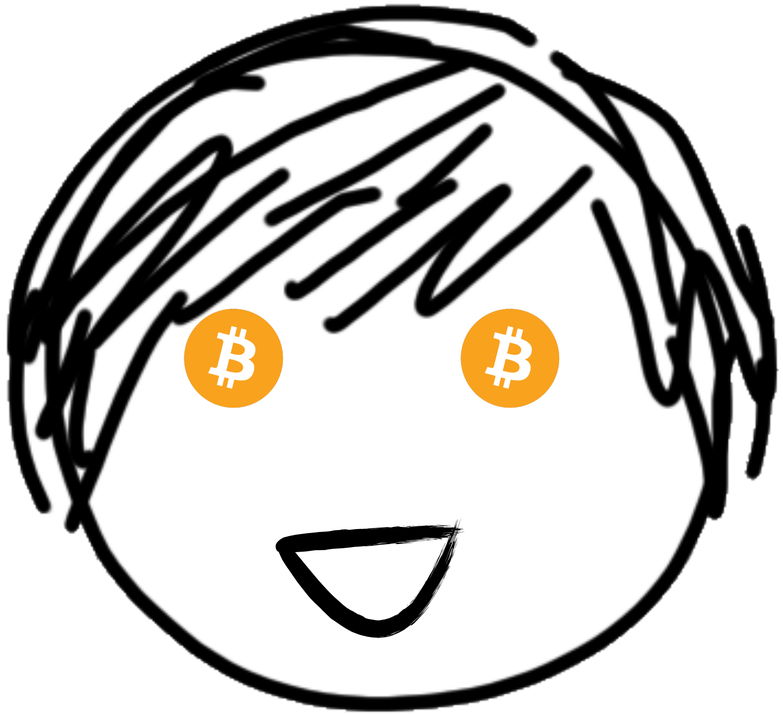
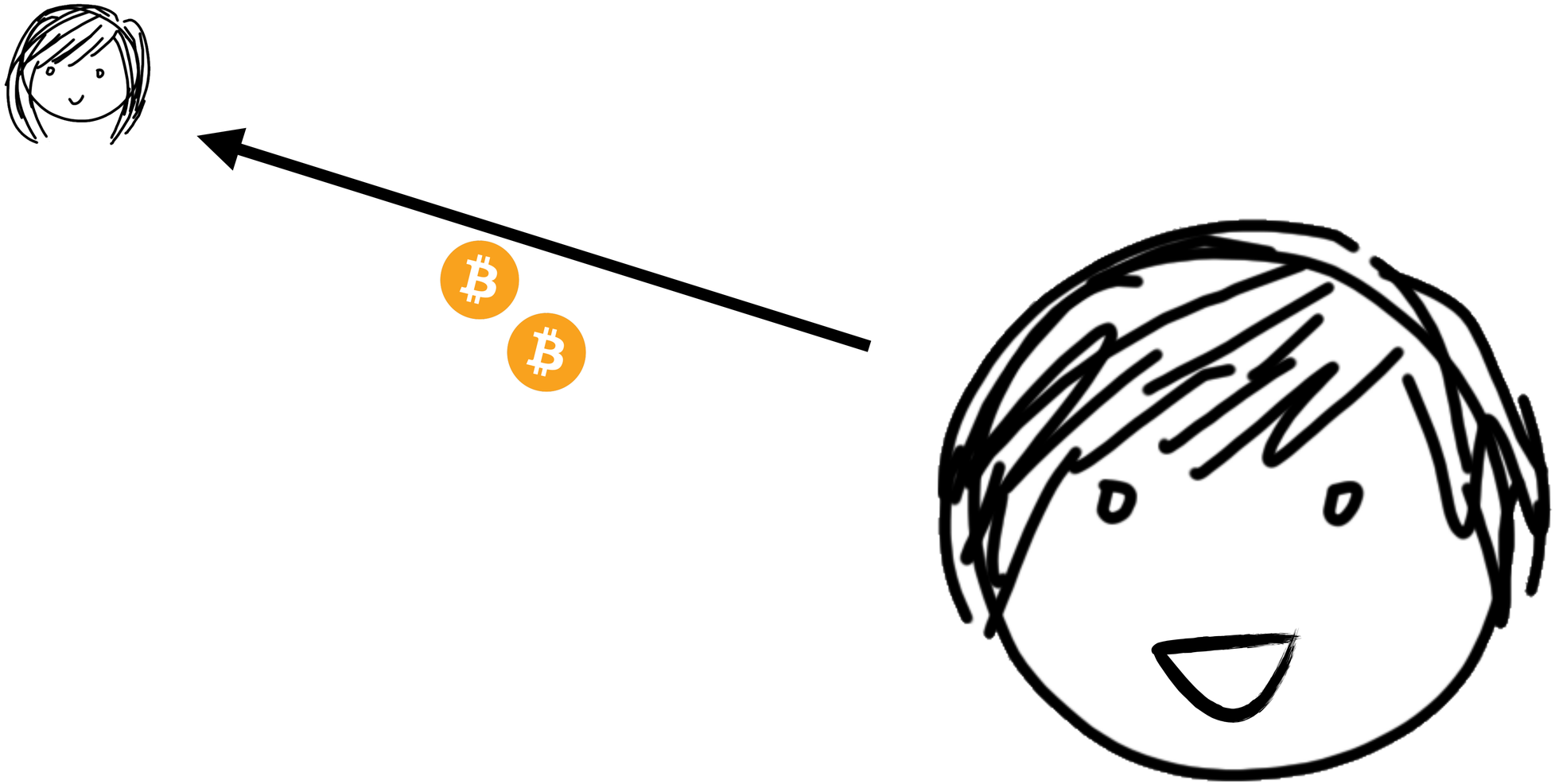
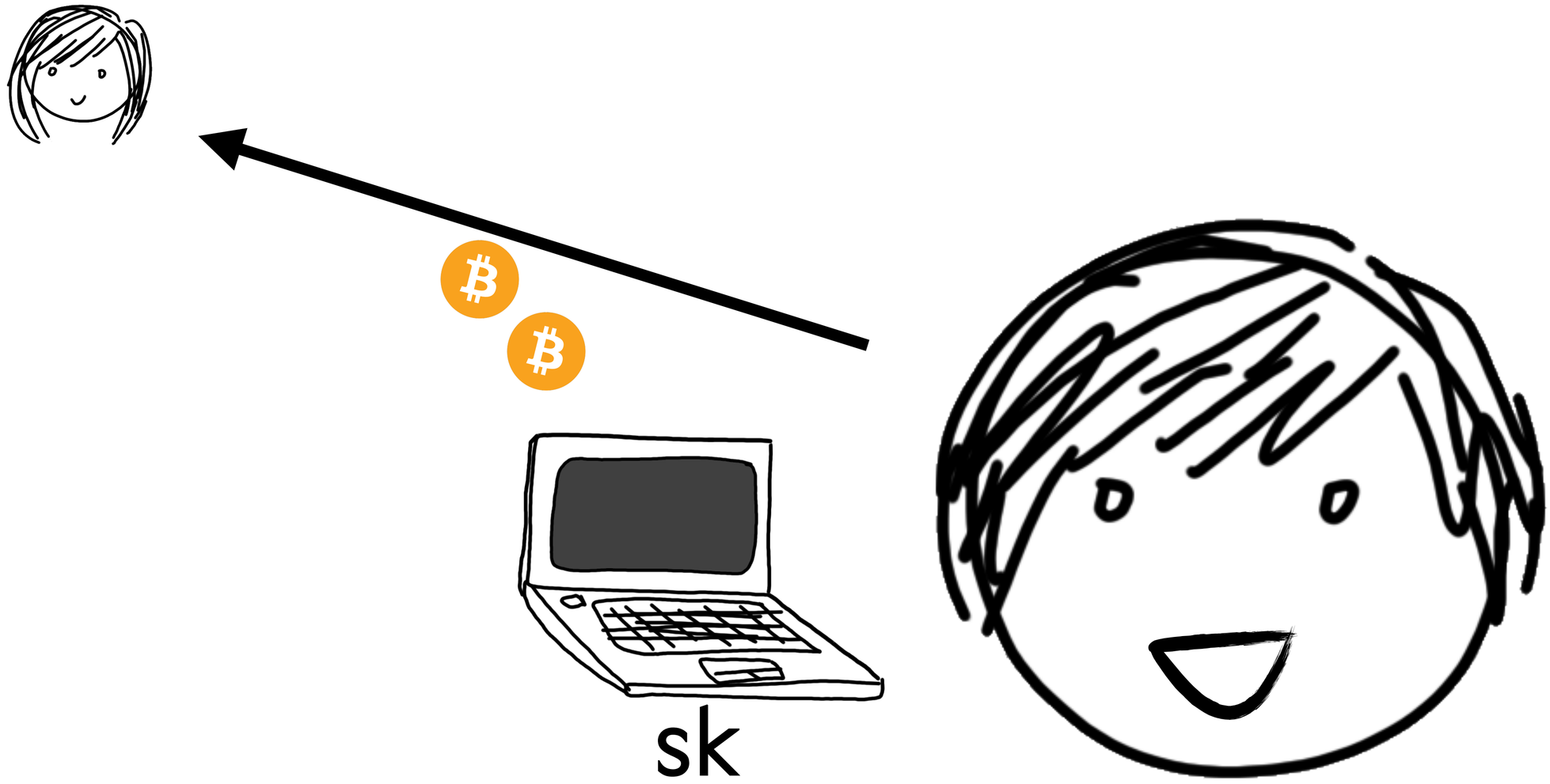
- Formalize notion of **unanimous erasure**
- **(2,*n*) setting**: **novel protocol** native to mode of operation for wallets, shown practical via implementation
- **(*t*,*n*) setting**: prove it’s **impossible** to achieve unanimous erasure in standard model (even given trusted setup, ledger)



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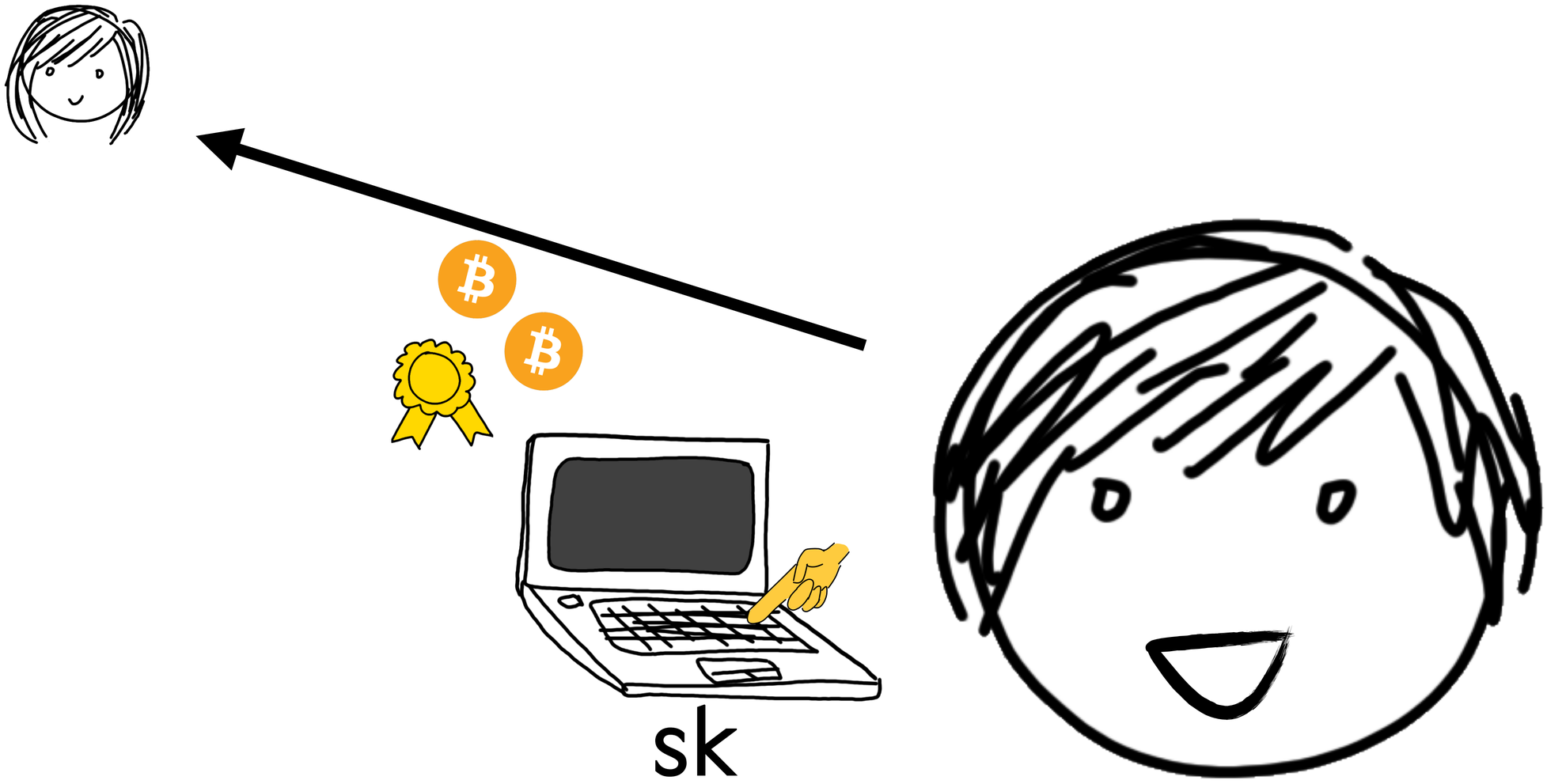
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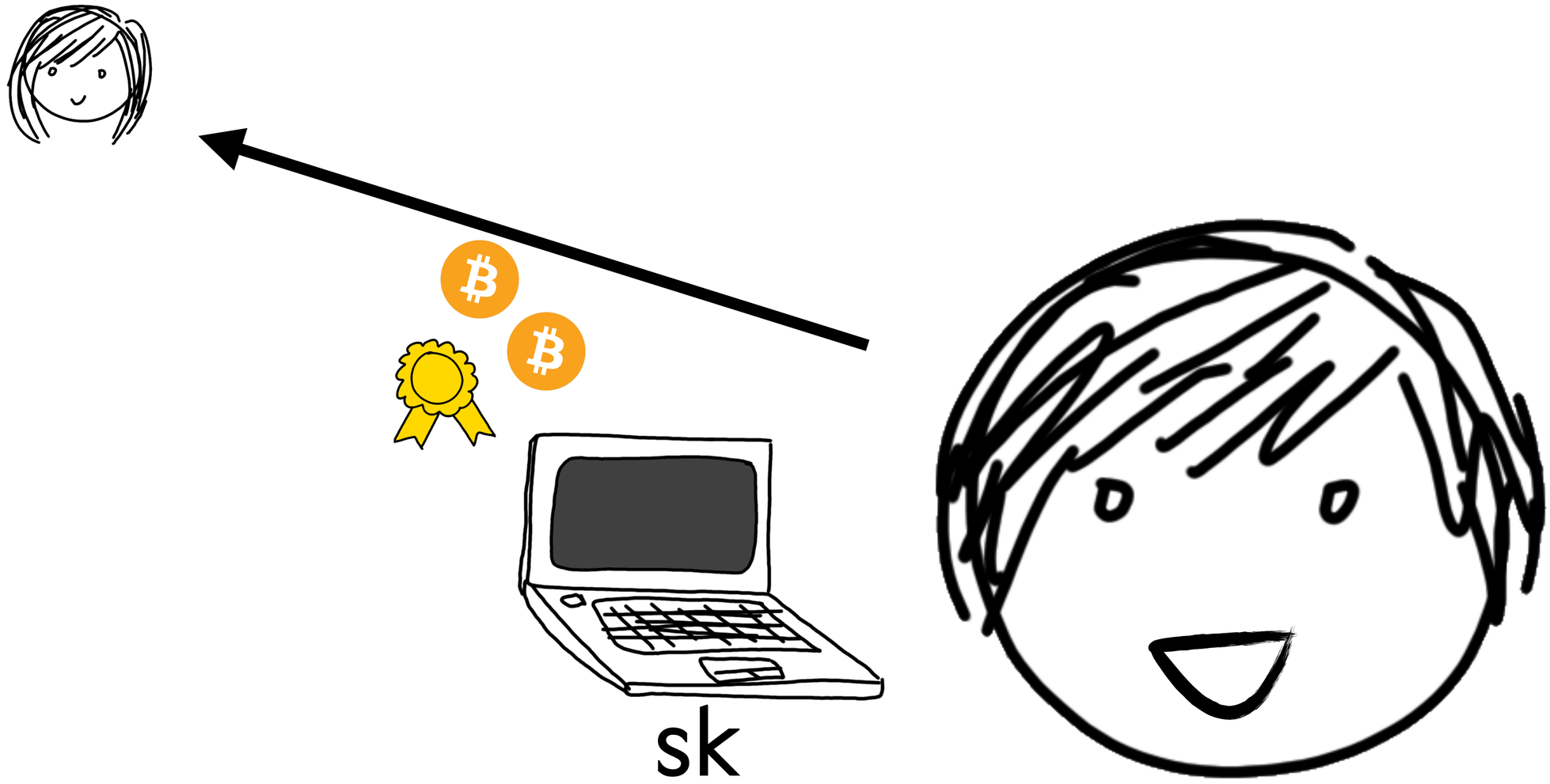
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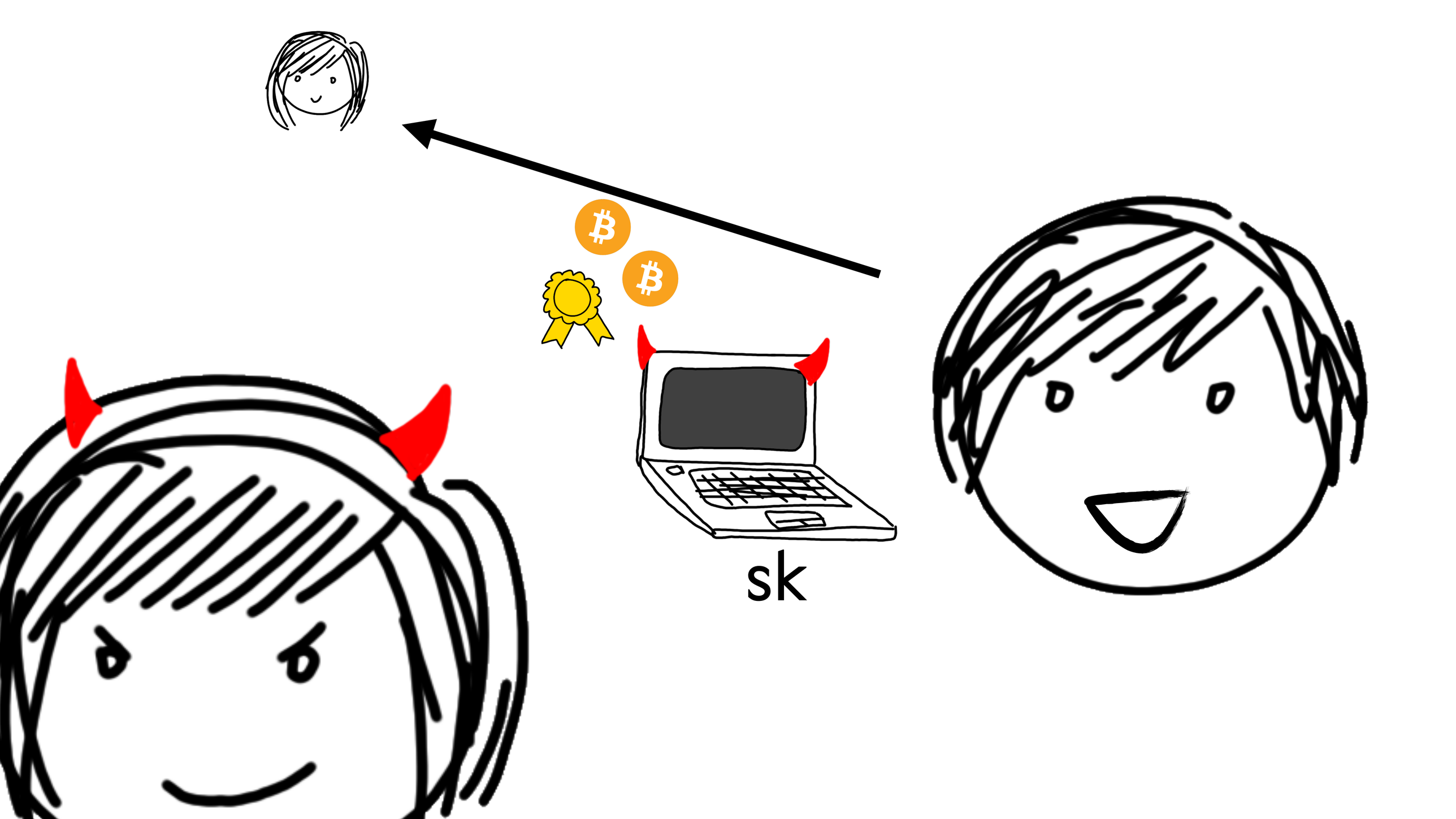
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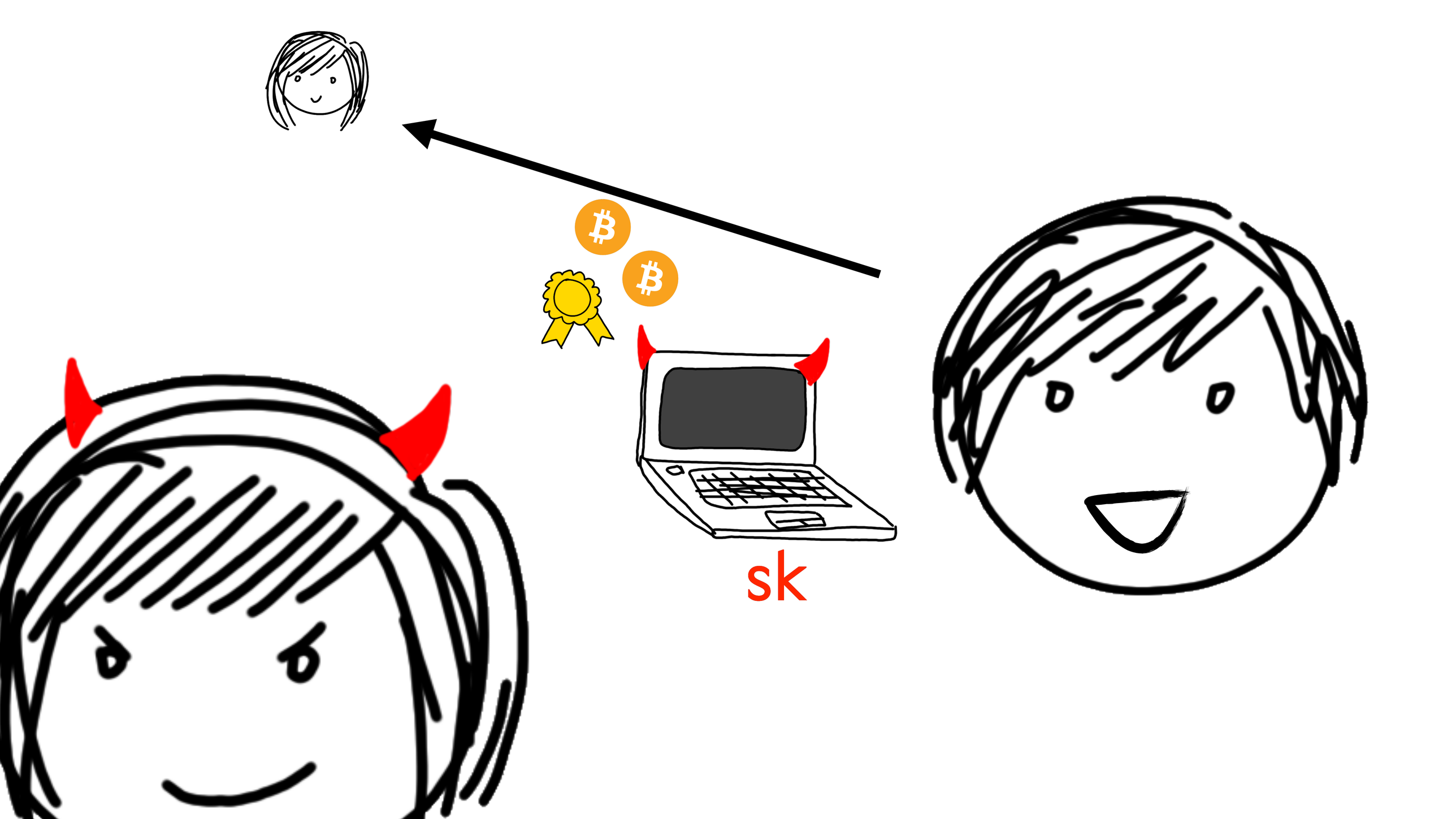
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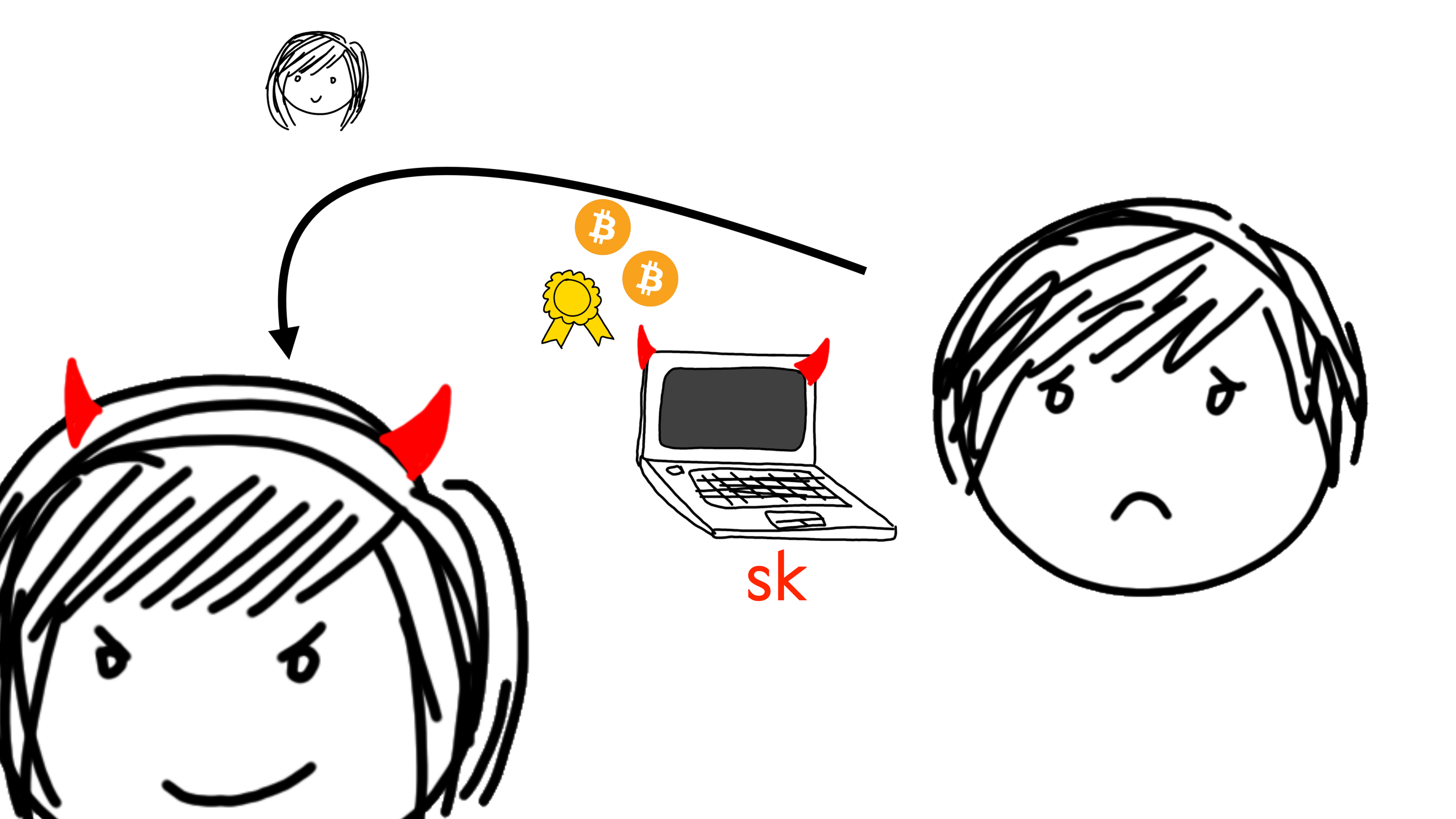
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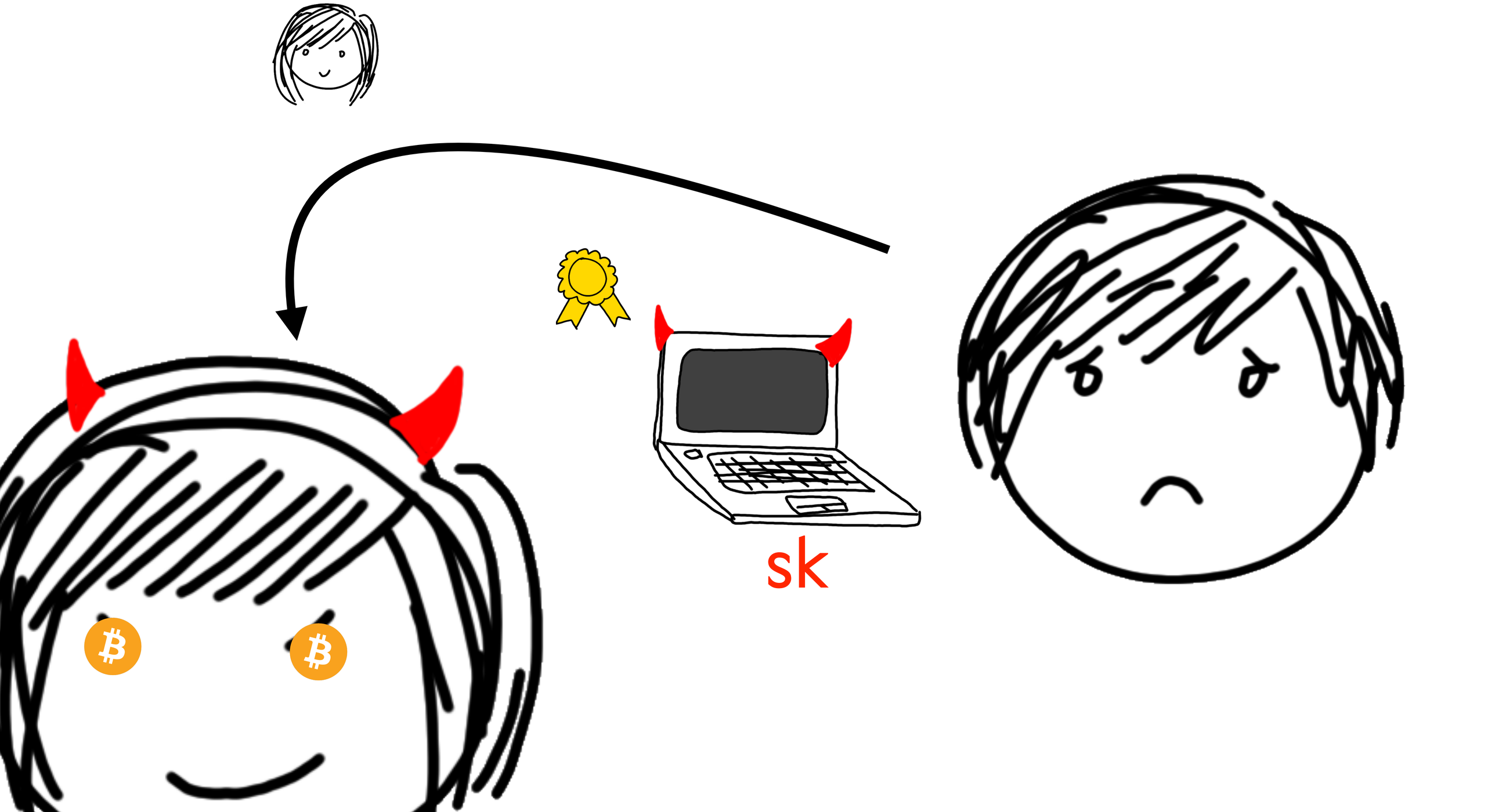
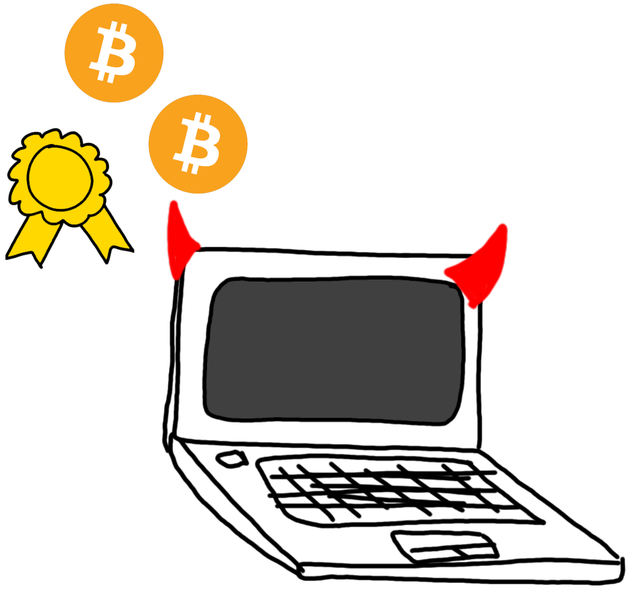
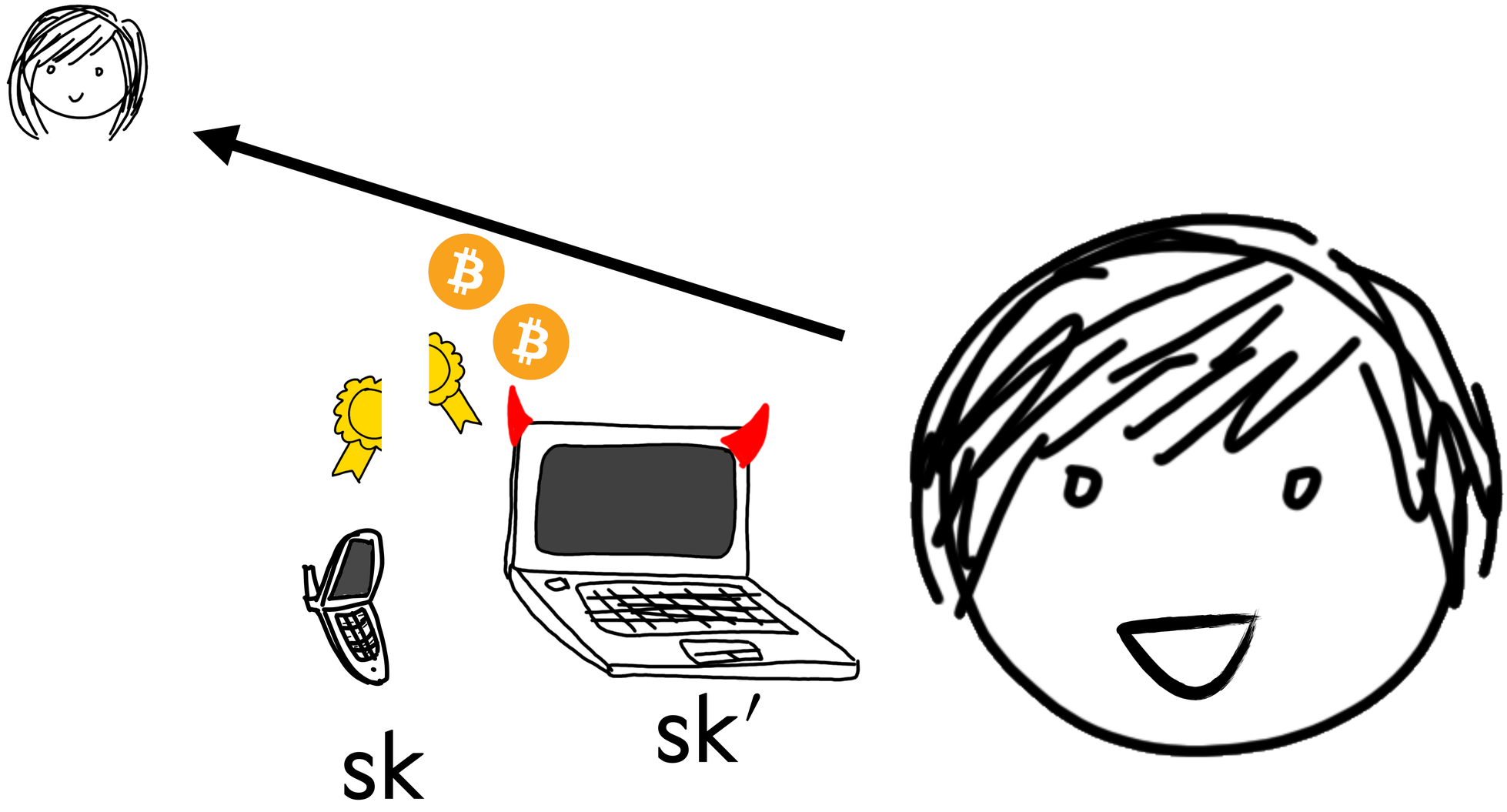
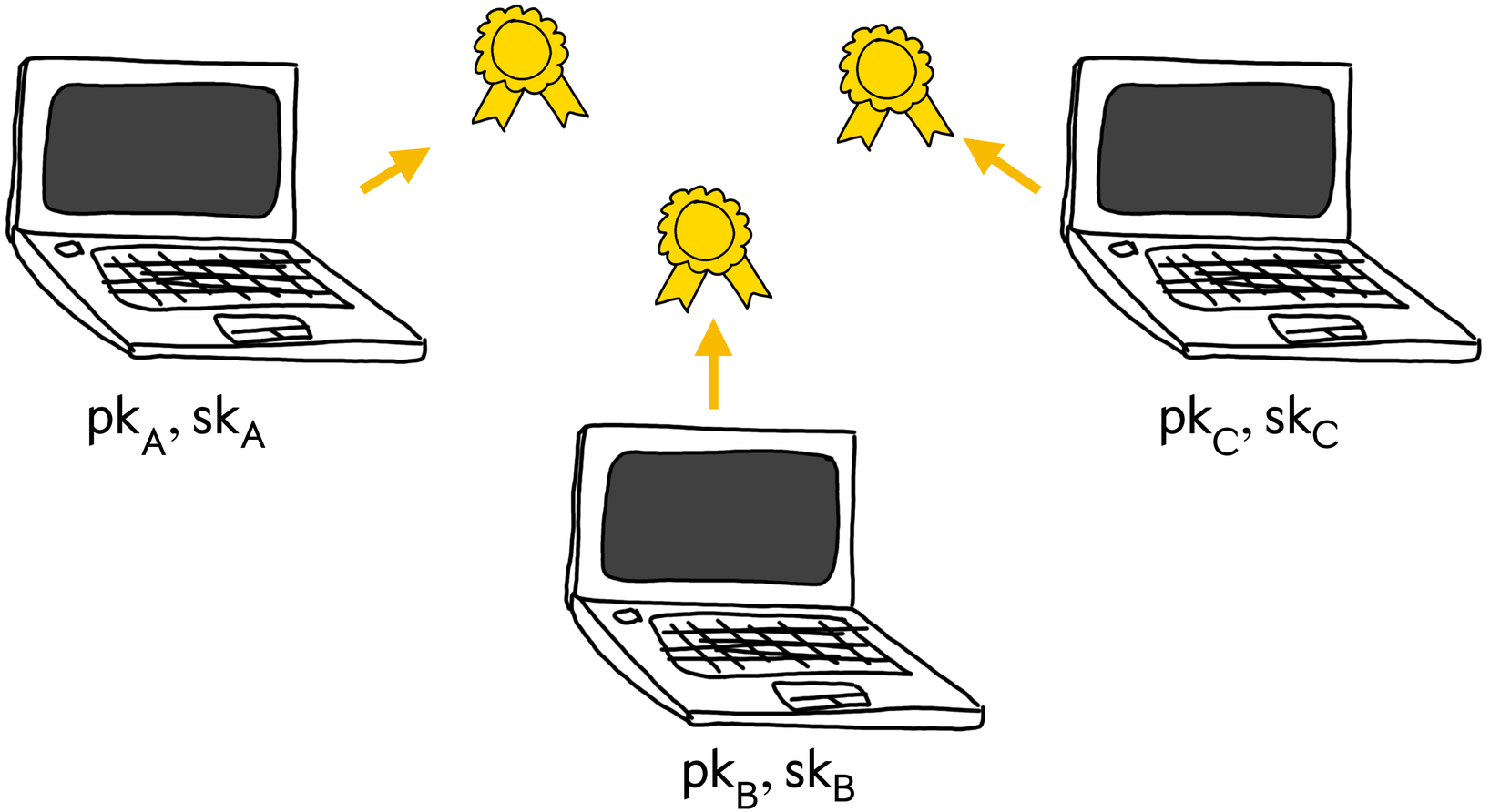

sk




sk
sk′

Multi-Sig



Disadvantages

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- No Anonymity (org structure revealed)
- Size is linear in party count
- Not drop-in replacement

Threshold Signature

$$\{\mathsf{sk}_A, \mathsf{sk}_B, \mathsf{sk}_C\} \leftarrow \mathrm{Share}(\mathsf{sk})$$

pk

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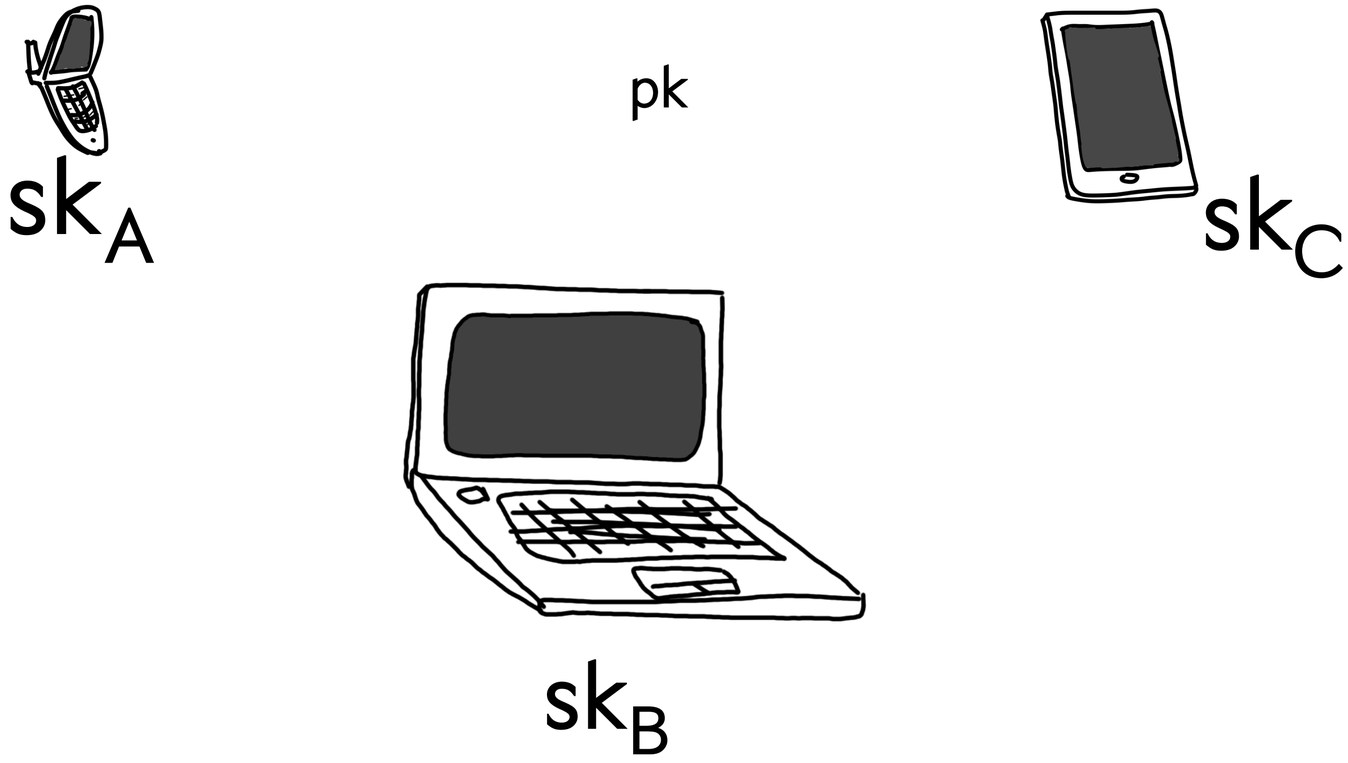

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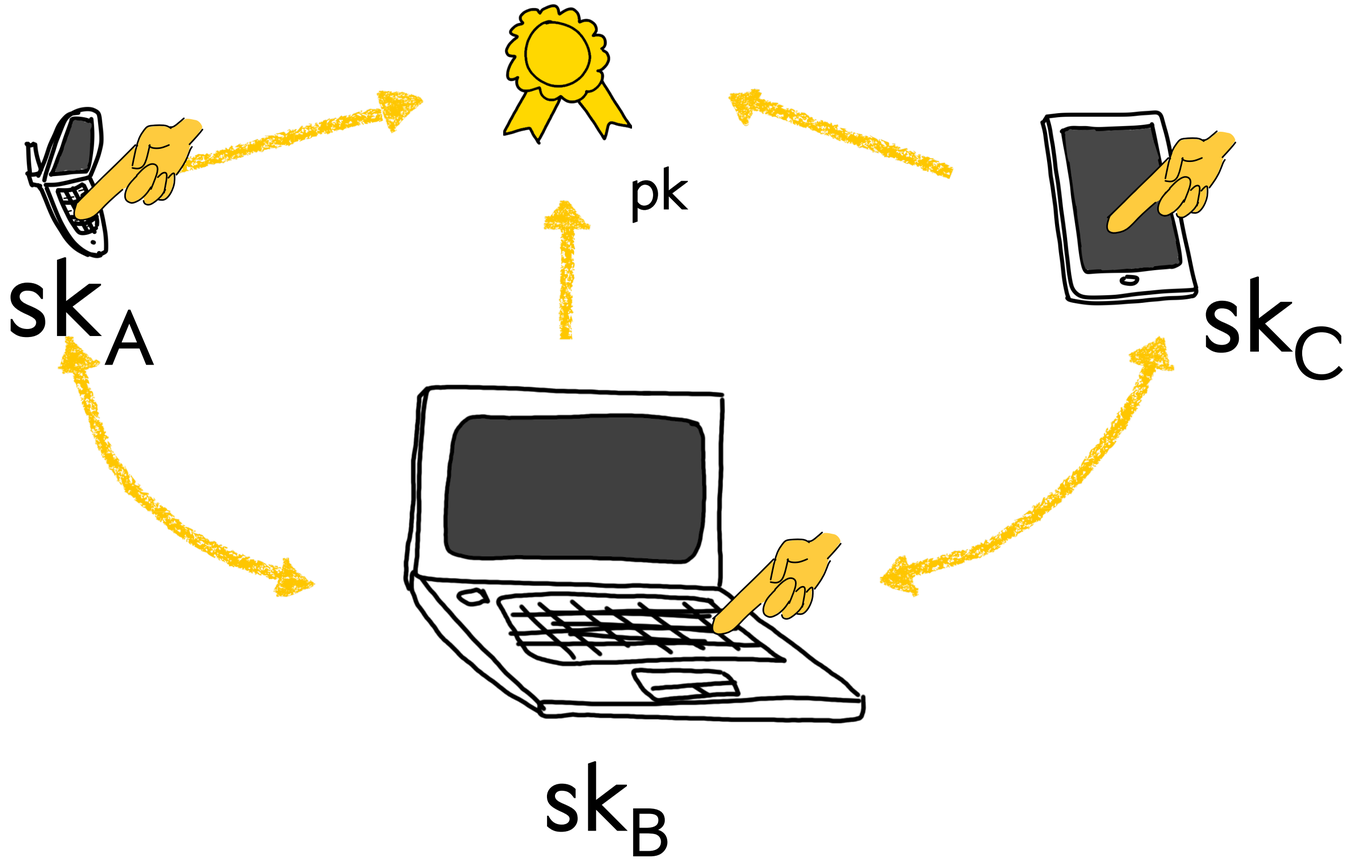

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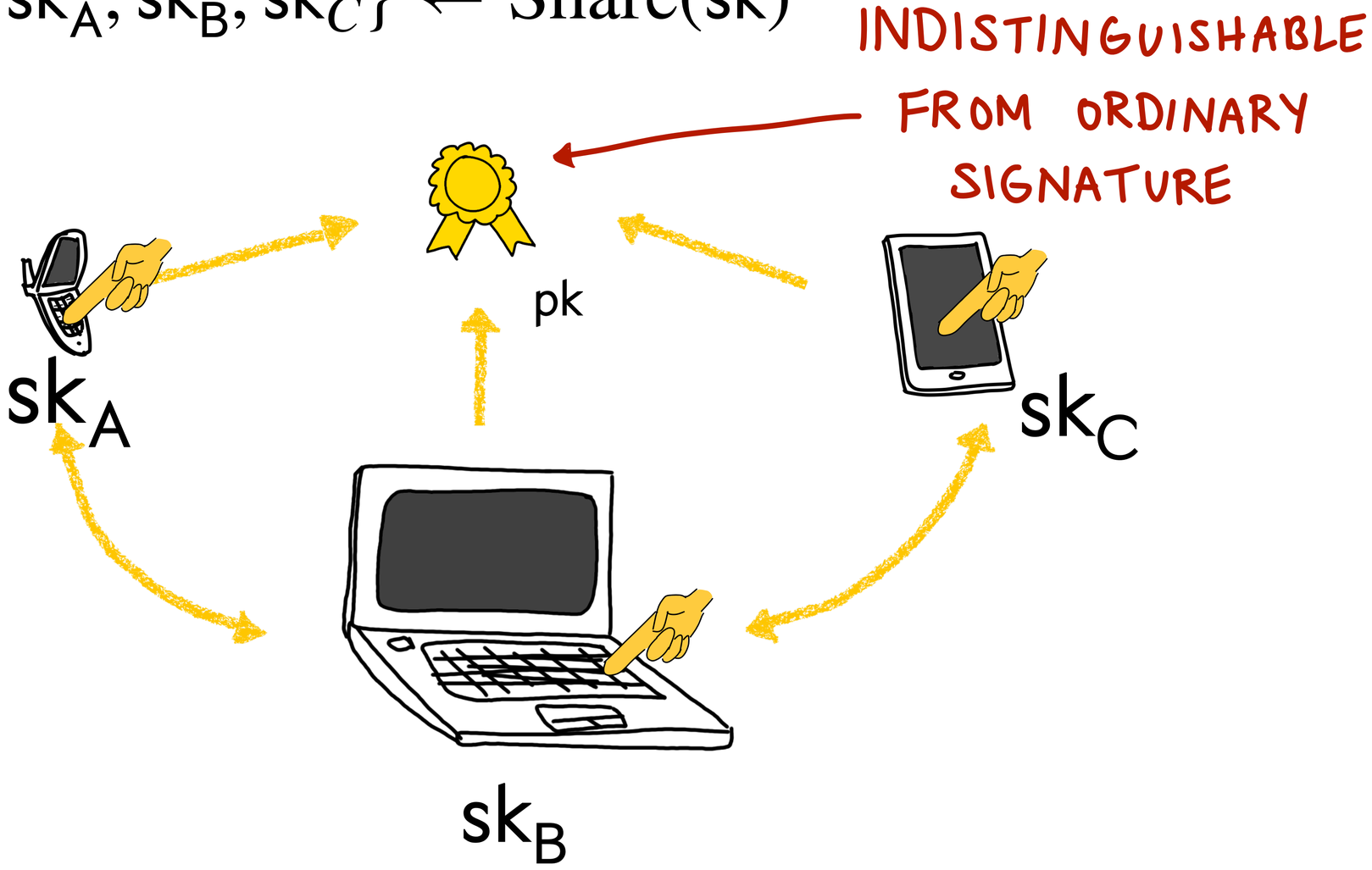
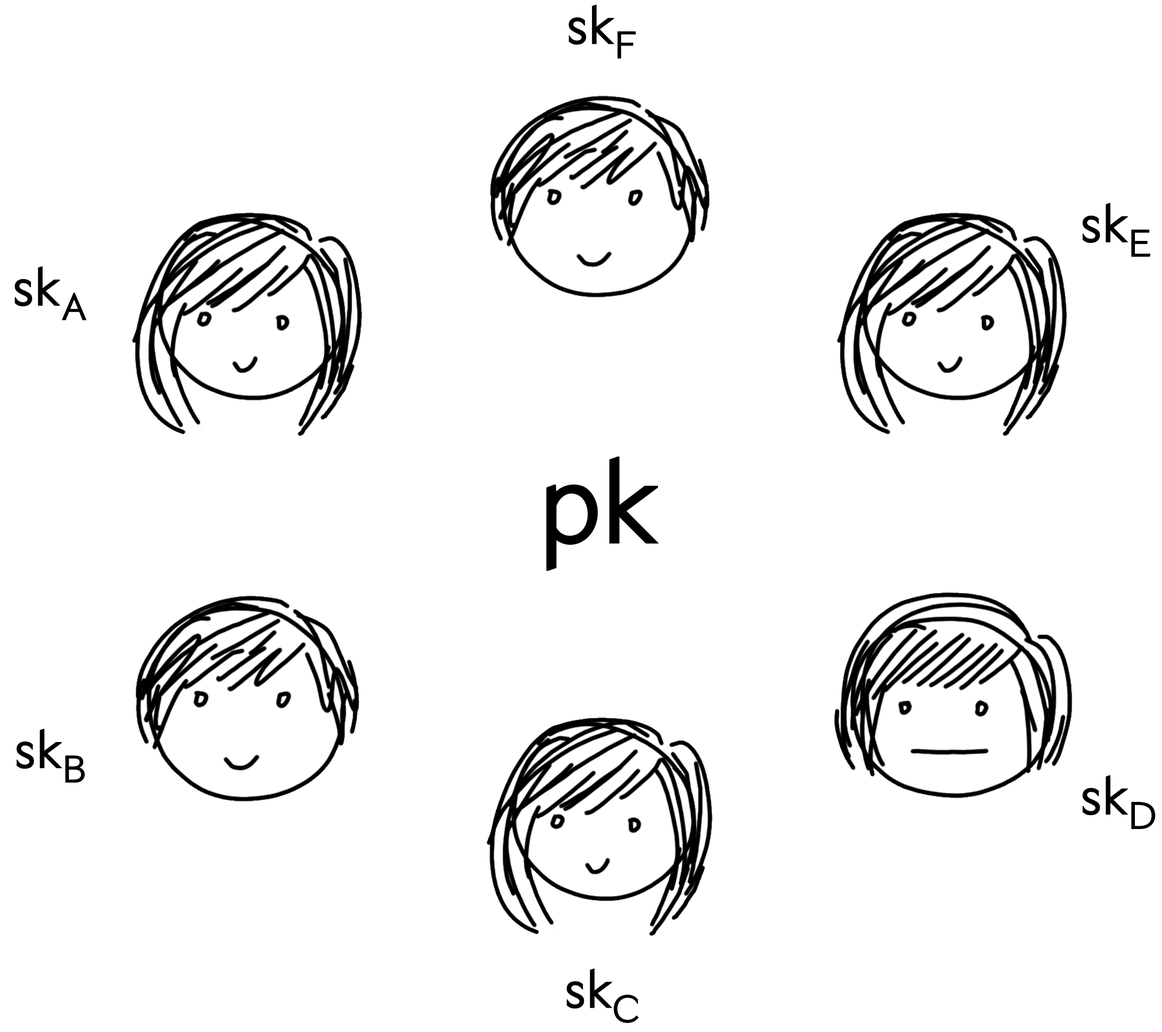


3-of-n Signature Scheme



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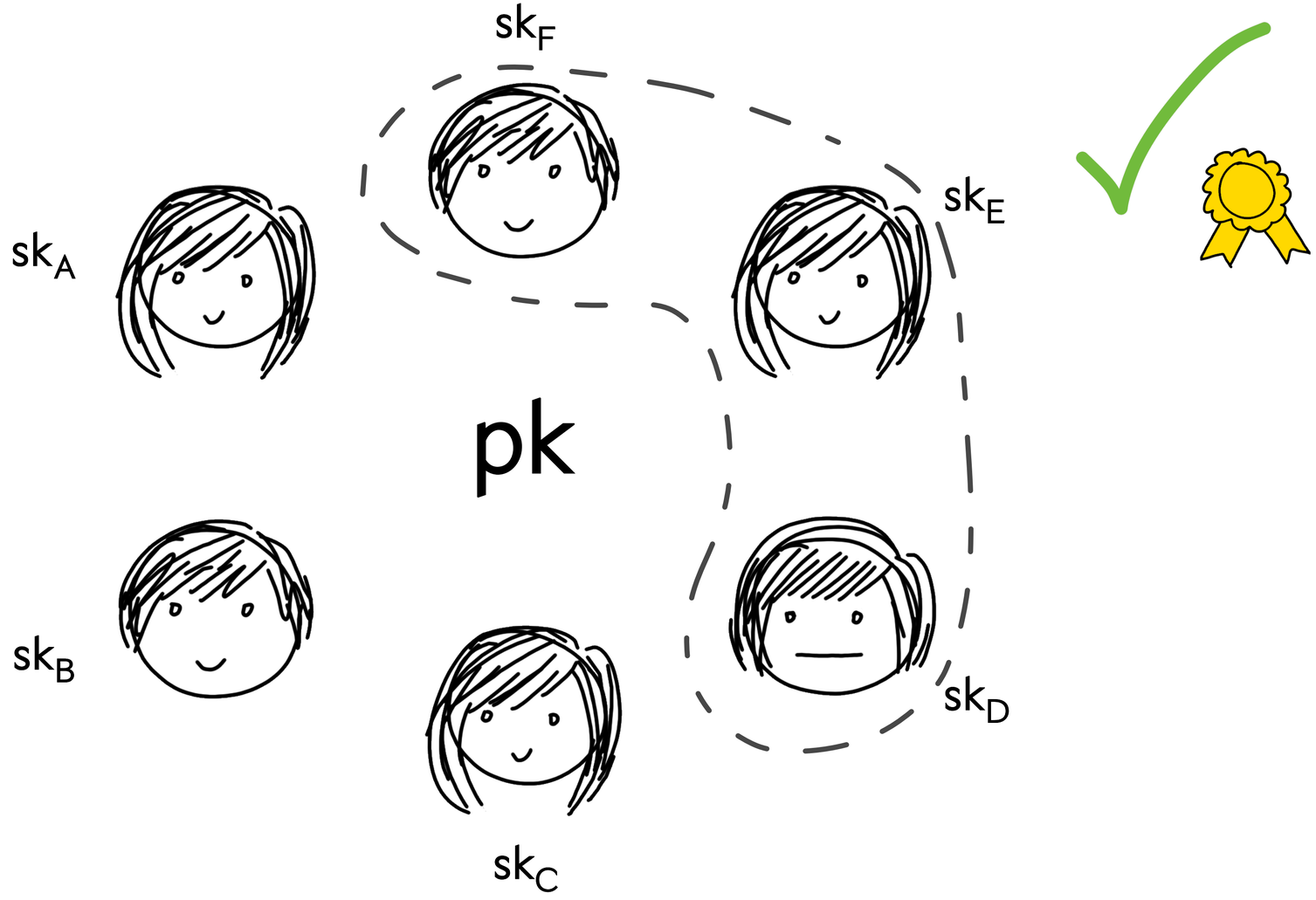

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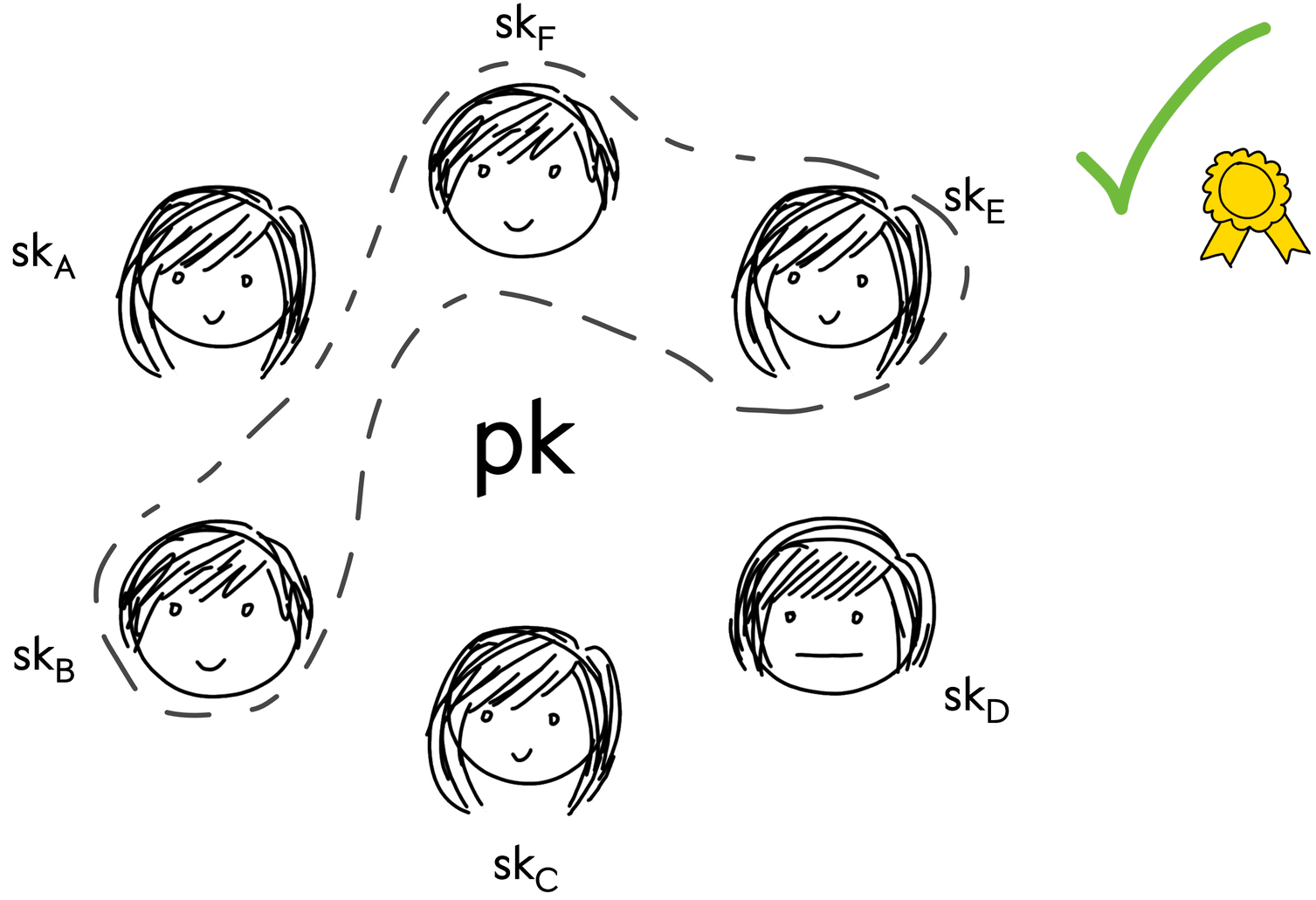

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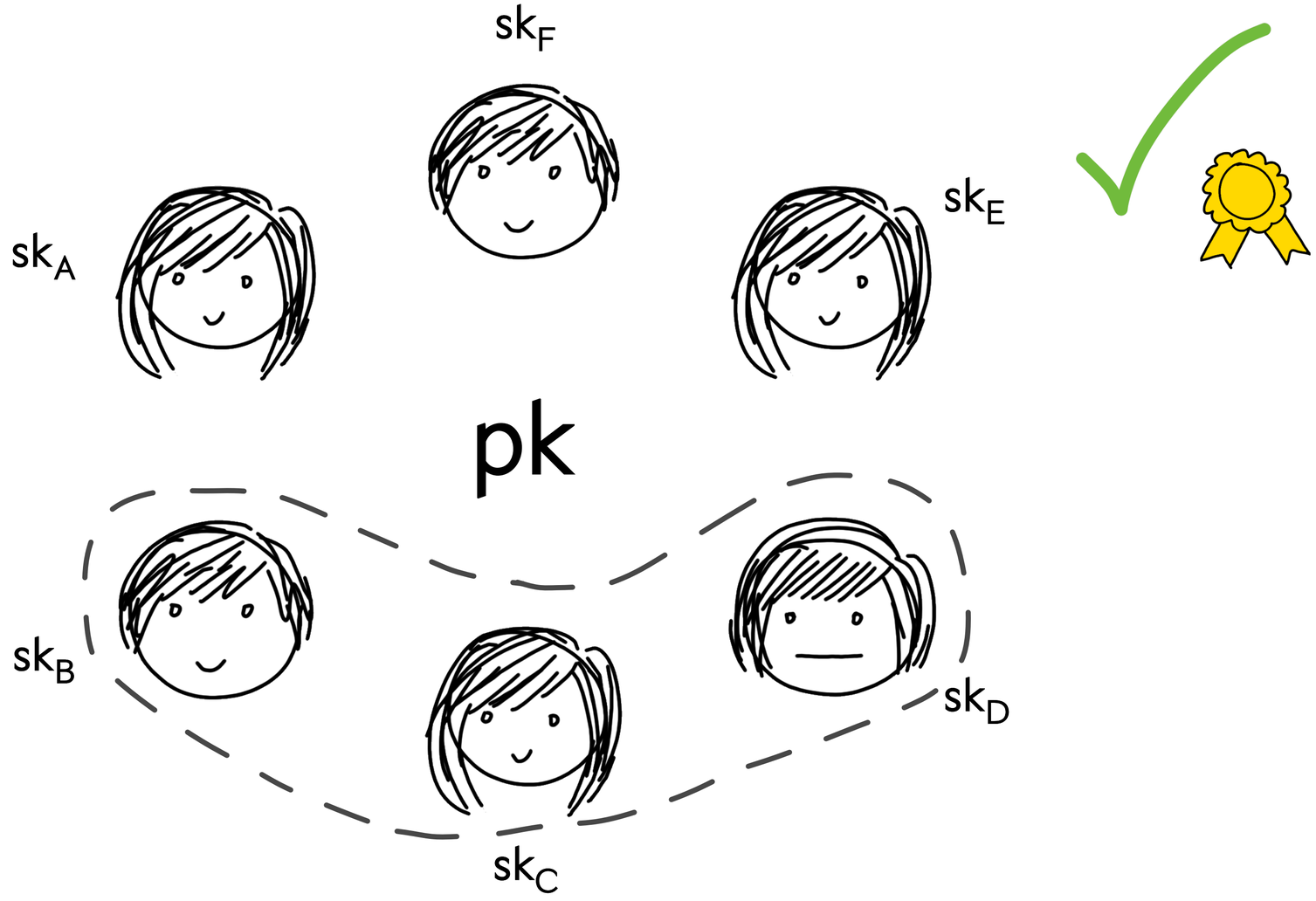

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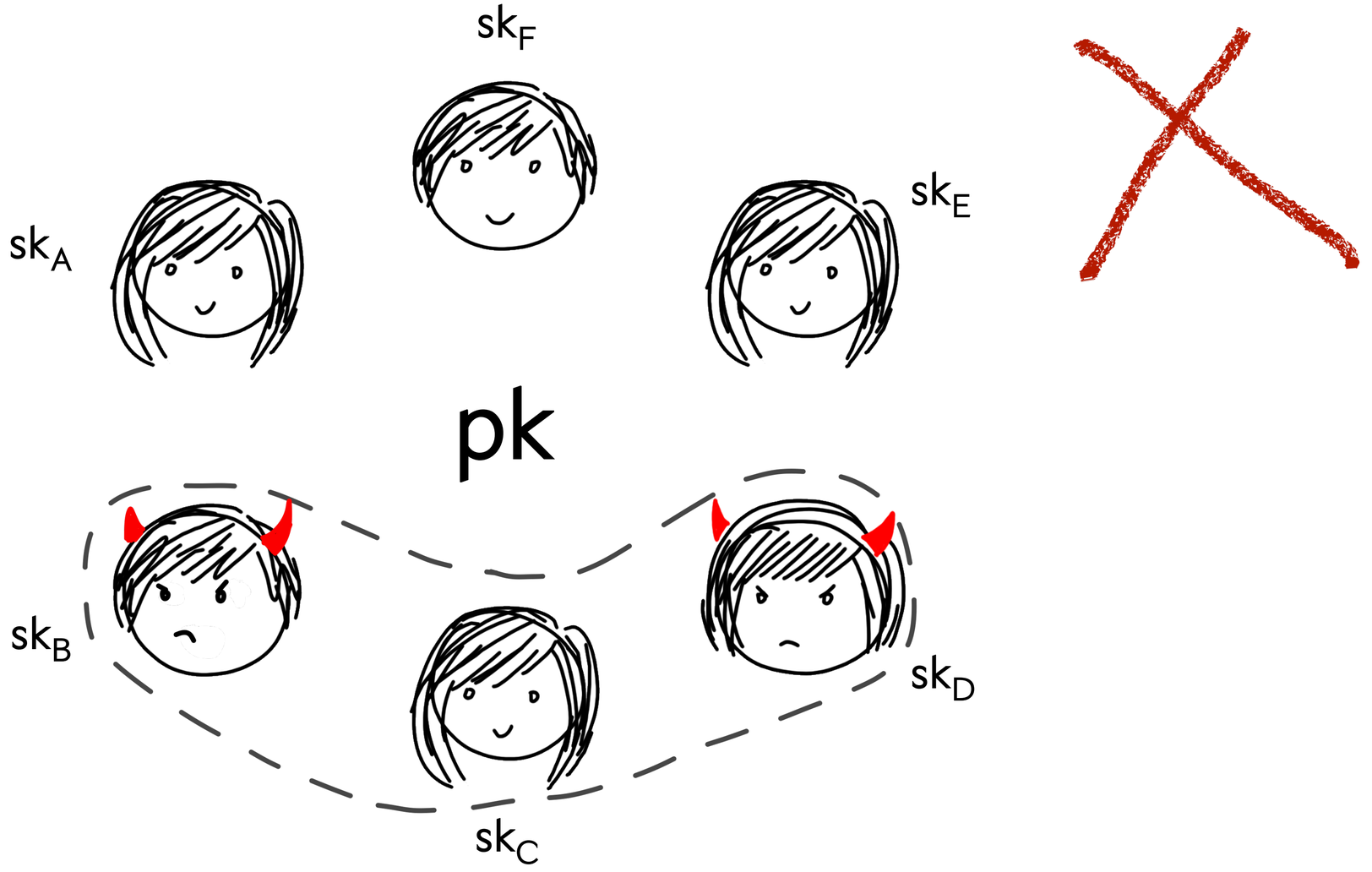

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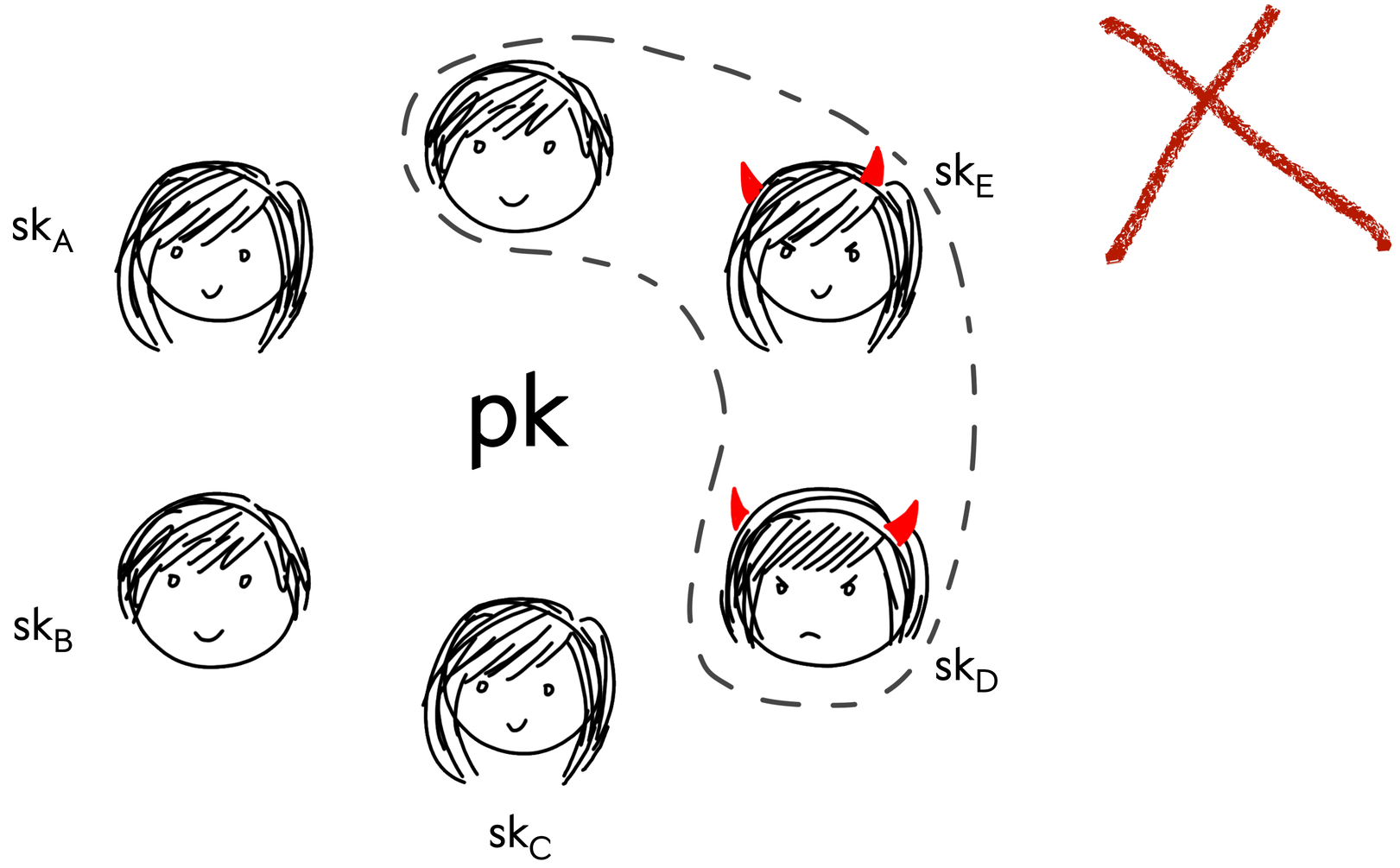
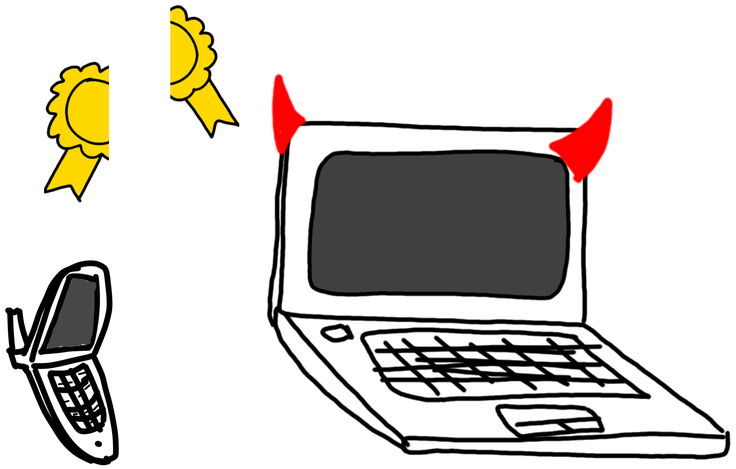




sk

sk′

sk′

sk′

sk

sk′ sk

sk′

sk′

sk

sk′ sk

sk′

sk′

sk′

sk′ sk

sk

sk′

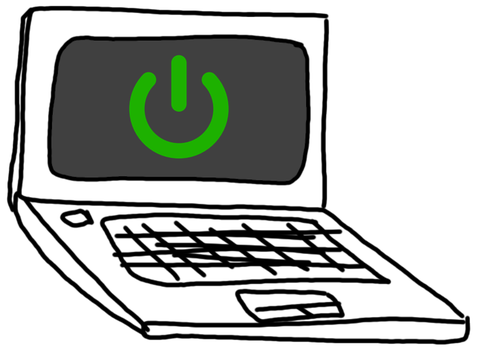
sk′ sk

sk′

sk

MON

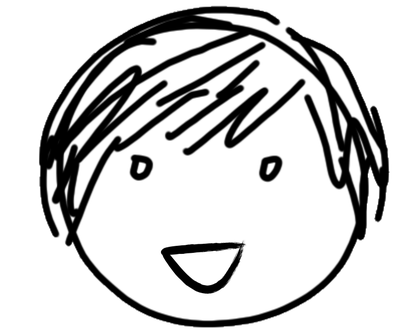
sk′



sk

TUE

sk′



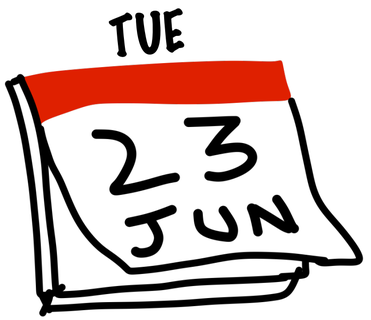
sk′ sk

sk′

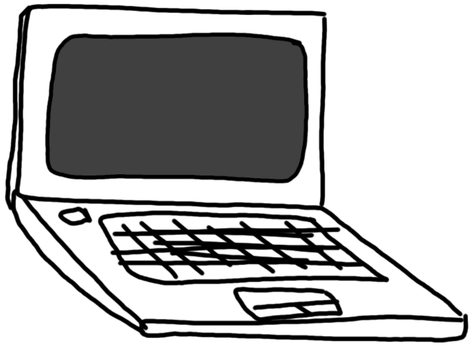
sk

sk′

sk



sk′



sk

sk′ sk

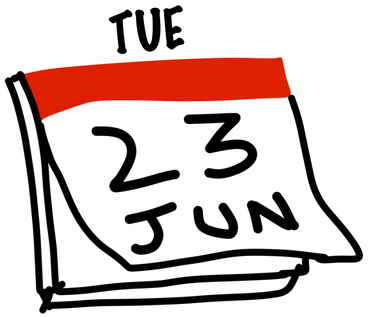
sk′ sk

sk′

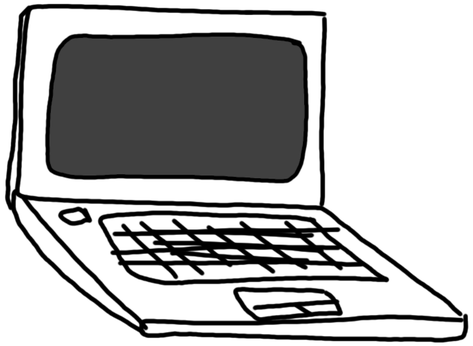
sk

sk′

sk



sk′



sk

sk′ sk

sk′ sk

sk′

sk

MON

sk′

sk

TUE

sk′

sk

WED

sk′ sk

sk′ sk

sk′

sk

MON

sk′

sk

TUE

sk′

sk

WED

sk′ sk

sk′ sk

sk′

sk

MON

sk′

sk

TUE

sk′

sk

WED

sk′

sk

sk'

sk'

sk

sk

sk'

sk

sk'

$sk + sk' = x$

sk

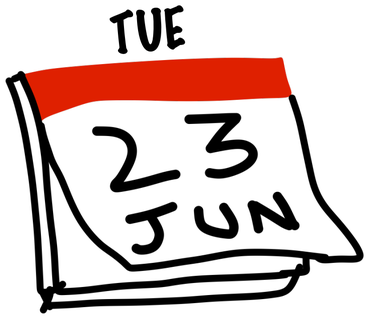
sk'

sk

sk'

$sk + sk' = x$

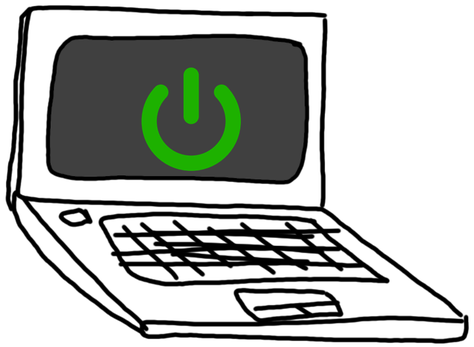
sk



sk'

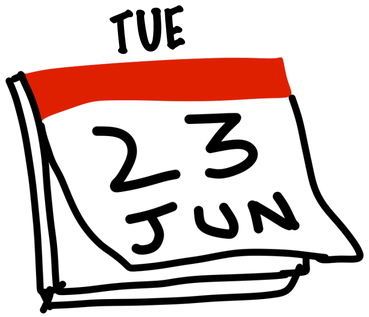
sk'

$sk + sk' = x$



sk

sk



sk'

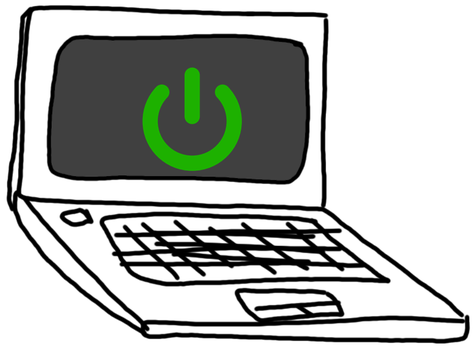
sk

sk'

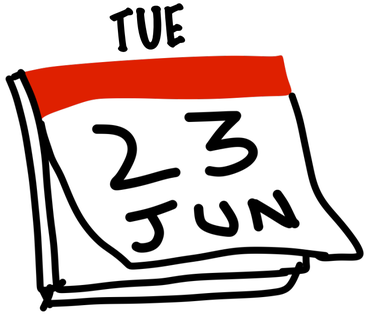
$sk + sk' = x$

sk

sk'_T



sk_T



sk'

sk

sk'

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sk

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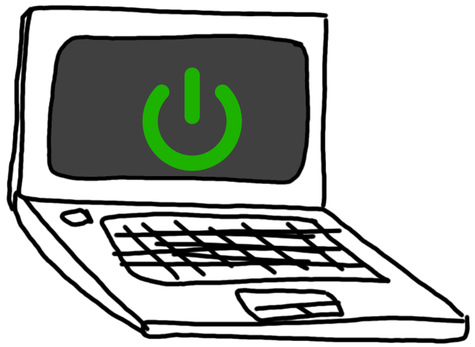

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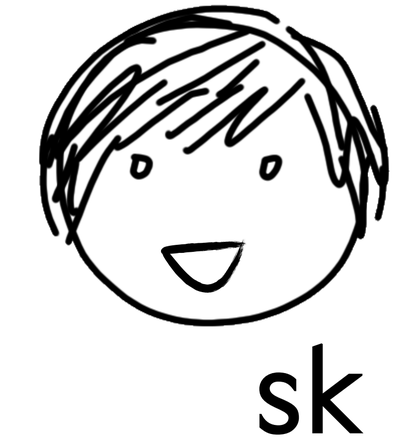
sk_T

sk'



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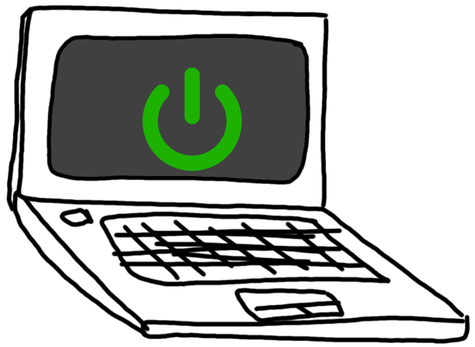

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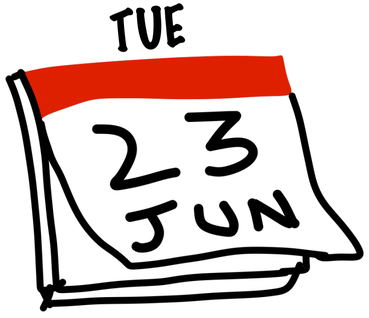
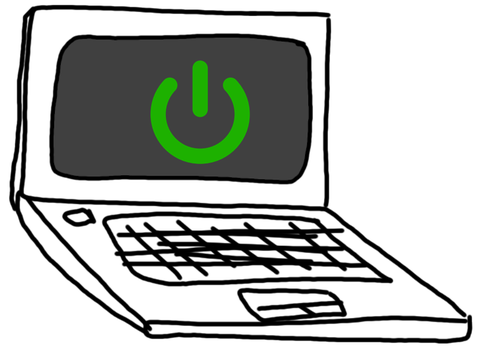
sk_T



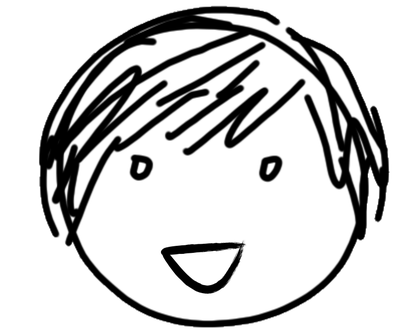
sk'_W



$sk'_W + sk_W = x$

sk_W

sk'



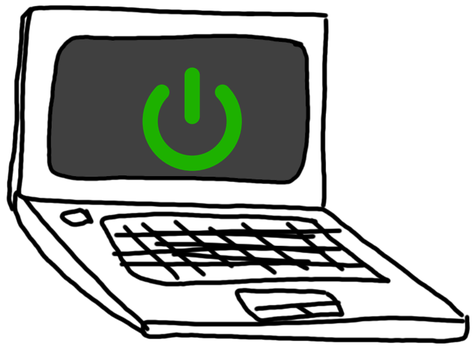
sk

sk'

$sk + sk' = x$

sk

sk'_T



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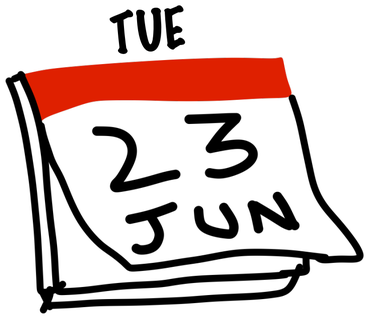
sk_T



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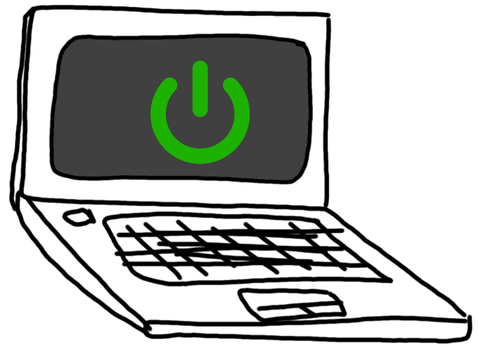


$sk'_W + sk_W = x$

sk_W

sk' sk_w

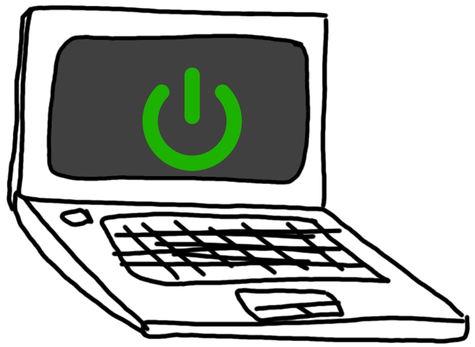
sk

sk'

$sk + sk' = x$

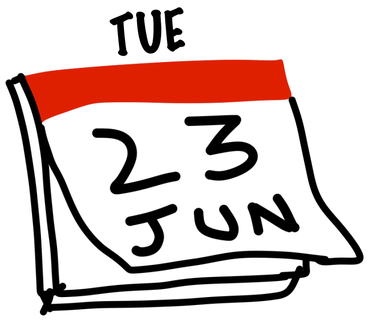
sk

sk'_T

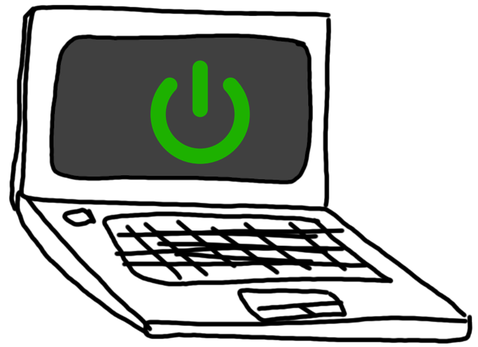


$sk_T + sk'_T = x$

sk_T



sk'_W



$sk'_W + sk_w = x$

sk_w

sk' sk_w

sk

$sk + sk' = x$

$sk_T + sk'_T = x$

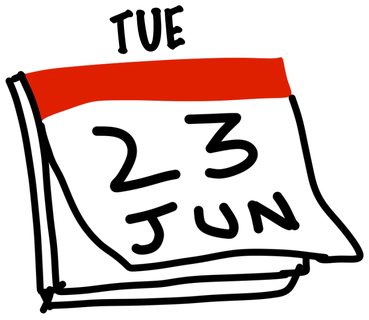
$sk'_W + sk_W = x$

sk' sk_w

sk

? + sk' = ?

? + sk_w = ?



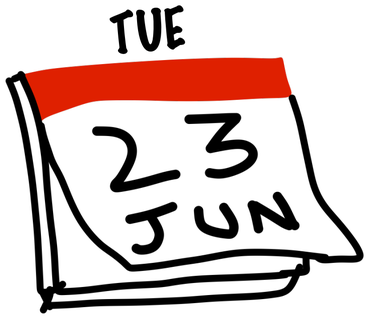
2 Equations in 3 variables

sk' sk_w

sk

? ? ?

? + sk' = ? ? + sk_w = ?



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  - Dynamic committees [MZWLZJS19]

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- We study: refresh where **dishonest majority speaks**

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- We study: refresh where **dishonest majority speaks**
  - Correct definition is subtle

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- In order to progress, in all prior works:
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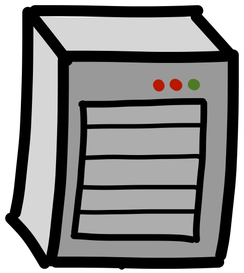
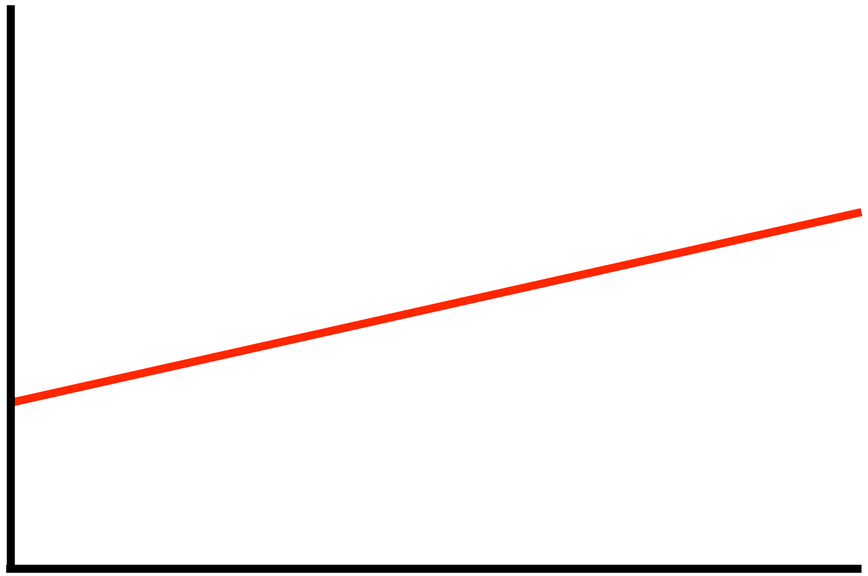
Defining Offline Refresh

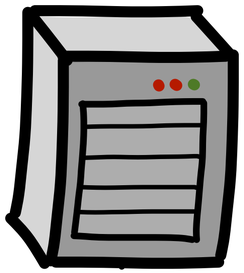


Defining Offline Refresh

$$f \leftarrow \mathbb{Z}_q[x]$$

Degree 1





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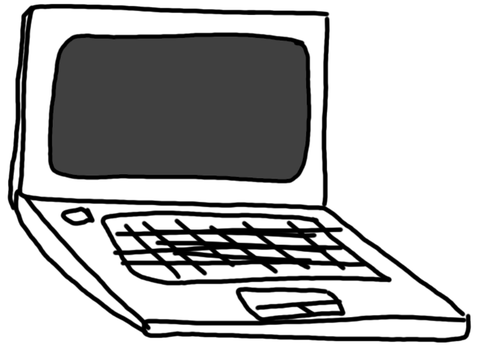
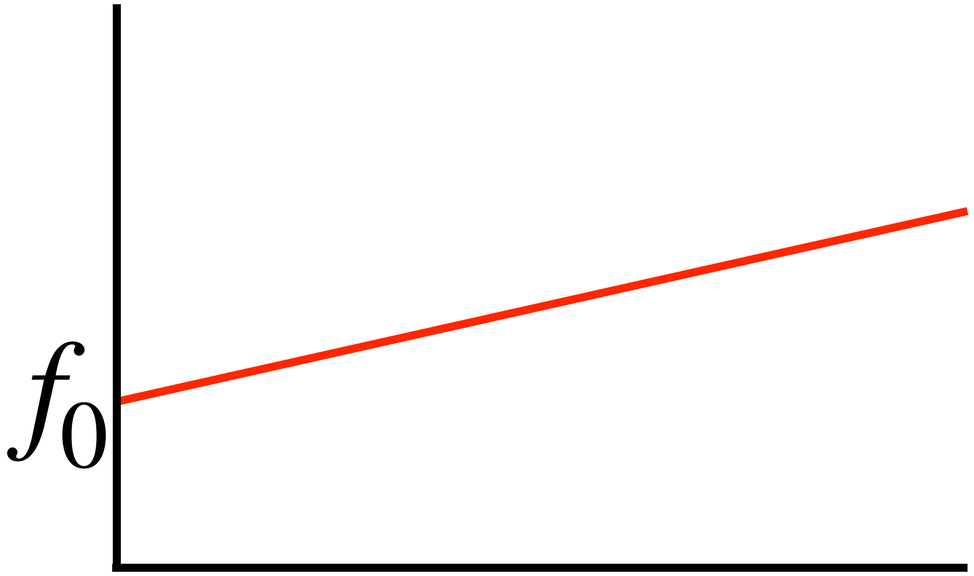
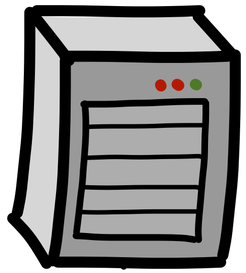


Degree 1





Defining Offline Refresh

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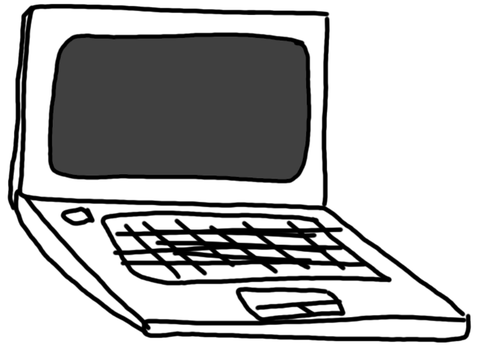

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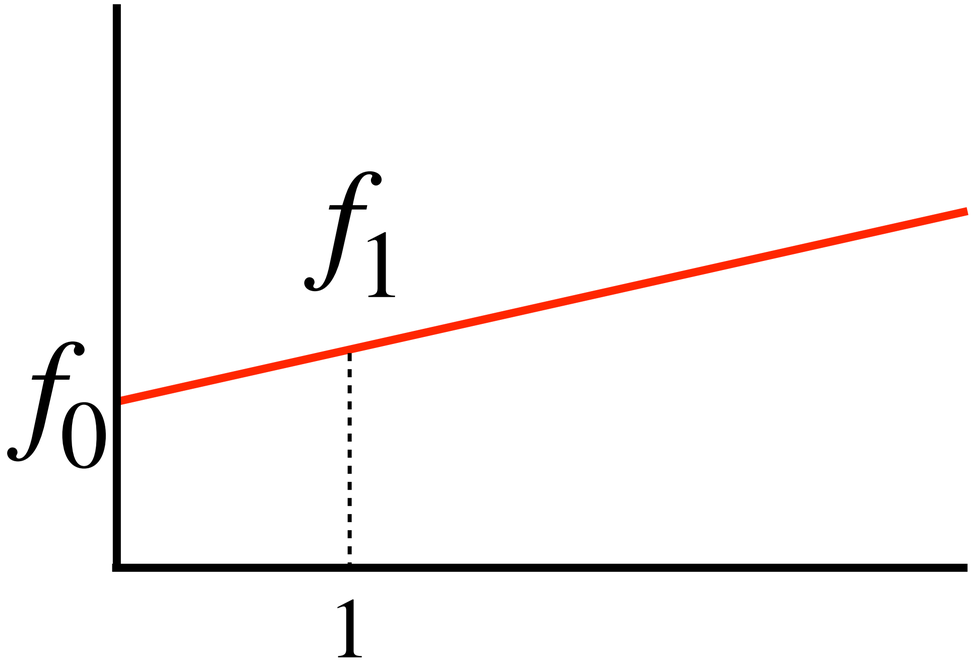

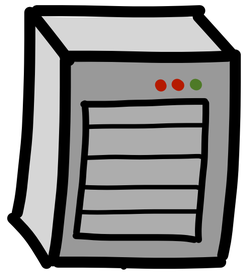

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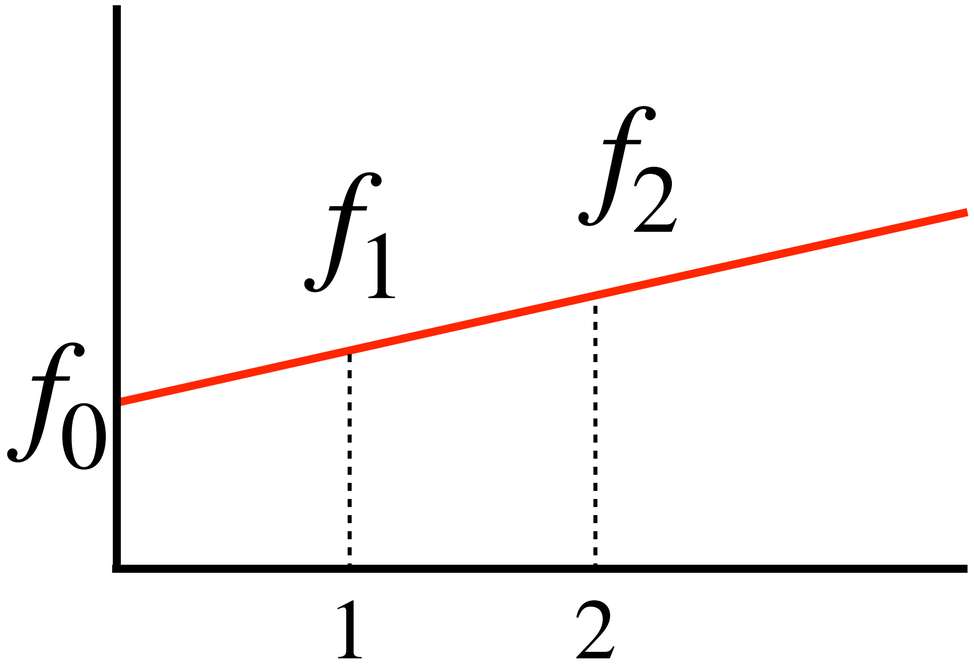

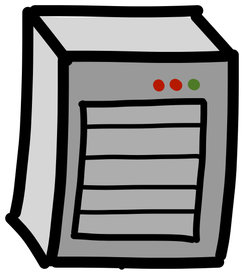

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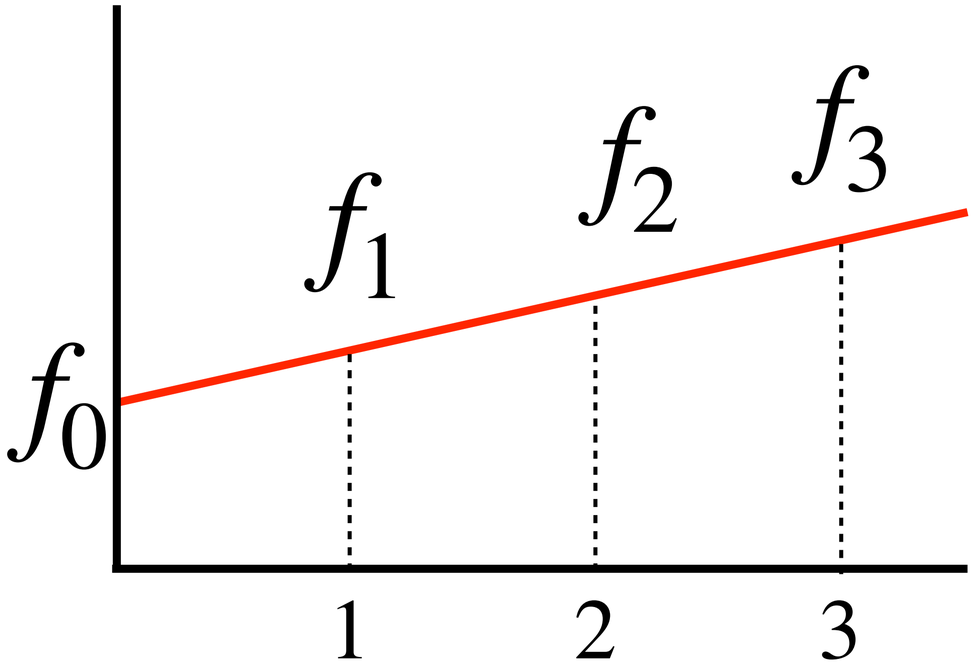
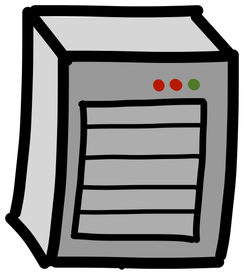
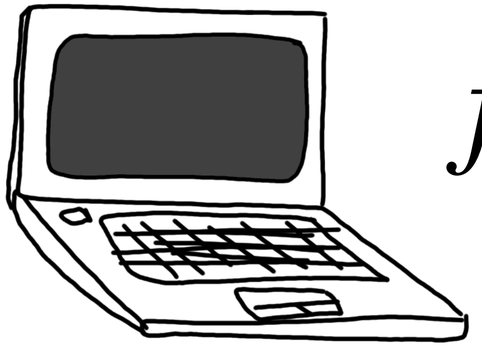


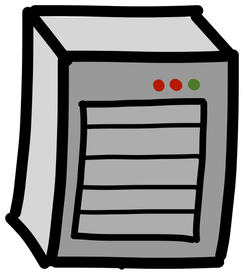


Defining Offline Refresh

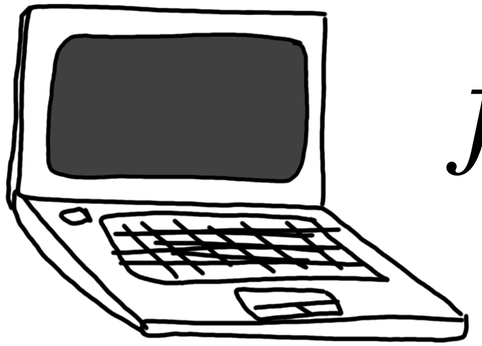
f_1 

 f_2

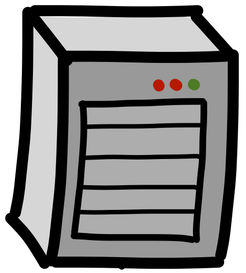
f_0

 f_3

Defining Offline Refresh

f_1   f_2

$\mathsf{sk} = f_0$

 f_3

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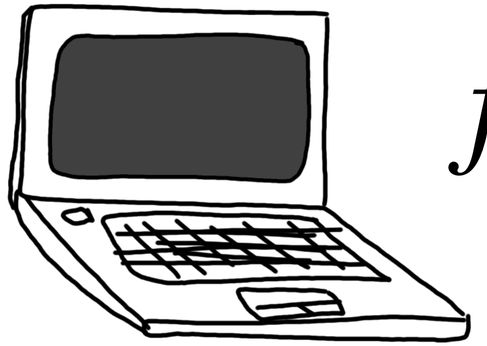
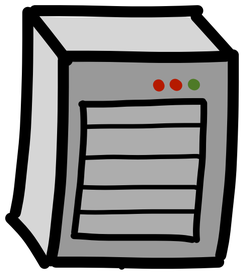
f_1   f_2

$$\mathsf{sk} = f_0$$

Enough information to:
- Sign with two online
- Recover from a crash

 f_3

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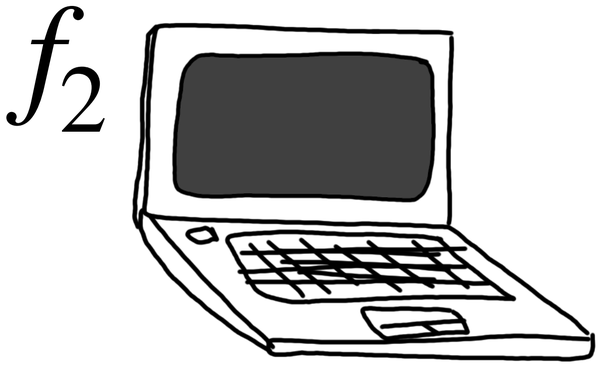

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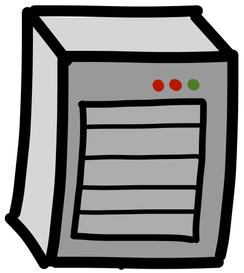

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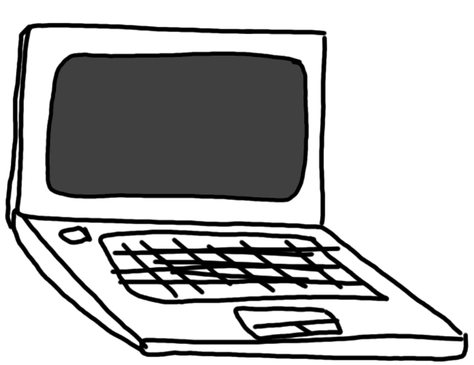

f_2

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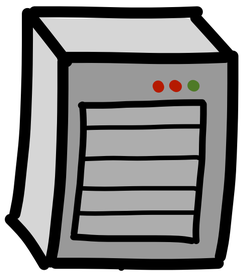
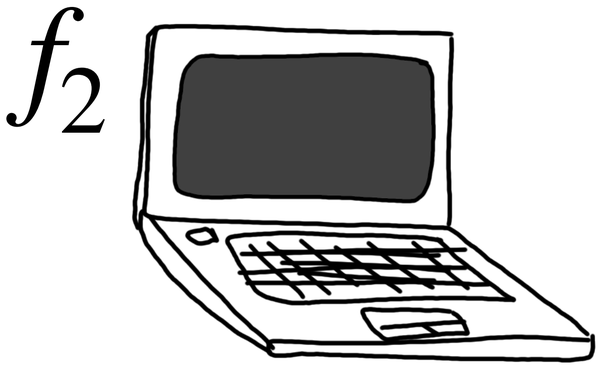


f_3

Defining Offline Refresh



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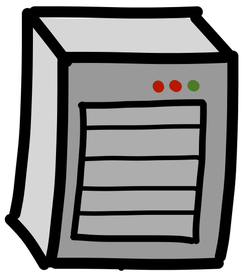

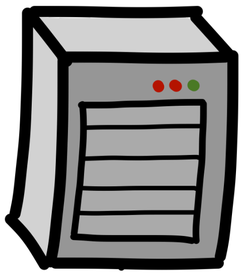

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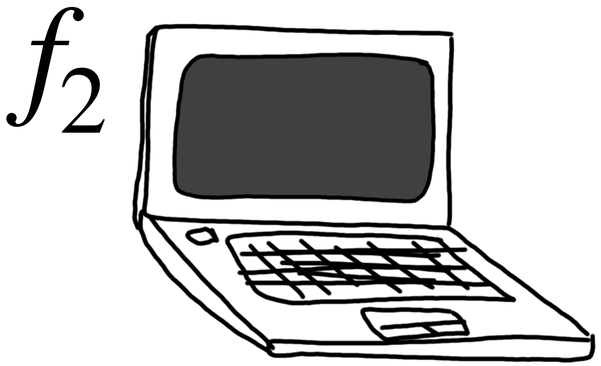

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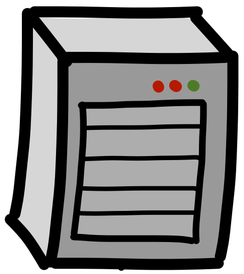

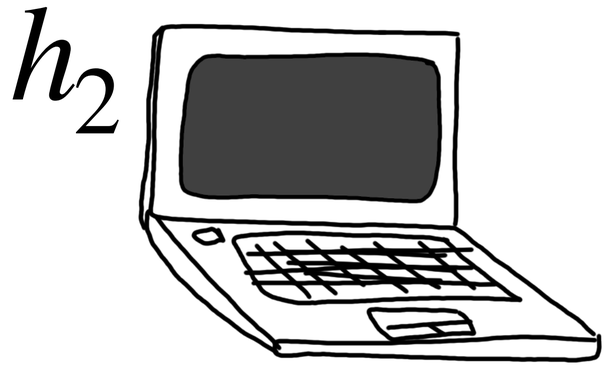

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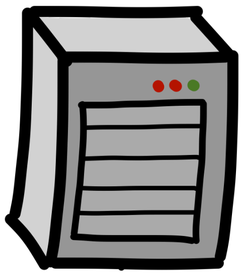
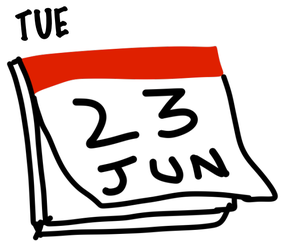


Defining Offline Refresh

f_1

f_2

f_3



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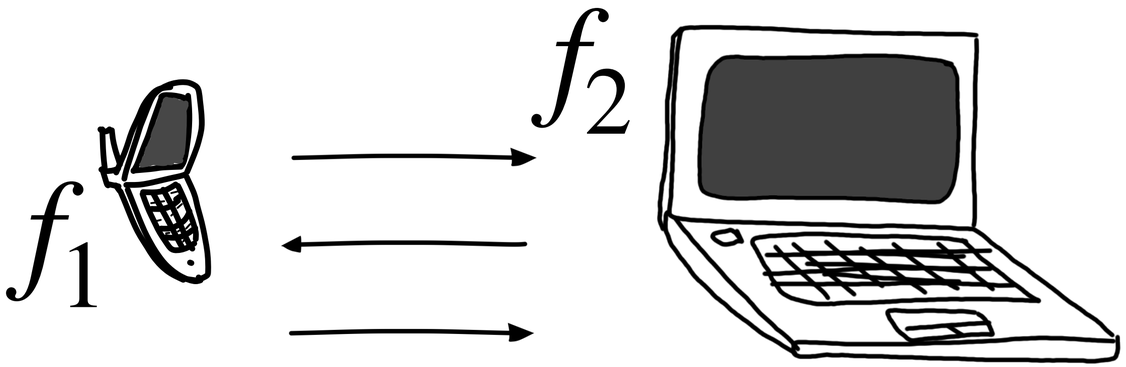

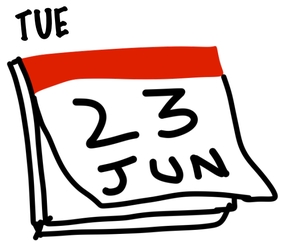

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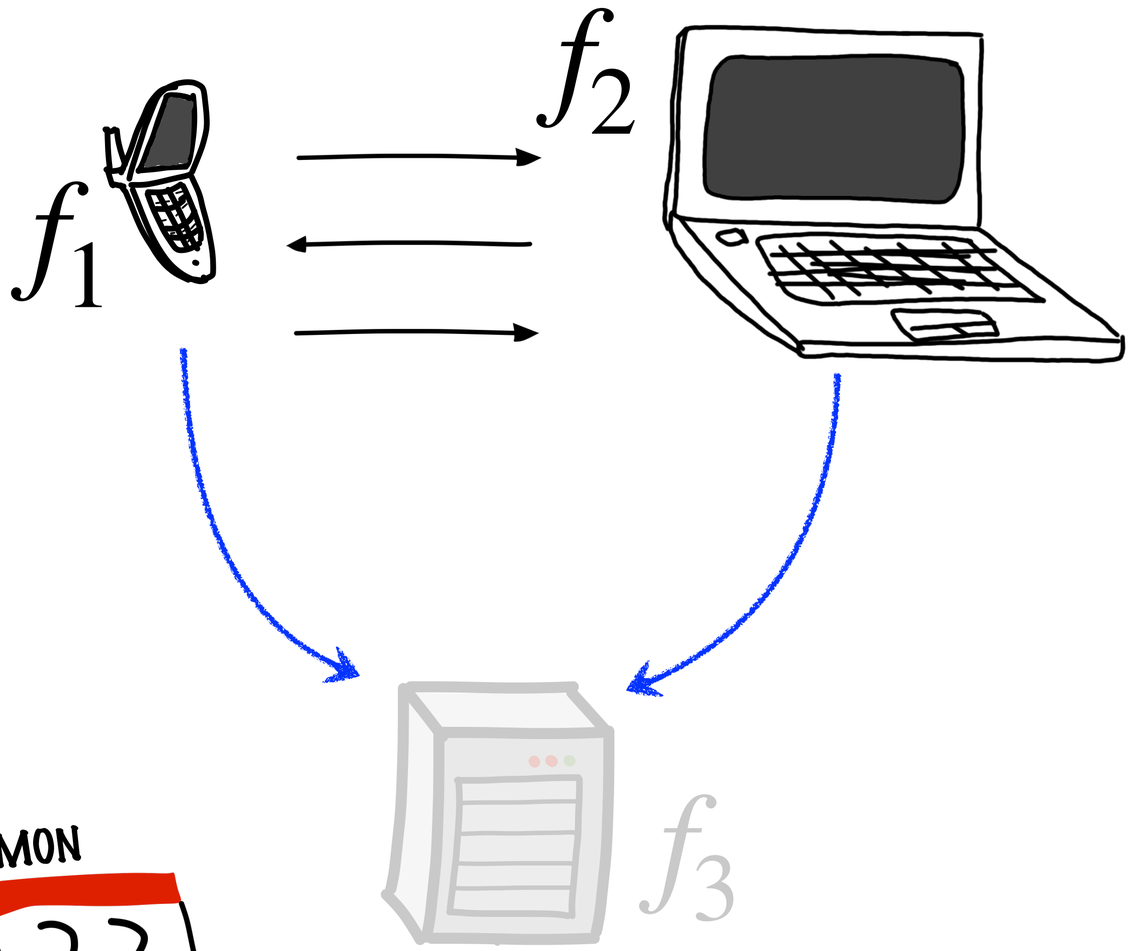

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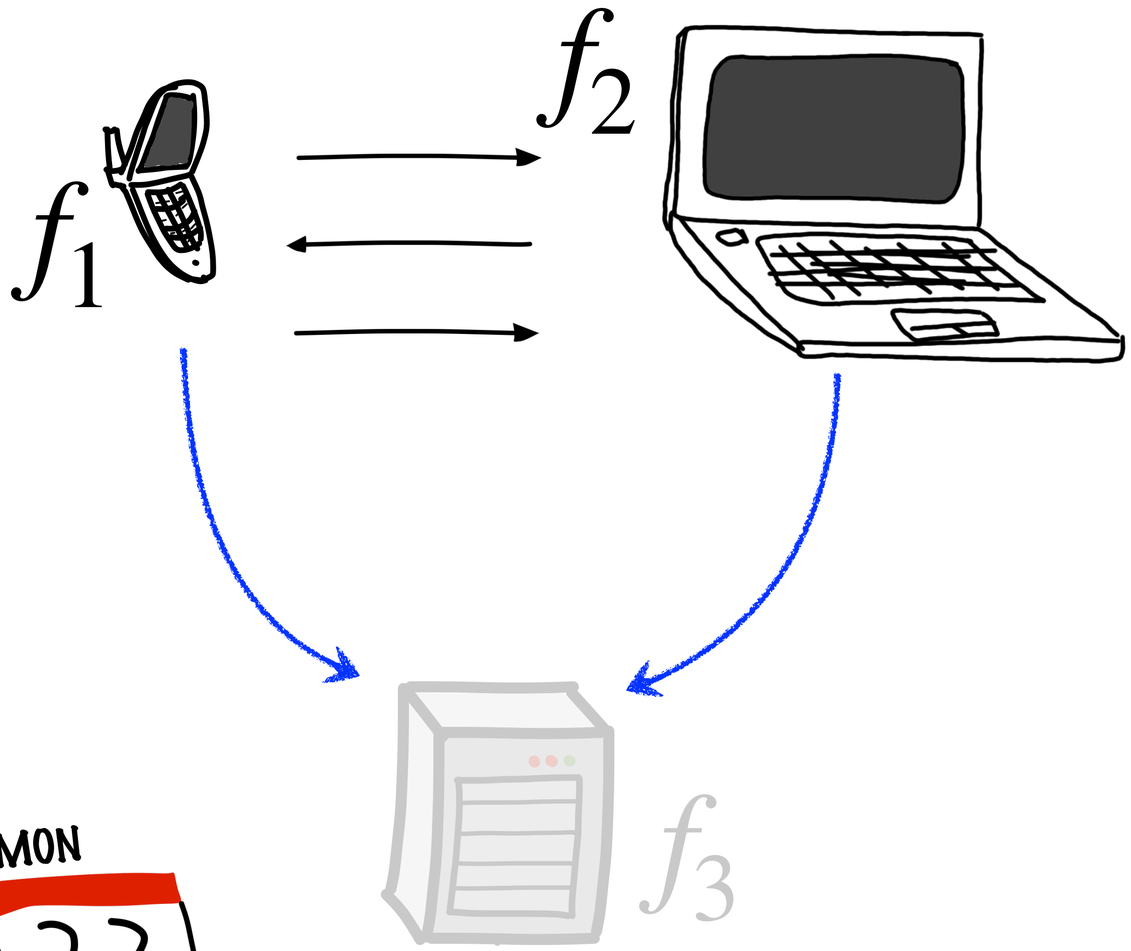

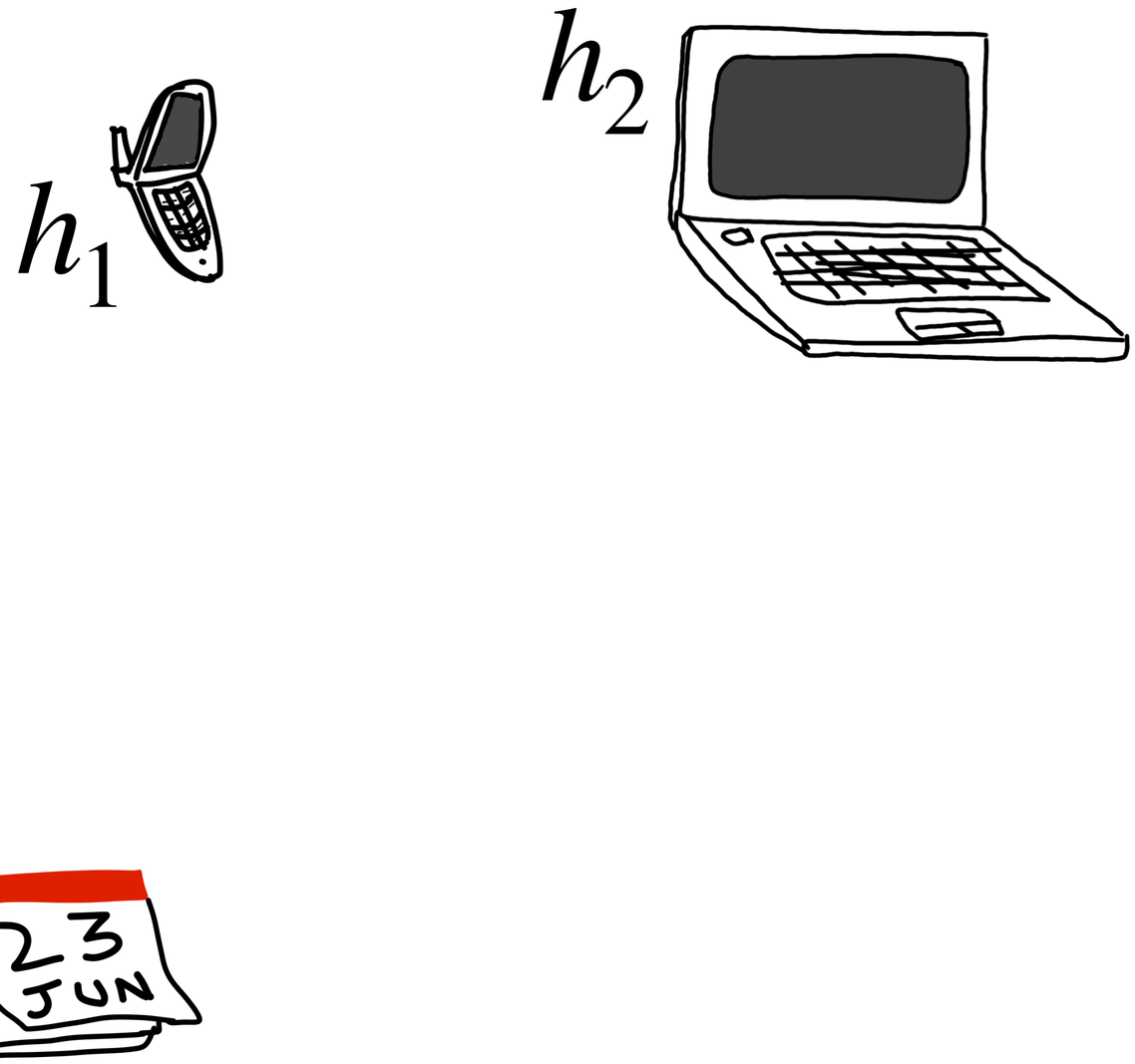

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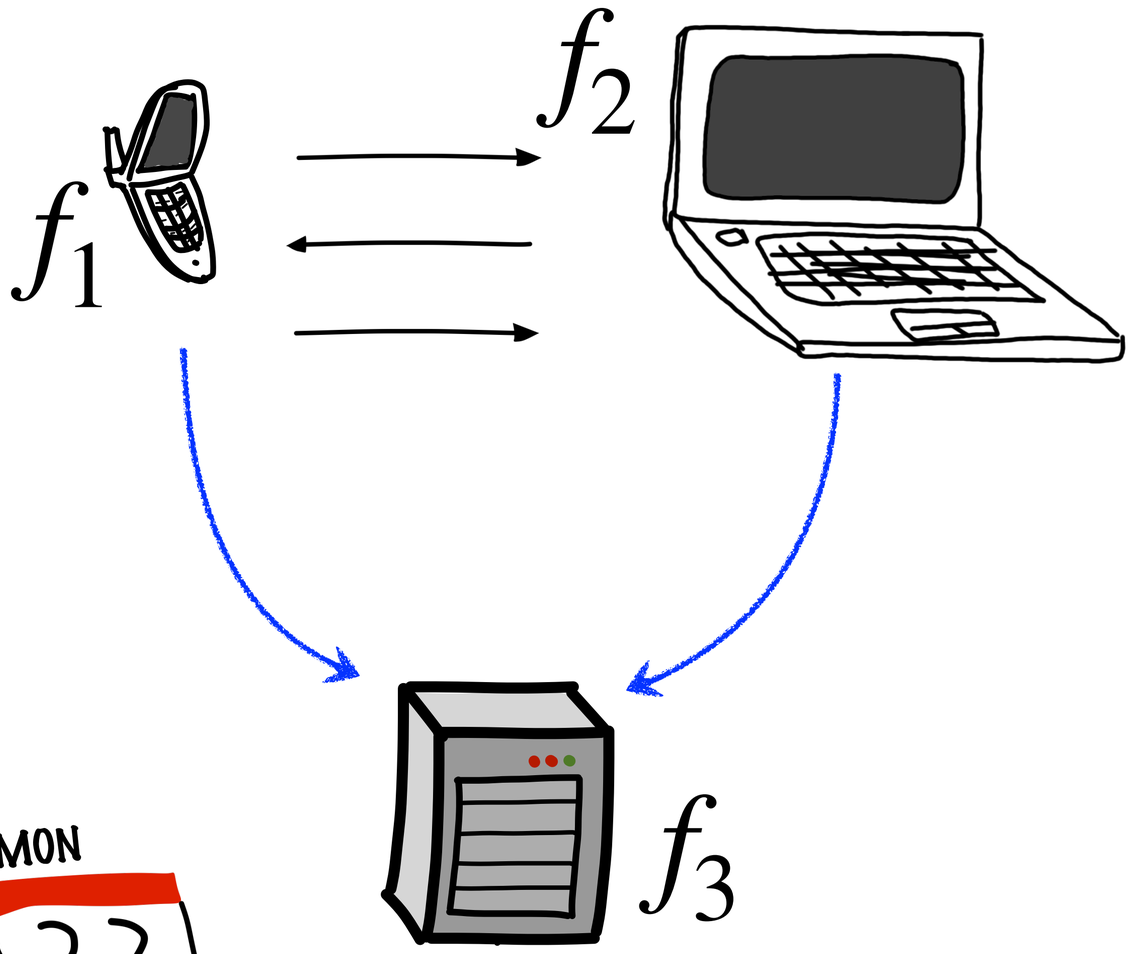

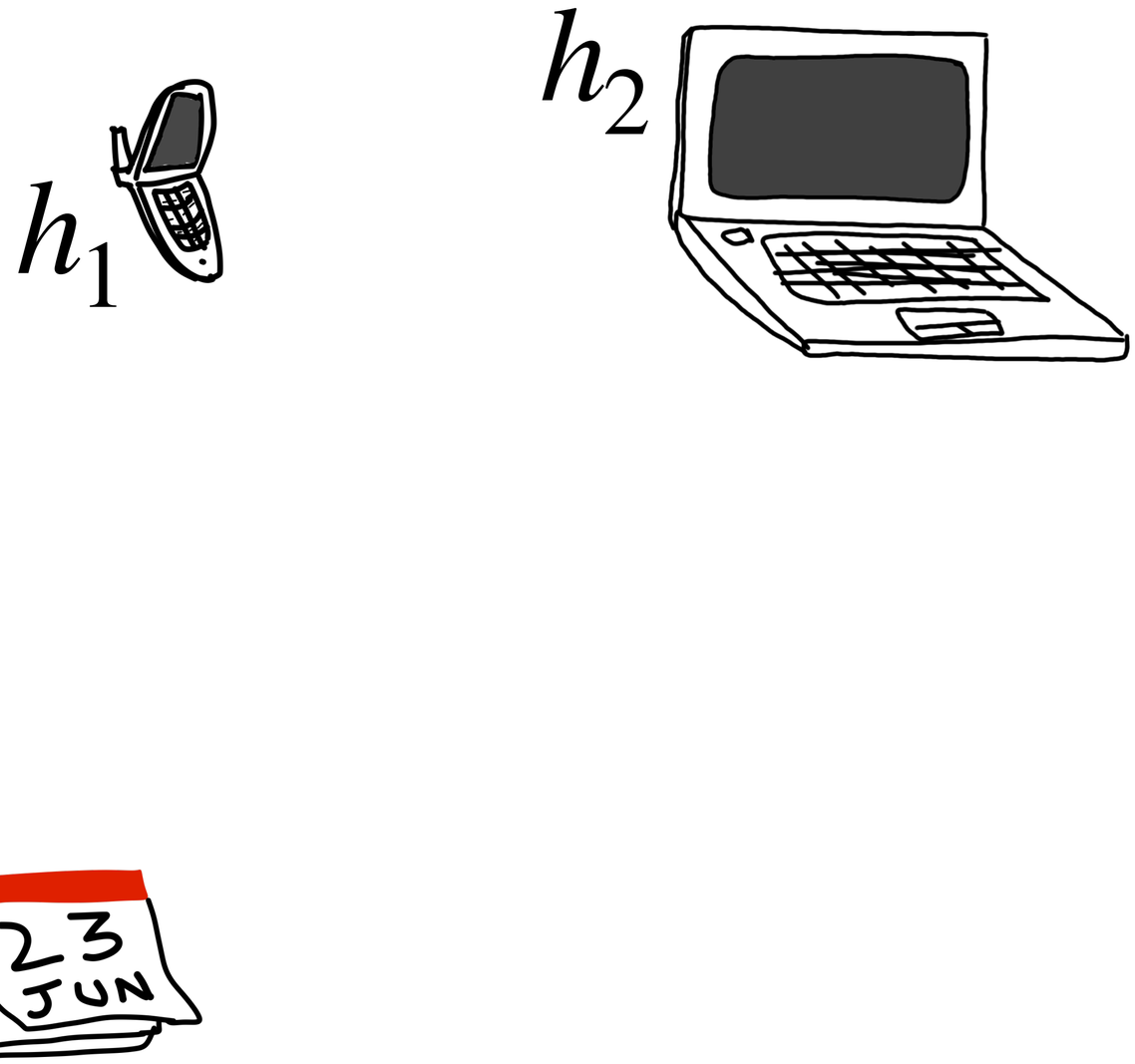

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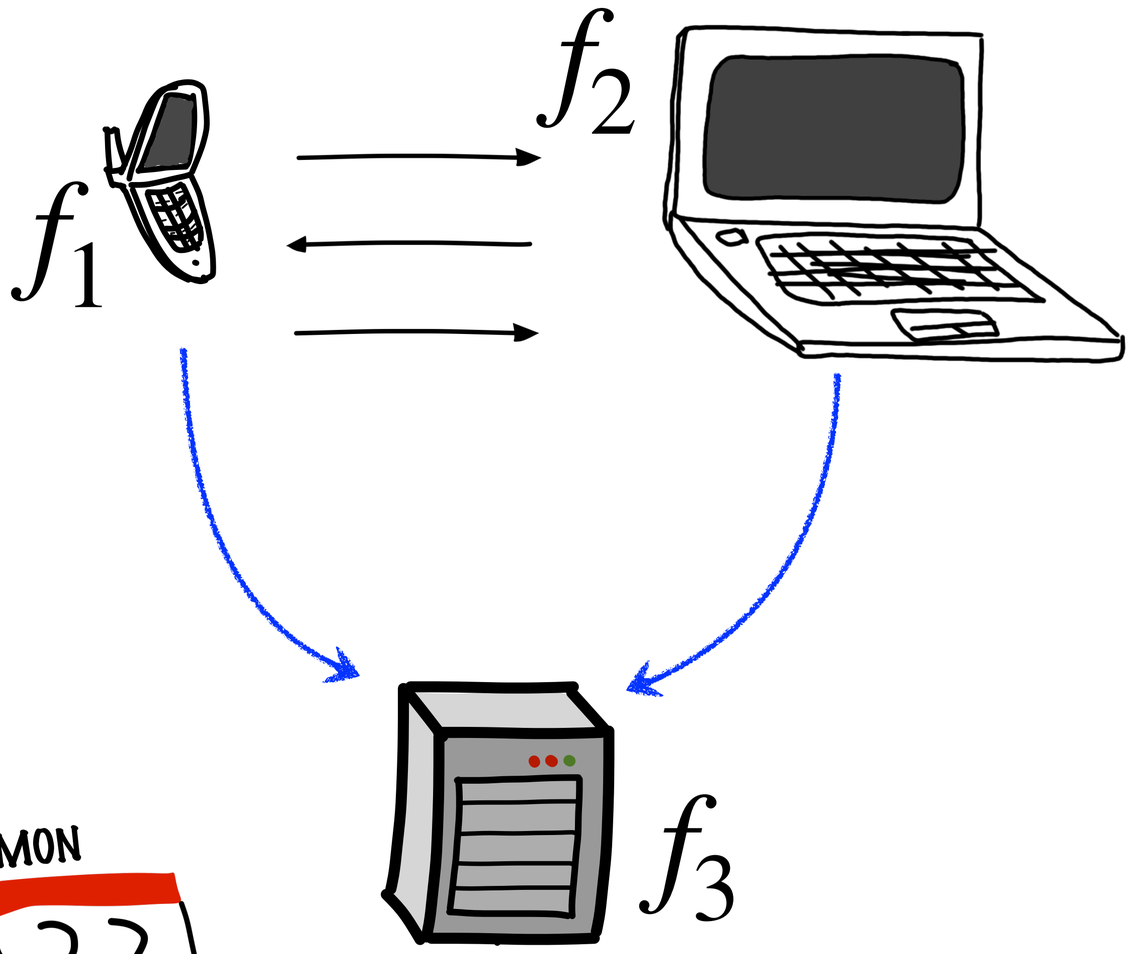

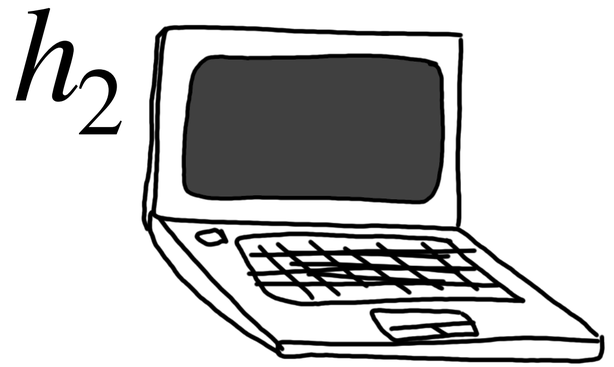

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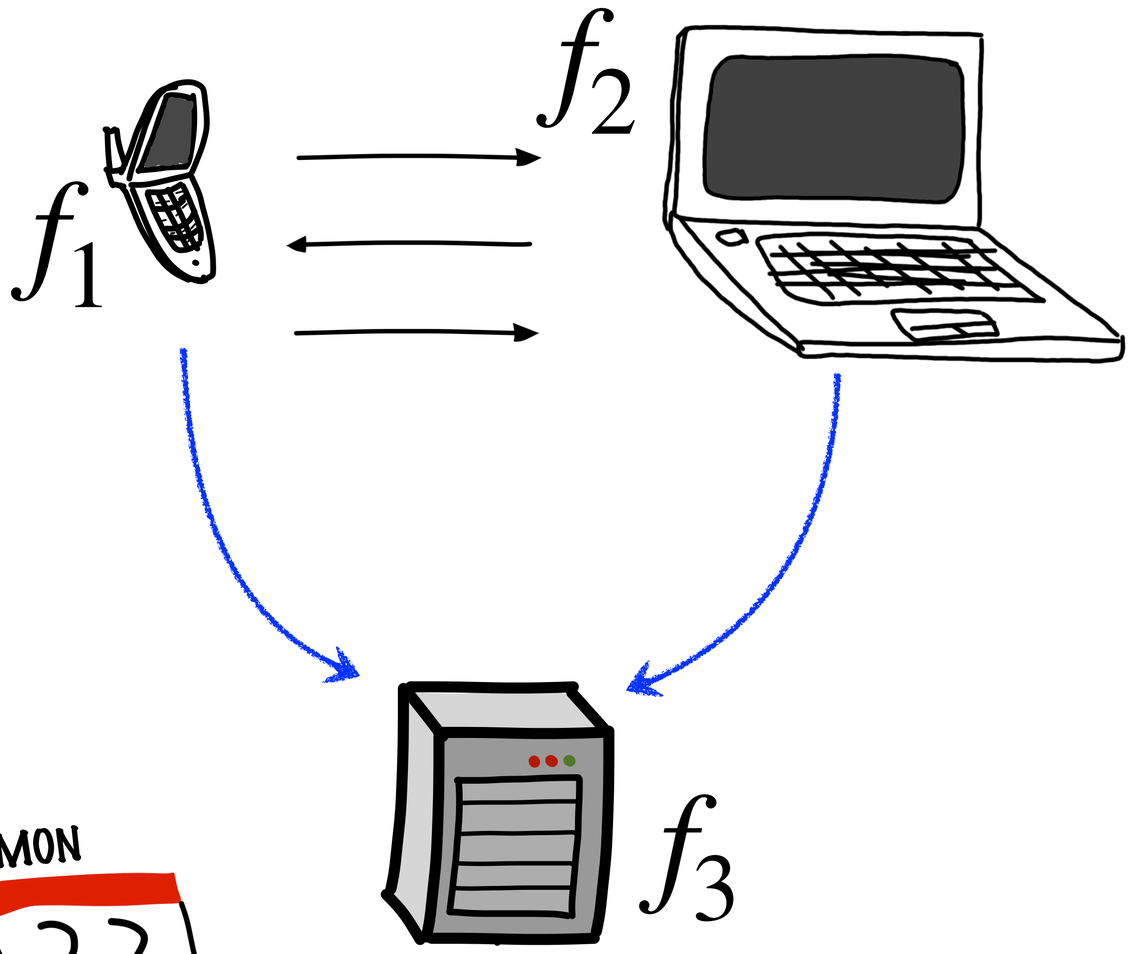
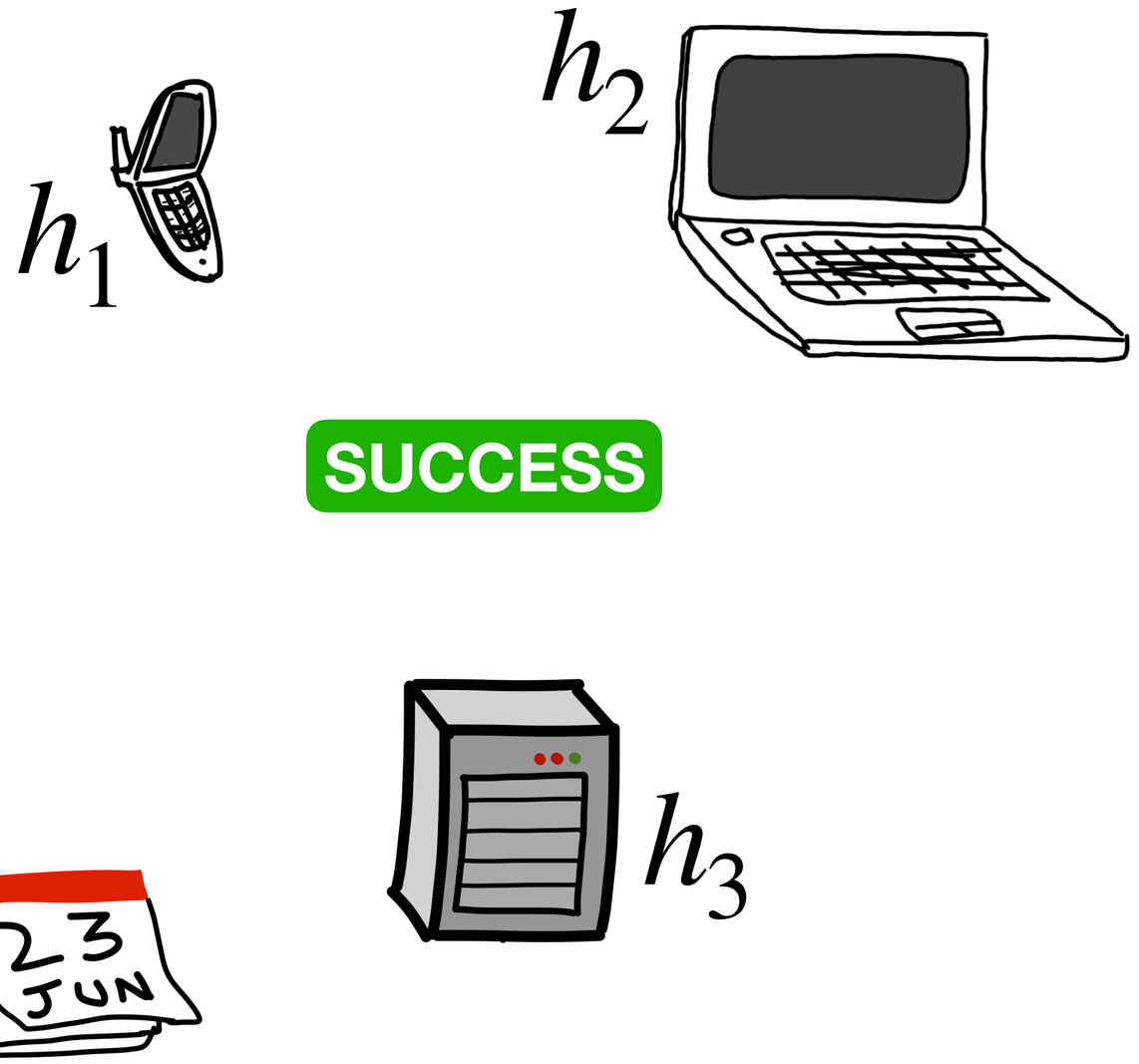


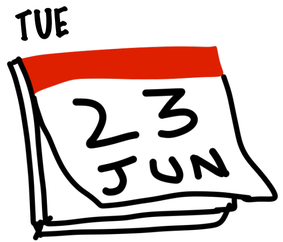


Defining Offline Refresh

f_1

f_2

f_3



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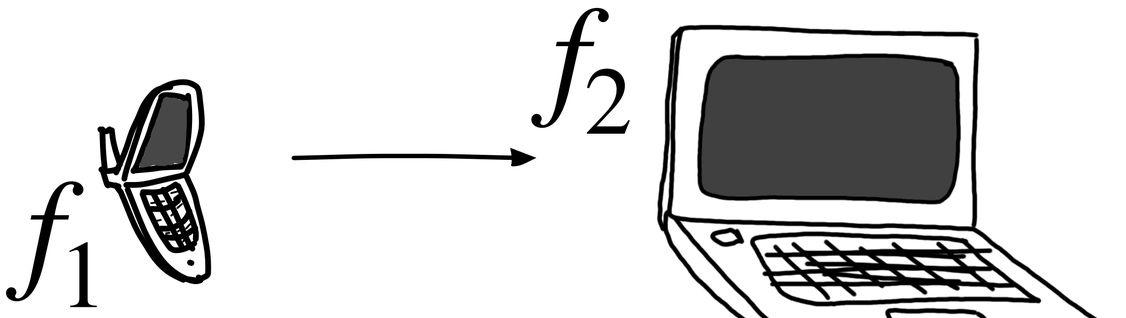

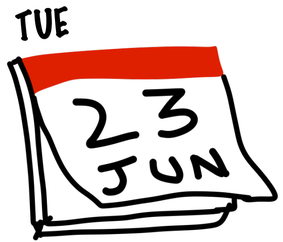

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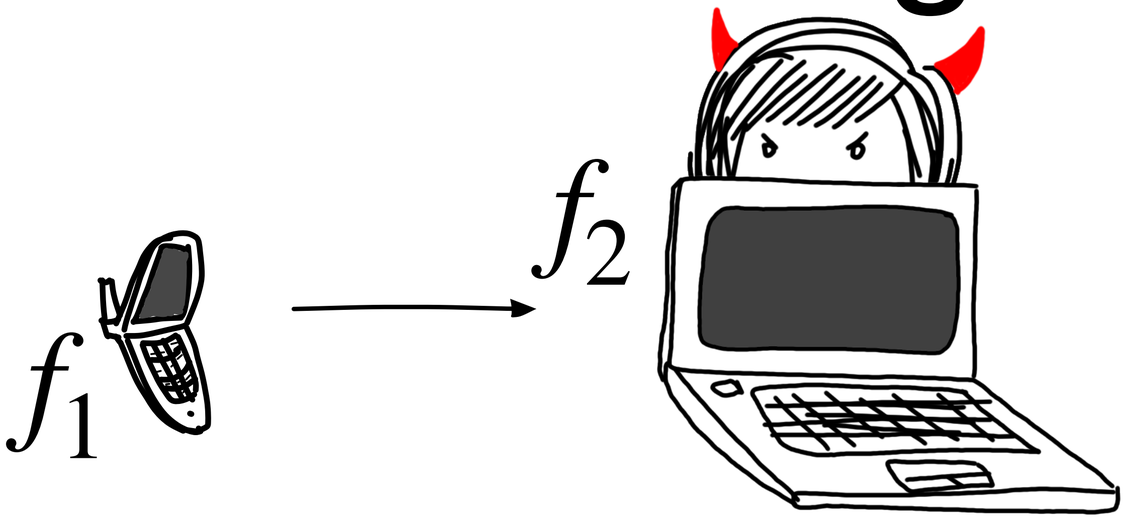

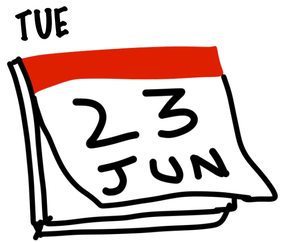

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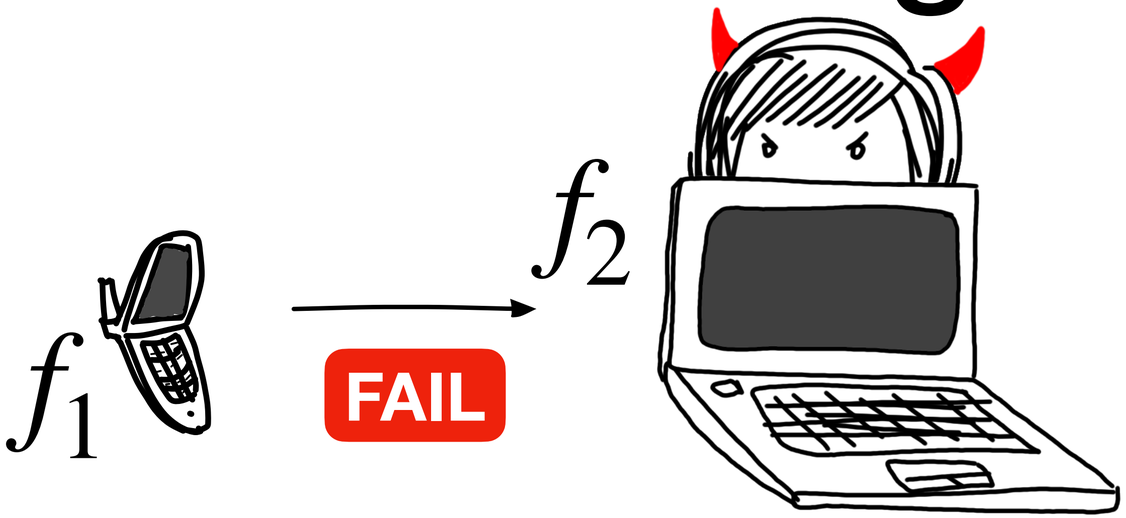

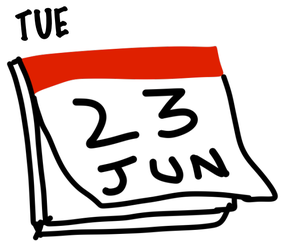

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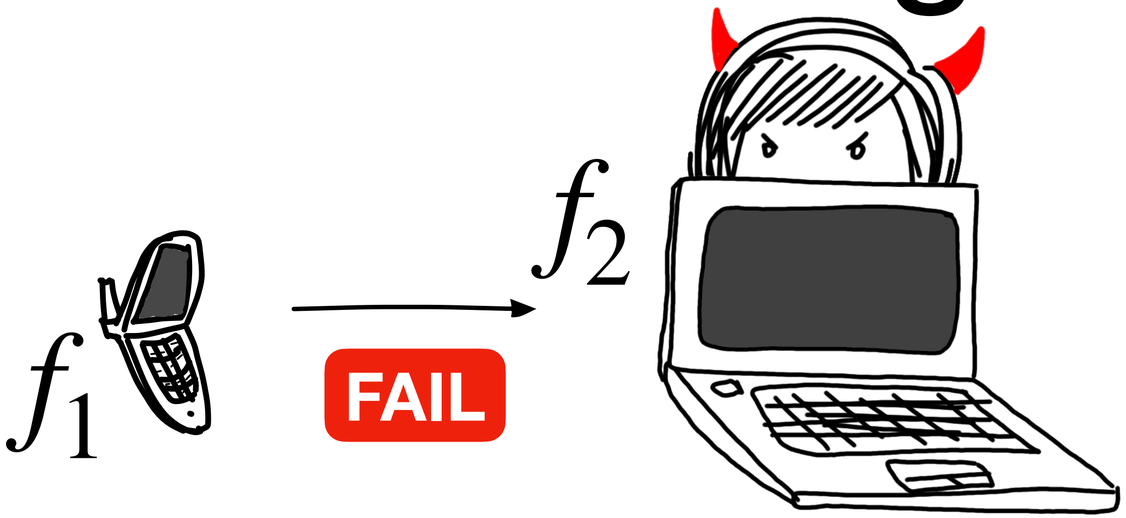

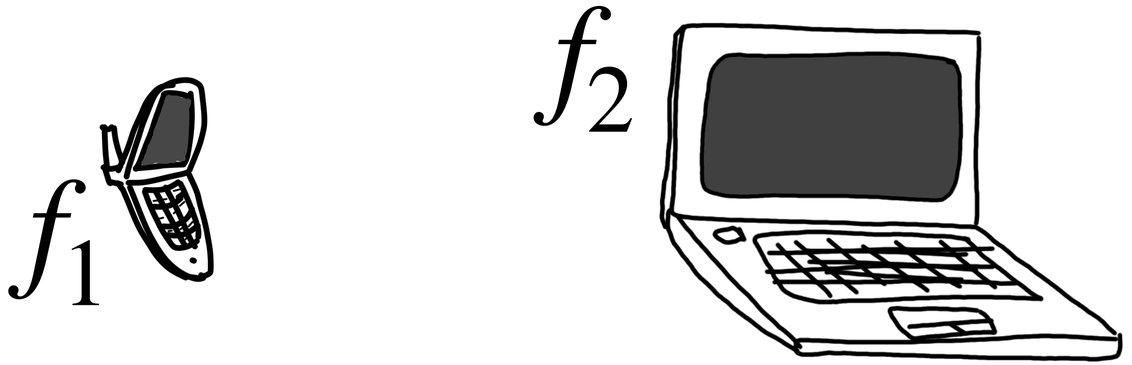

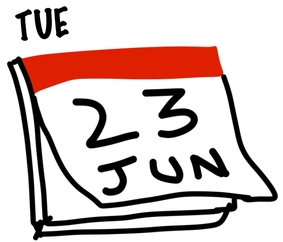

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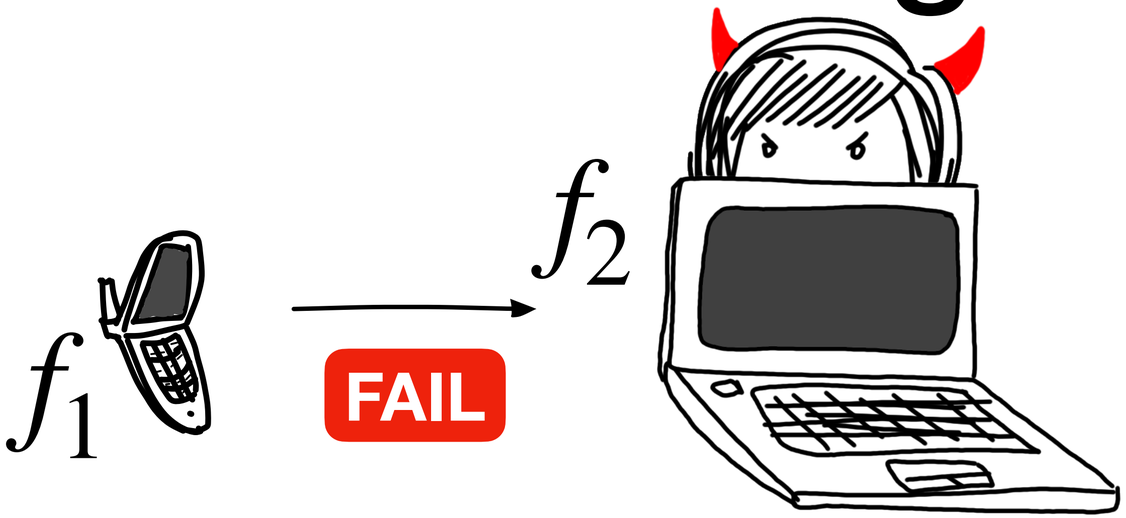
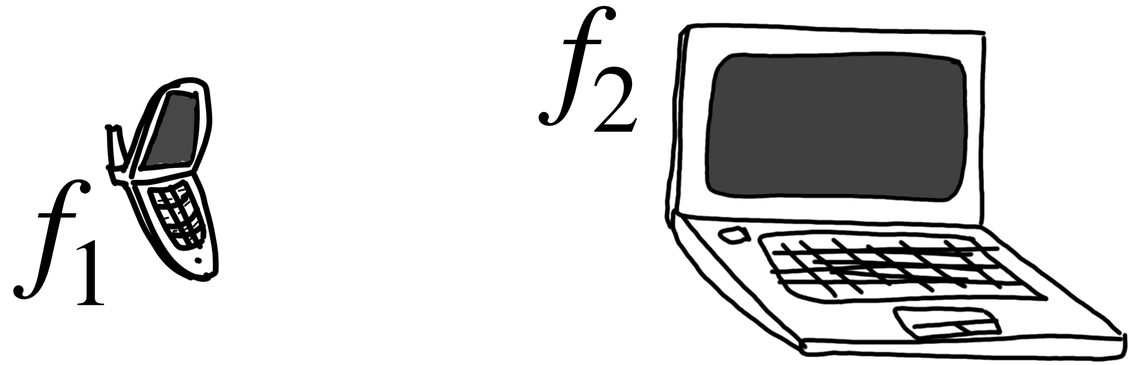
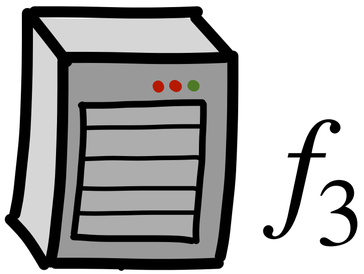
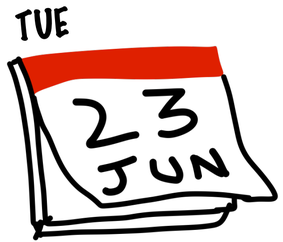
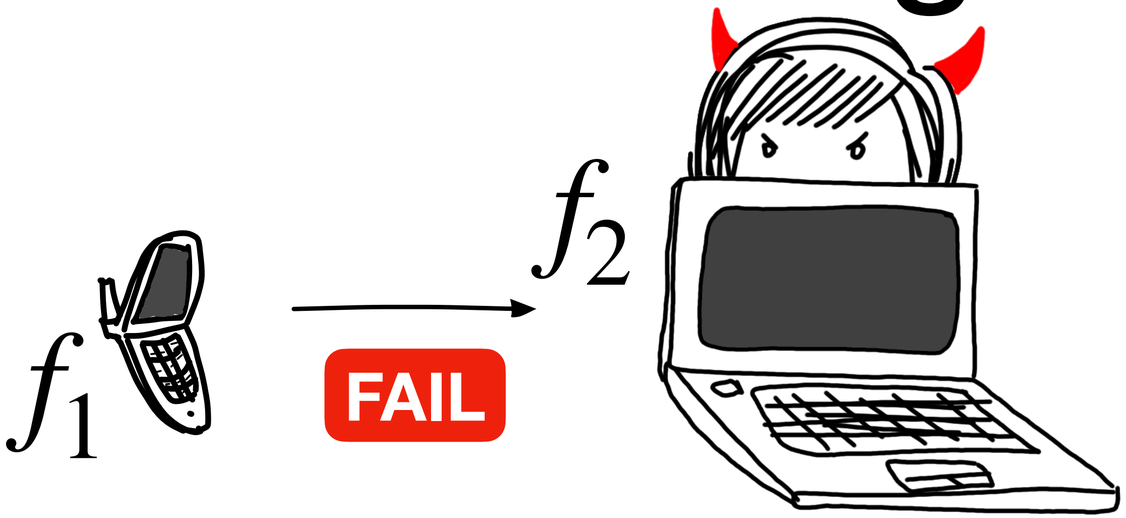


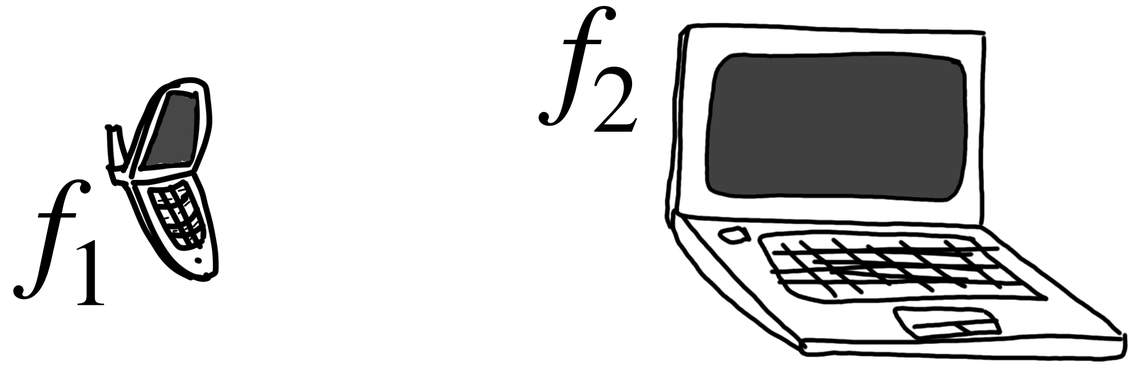


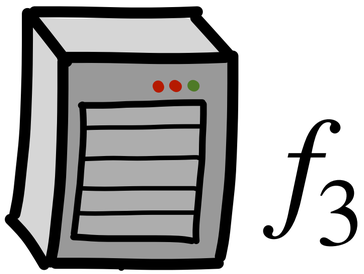


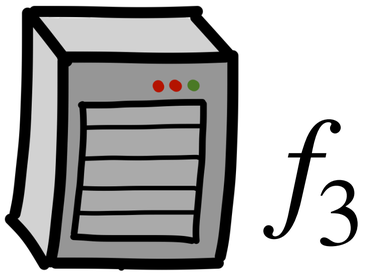


Defining Offline Refresh







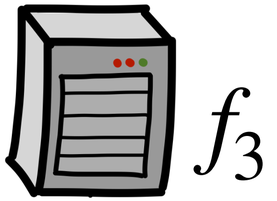


Defining Offline Refresh

Defining Offline Refresh

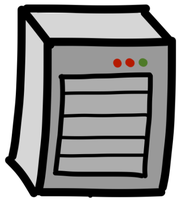
SUCCESS

FAIL



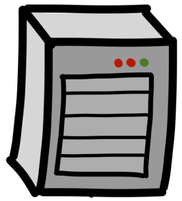
Defining Offline Refresh

SUCCESS



HMMMMMM

FAIL

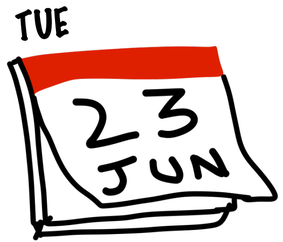


Defining Offline Refresh

f_1

f_2

f_3



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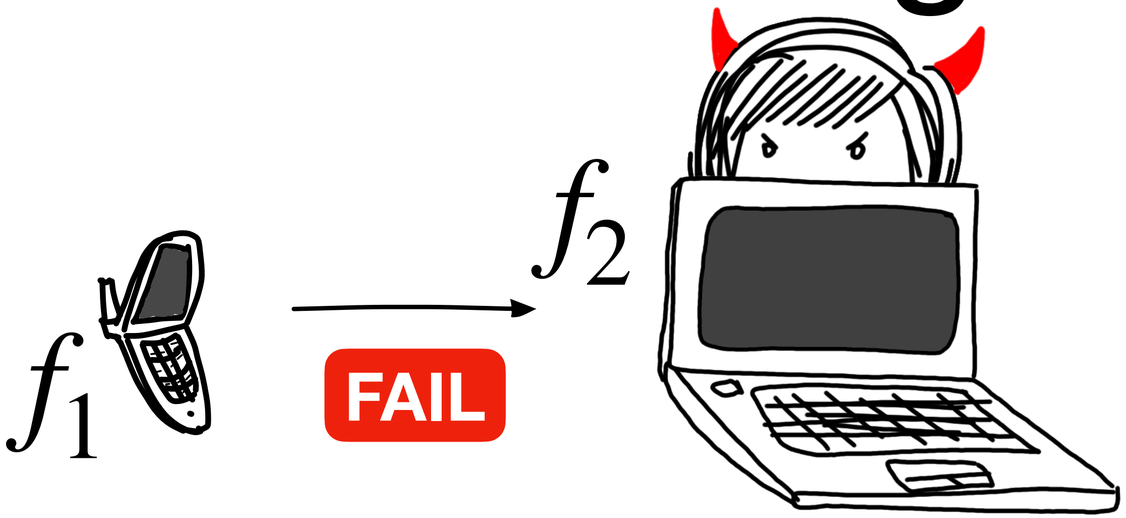

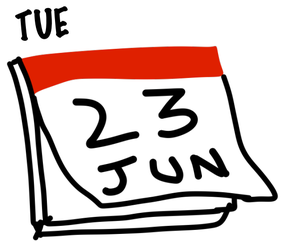

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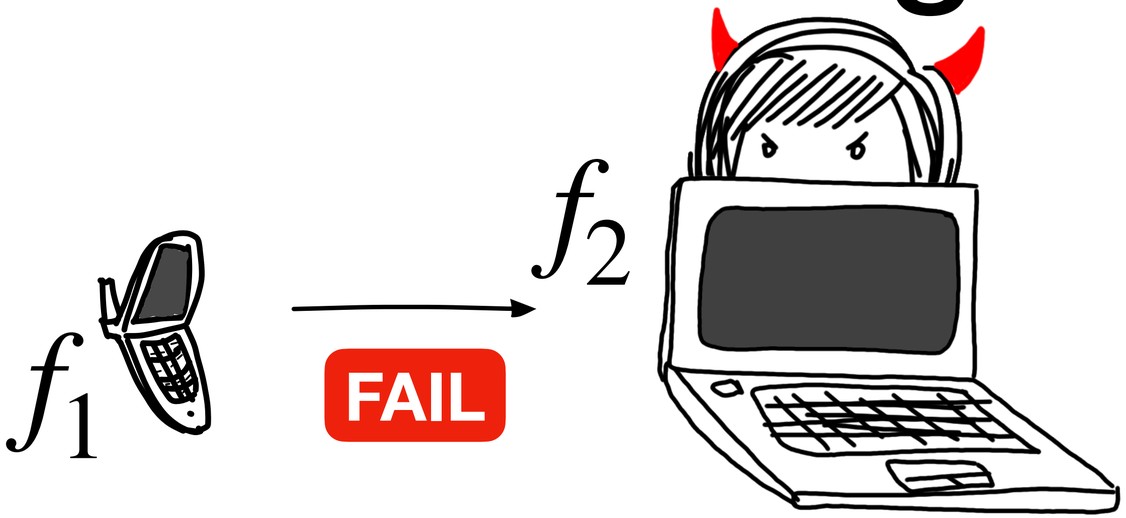

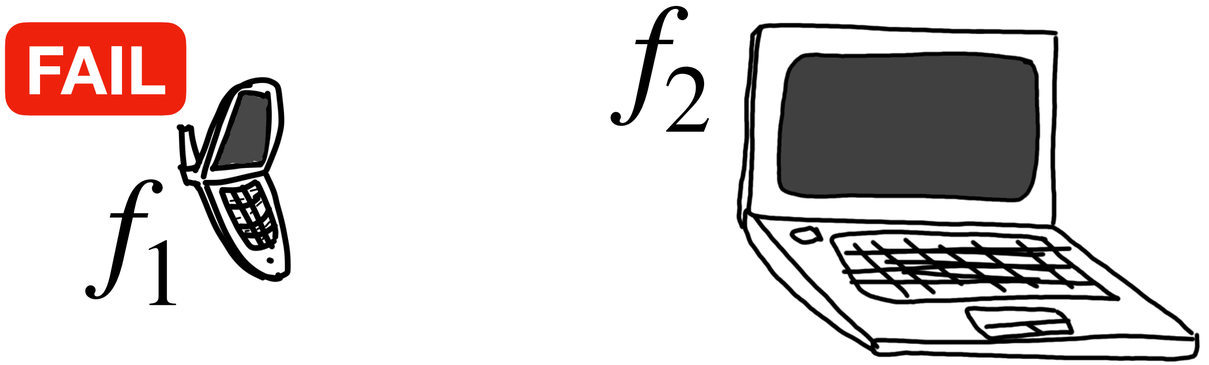

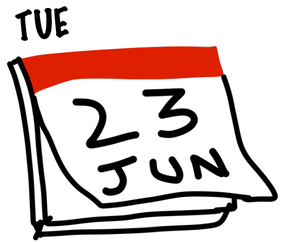

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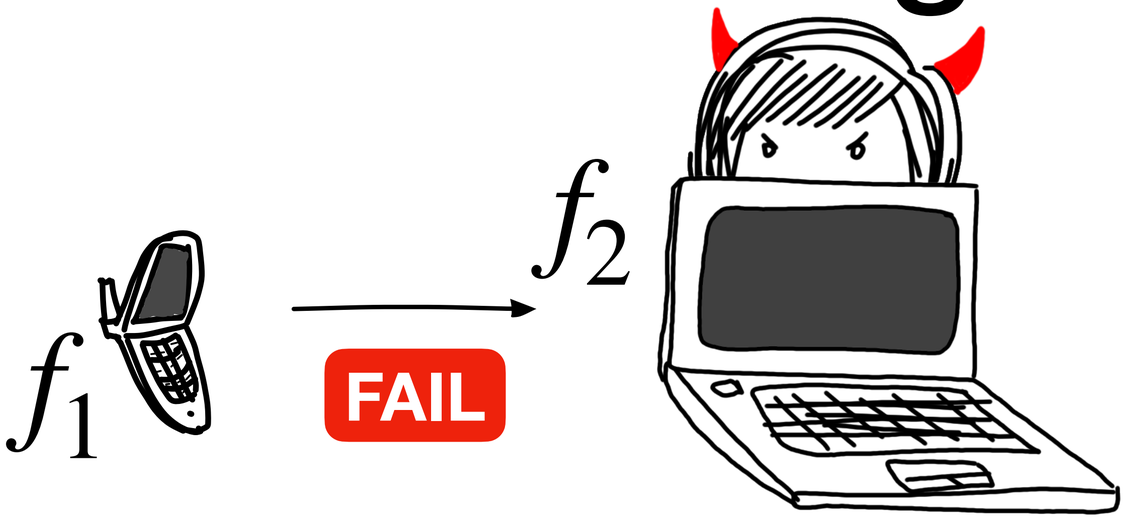

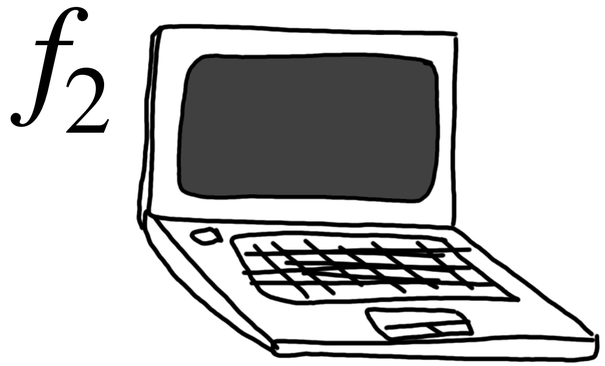

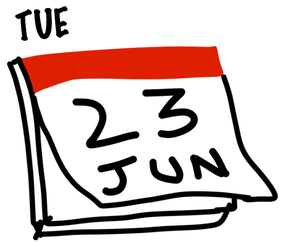

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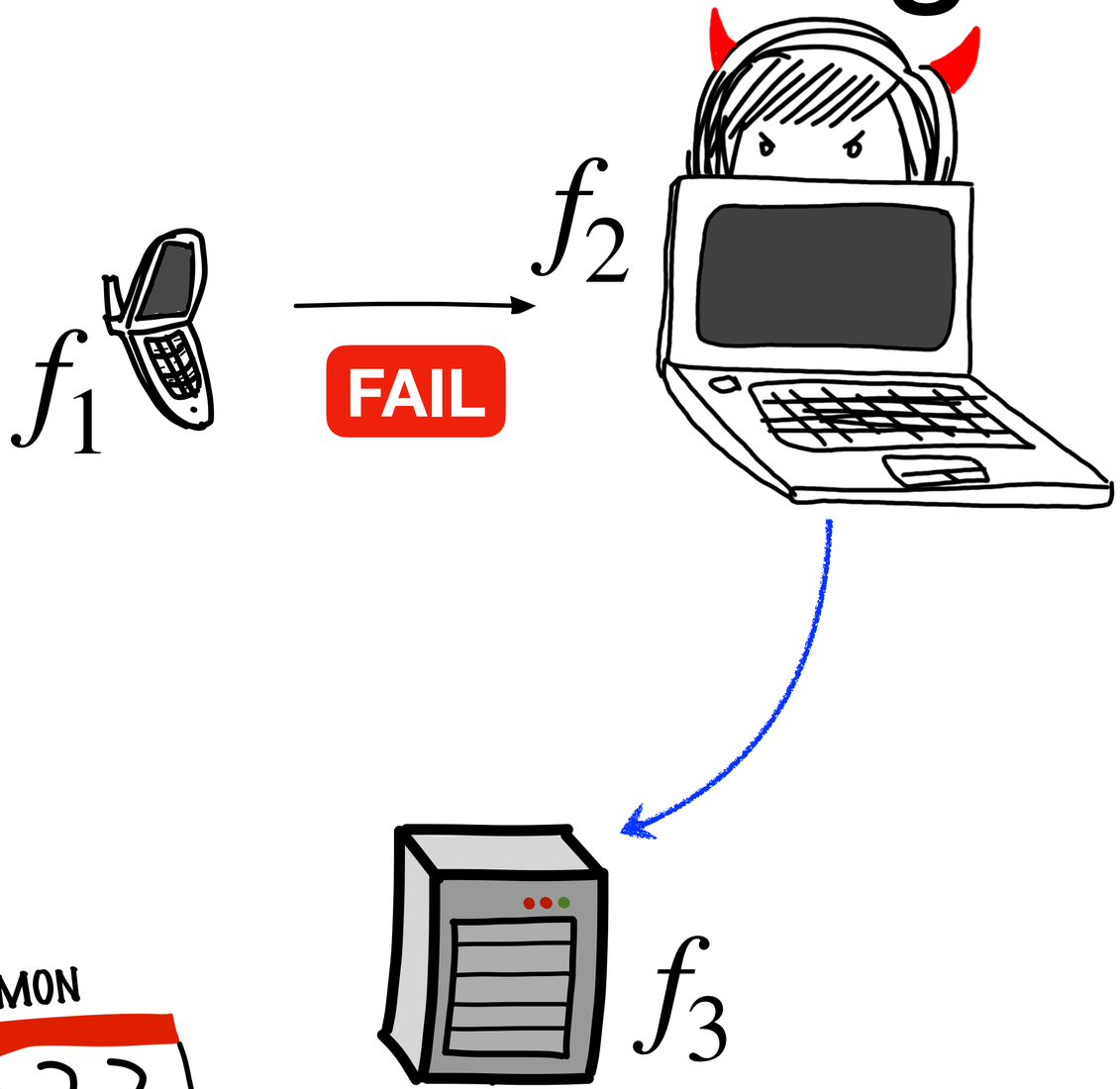

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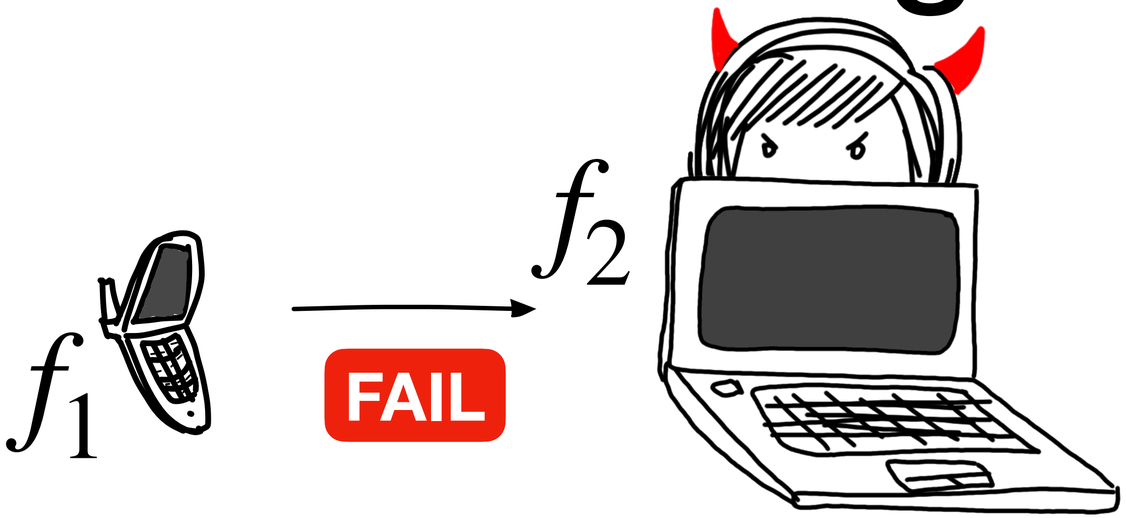
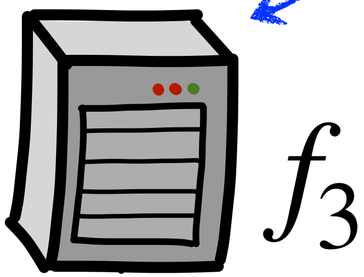
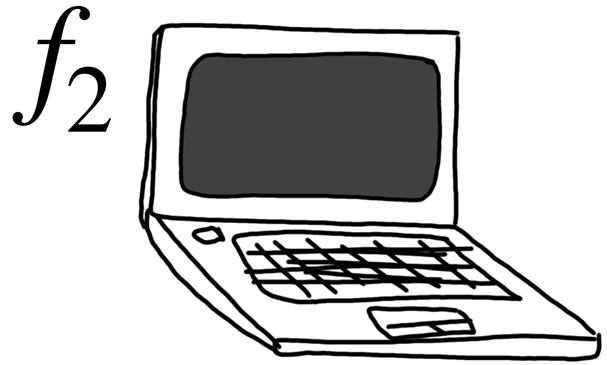
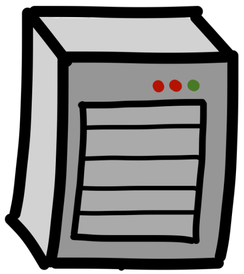


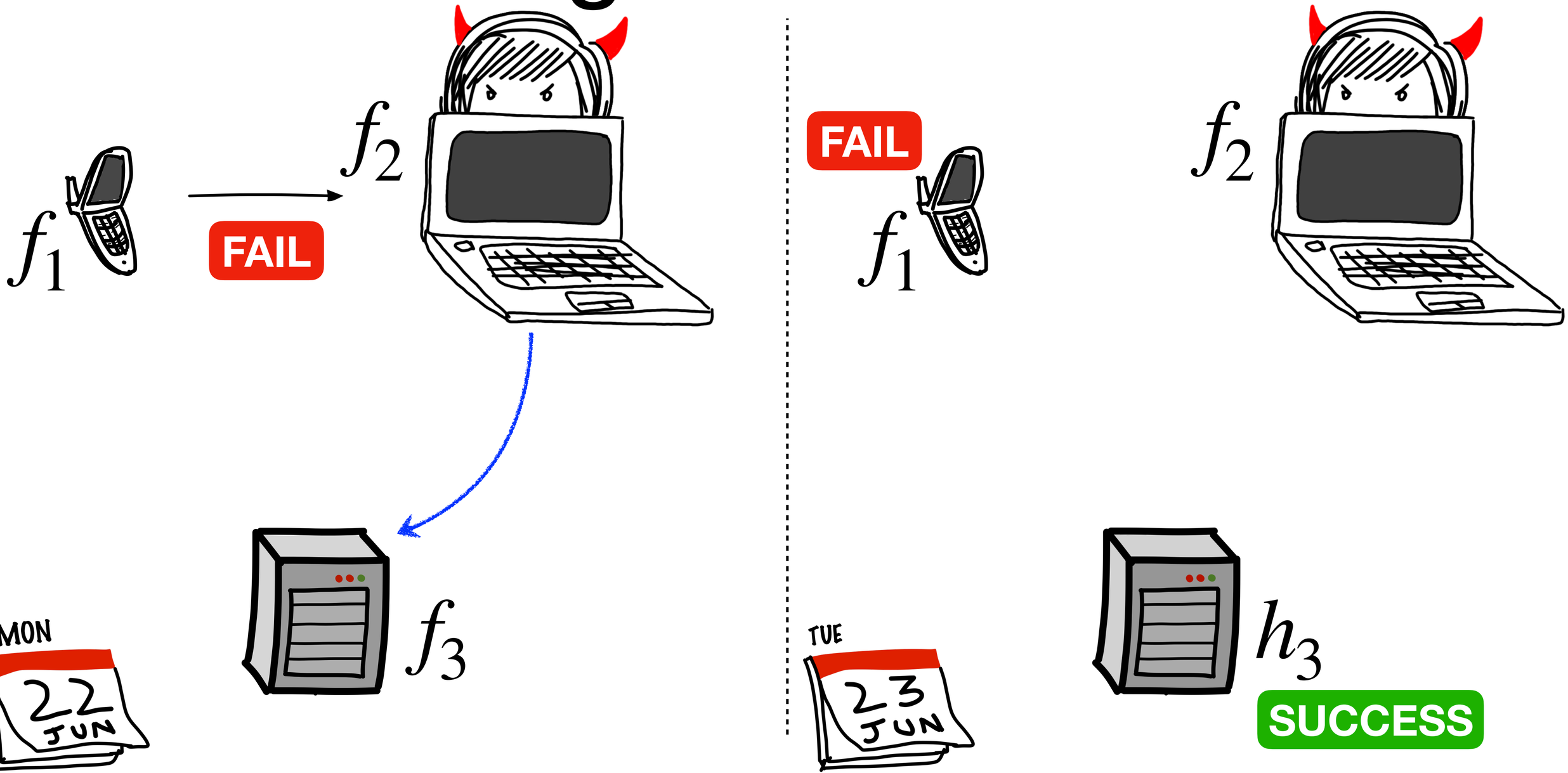






SUCCESS

Defining Offline Refresh



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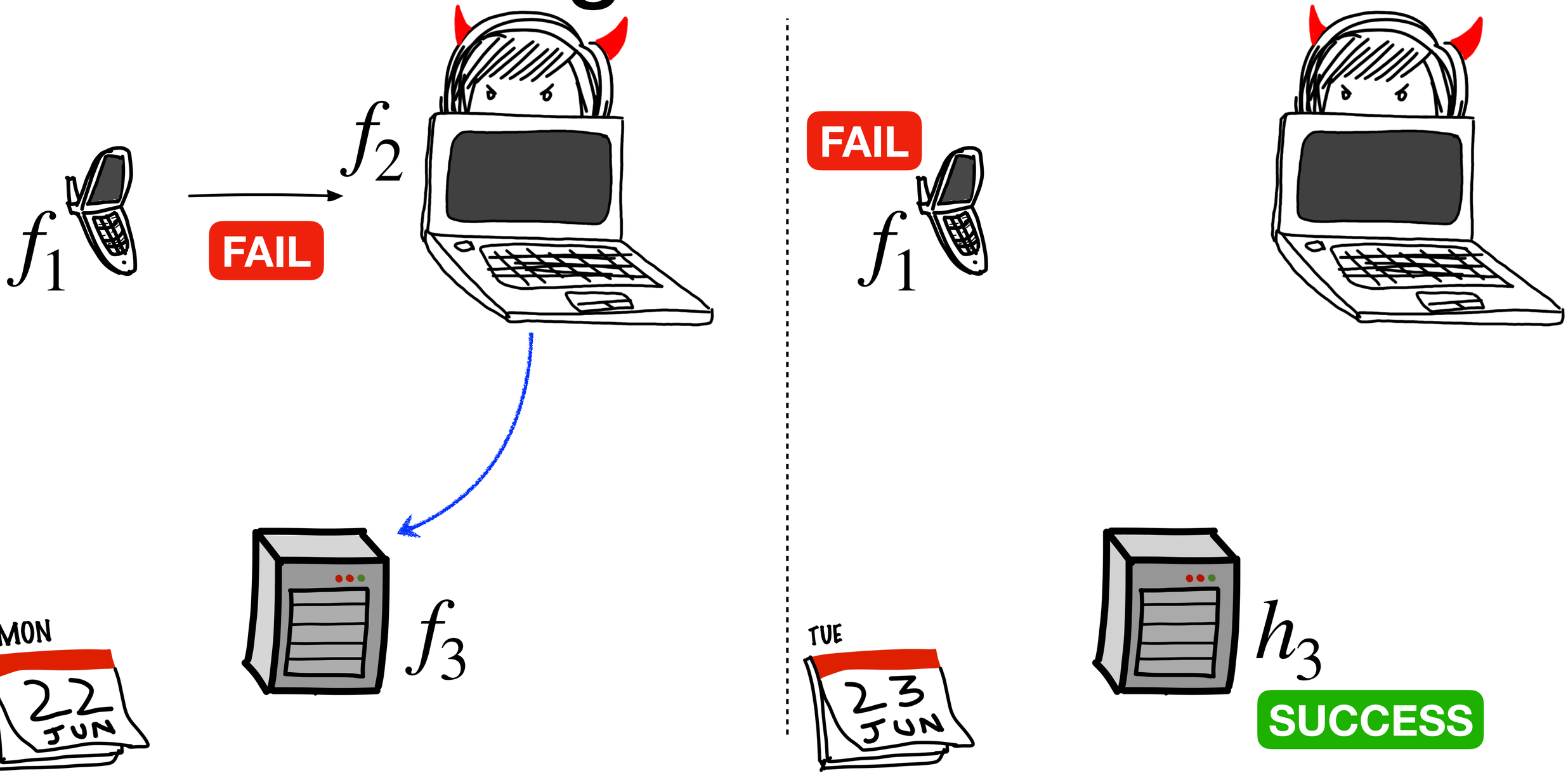

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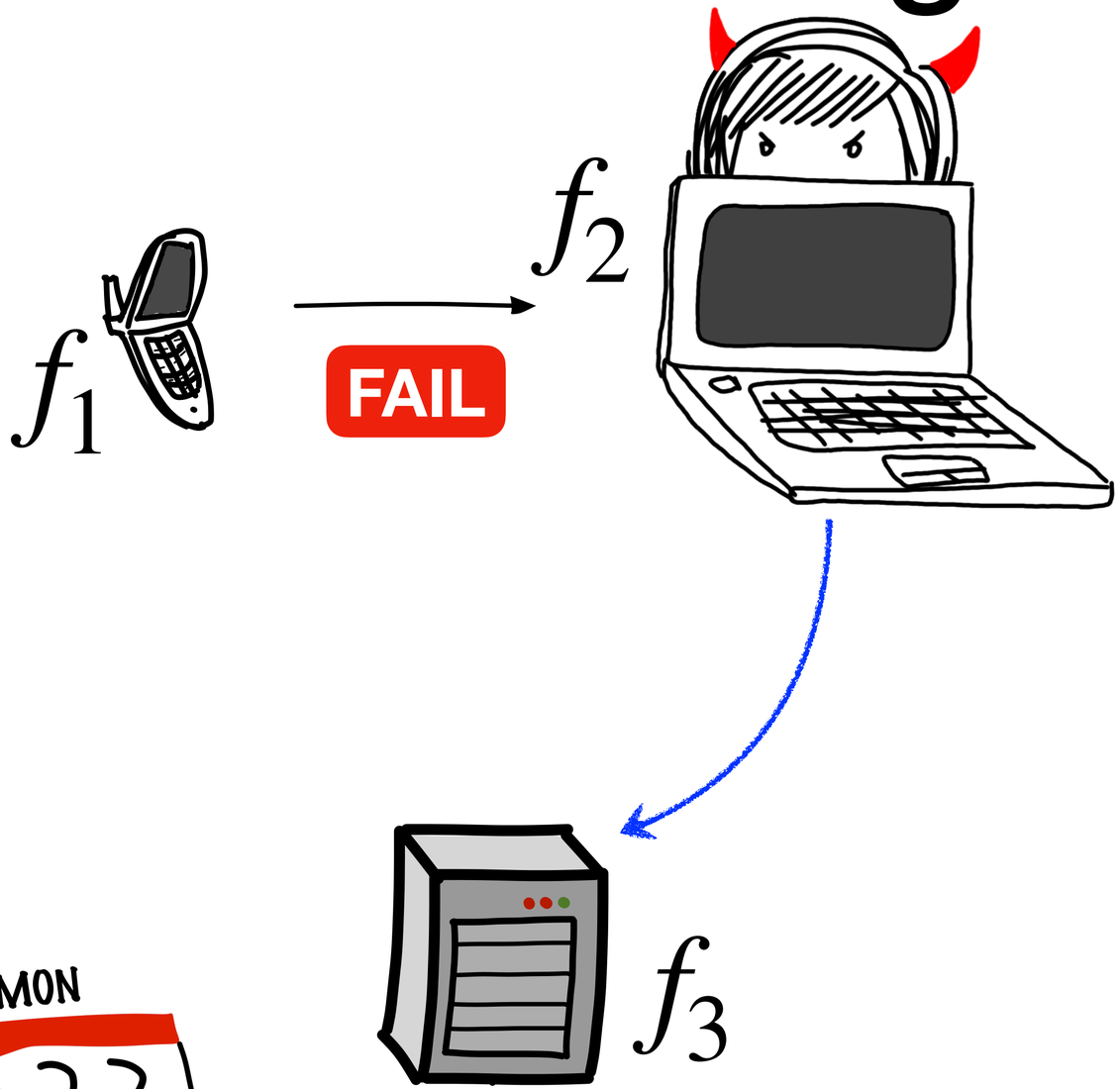

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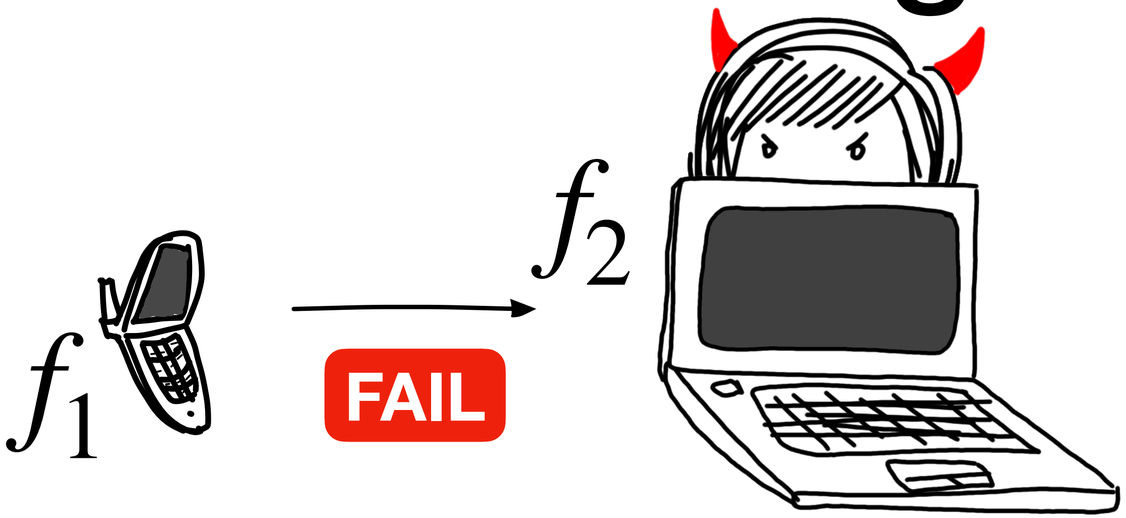
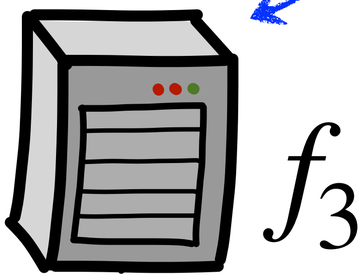
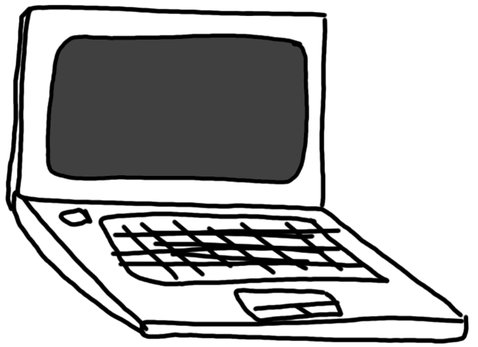
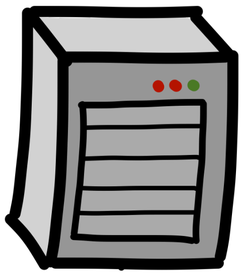






Agree to FAIL



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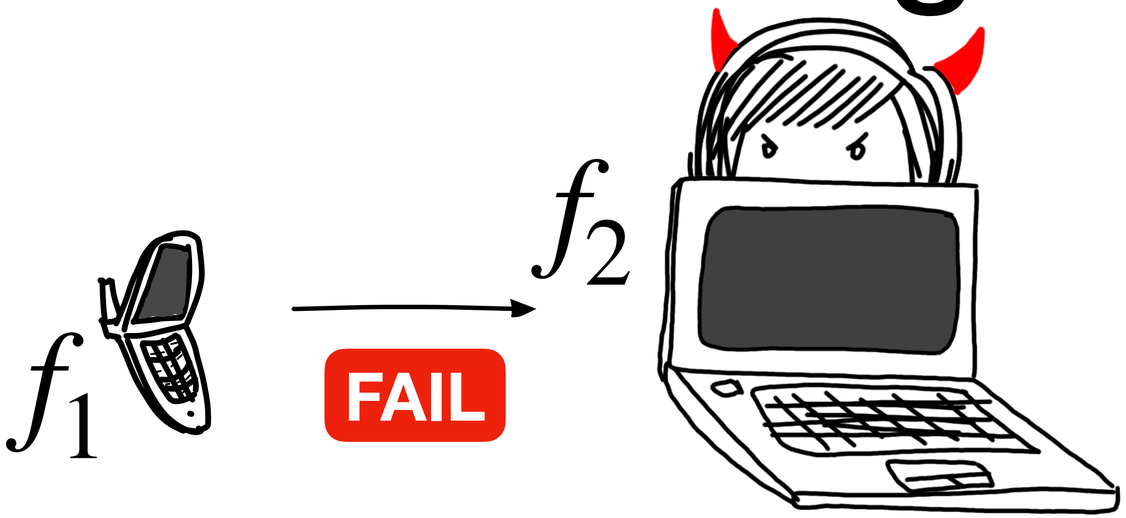
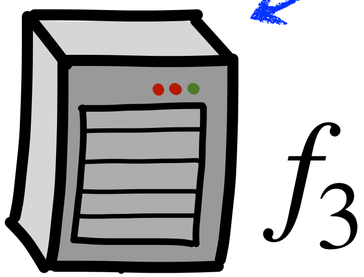
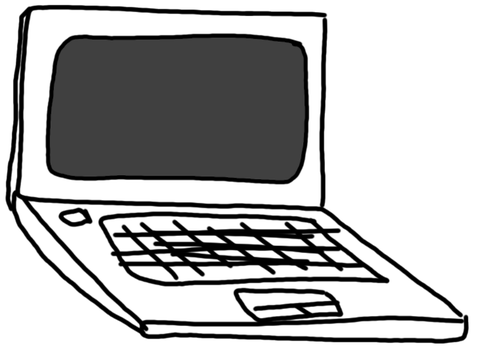


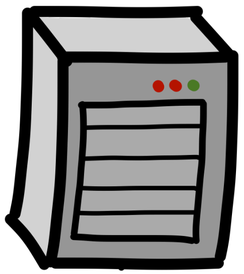


FAIL



Agree to FAIL

i.e. Unanimous Erasure



FAIL

This Work

- Correct definition is subtle
  - Guaranteed progress is impossible
  - We formulate **unanimous erasure**

- (*2*,*n*) setting: Efficient new protocol **native** to wallets

- (*t*,*n*) setting: **Impossible**!

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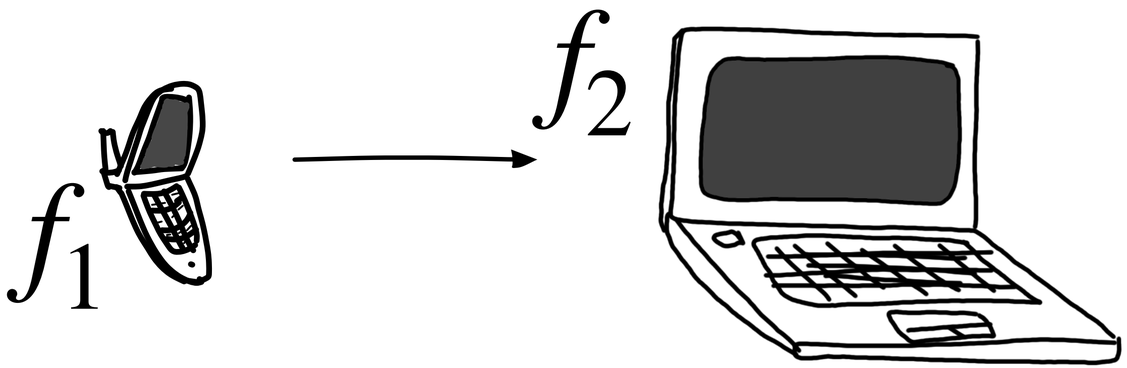

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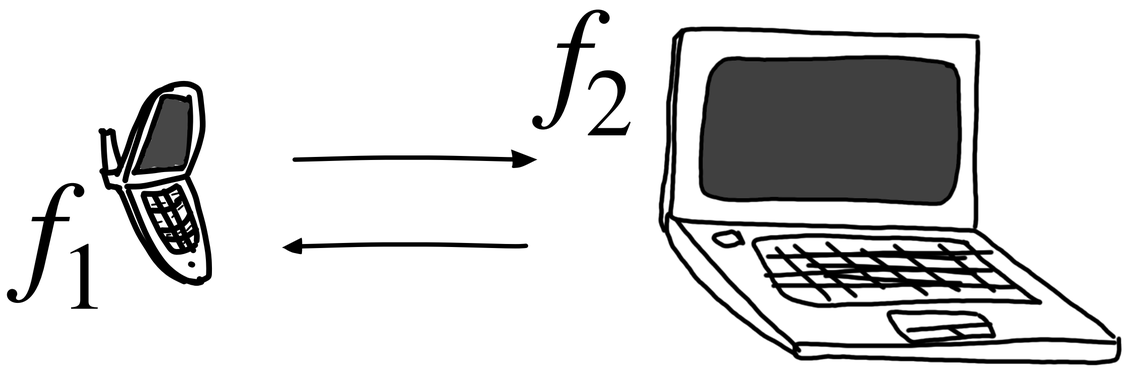

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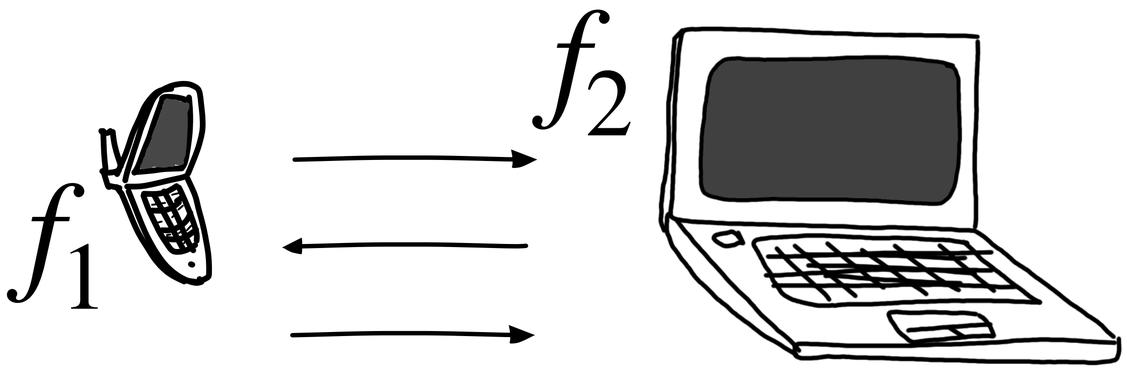

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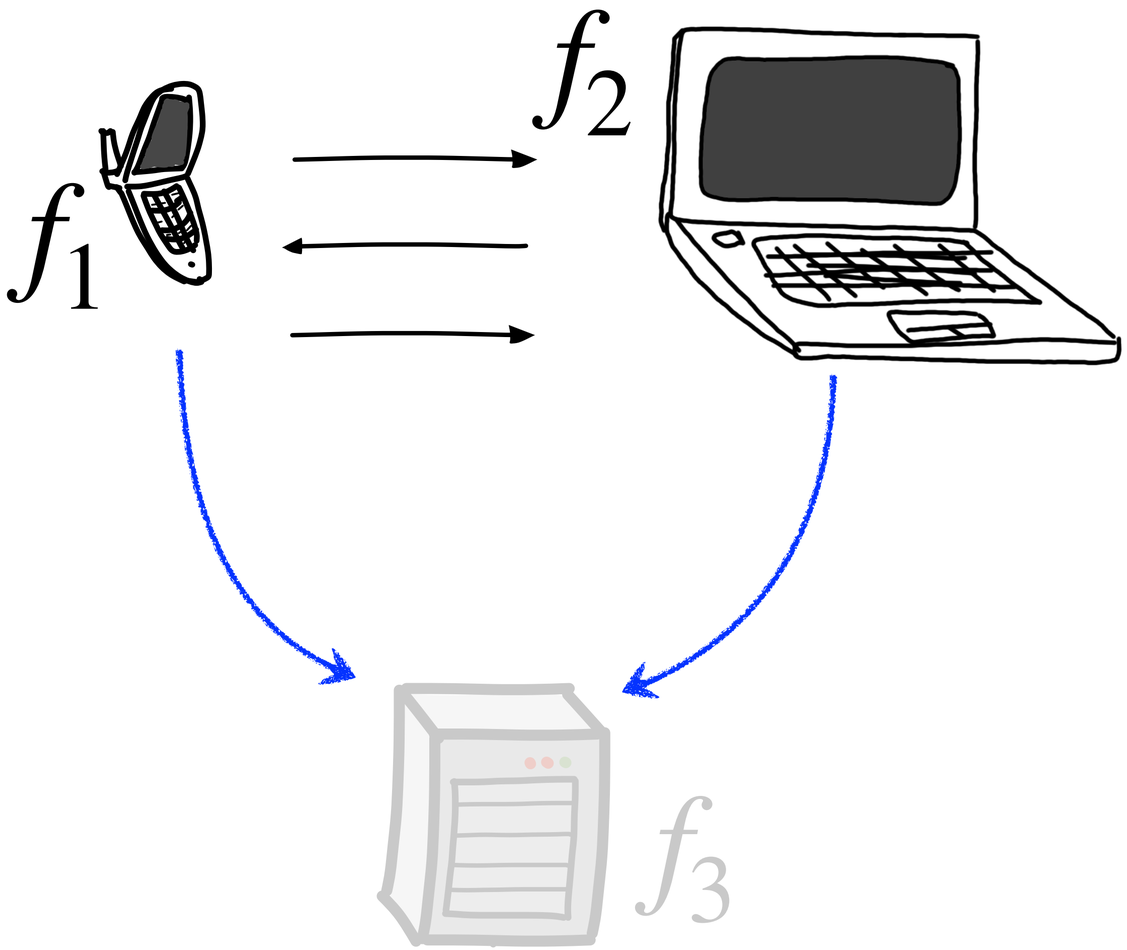

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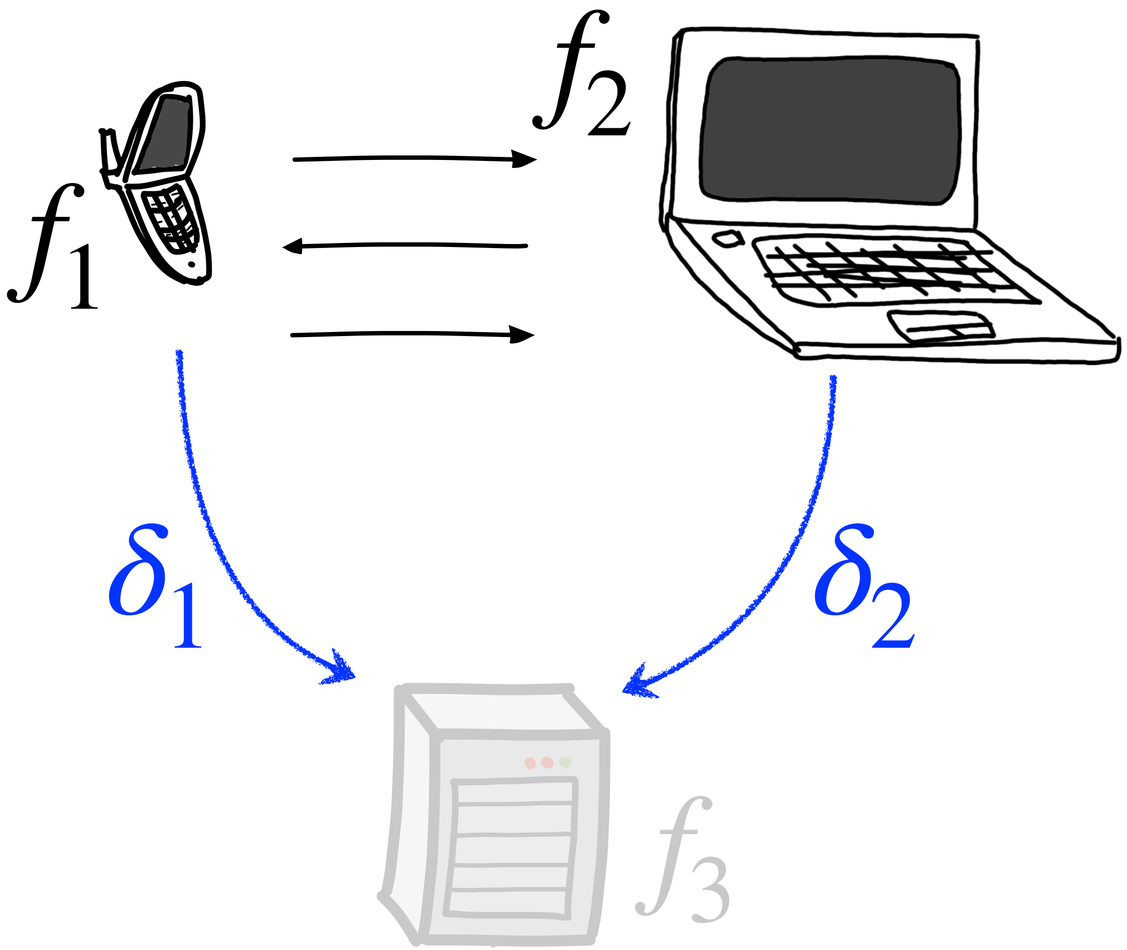

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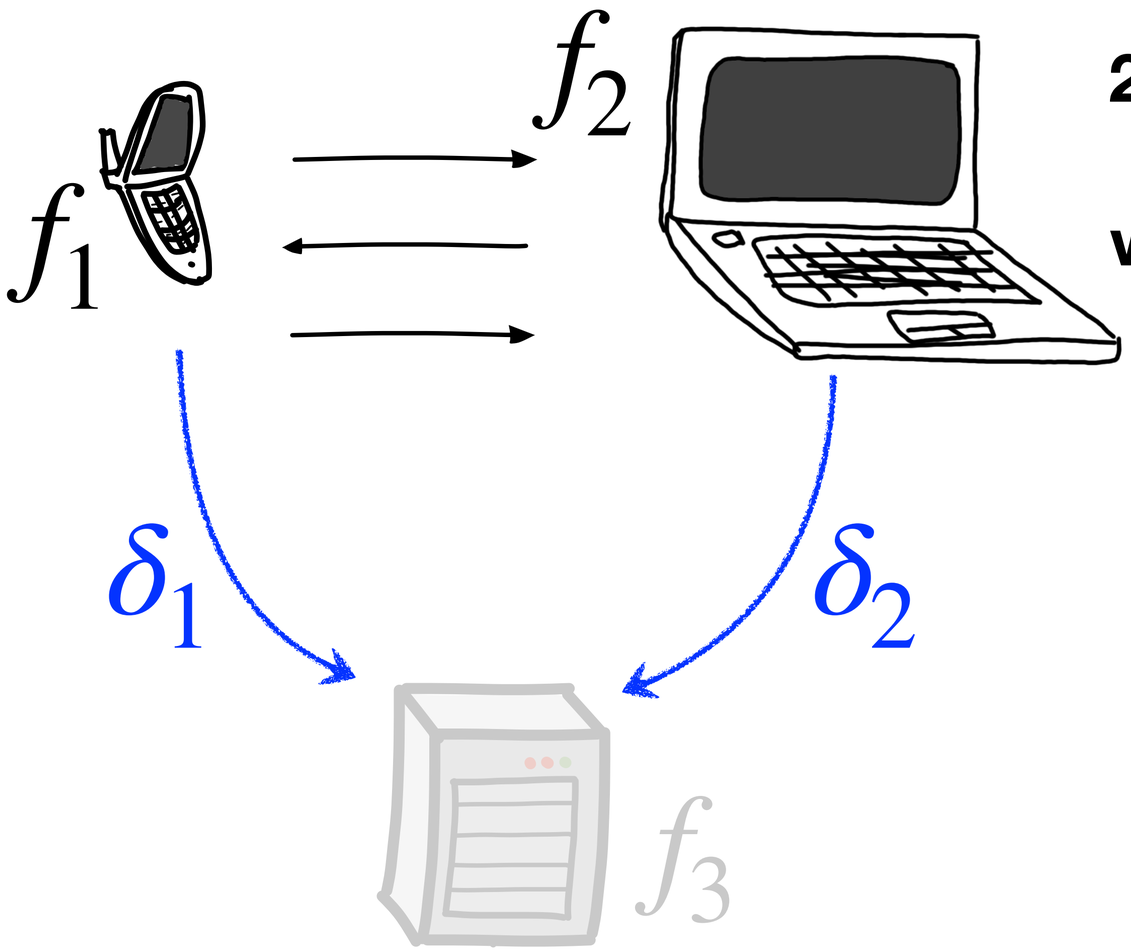

2 party computation (2PC) protocol with outputs δ_1, δ_2.

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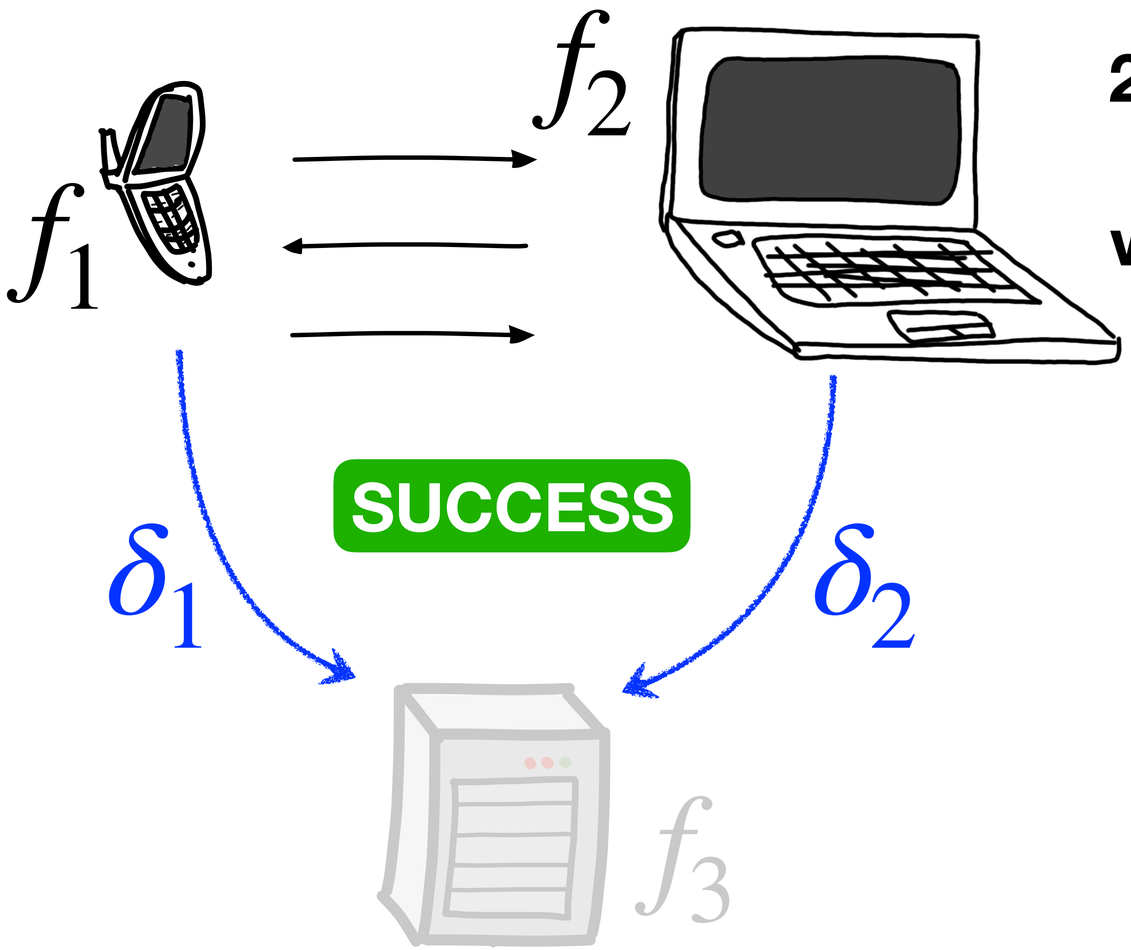

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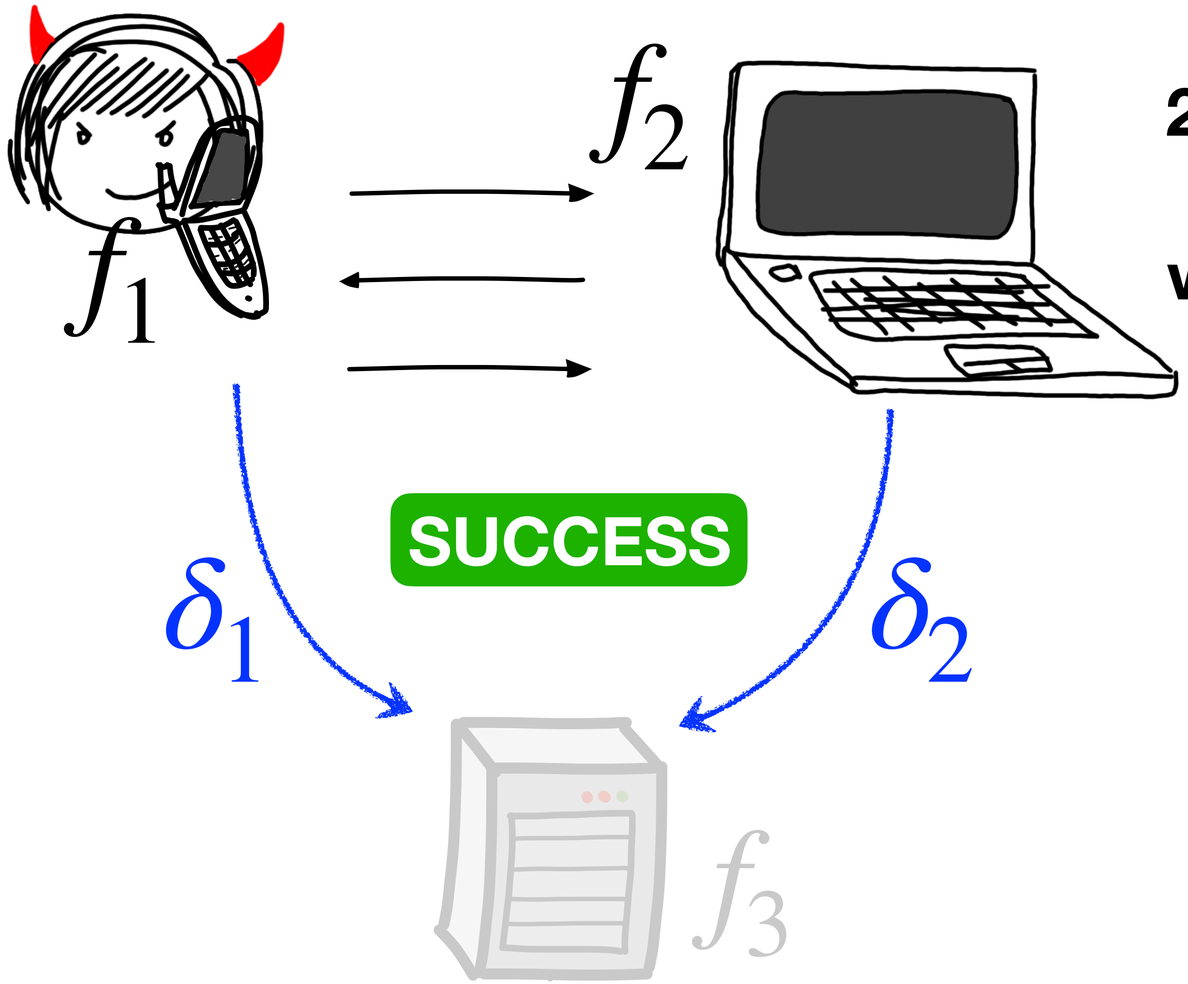

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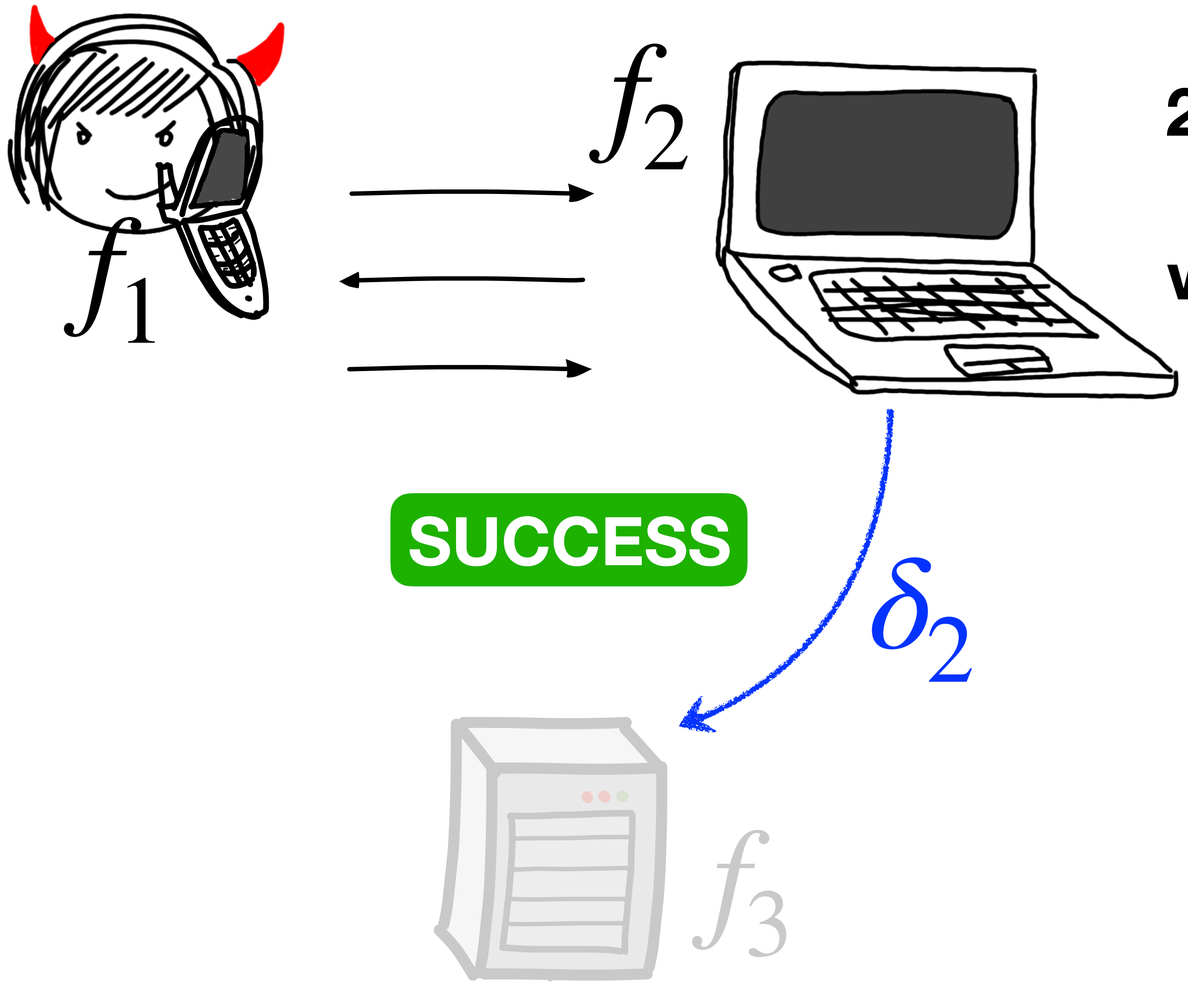

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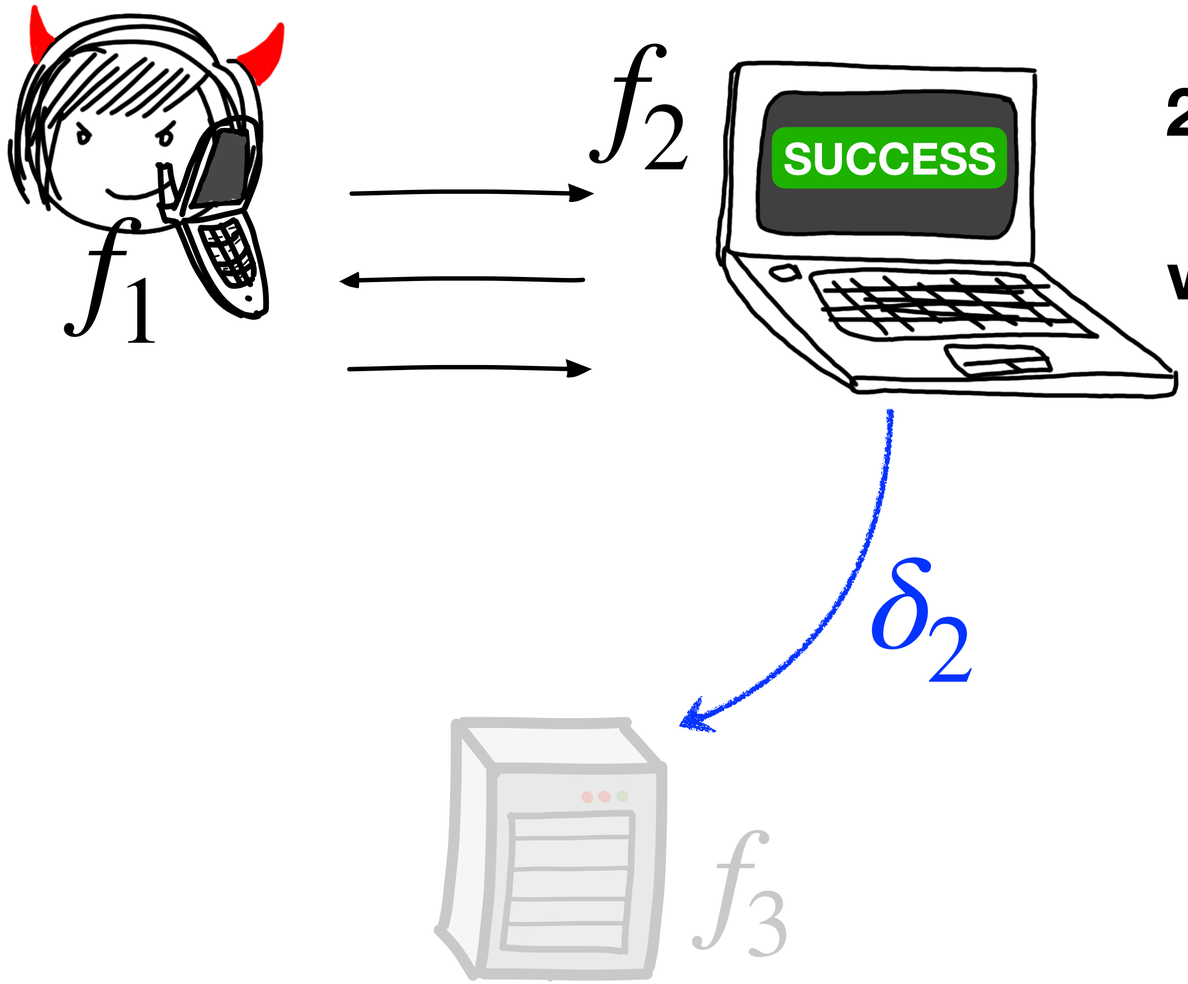

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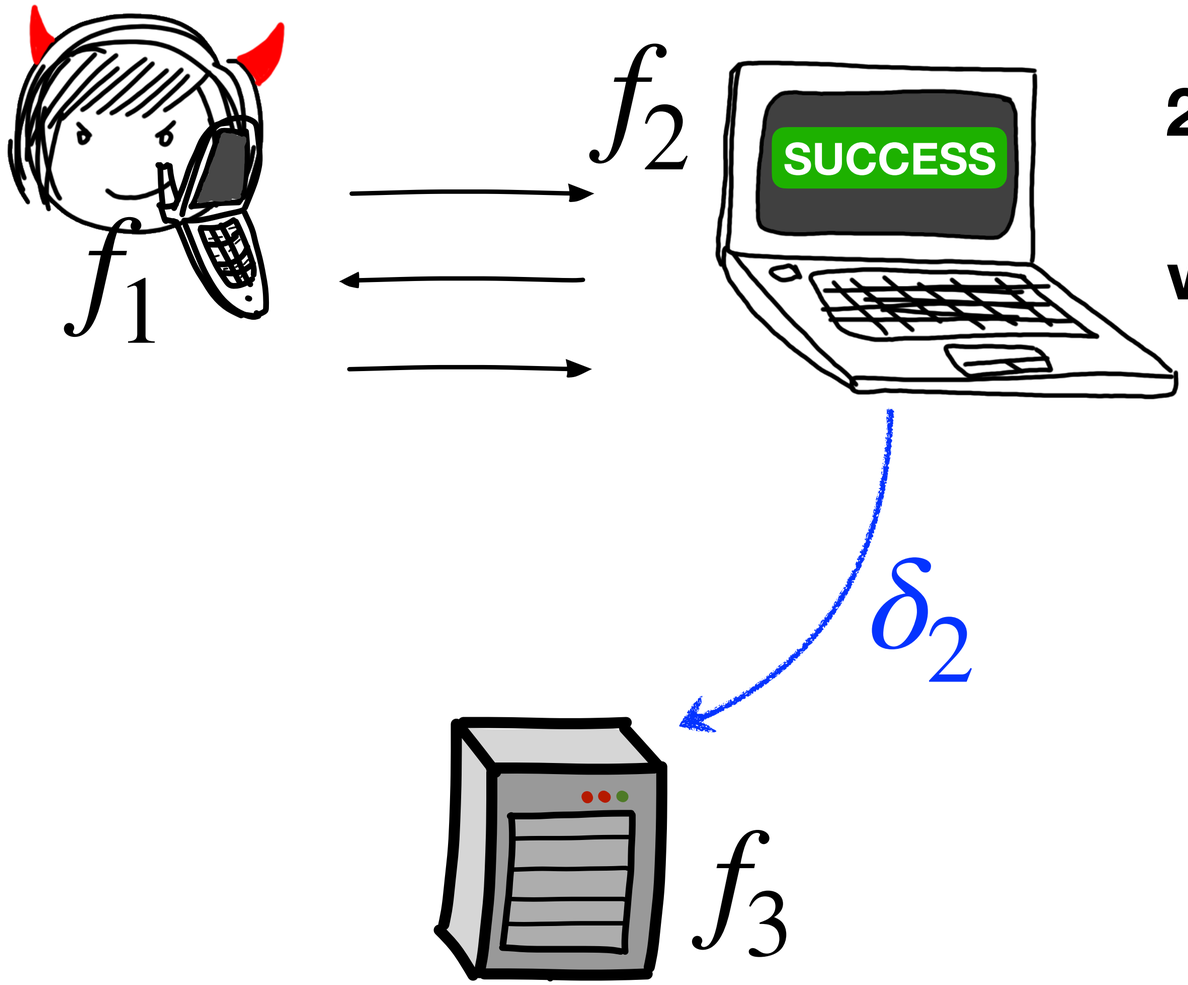

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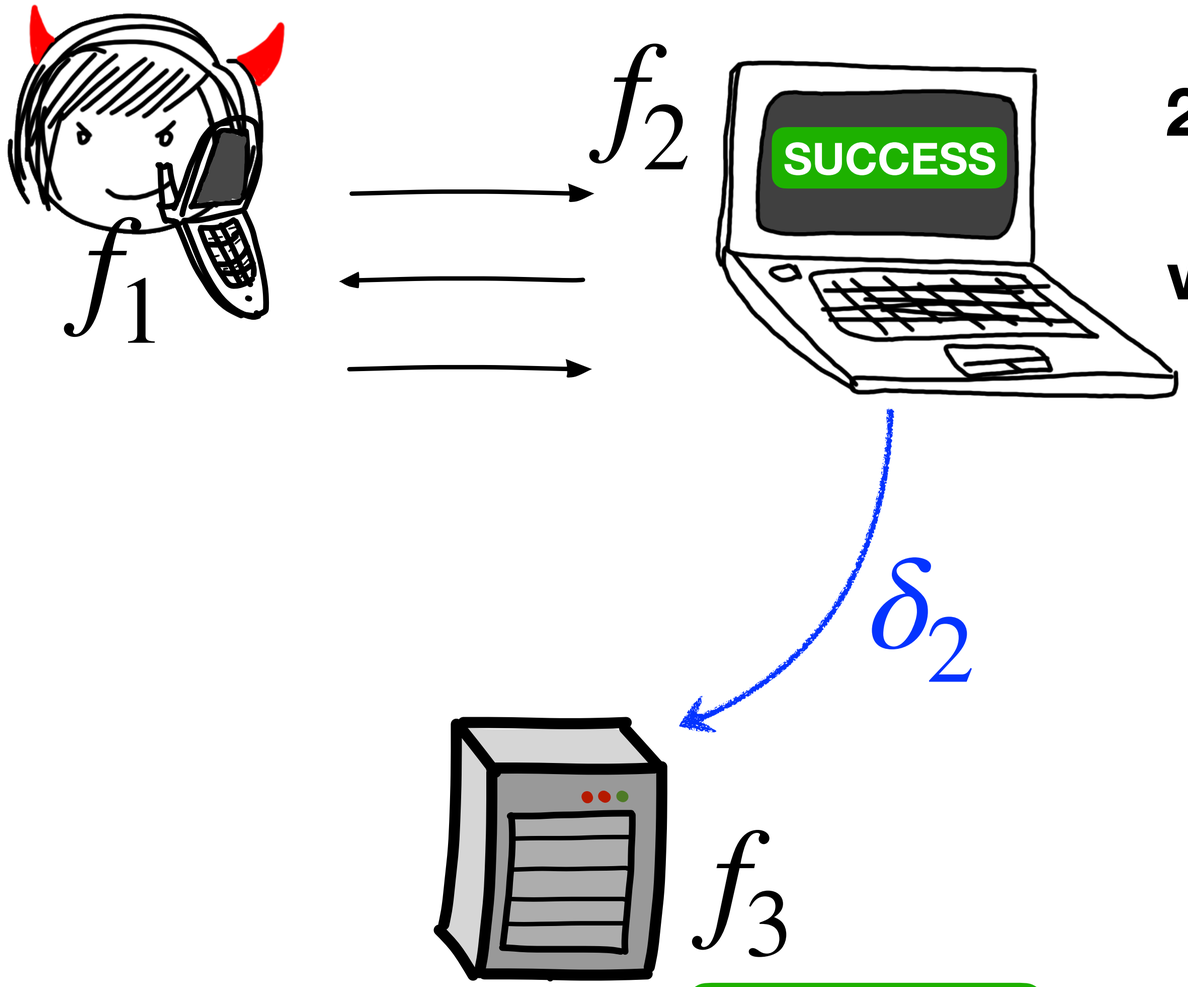

2 party computation (2PC) protocol with outputs δ_1, δ_2.

SUCCESS (unanimous erasure)

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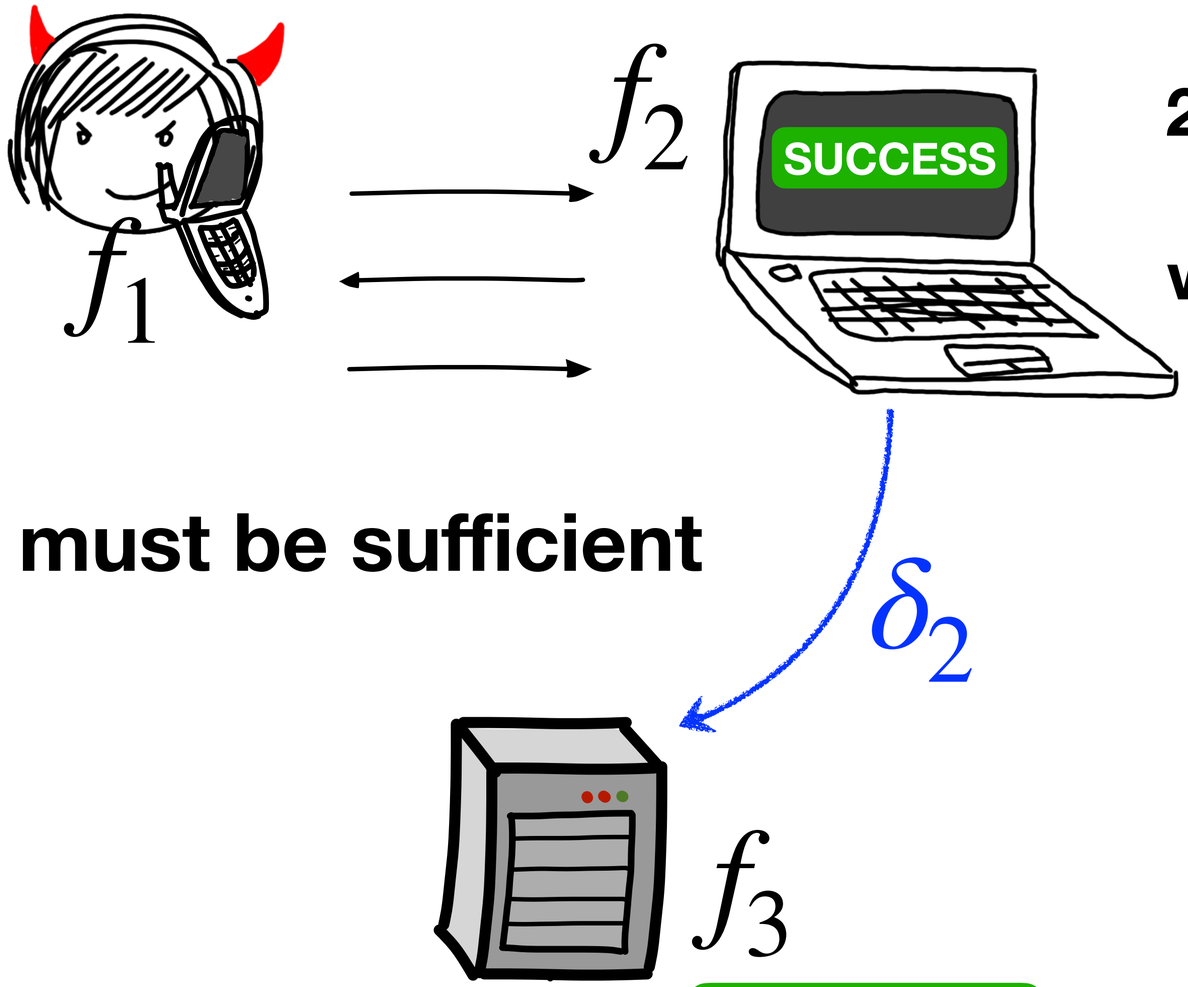

2 party computation (2PC) protocol with outputs δ_1, δ_2.

Lesson: δ_2 must be sufficient

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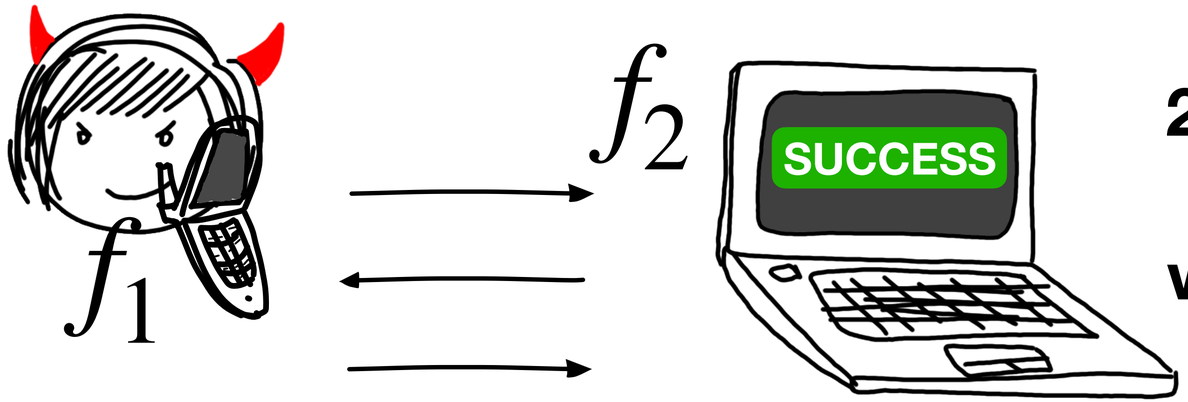
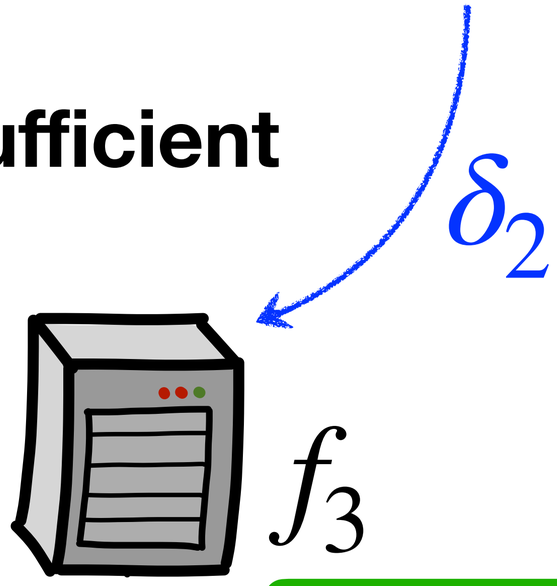


2 party computation (2PC) protocol with outputs δ_1, δ_2.

Lesson: δ_2 must be sufficient

(Equivalently δ_1)



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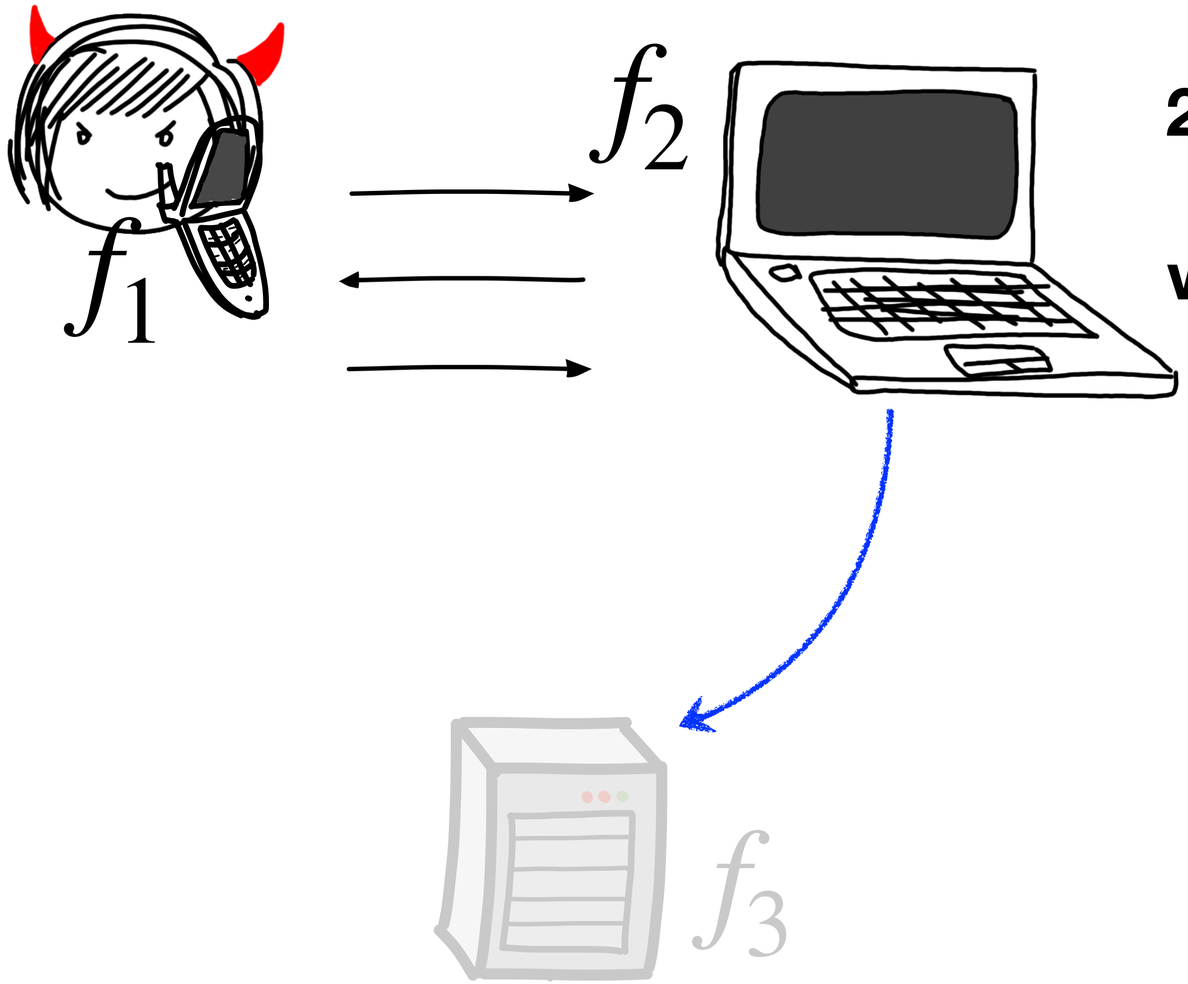

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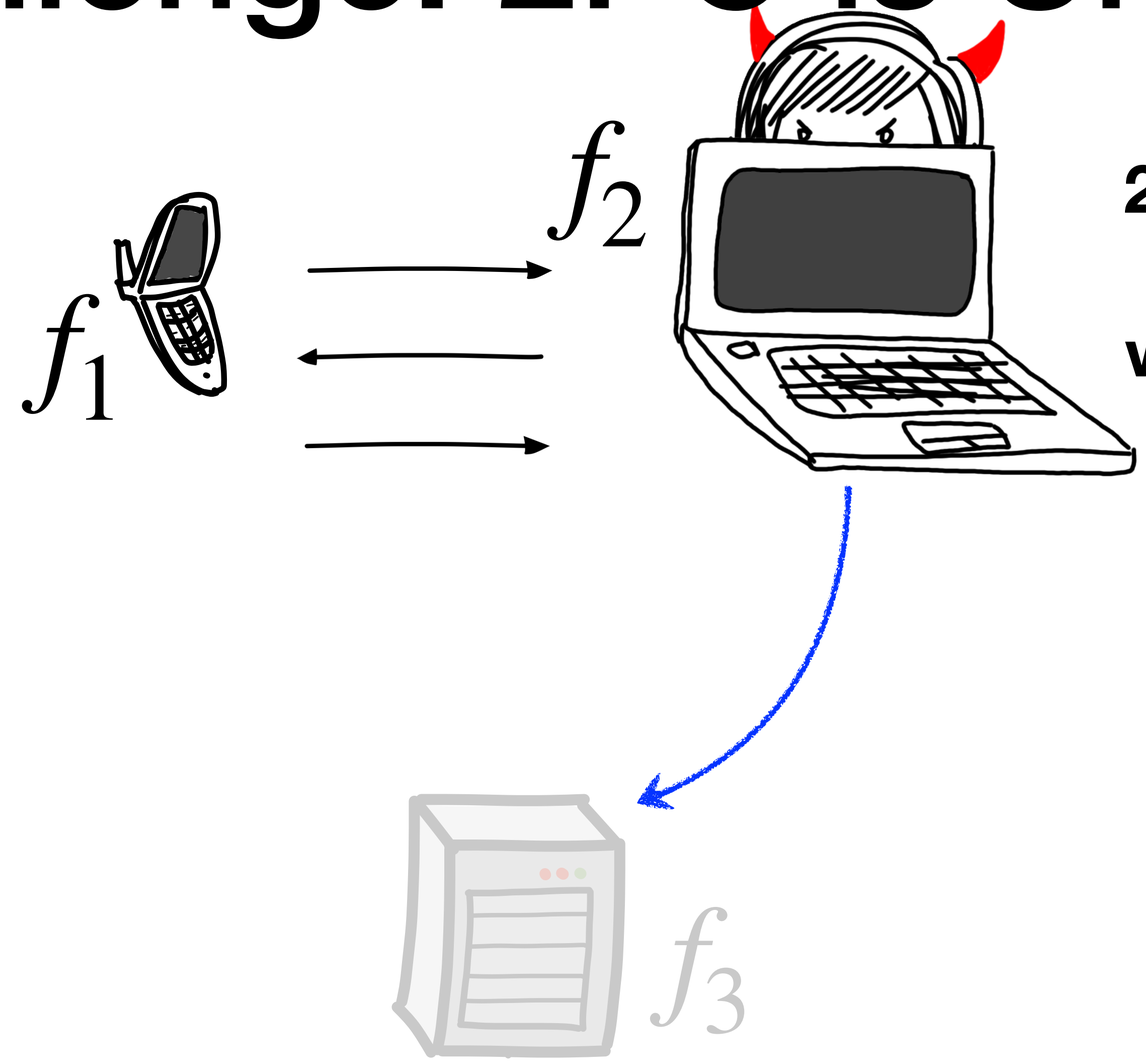

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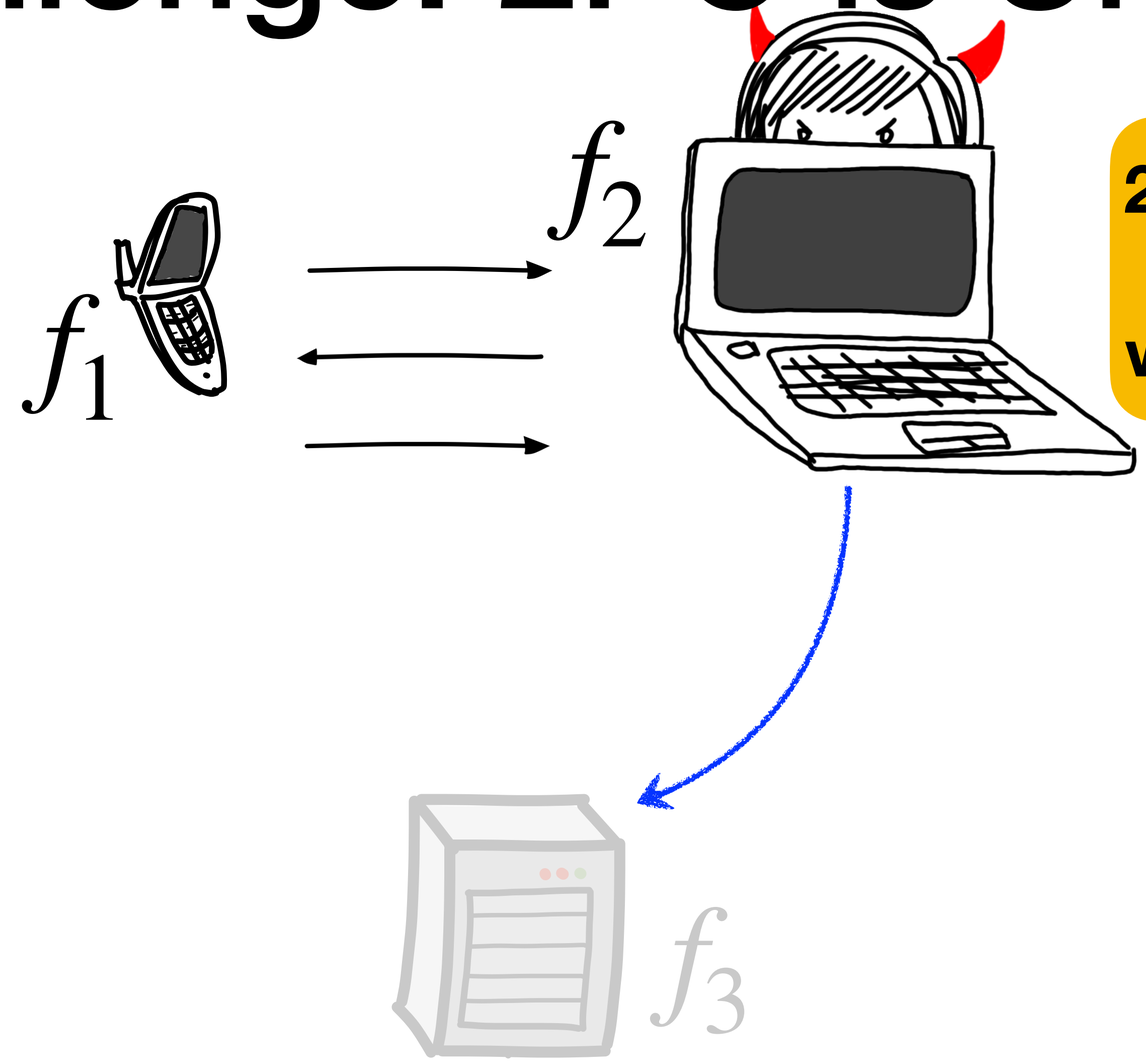

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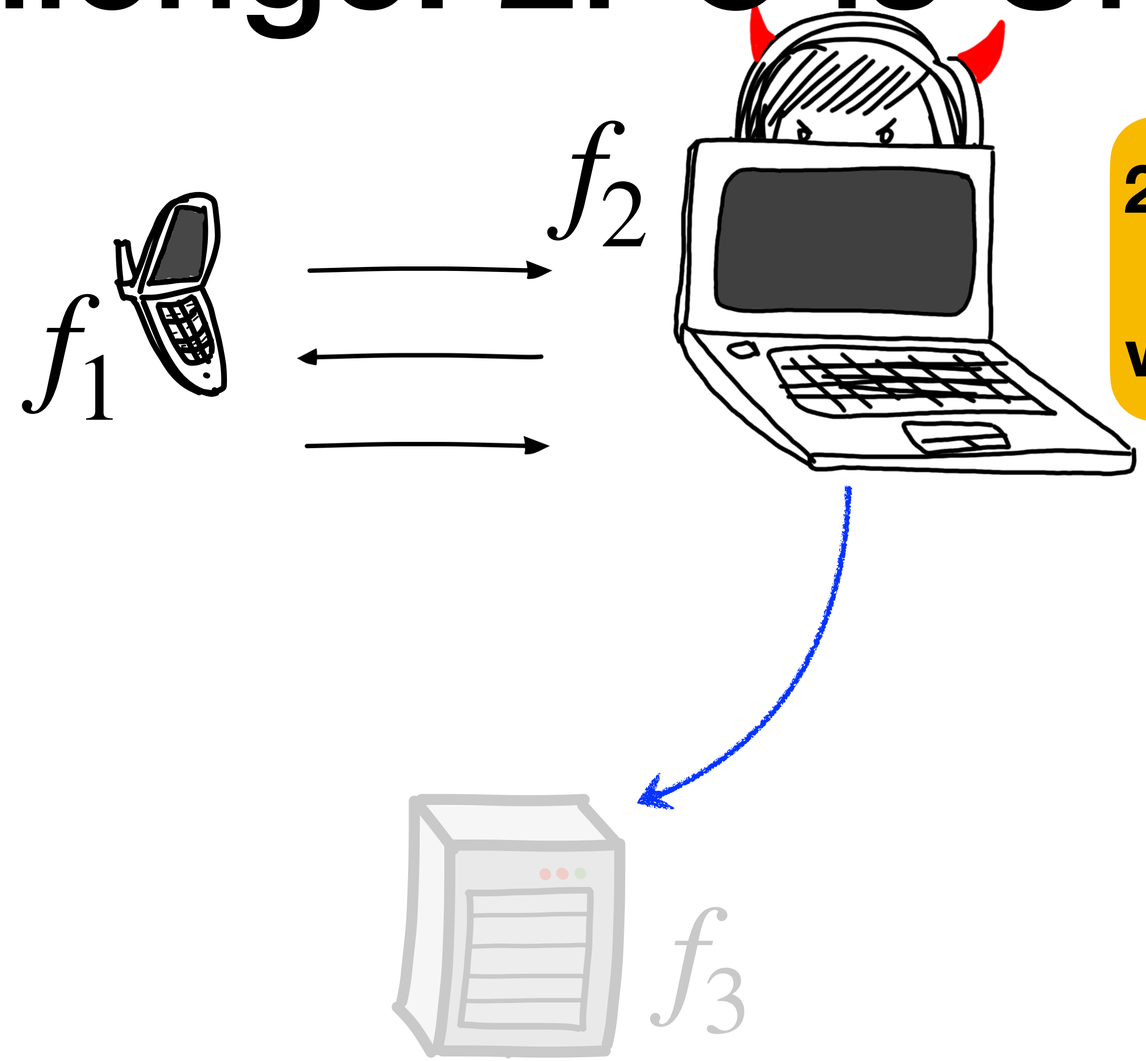

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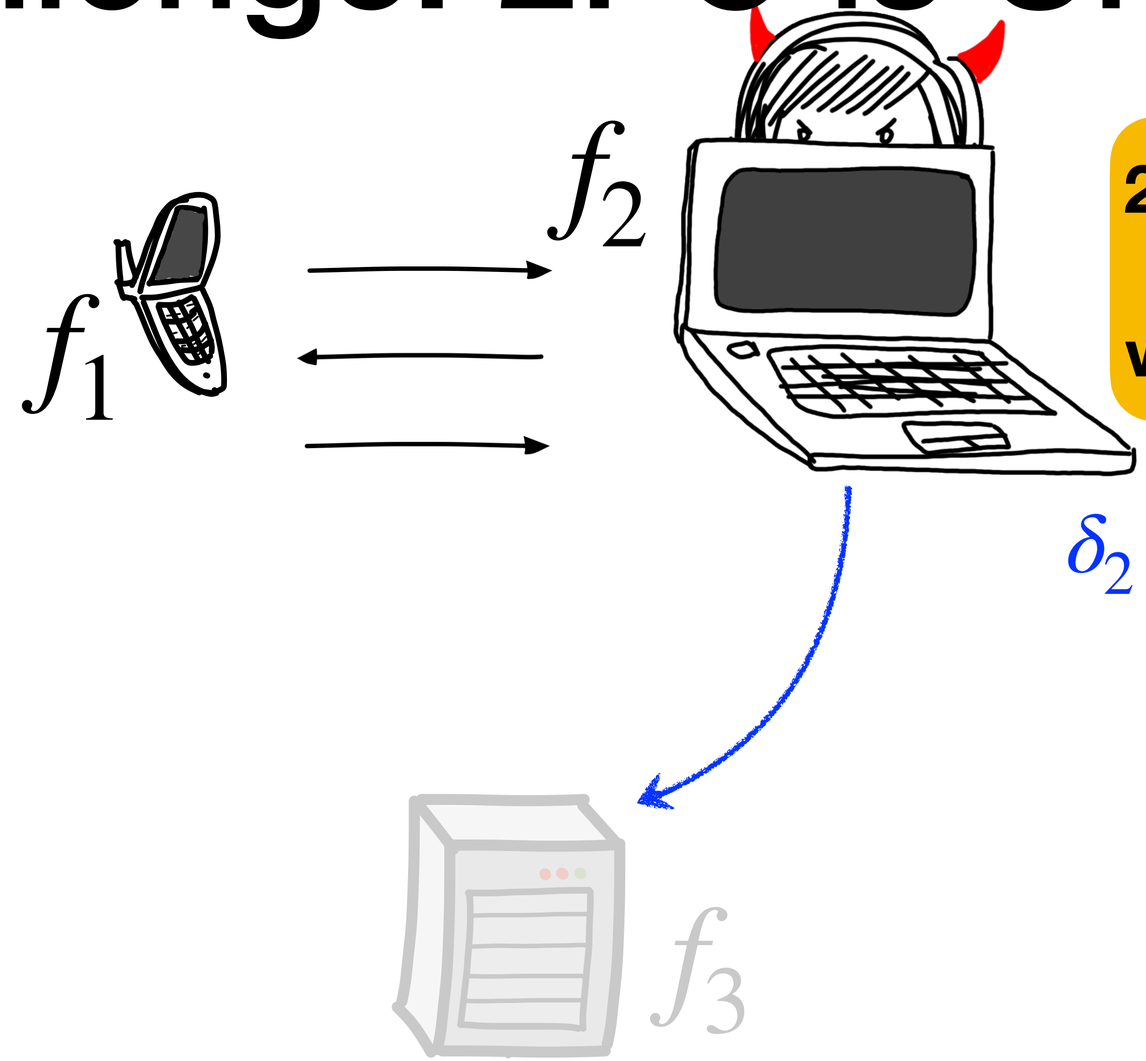


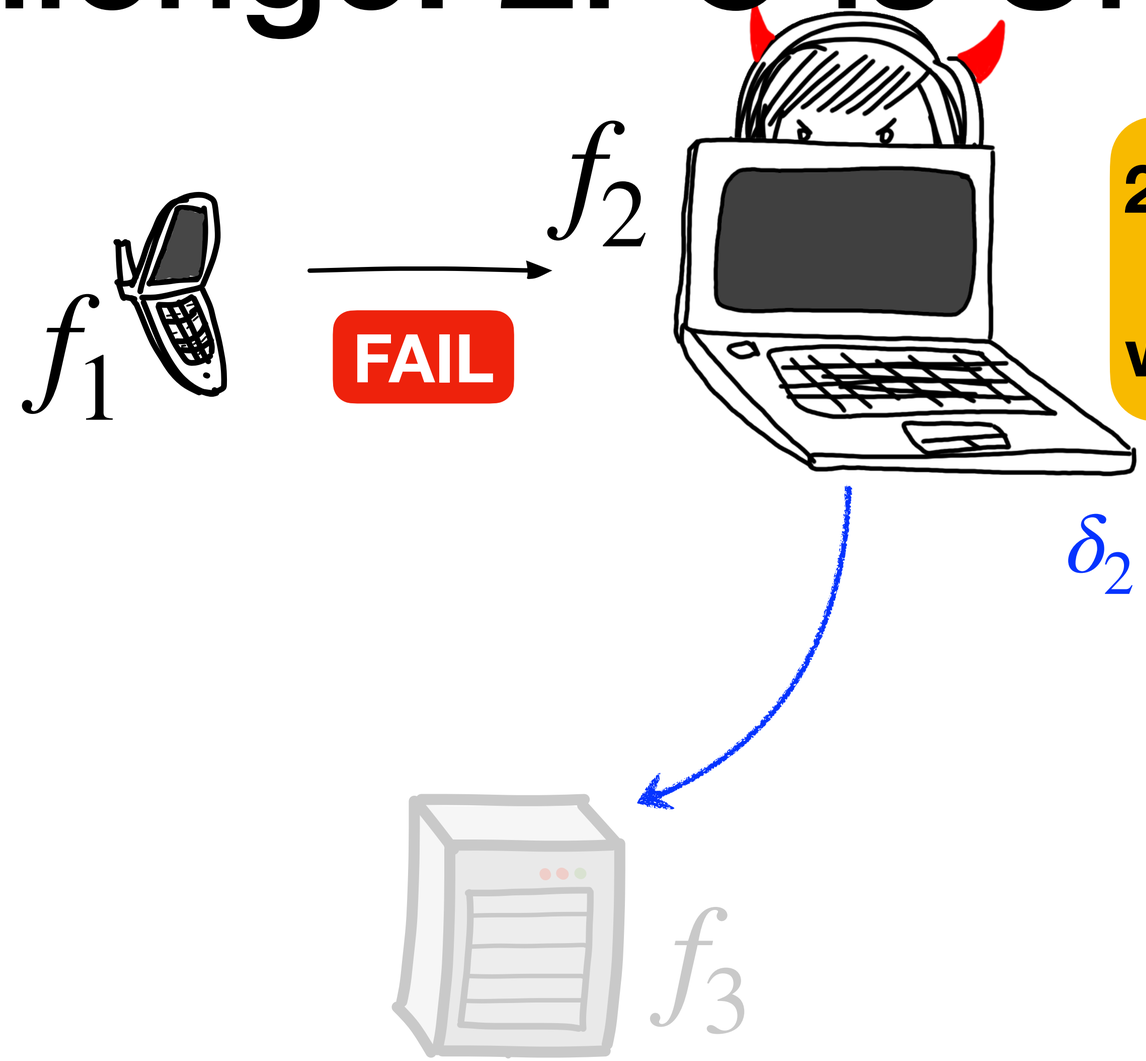
2 party computation (2PC) protocol with outputs δ_1, δ_2.

2PC is UNFAIR

δ_2 is delivered before δ_1

Lesson: δ_2 must be sufficient

Challenge: 2PC is Unfair



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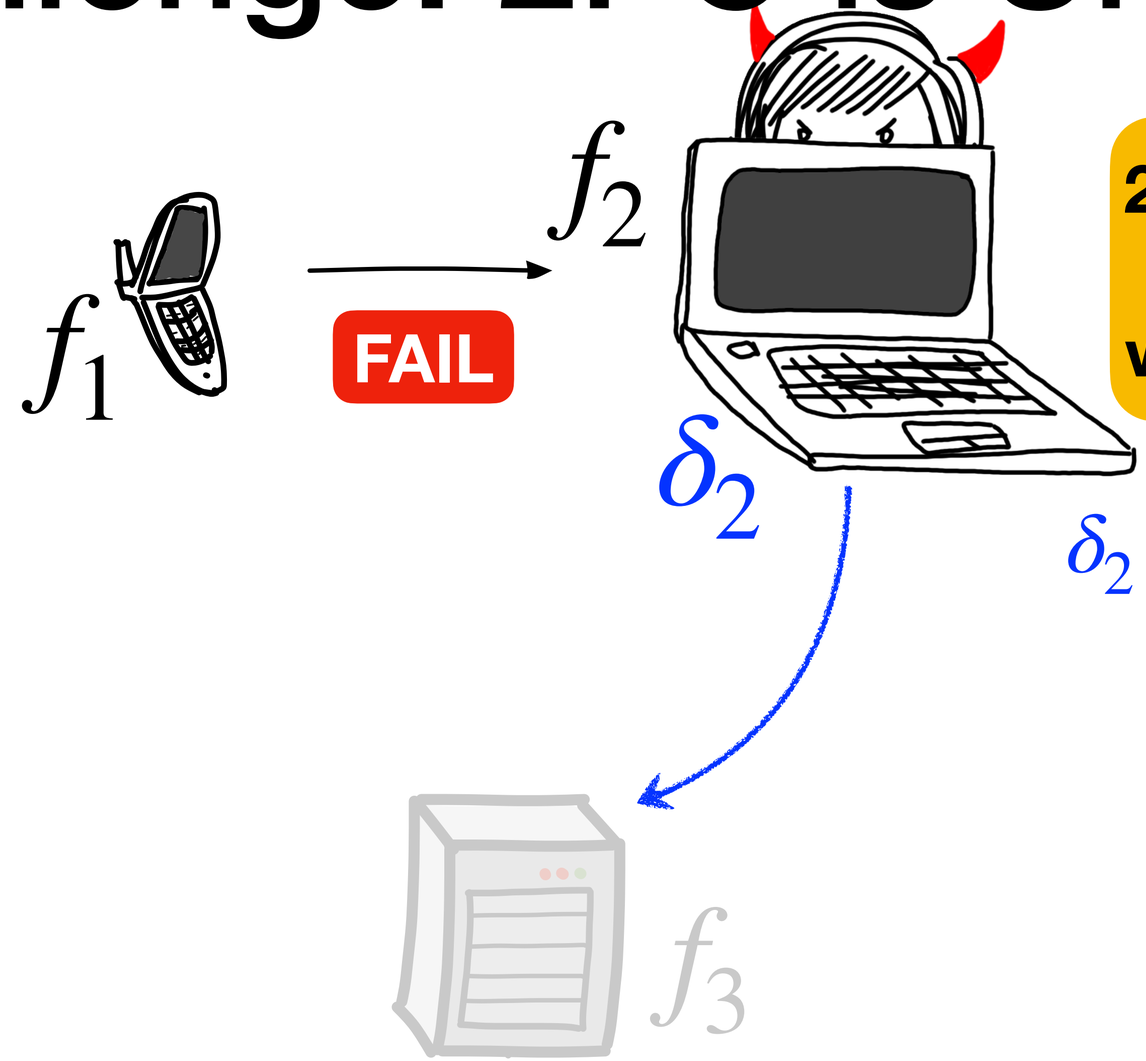
2PC is UNFAIR

δ_2 is delivered before δ_1

Lesson: δ_2 must be sufficient

Challenge: 2PC is Unfair



2 party computation (2PC) protocol with outputs δ_1, δ_2.

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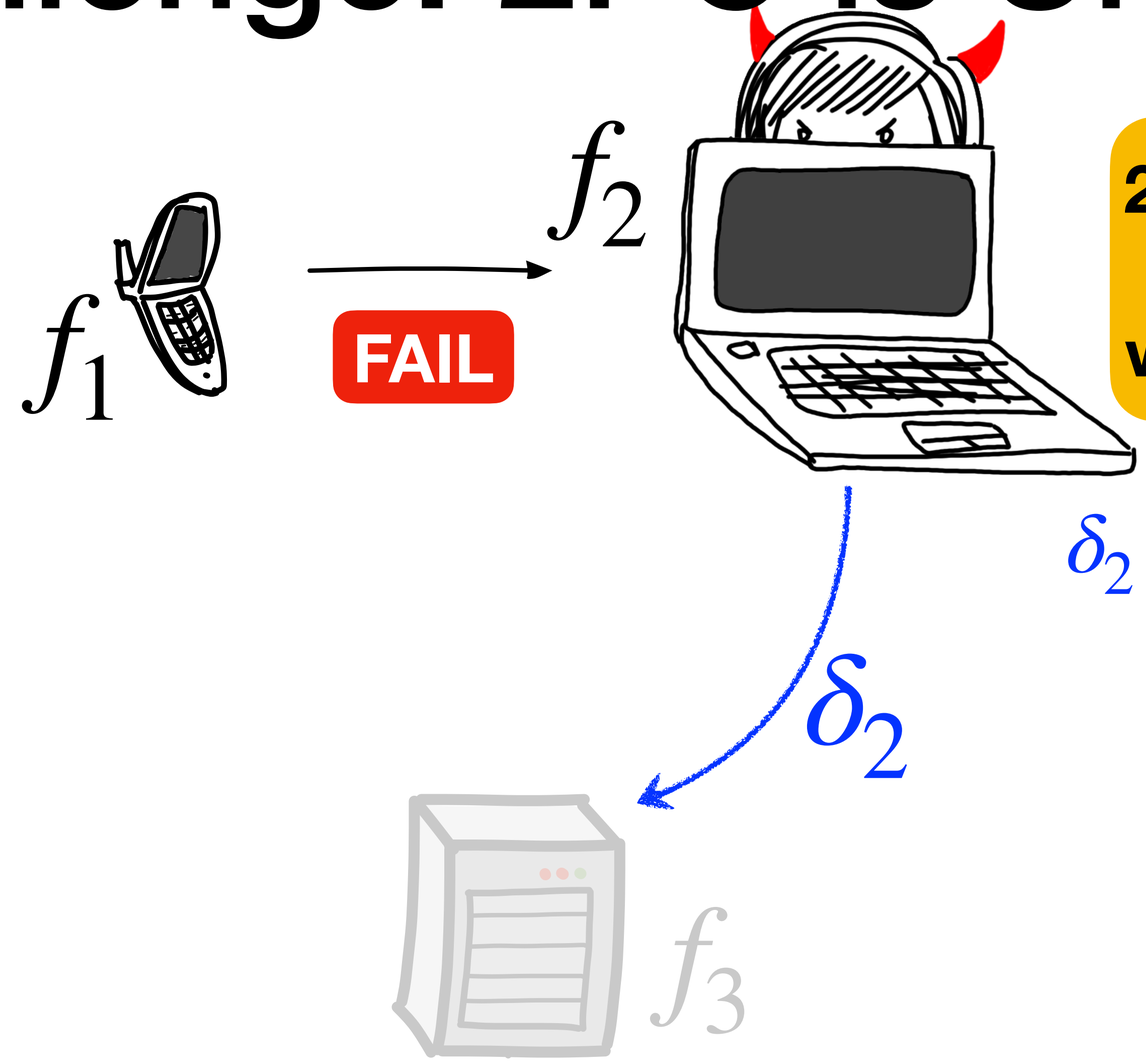

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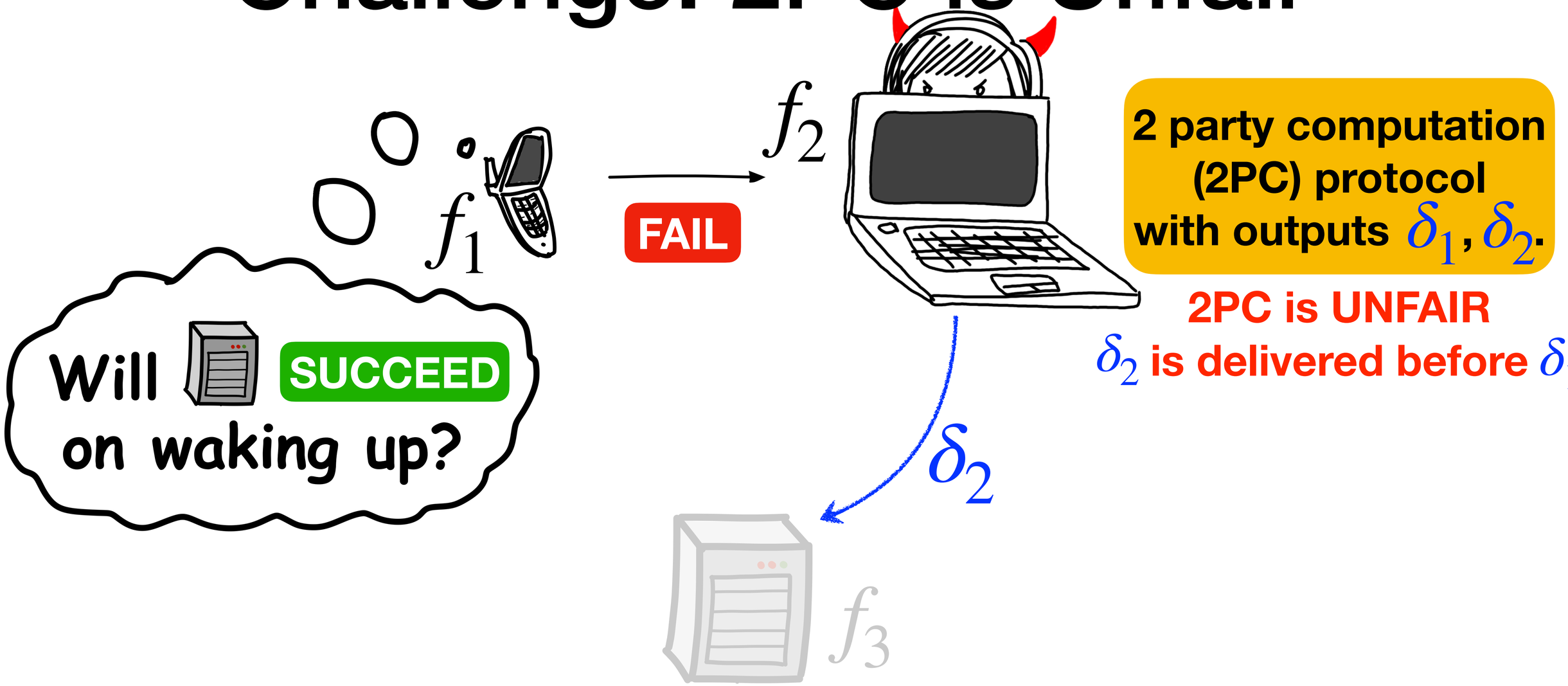

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2 party computation (2PC) protocol with outputs δ_1, δ_2.

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f_3

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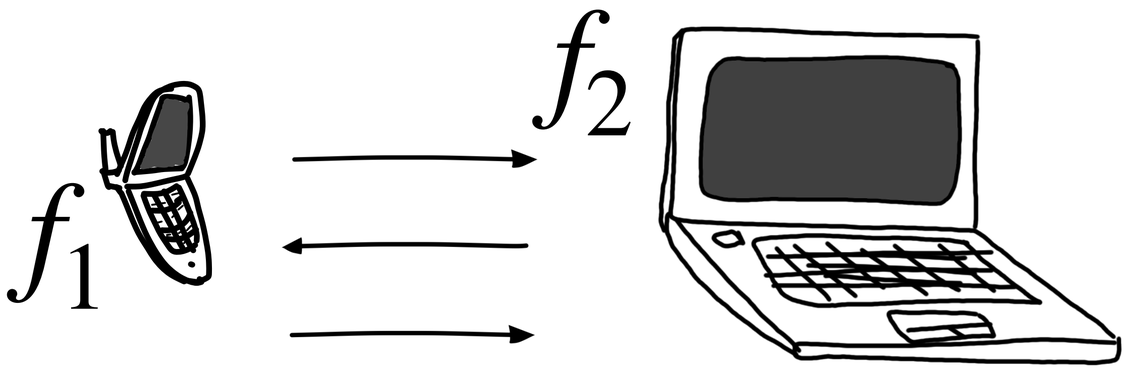
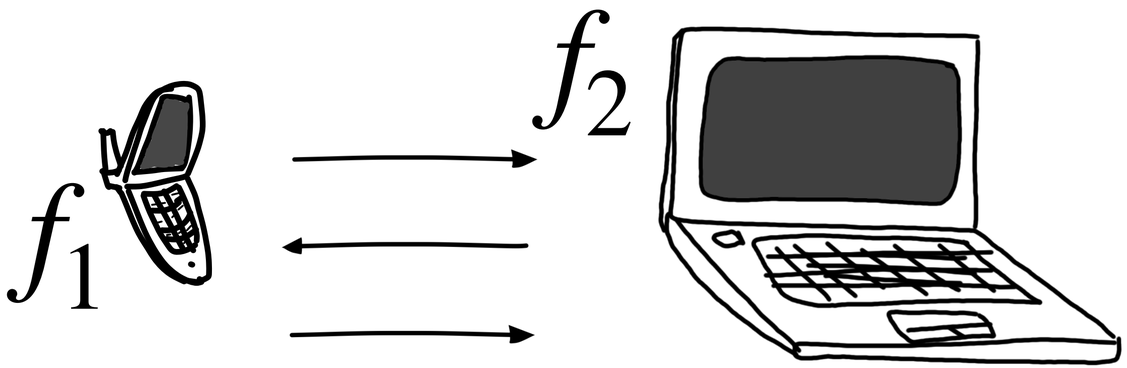
Towards a Solution

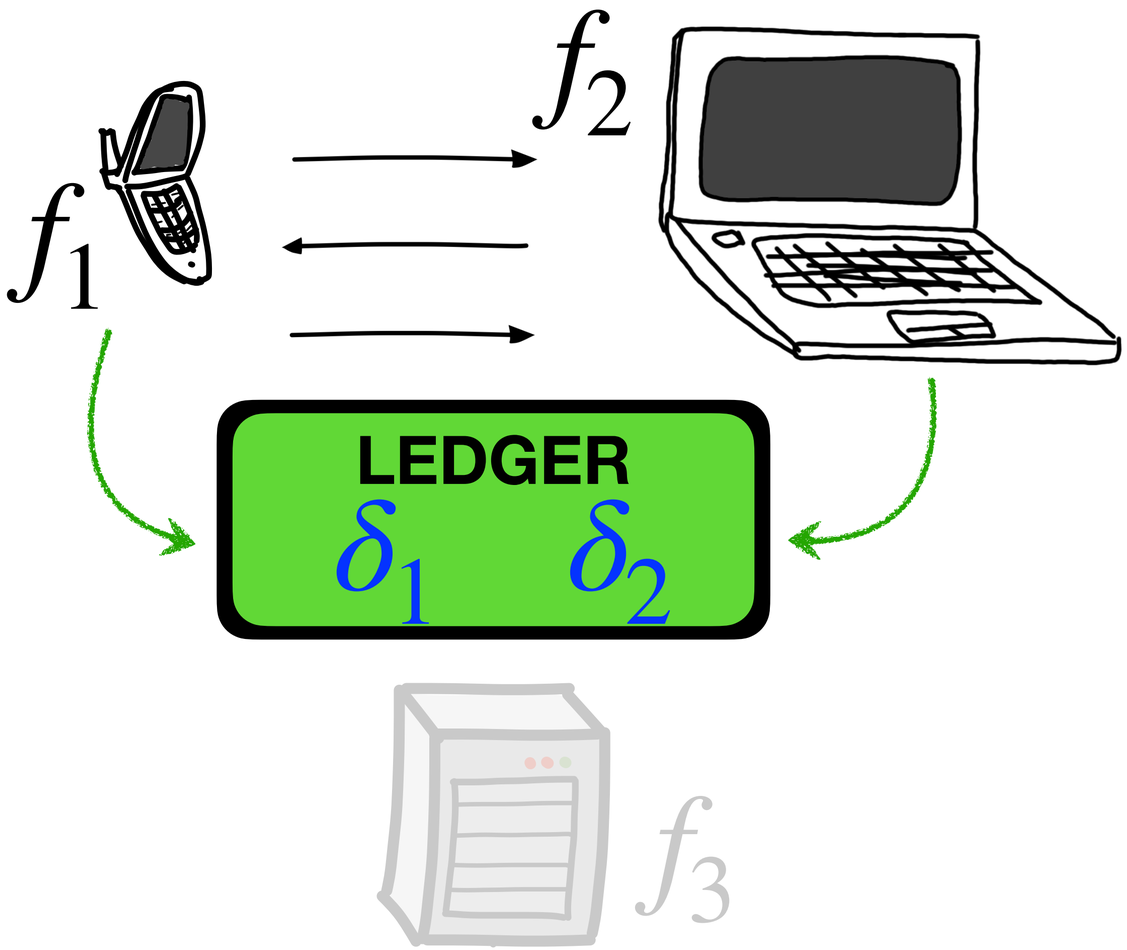


Towards a Solution

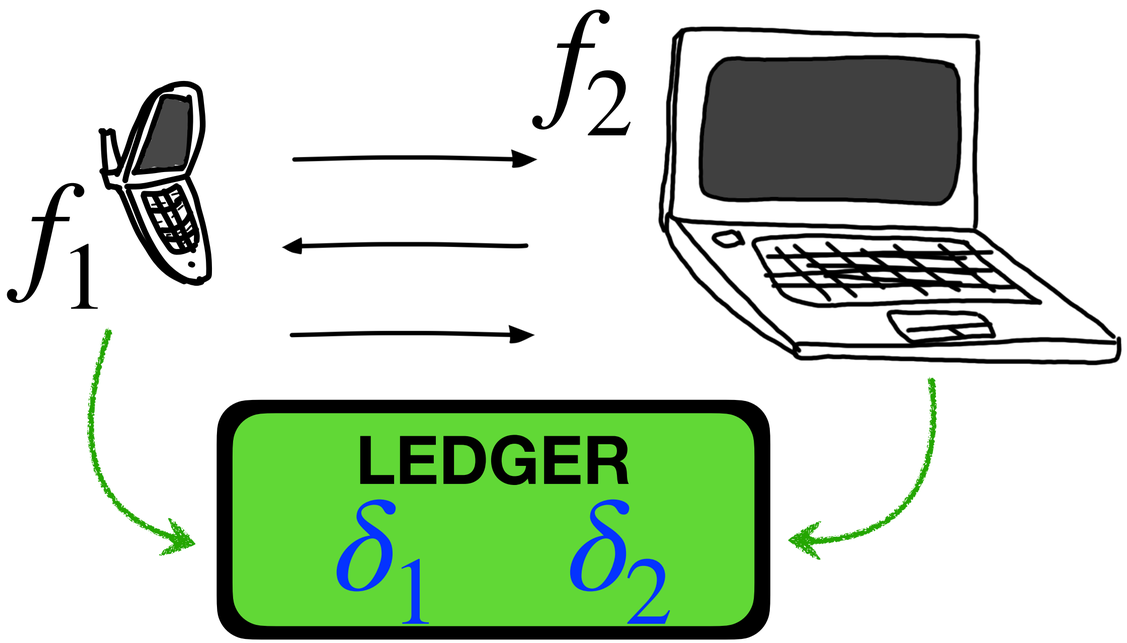


LEDGER

Towards a Solution

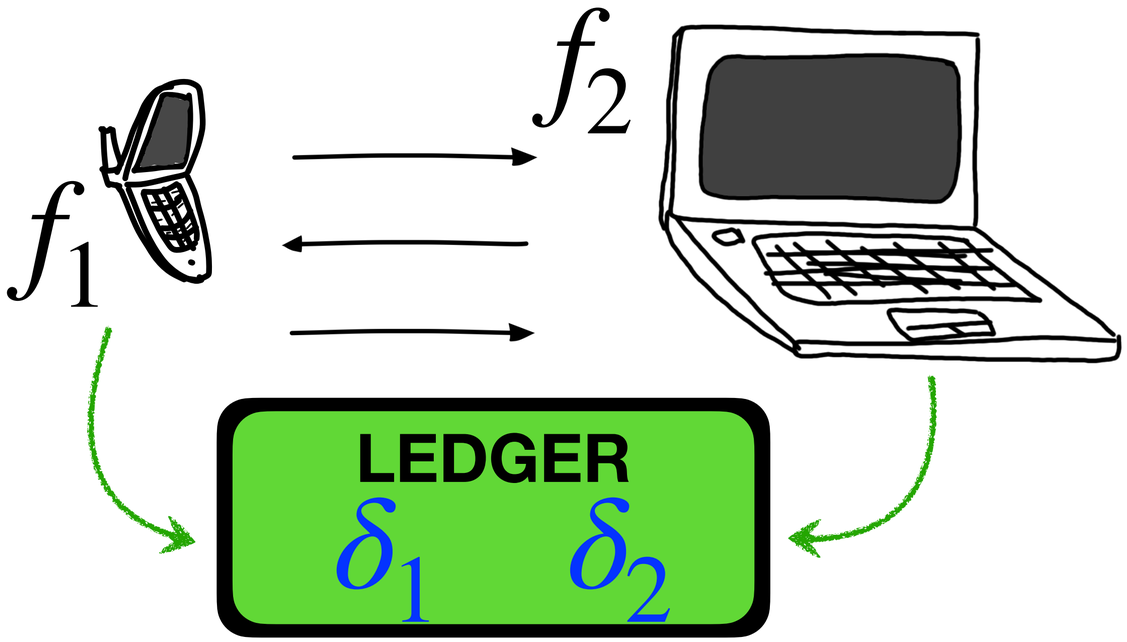


Towards a Solution



No ambiguity about what will see on waking up

Towards a Solution



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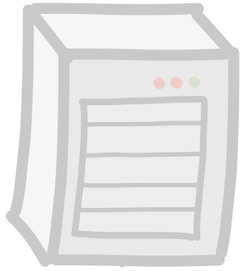

Solves unanimous erasure, but kills privacy

General Problem Flavour

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- P2P channels convey information privately, but can’t be verified

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General Problem Flavour

- P2P channels convey information privately, but can't be verified
- Public channels can be verified but can't convey private information
- **Our approach**: use P2P channels to convey δ_1, δ_2 and ledger to achieve consensus on whether or not to use them.
- Public and private values are linked via nonces of sigs created by *interleaved threshold signing*

ECDSA / Schnorr

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Discrete logarithm based signatures

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Discrete logarithm based signatures

Public key: $X = x \cdot G$

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$X \in \mathbb{G}$ $x \in \mathbb{Z}_q$

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Signatures: (R, σ)

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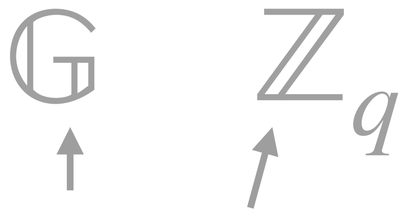

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Discrete logarithm based signatures

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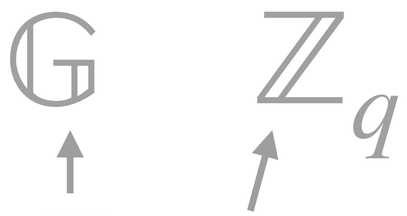
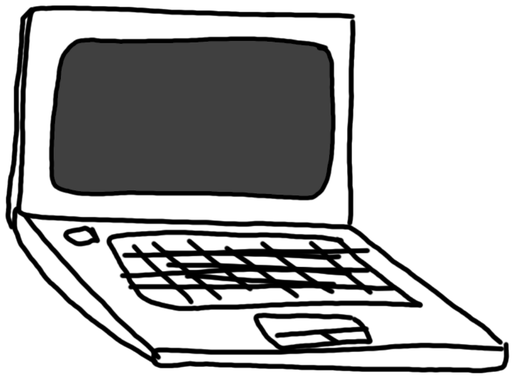


Signatures: (R, σ)

Random

Threshold ECDSA/Schnorr



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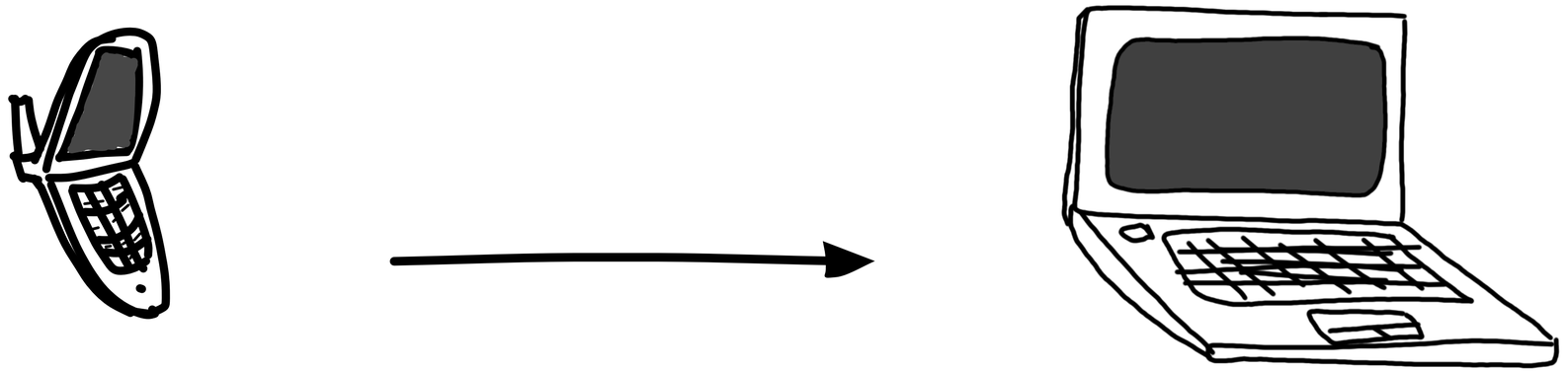

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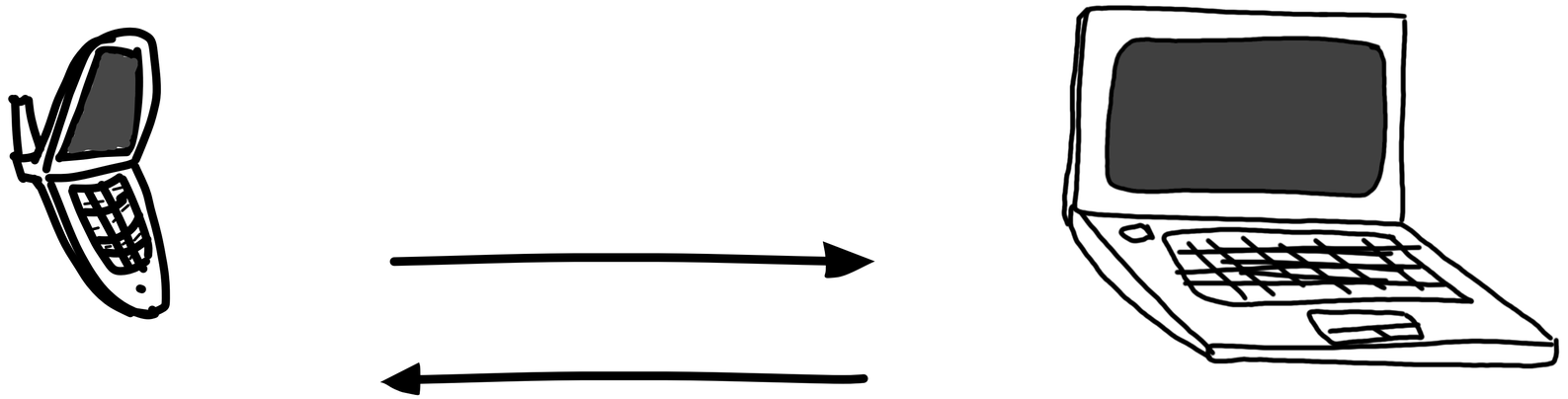

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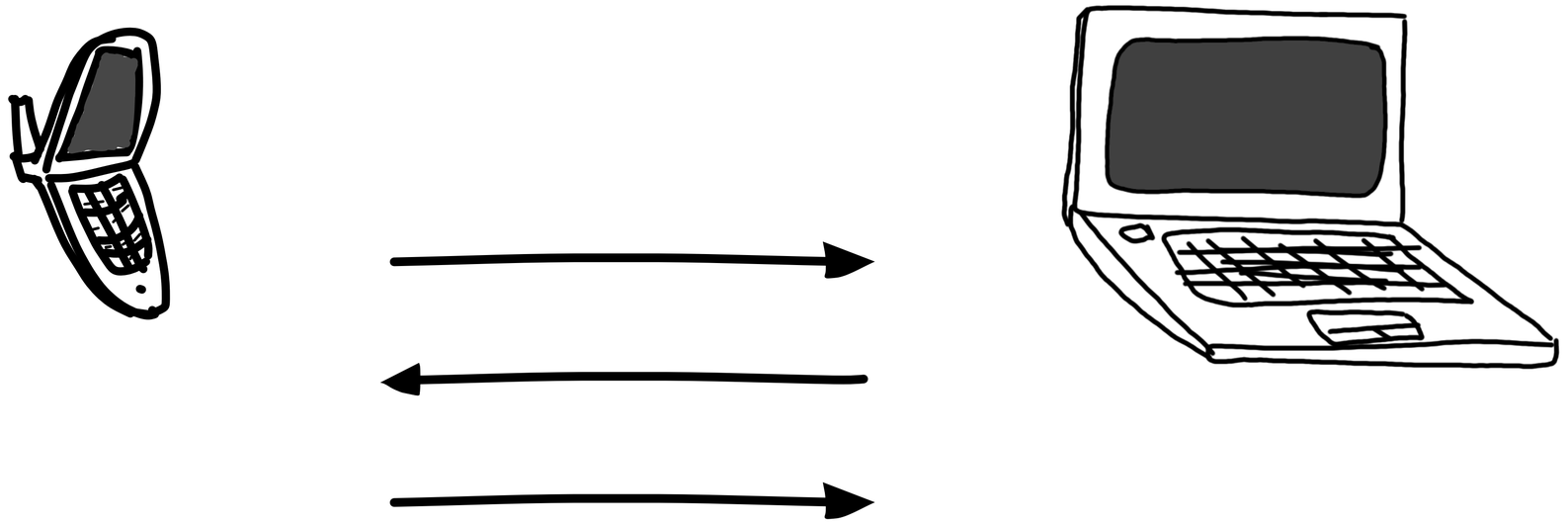

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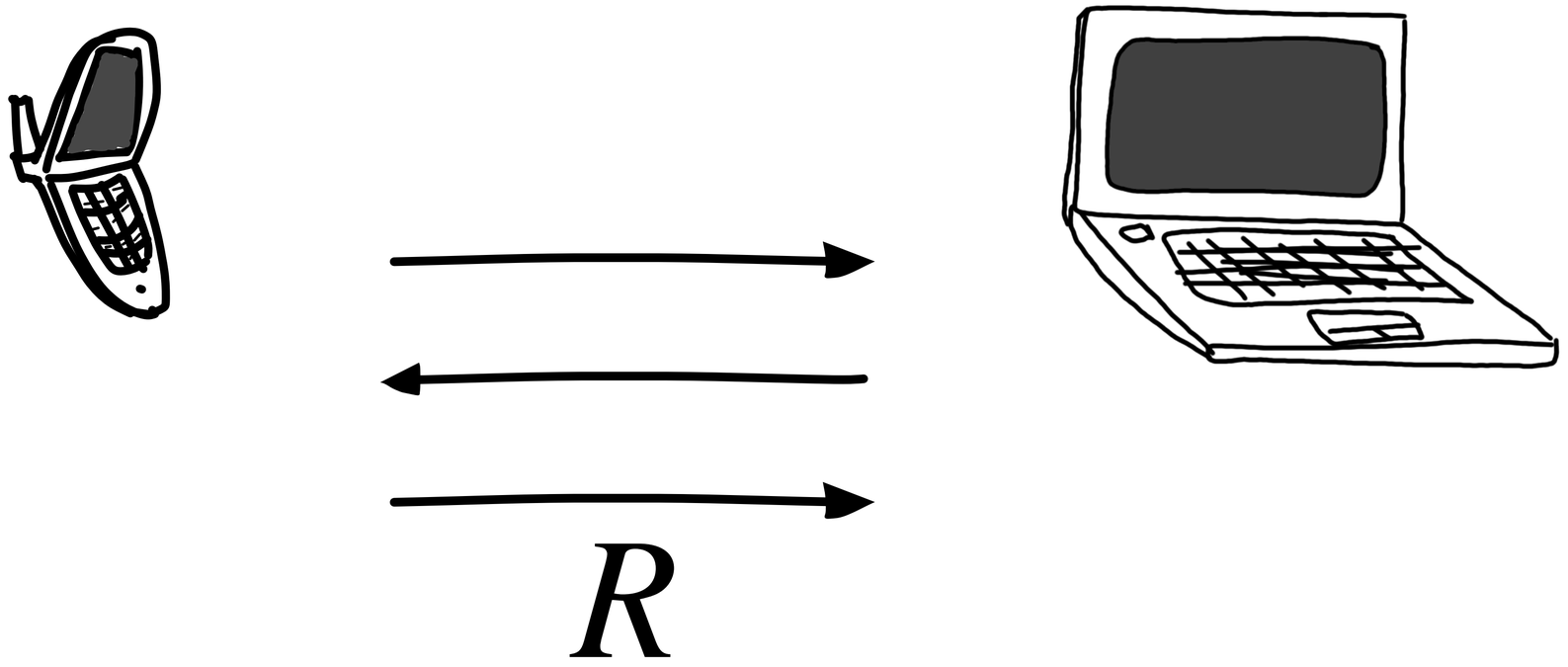

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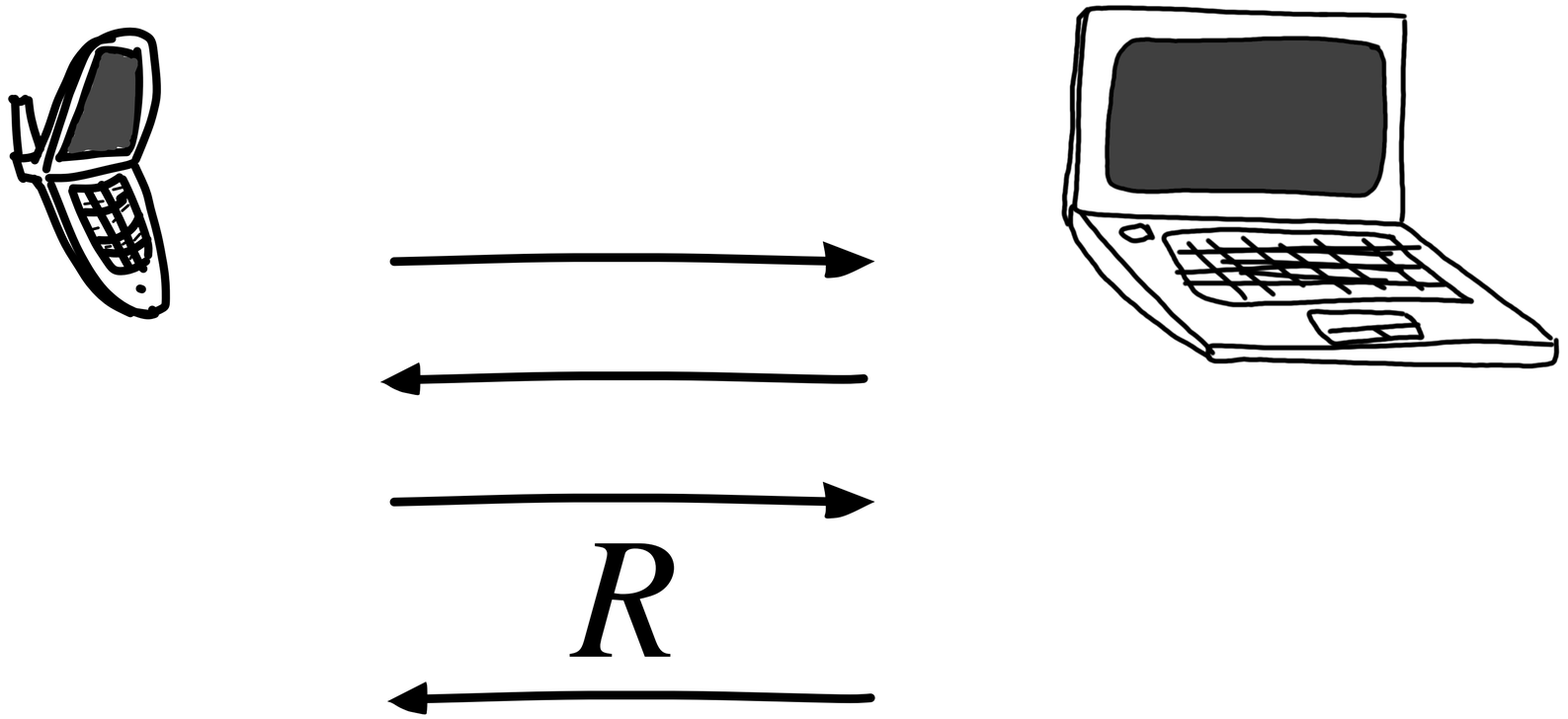

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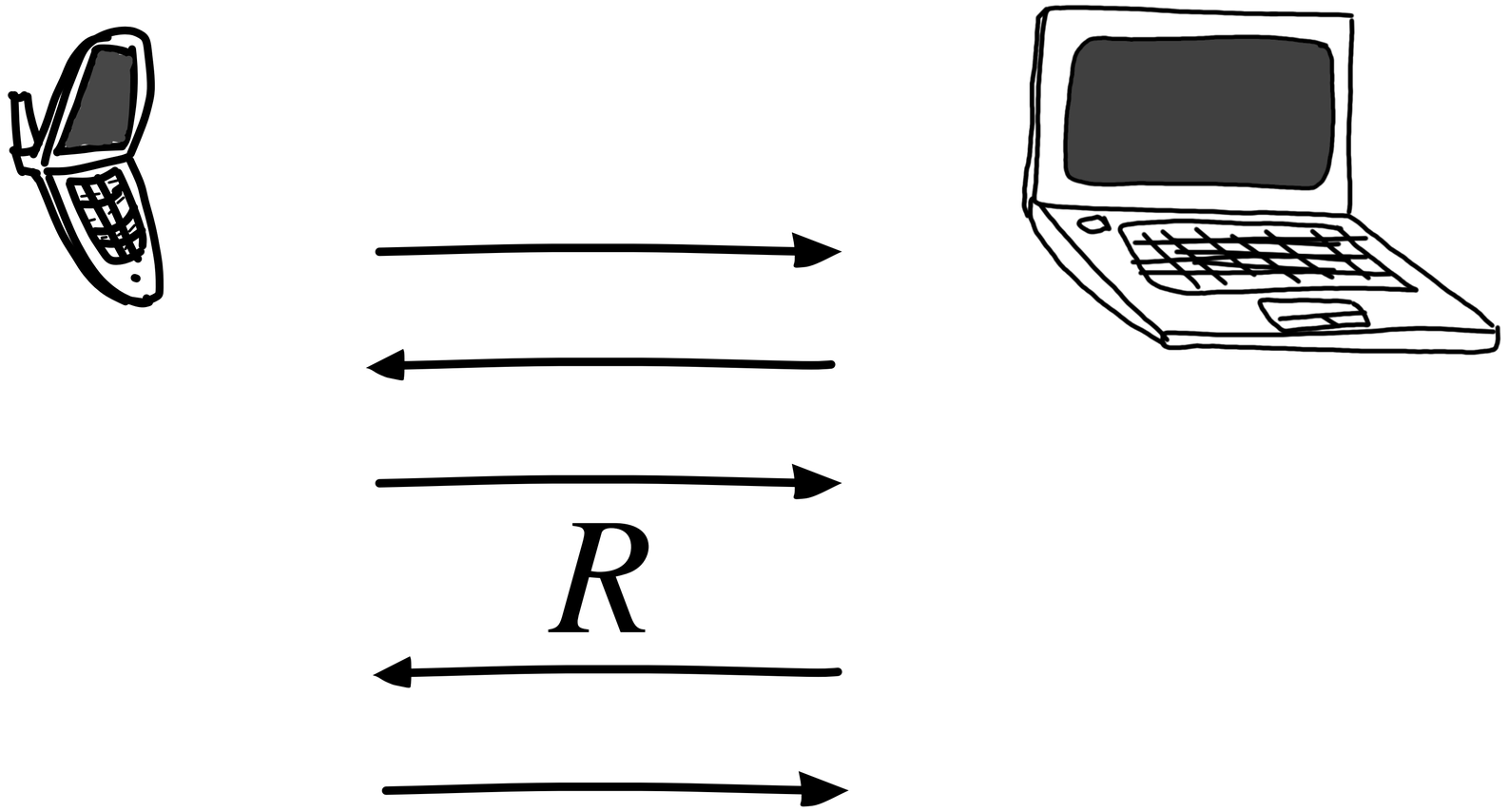

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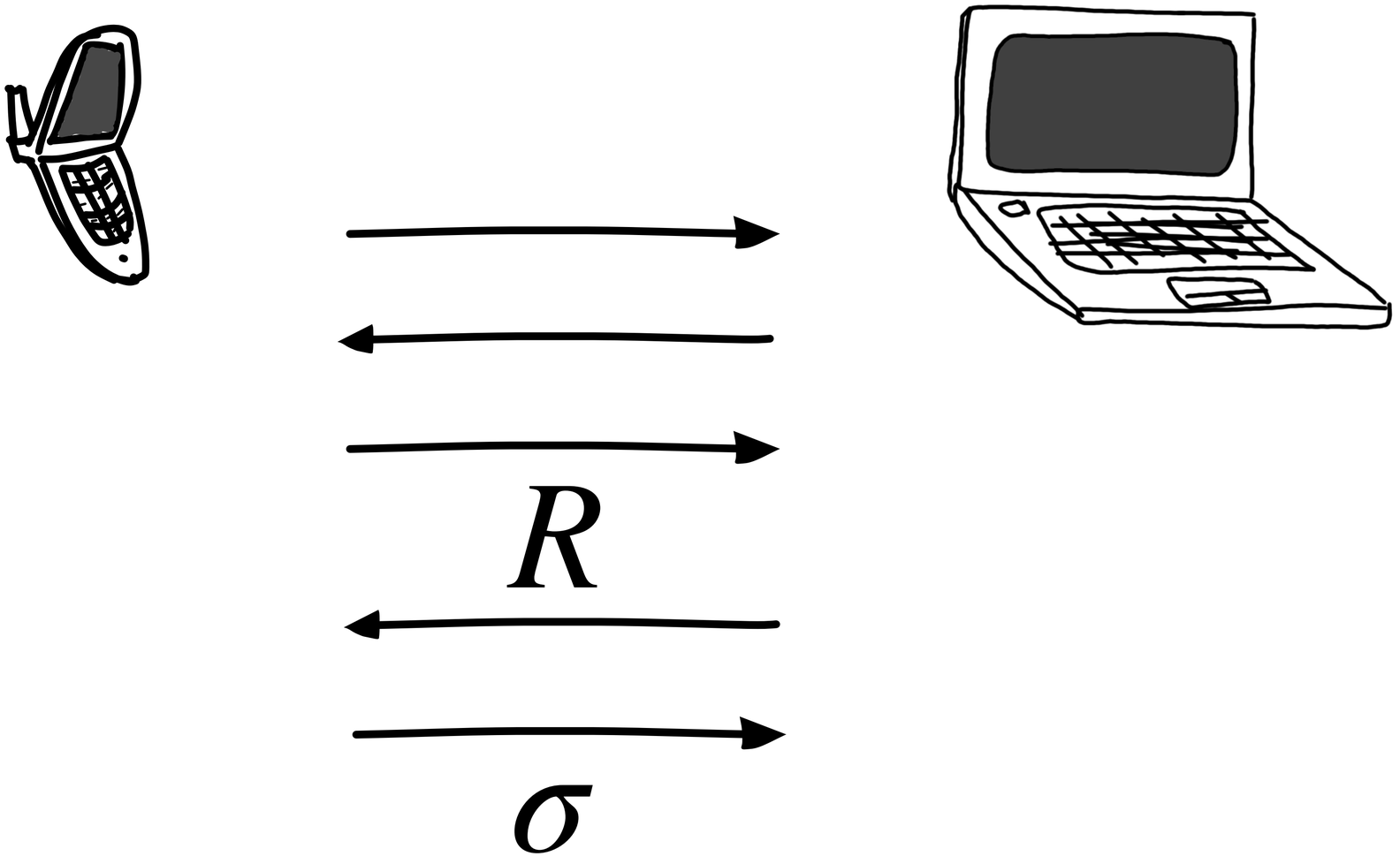

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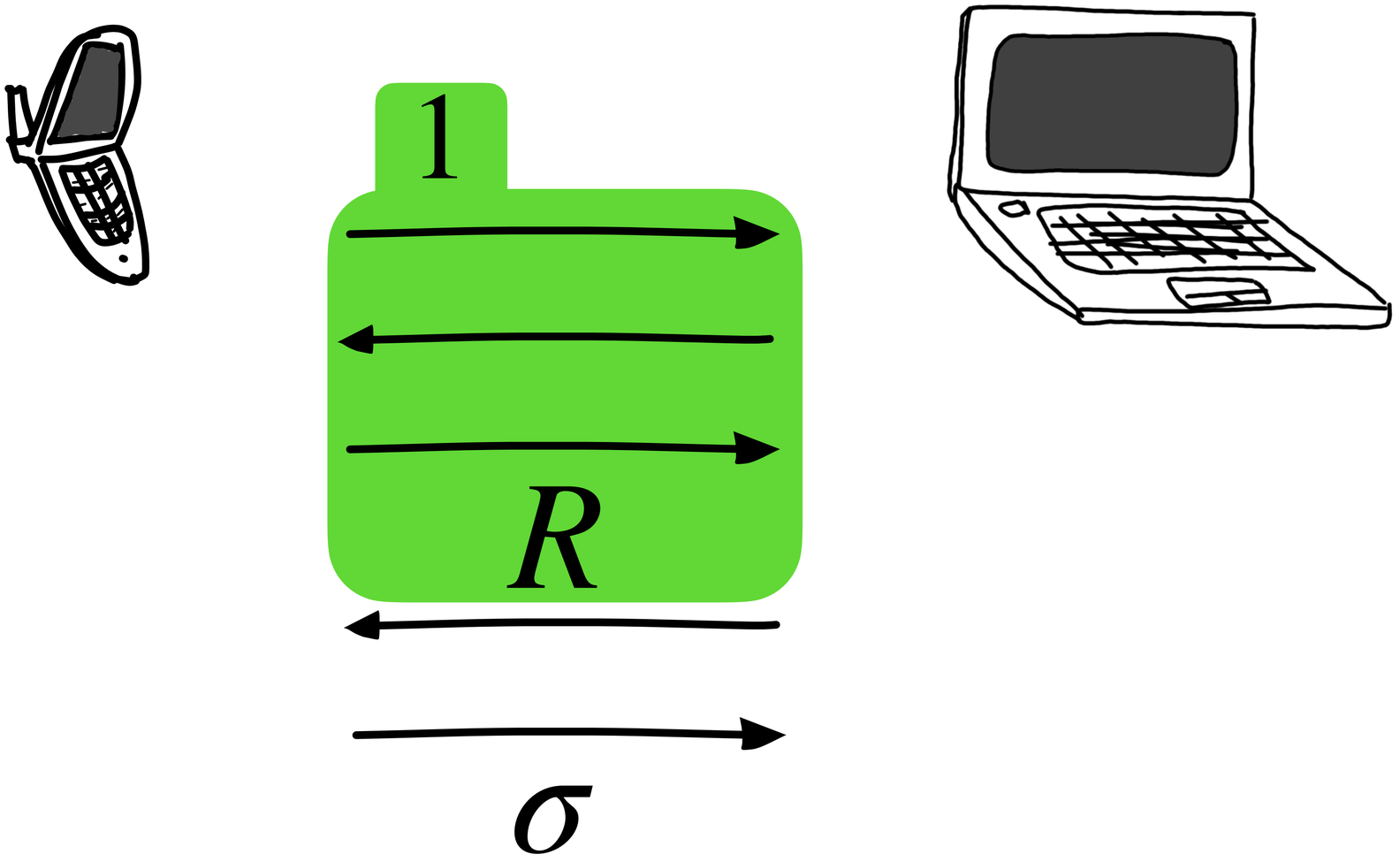

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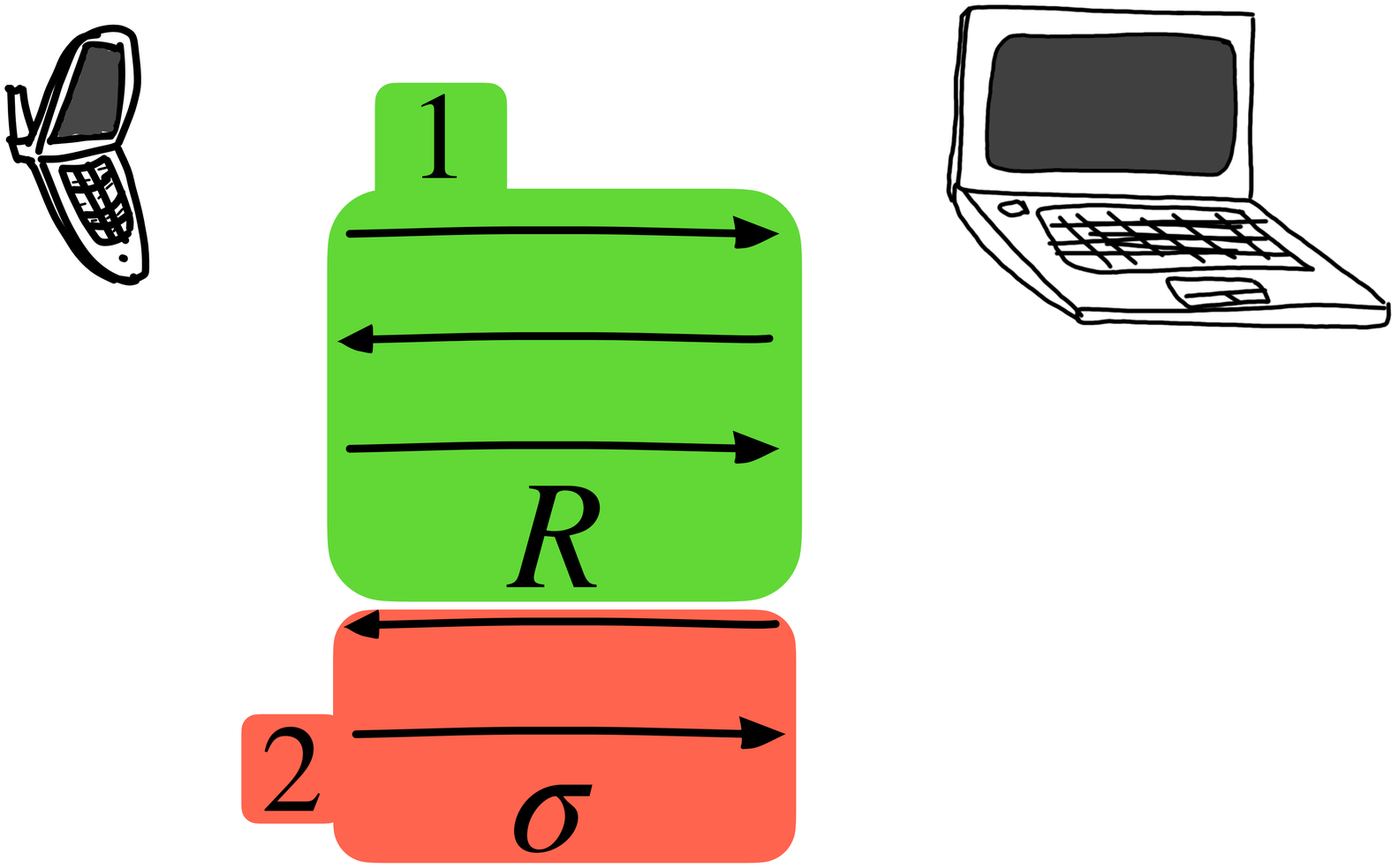

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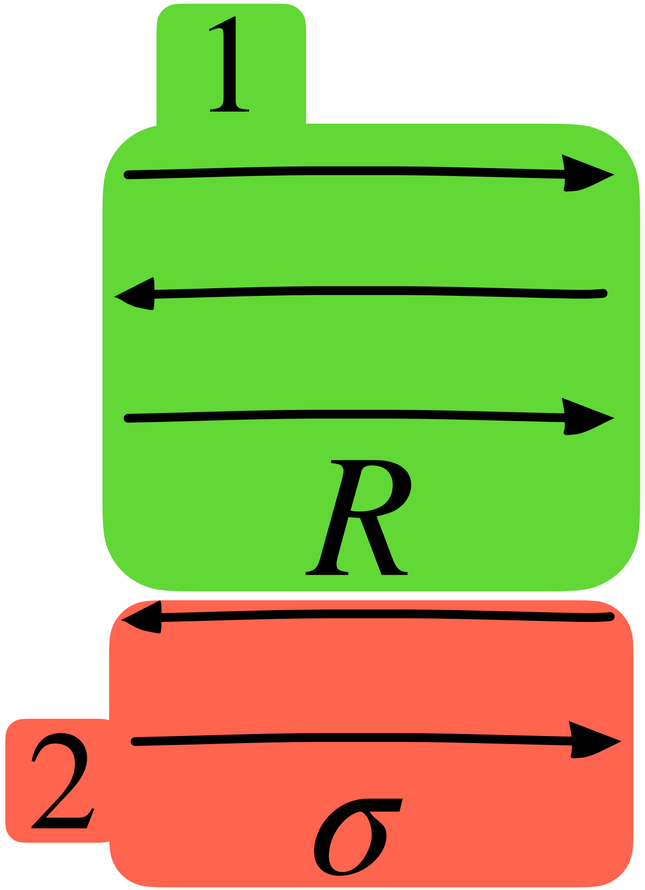

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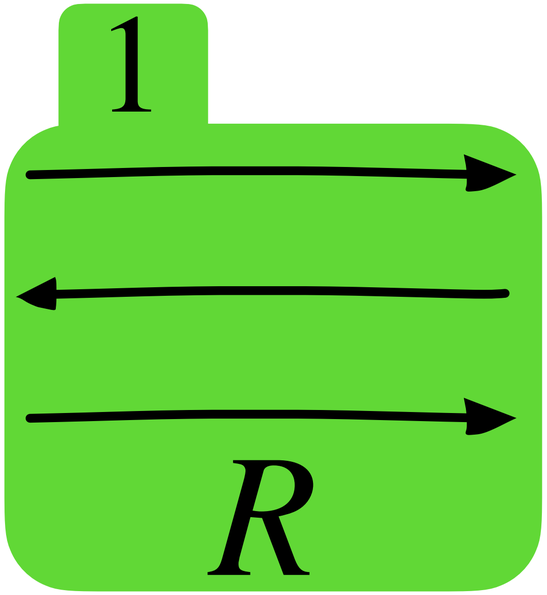

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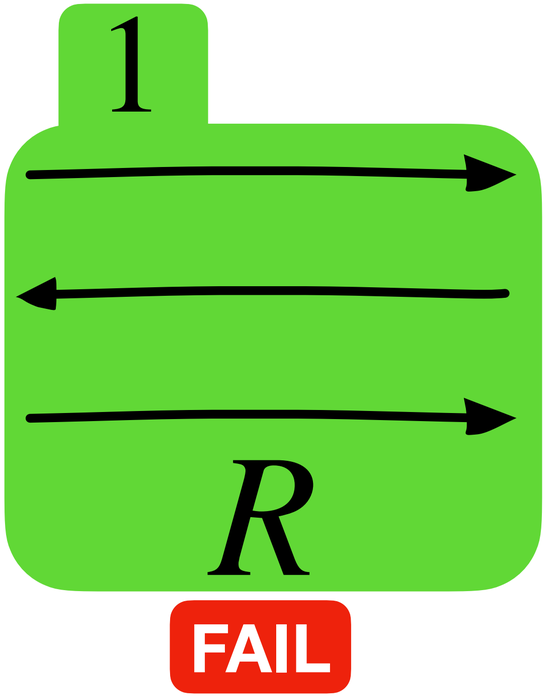

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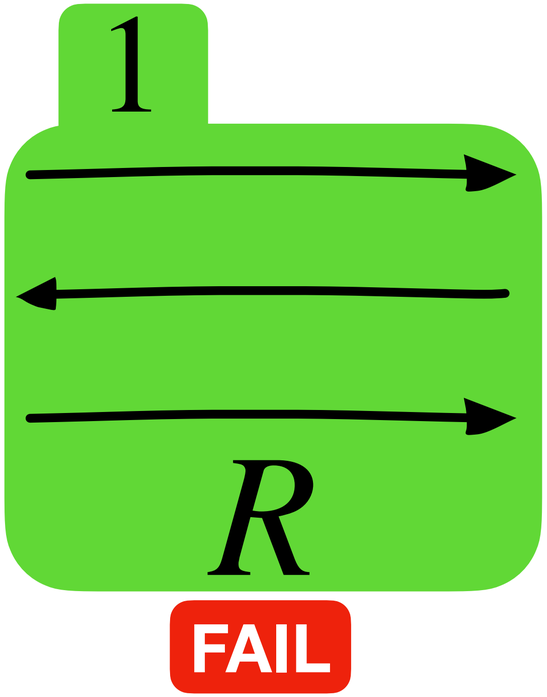

Signatures: (R, σ)

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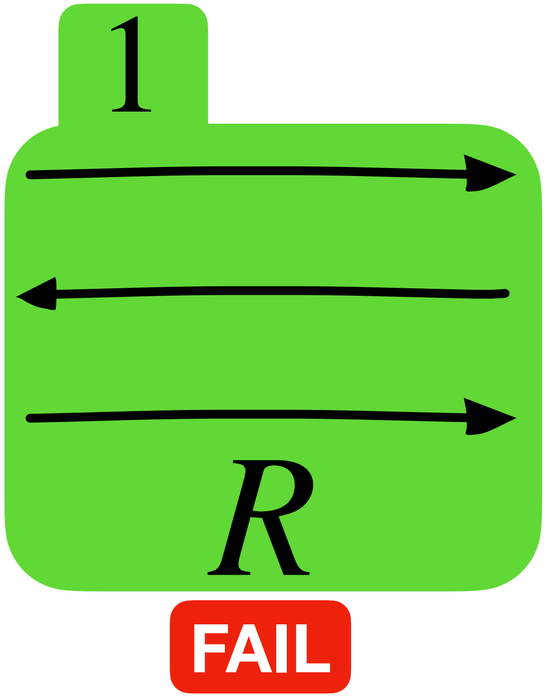

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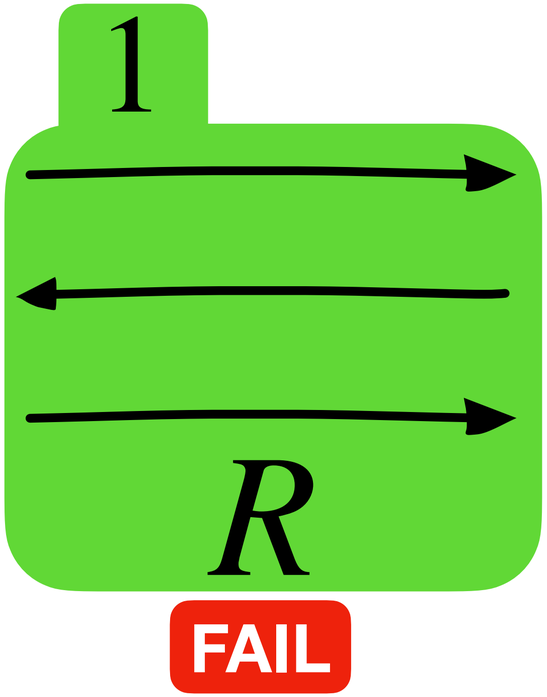

No advantage in computing this

Signatures: (R, σ)

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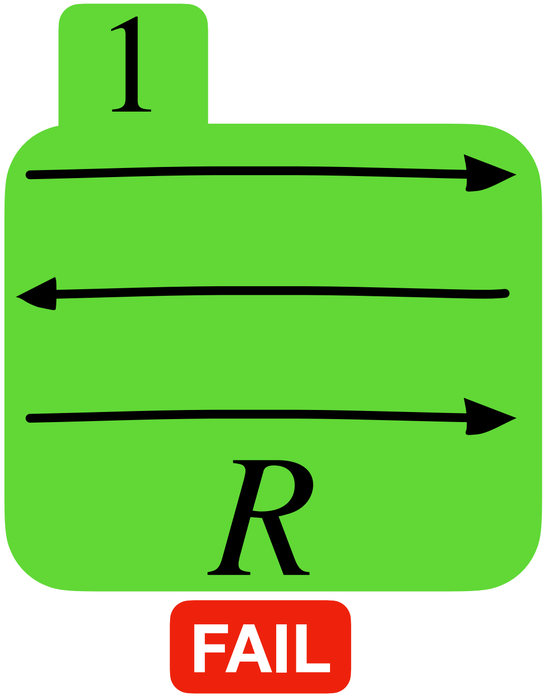


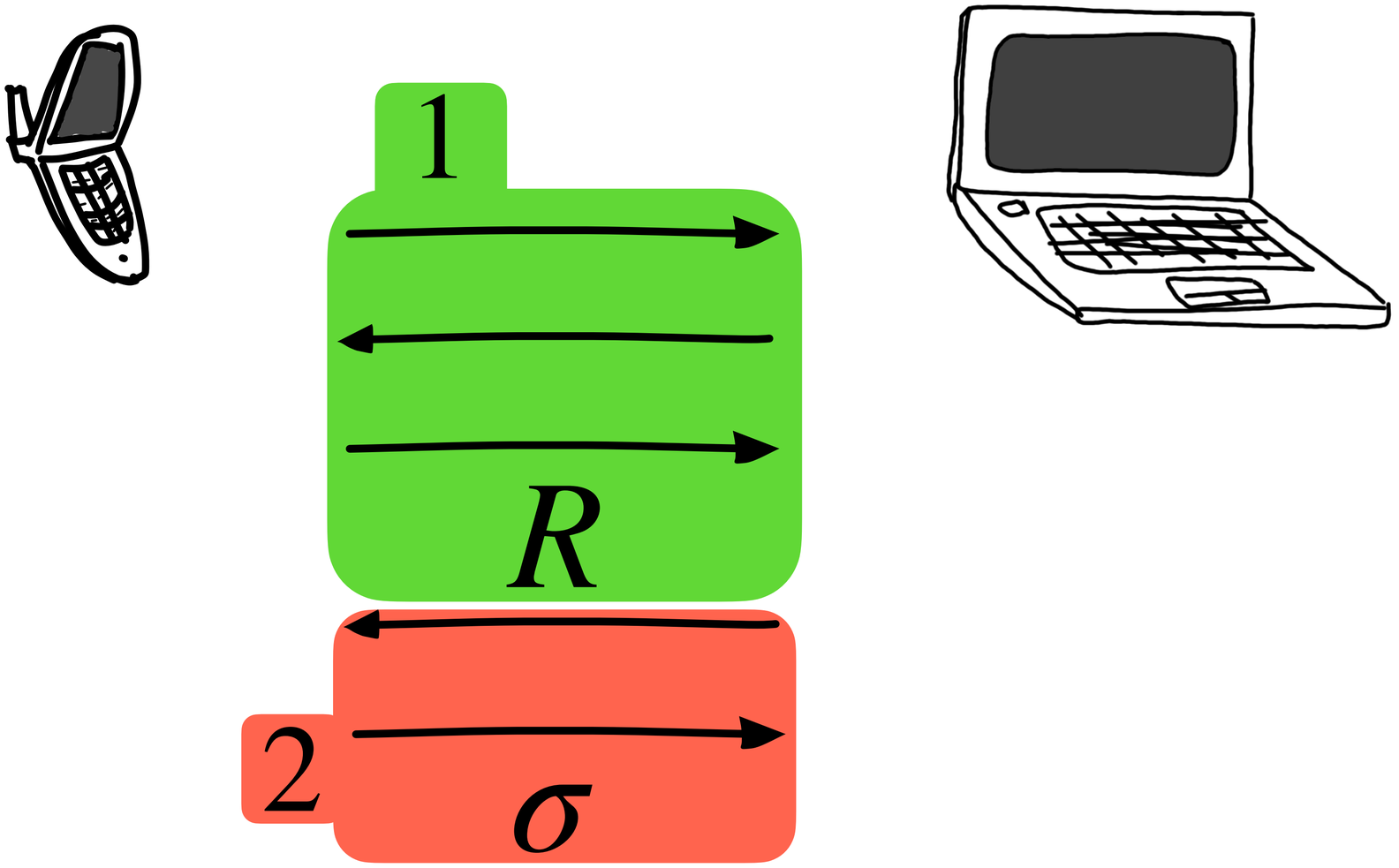
Achieved by most natural thresh Schnorr and ECDSA schemes

[DKLs19, GG18, LNR18, GJKR07]

No advantage in computing this

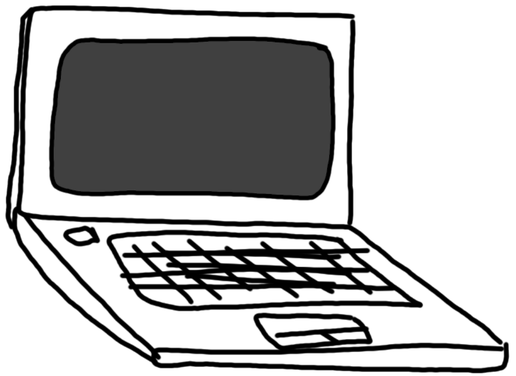
Signatures: (R, σ)

Threshold ECDSA/Schnorr



Interleaved Threshold Signing

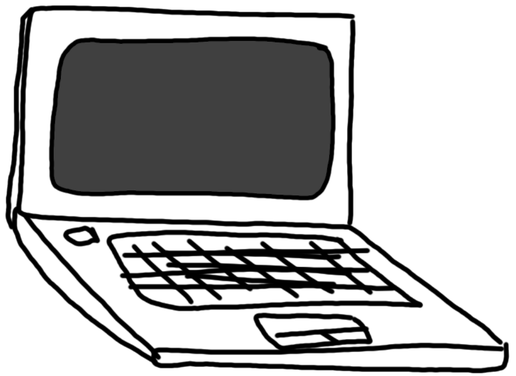
1 R



2 σ

Interleaved Threshold Signing

$1 \quad R$



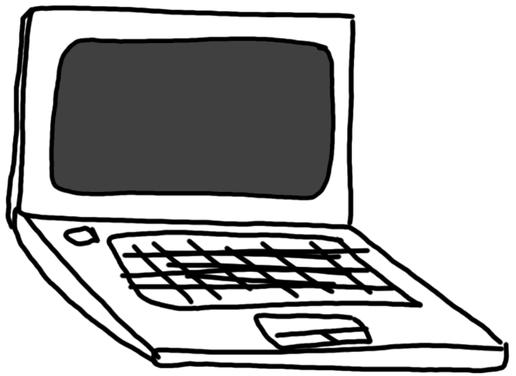
$\delta \longleftrightarrow \delta$

$2 \quad \sigma$

Interleaved Threshold Signing

Interleaved Threshold Signing

$1 \quad R$



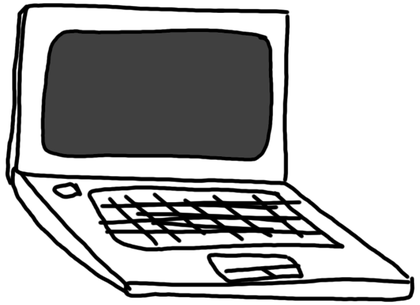
$\delta \quad \mathrm{sig}_{\delta,R}$

$2 \quad \sigma$

Interleaved Threshold Signing

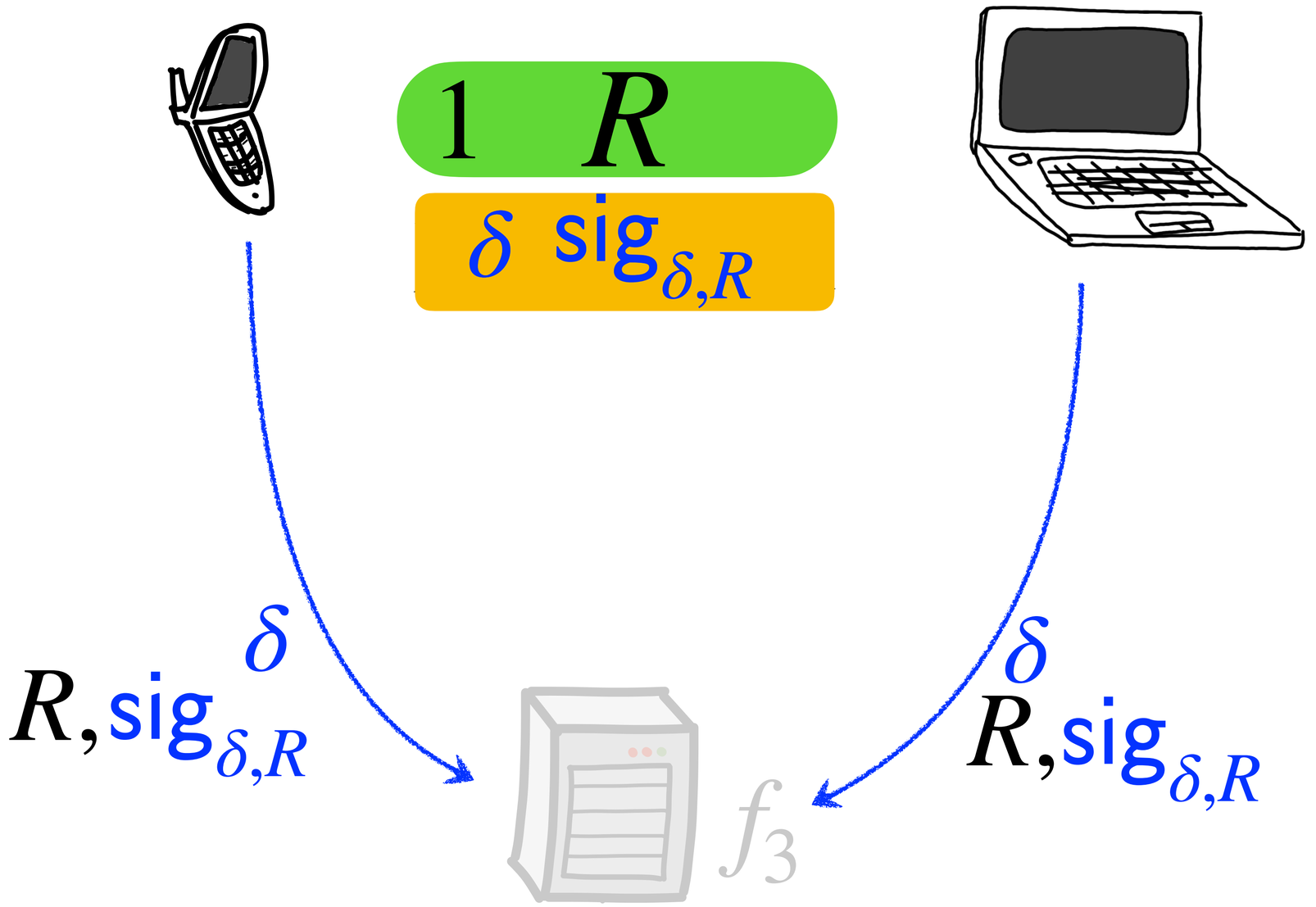
$1 \quad R$

$\delta \quad \mathrm{sig}_{\delta,R}$

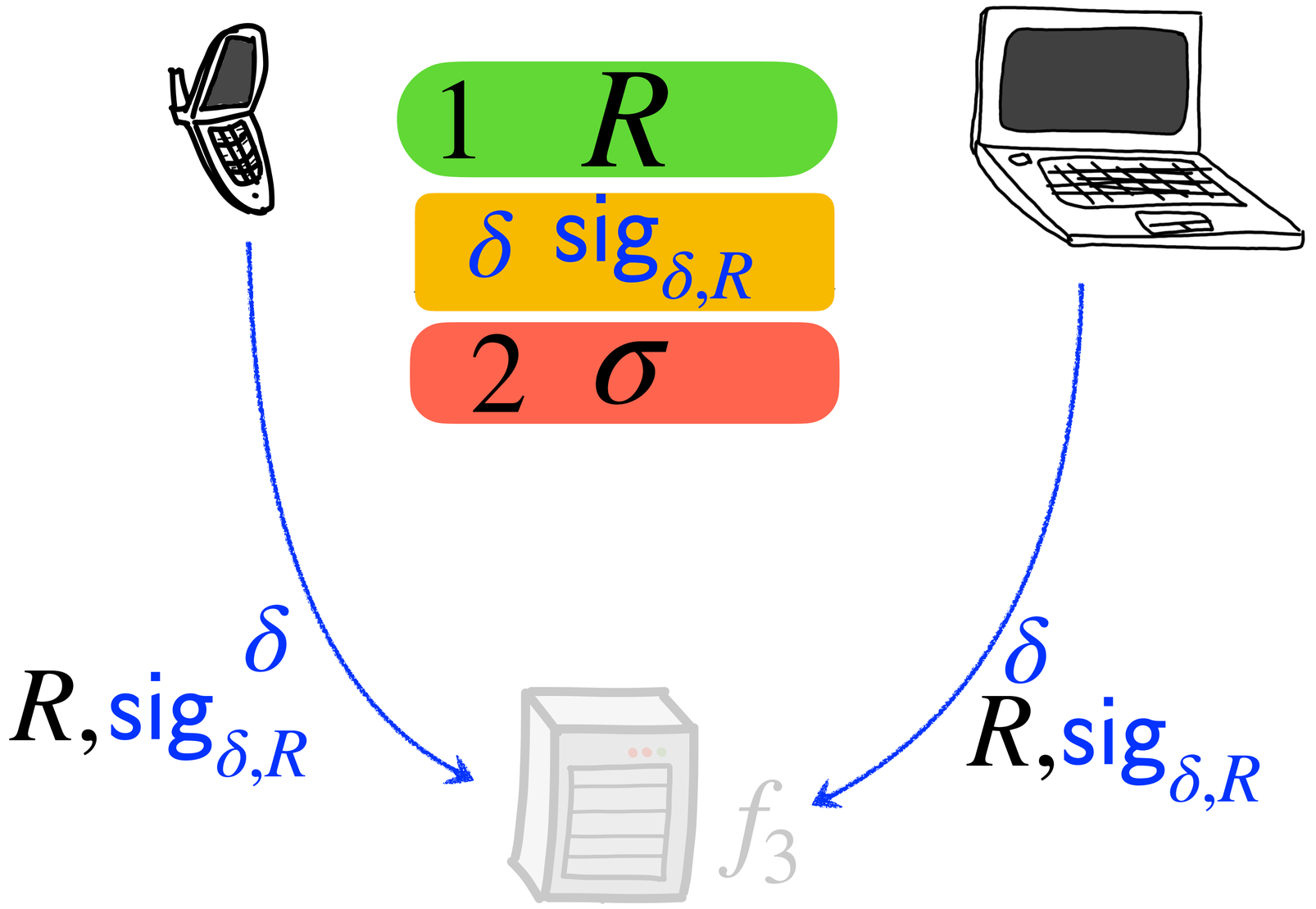


f_3

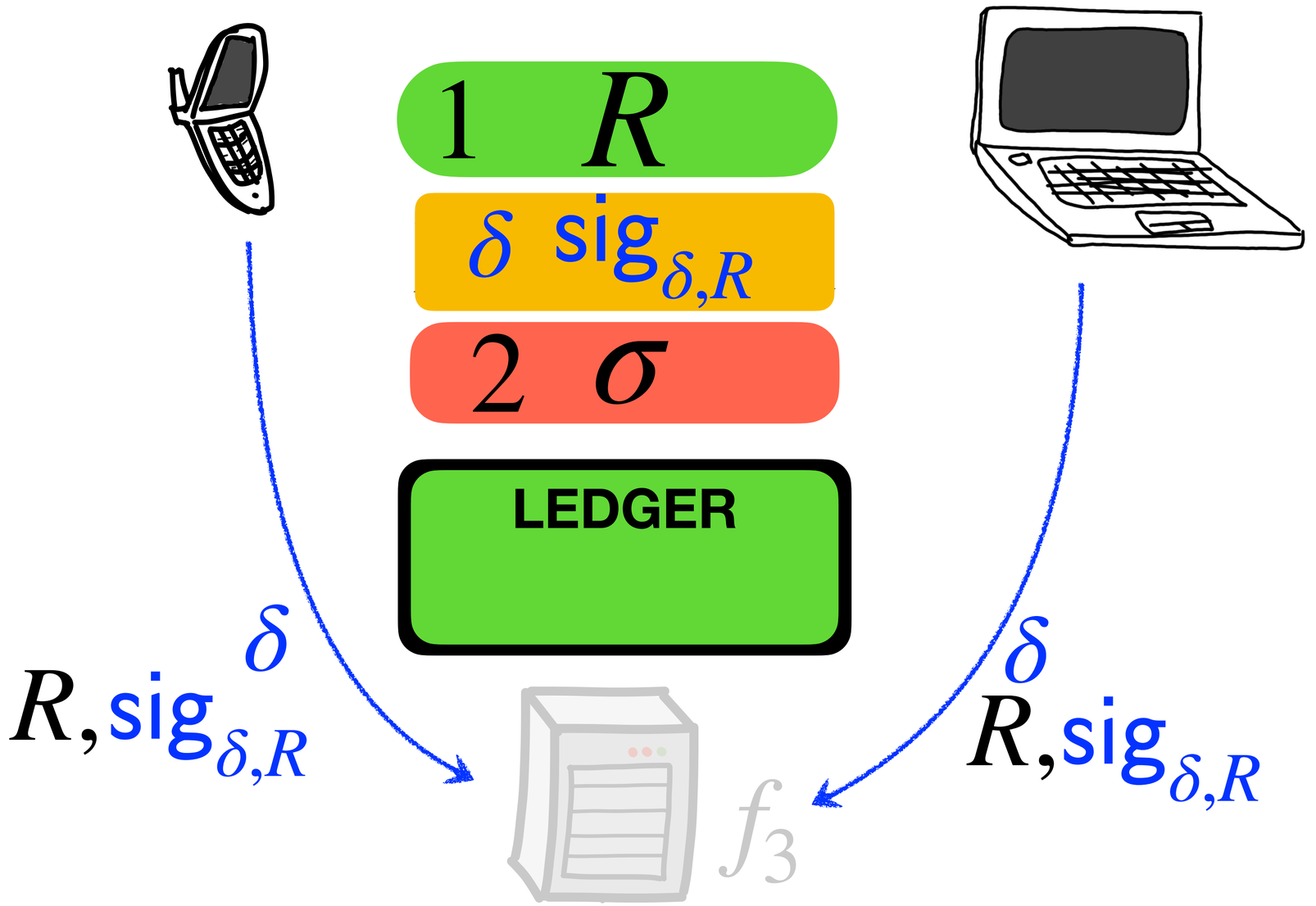
Interleaved Threshold Signing



Interleaved Threshold Signing

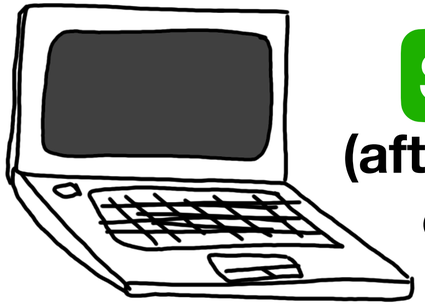


Interleaved Threshold Signing



Interleaved Threshold Signing

SUCCESS
(after tx,R appears on LEDGER)



SUCCESS
(after tx,R appears on LEDGER)

$1 \quad R$

$\delta \quad \text{sig}_{\delta,R}$

$2 \quad \sigma$

LEDGER
tx, R, σ

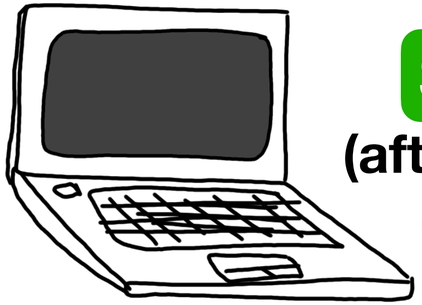
δ
$R, \text{sig}_{\delta,R}$

δ
$R, \text{sig}_{\delta,R}$

f_3

Interleaved Threshold Signing

SUCCESS
(after tx,R appears on LEDGER)



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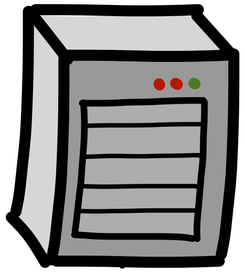
$2 \quad \sigma$

LEDGER
tx, R, σ

δ
$R, \mathrm{sig}_{\delta,R}$

δ
$R, \mathrm{sig}_{\delta,R}$



f_3

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SUCCESS
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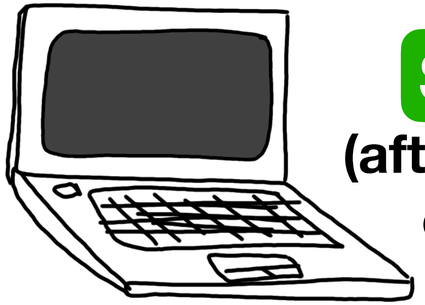

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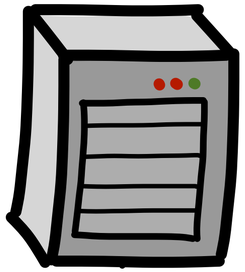
$\delta \quad \mathrm{sig}_{\delta,R}$

$2 \quad \sigma$

LEDGER
tx, R, σ

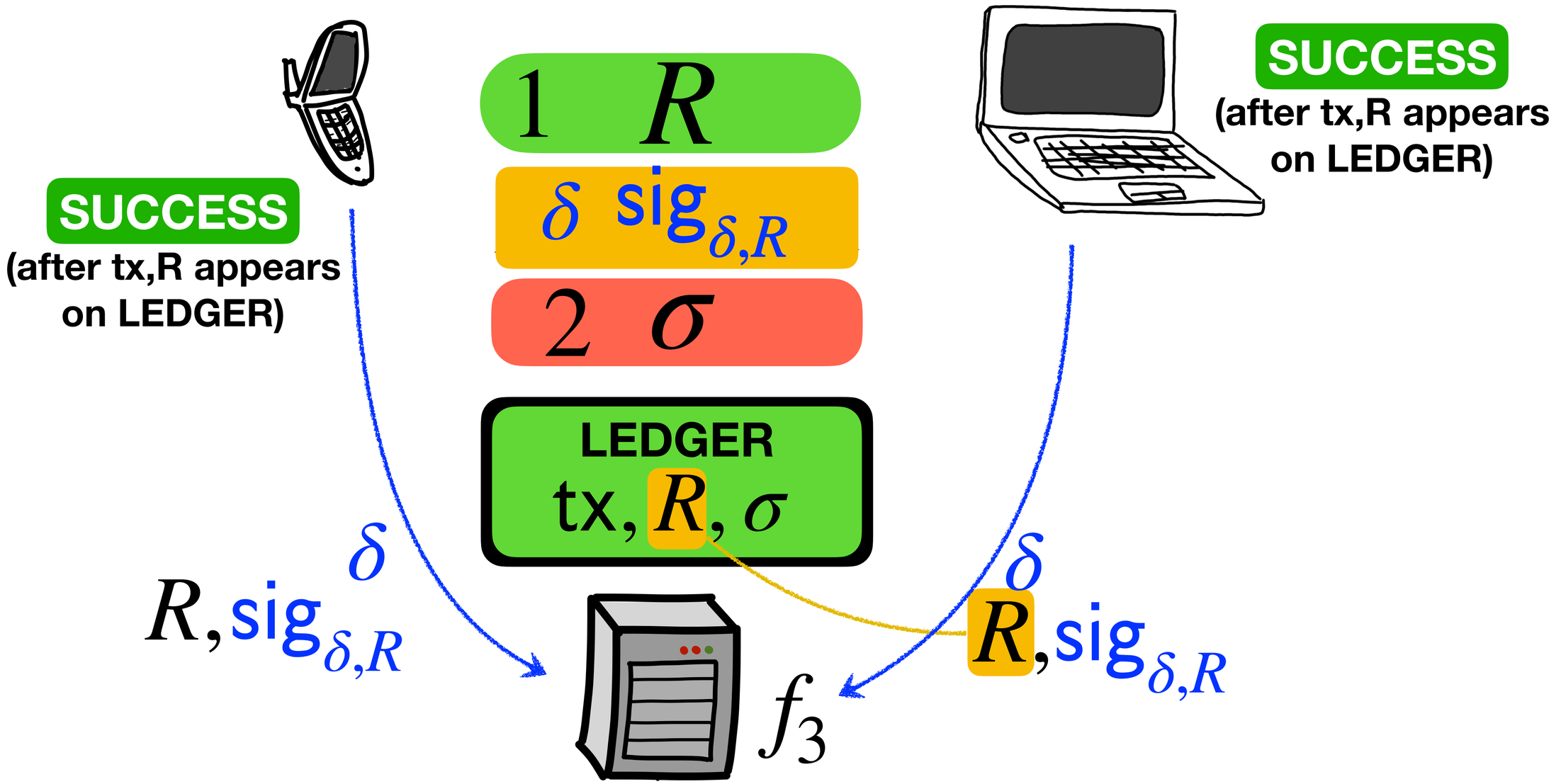
δ
$R, \mathrm{sig}_{\delta,R}$

δ
$R, \mathrm{sig}_{\delta,R}$

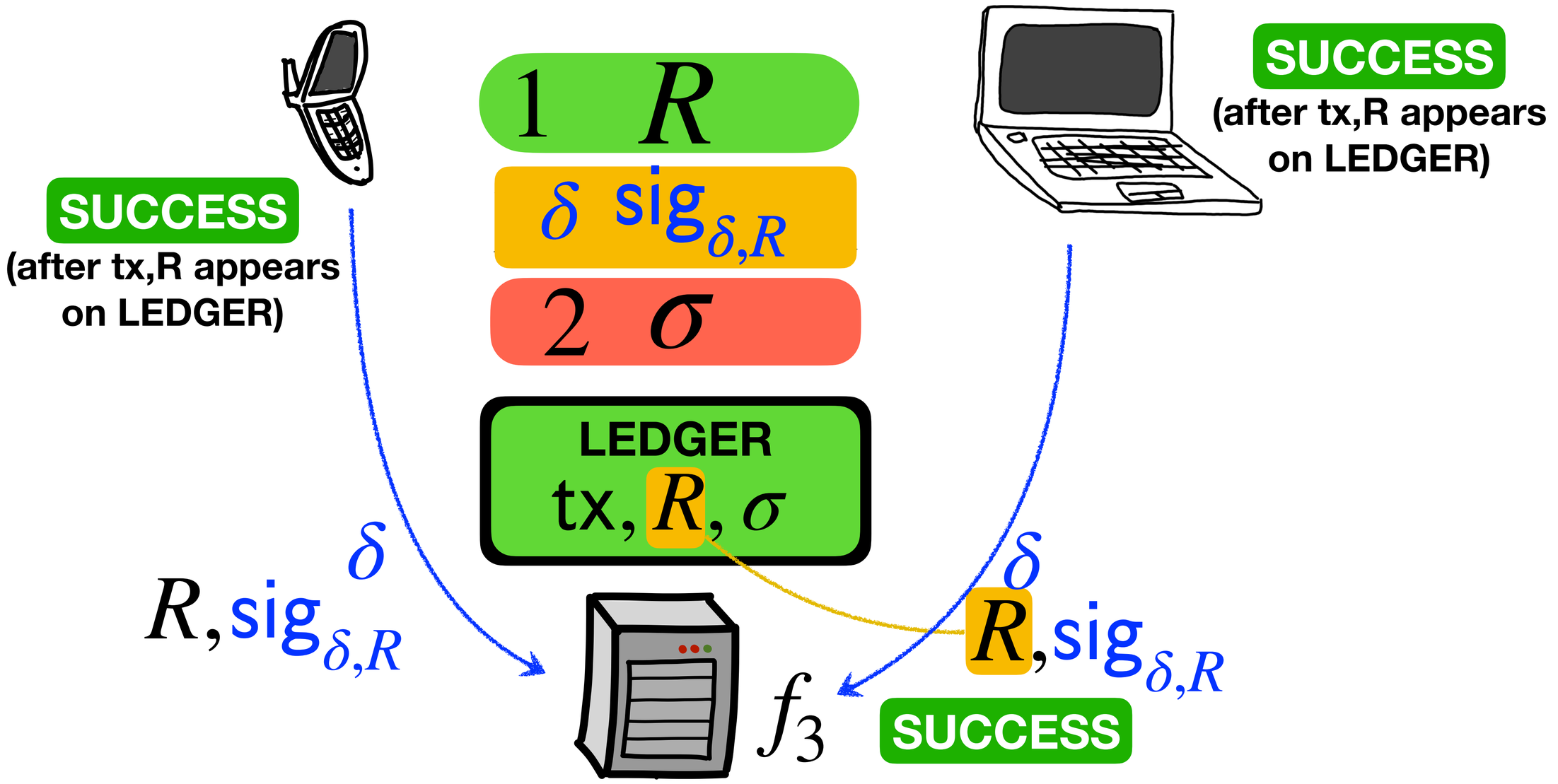


f_3

Interleaved Threshold Signing



Interleaved Threshold Signing



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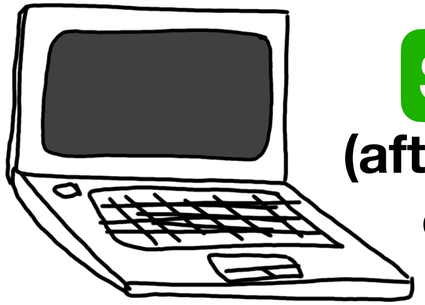


SUCCESS
(after tx,R appears on LEDGER)

1 R

δ $\text{sig}_{\delta,R}$

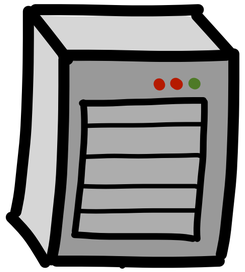
2 σ

LEDGER
tx, R, σ

Native: this was going on the ledger anyway

δ
$R, \text{sig}_{\delta,R}$

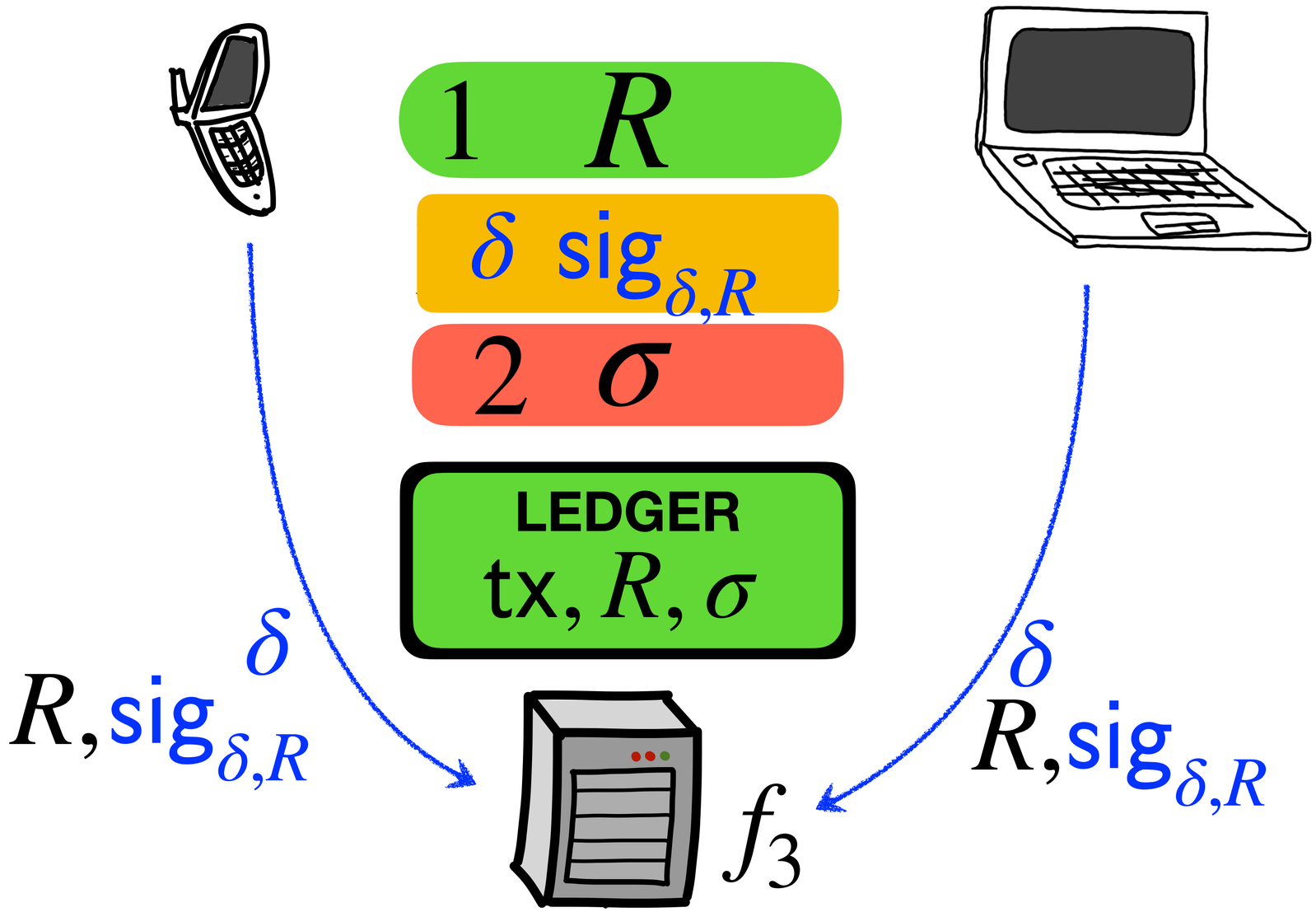
δ
$R, \text{sig}_{\delta,R}$



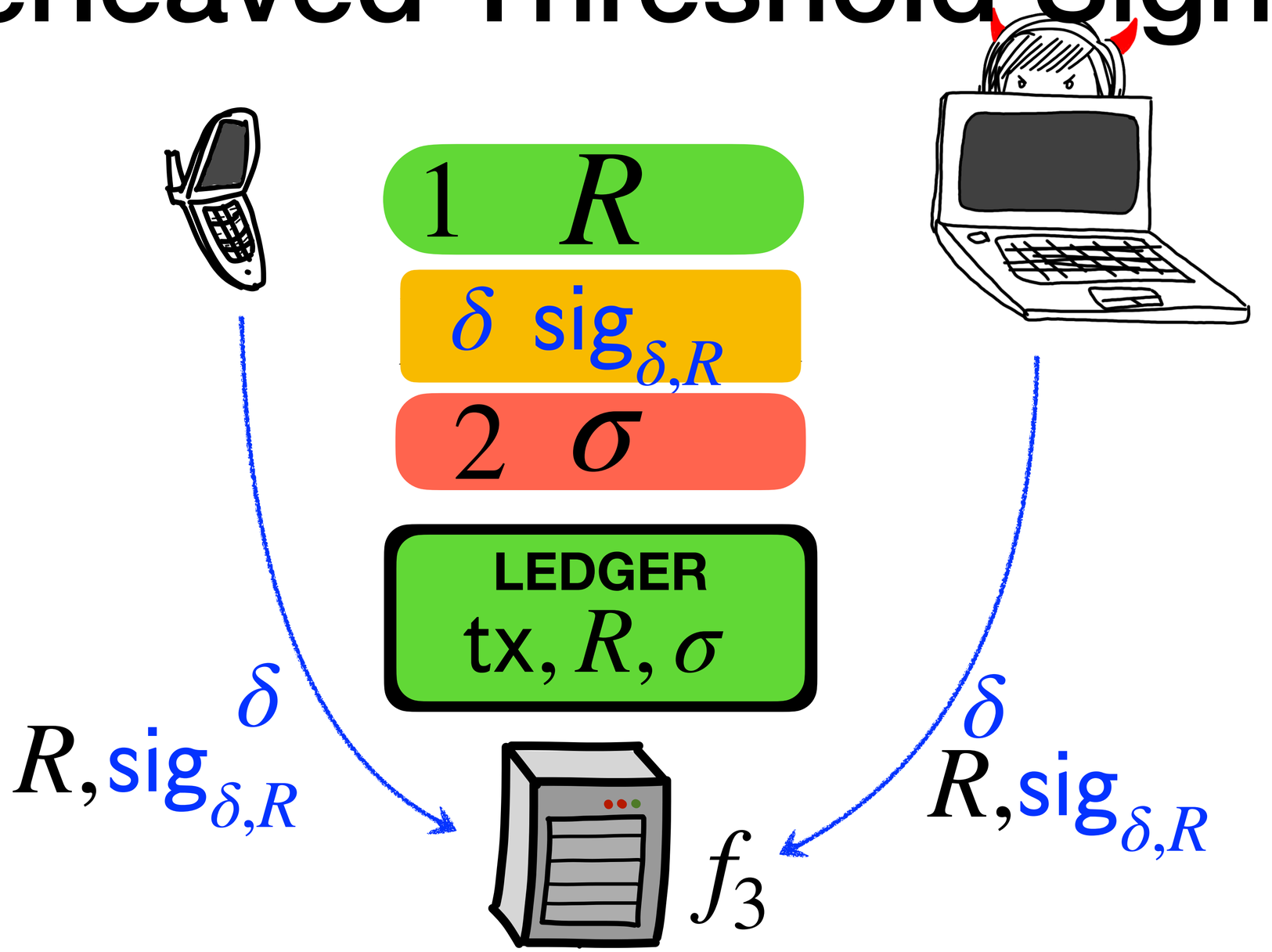
f_3

SUCCESS

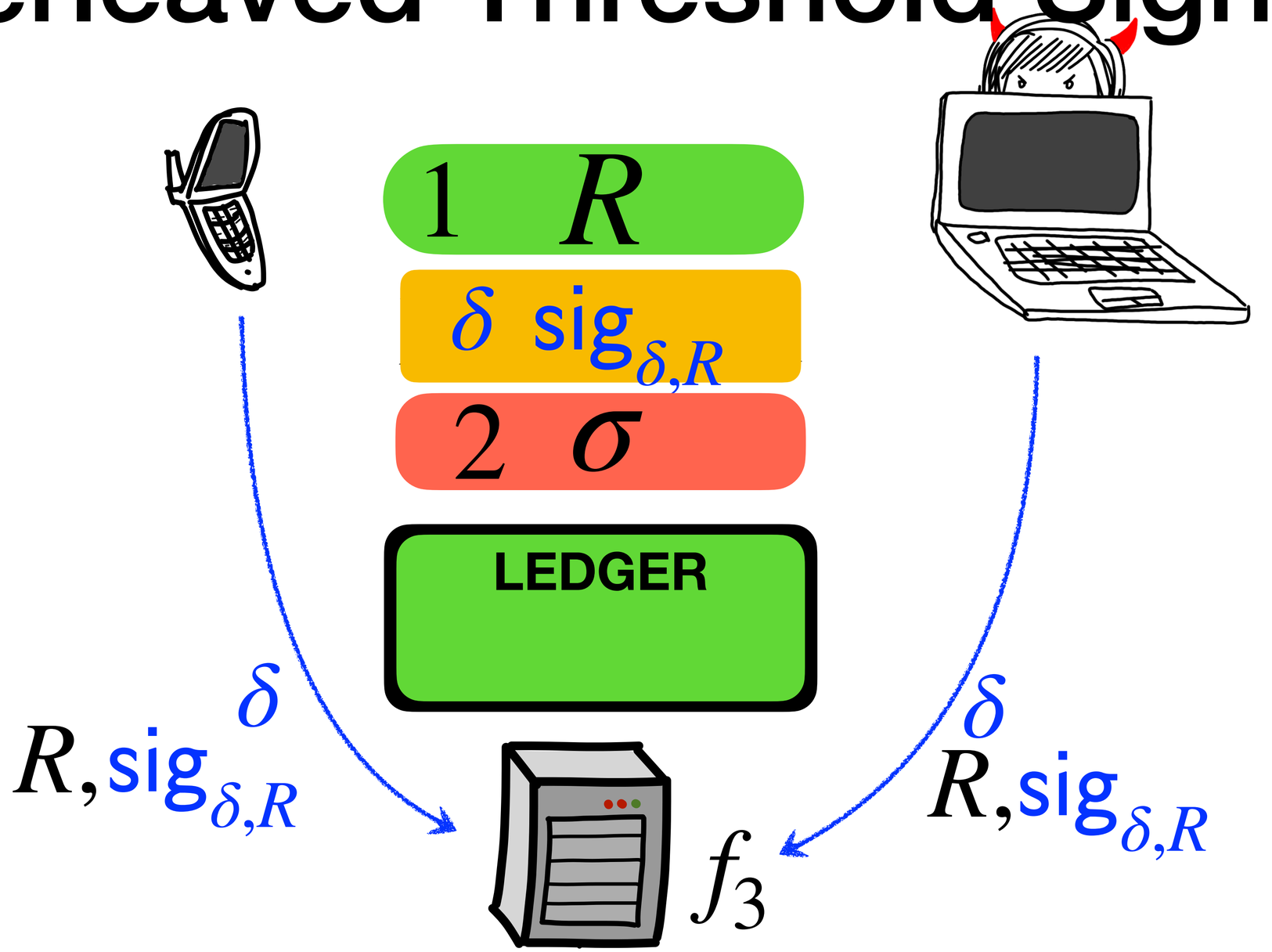
Interleaved Threshold Signing



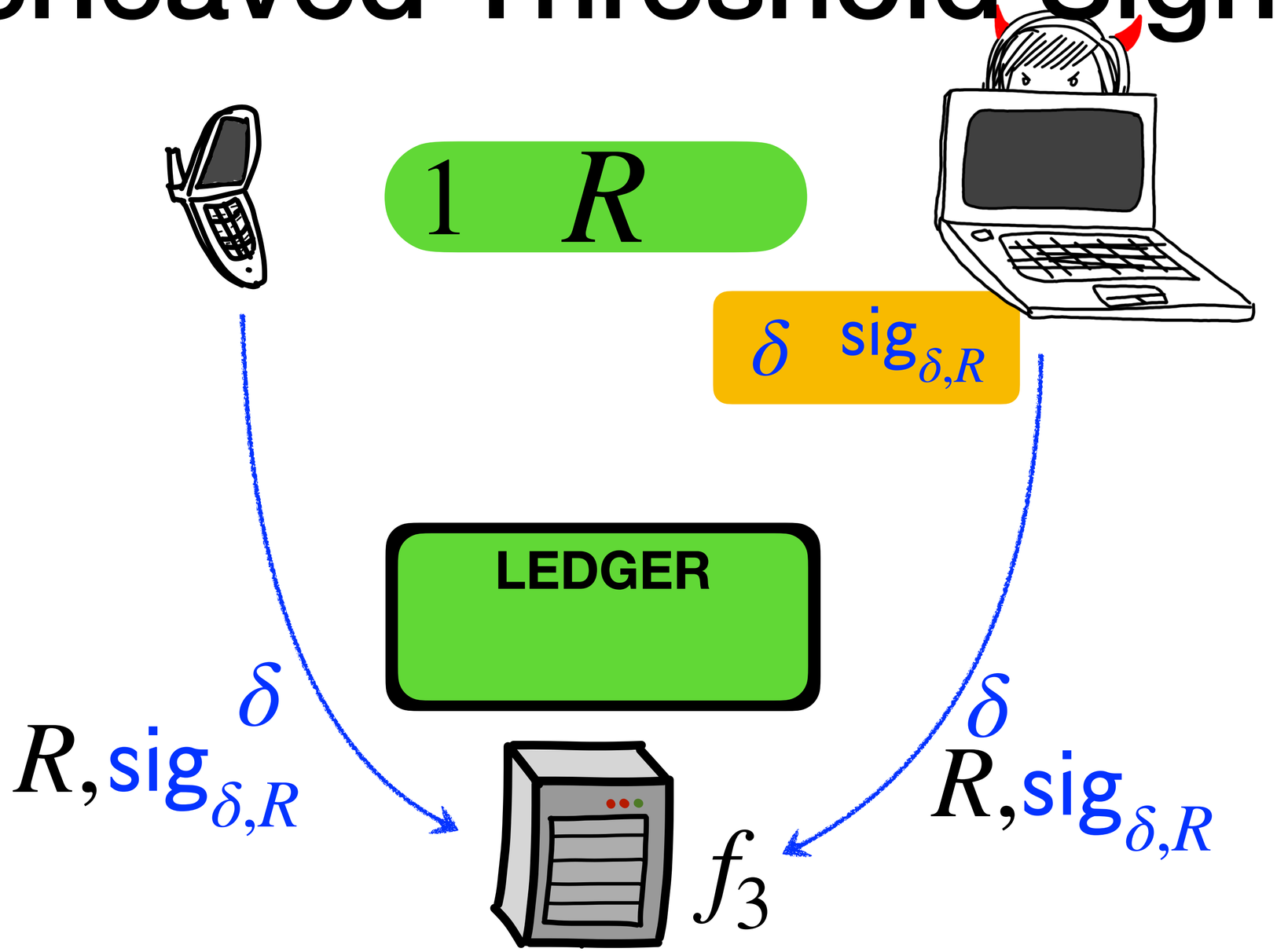
Interleaved Threshold Signing



Interleaved Threshold Signing



Interleaved Threshold Signing

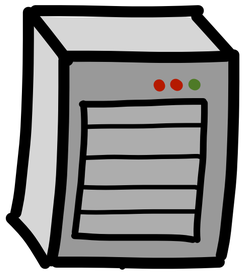


Interleaved Threshold Signing

$1 \quad R$

$\delta \quad \mathrm{sig}_{\delta,R}$

LEDGER



f_3

δ

$R, \mathrm{sig}_{\delta,R}$

Interleaved Threshold Signing

$1 \quad R$

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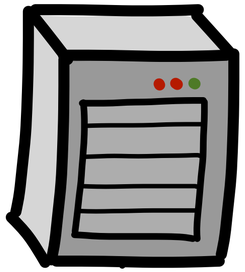
LEDGER will never receive valid signature under *R* (Phase 2 never run)

LEDGER



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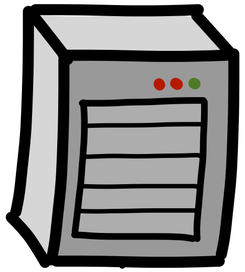

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Useless

δ
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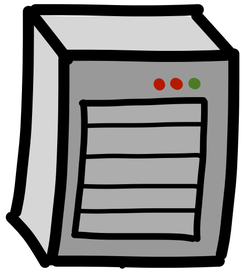

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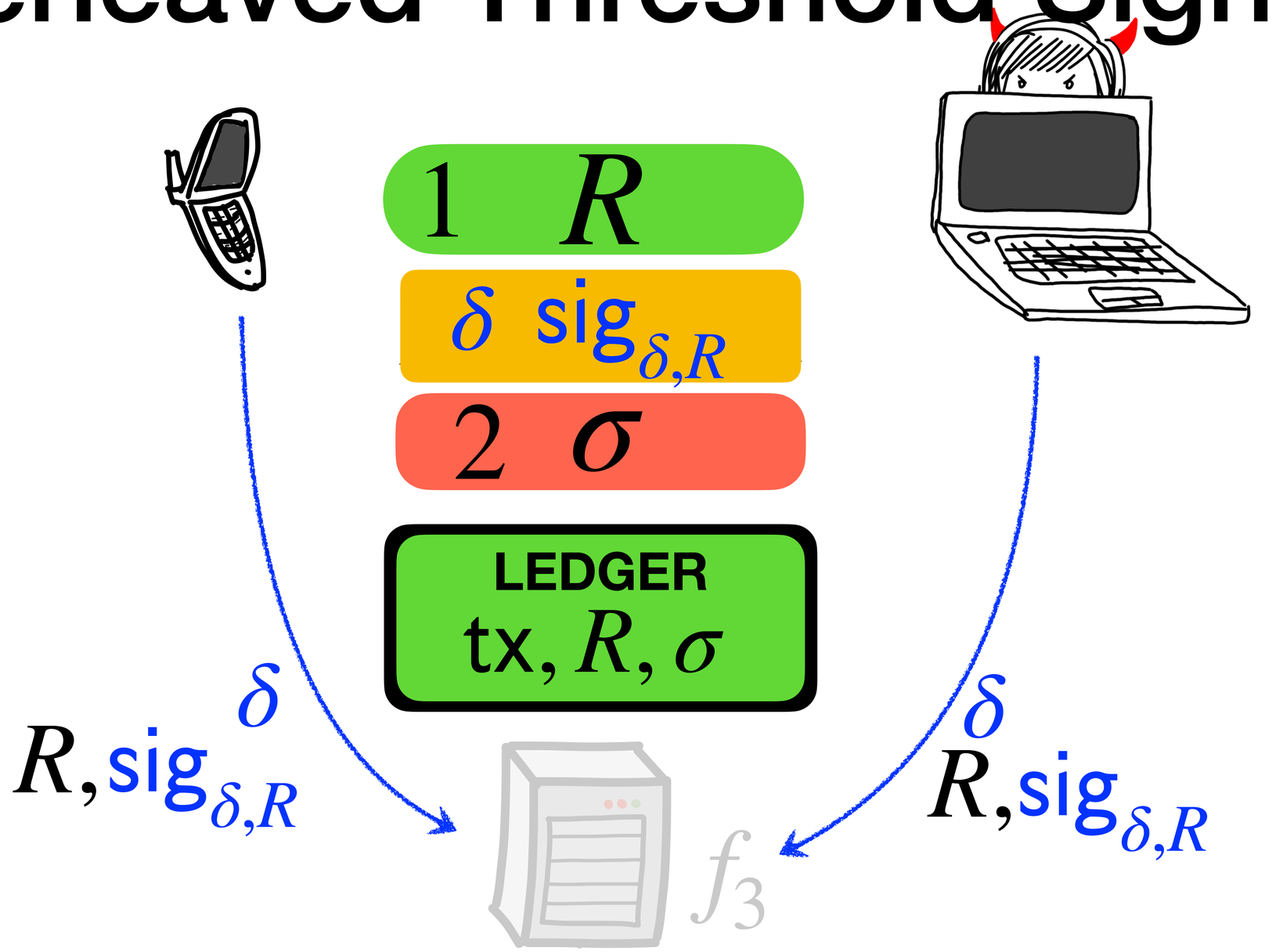

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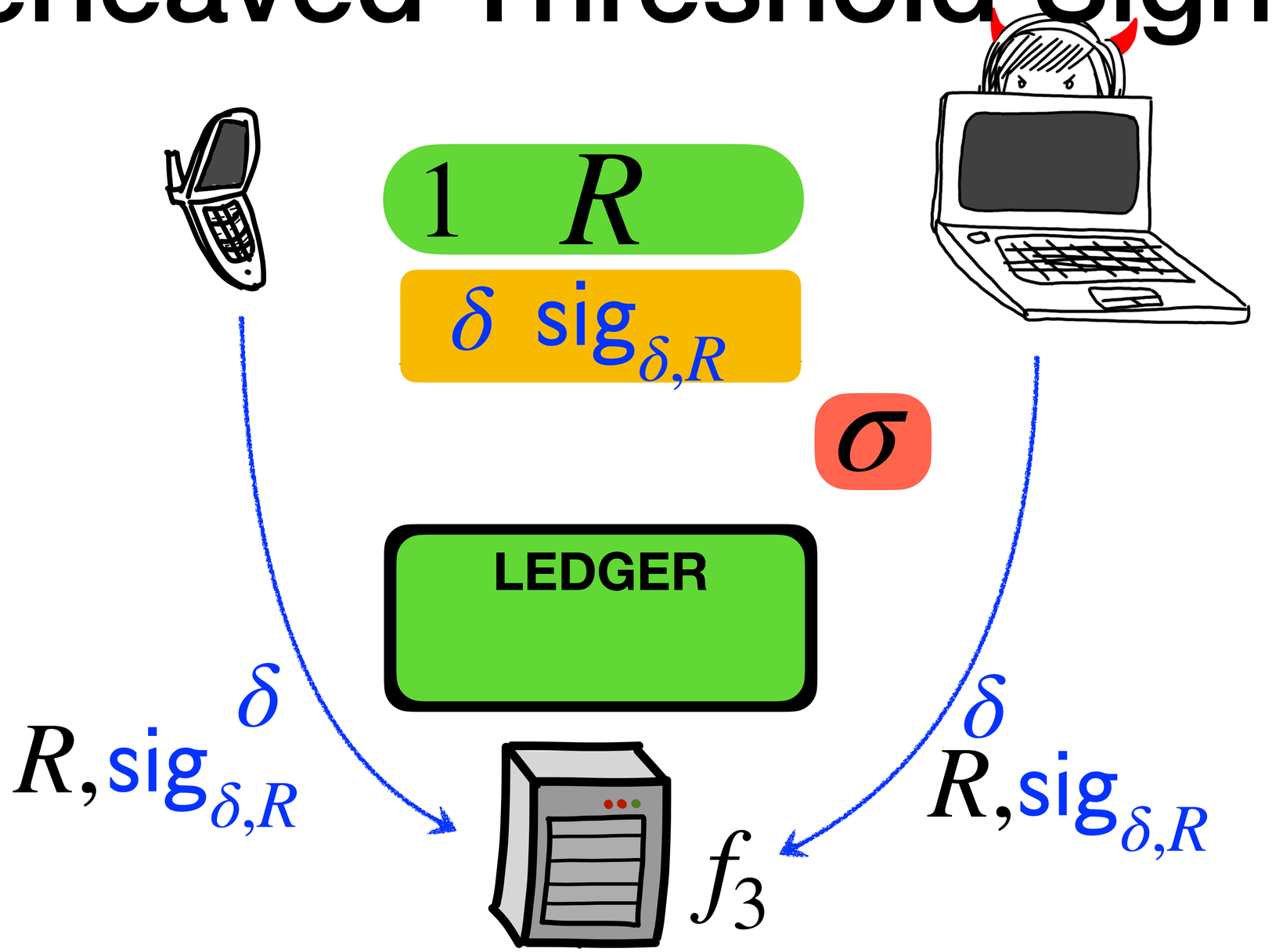

Interleaved Threshold Signing

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σ

Case 1:

never posts

tx, R, σ to ledger

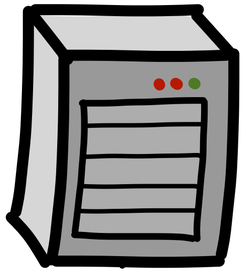
LEDGER

δ

$R, \text{sig}_{\delta,R}$

δ

$R, \text{sig}_{\delta,R}$



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LEDGER

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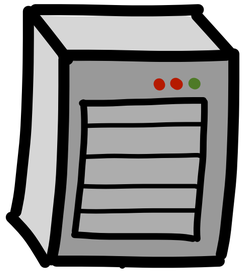
$R, \text{sig}_{\delta,R}$

Never used



f_3

δ
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Interleaved Threshold Signing

$1 \quad R$

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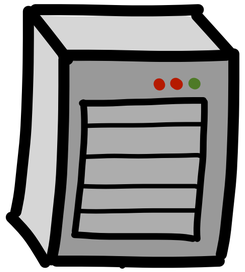
σ

Case 2:

does post tx, R, σ to ledger

LEDGER
tx, R, σ

δ
$R, \text{sig}_{\delta,R}$



f_3

δ
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Interleaved Threshold Signing

SUCCESS

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σ

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LEDGER
tx, R, σ

δ
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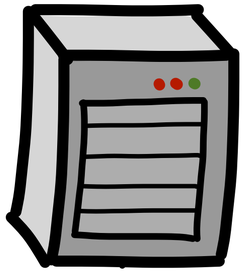

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Unanimous erasure

LEDGER
tx, R, σ

δ
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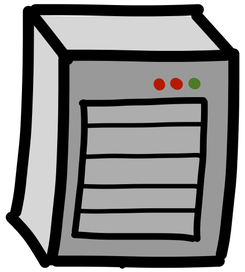

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$R, \text{sig}_{\delta,R}$

SUCCESS

Implementation

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- Augmented existing implementations of (2,n) **ECDSA** [DKLs19, GG18]

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- **Communication: 200 bytes, no extra rounds**

This Work

- Correct definition is subtle
  - Guaranteed progress is impossible
  - We formulate **unanimous erasure**

- (*2*,*n*) setting: Efficient new protocol **native** to wallets
  - New interleaved threshold sig technique
  - Offline parties can miss arbitrary number of epochs
  - Implementation shows practicality

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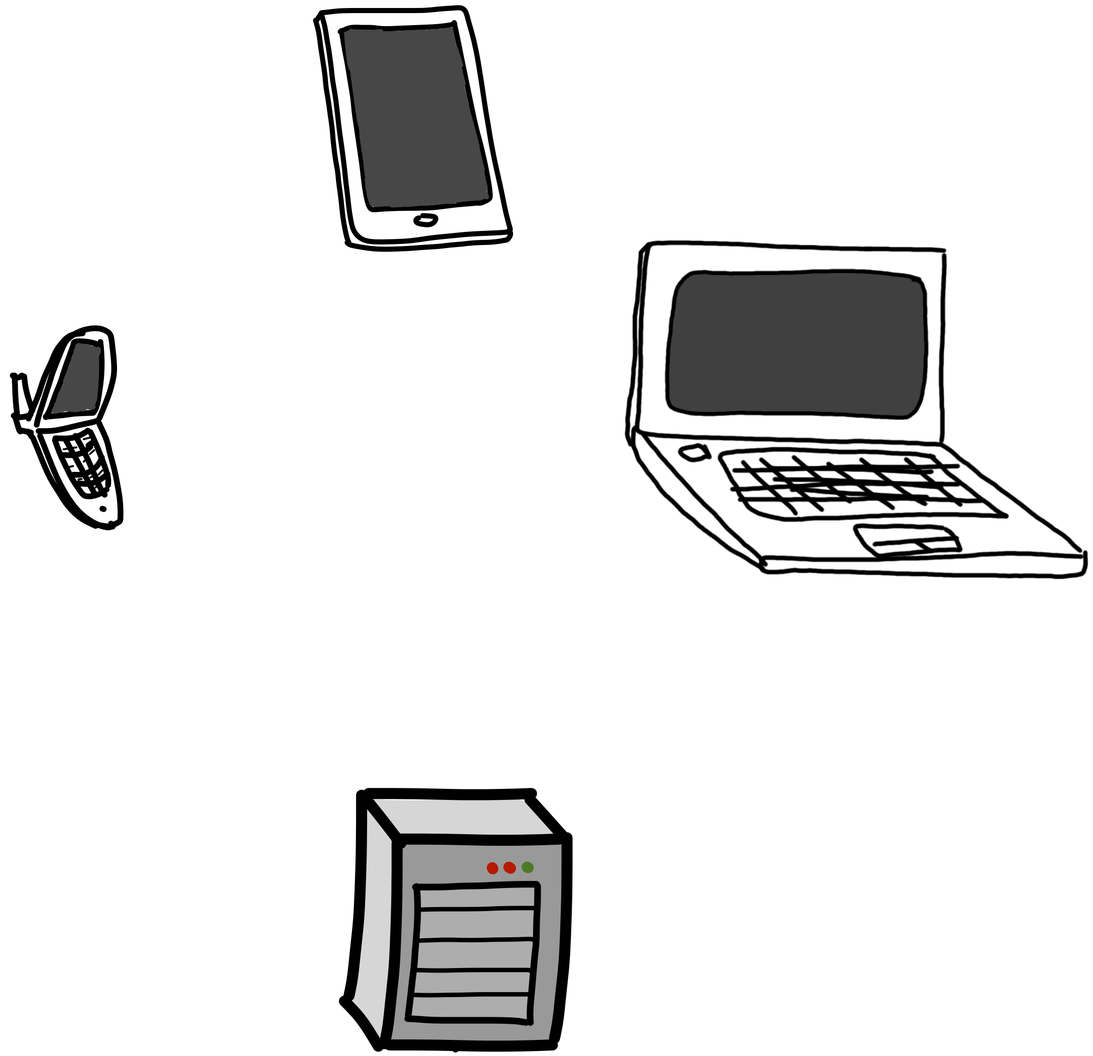
- Indicates intuition that (t,n) proactivization with offline refresh should be solvable with heavy tools
- Intuition turns out to be wrong!

Intuition: (3,4) case



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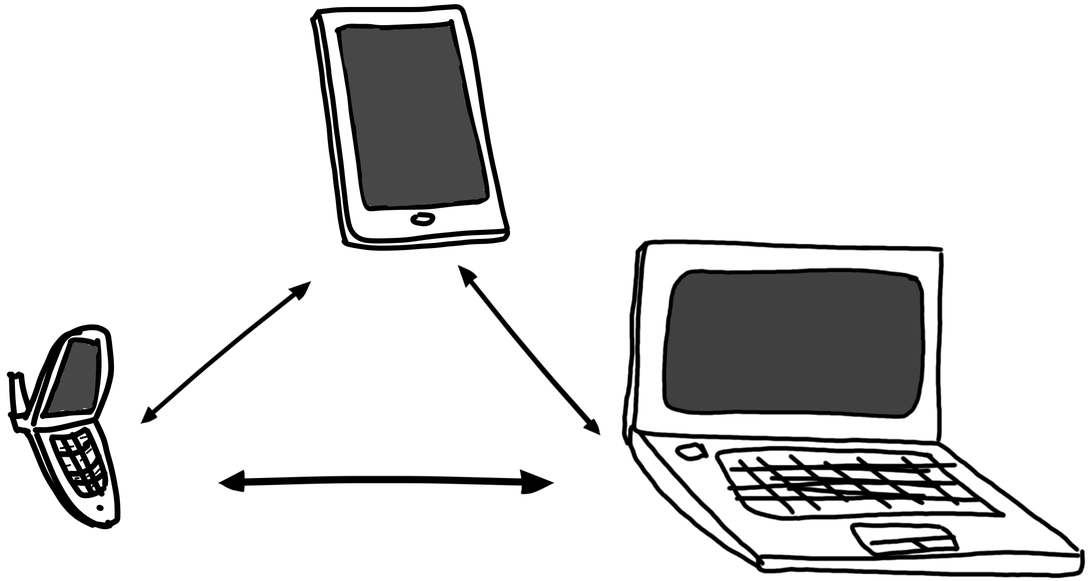

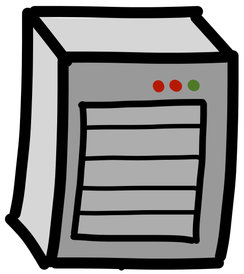

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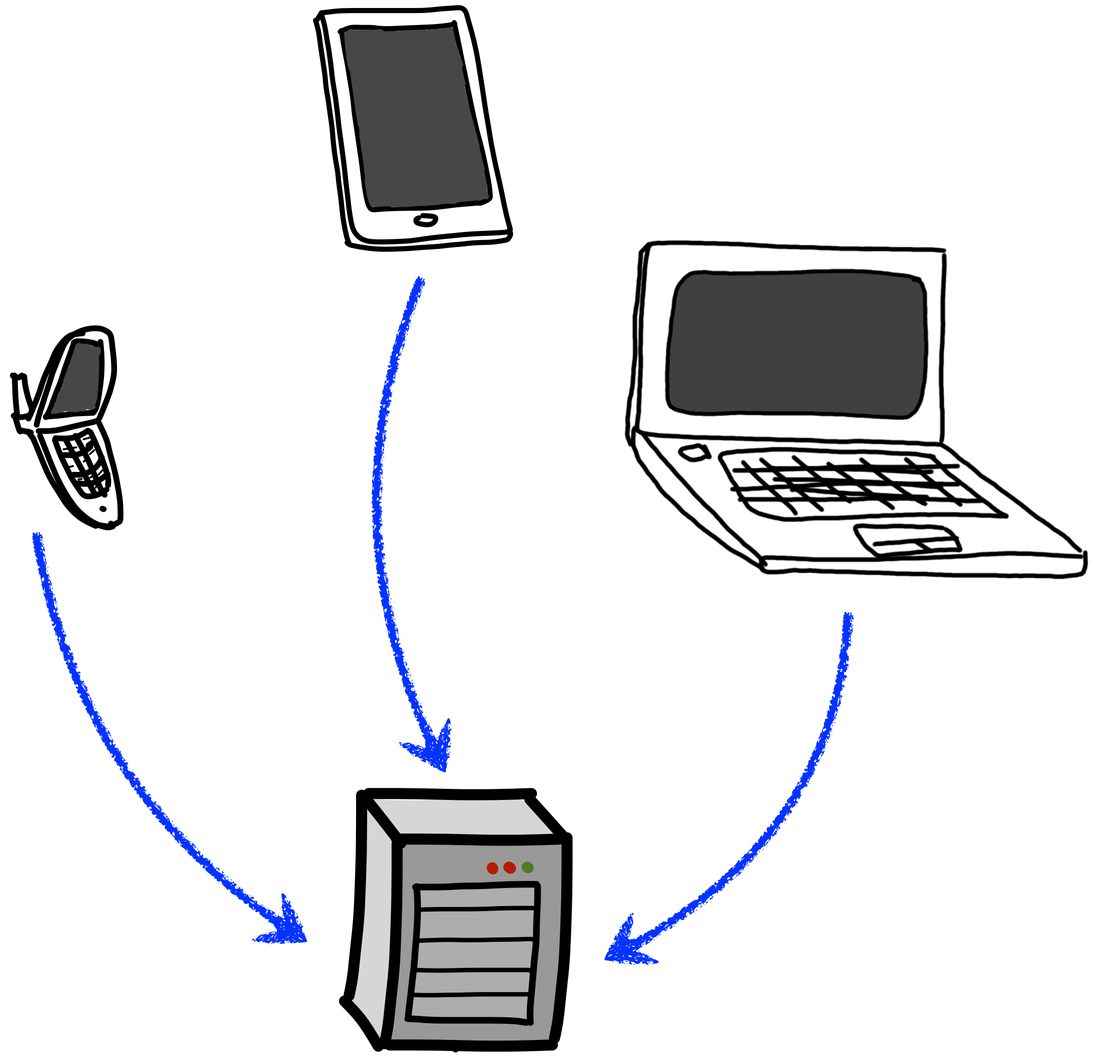

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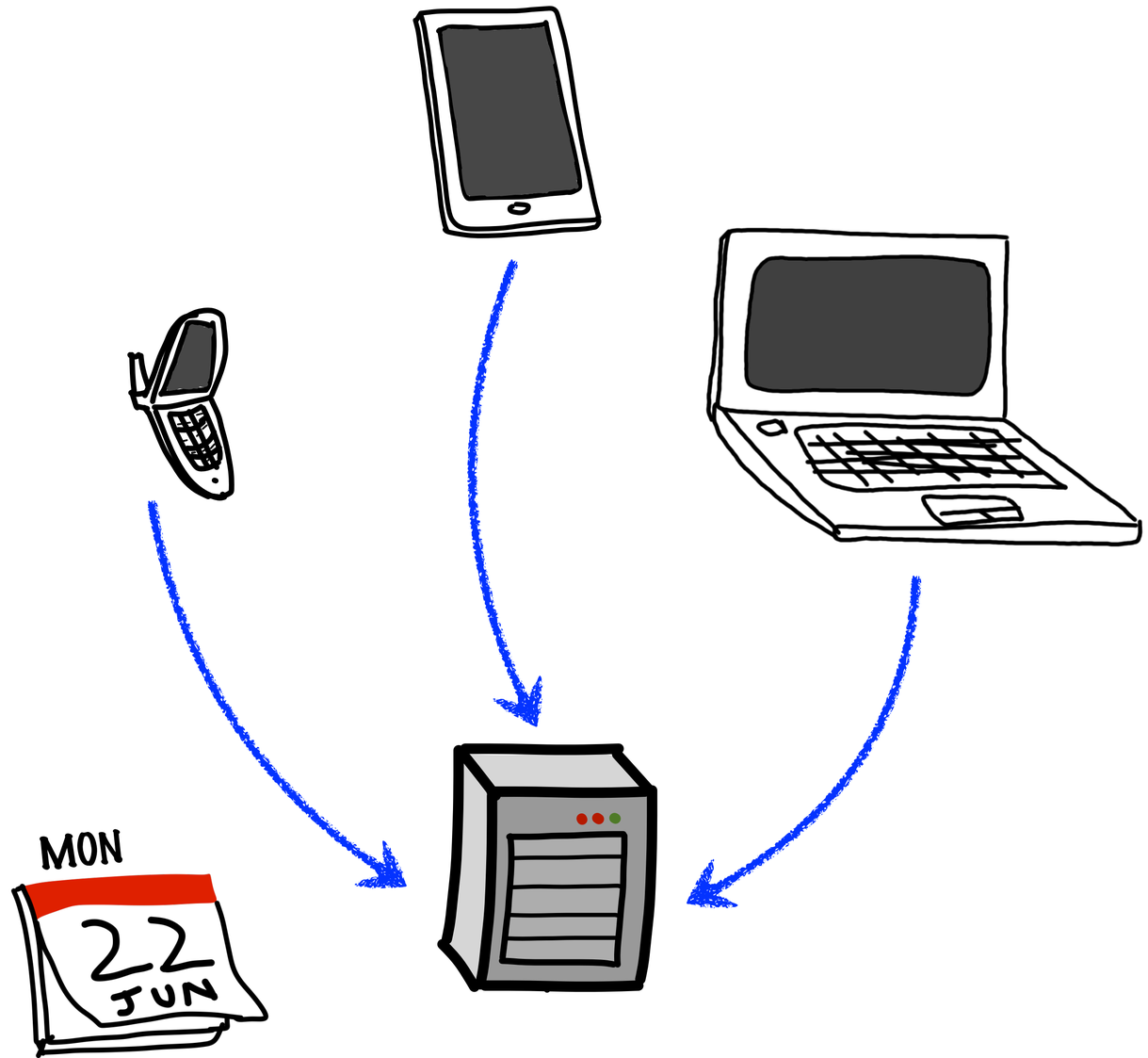

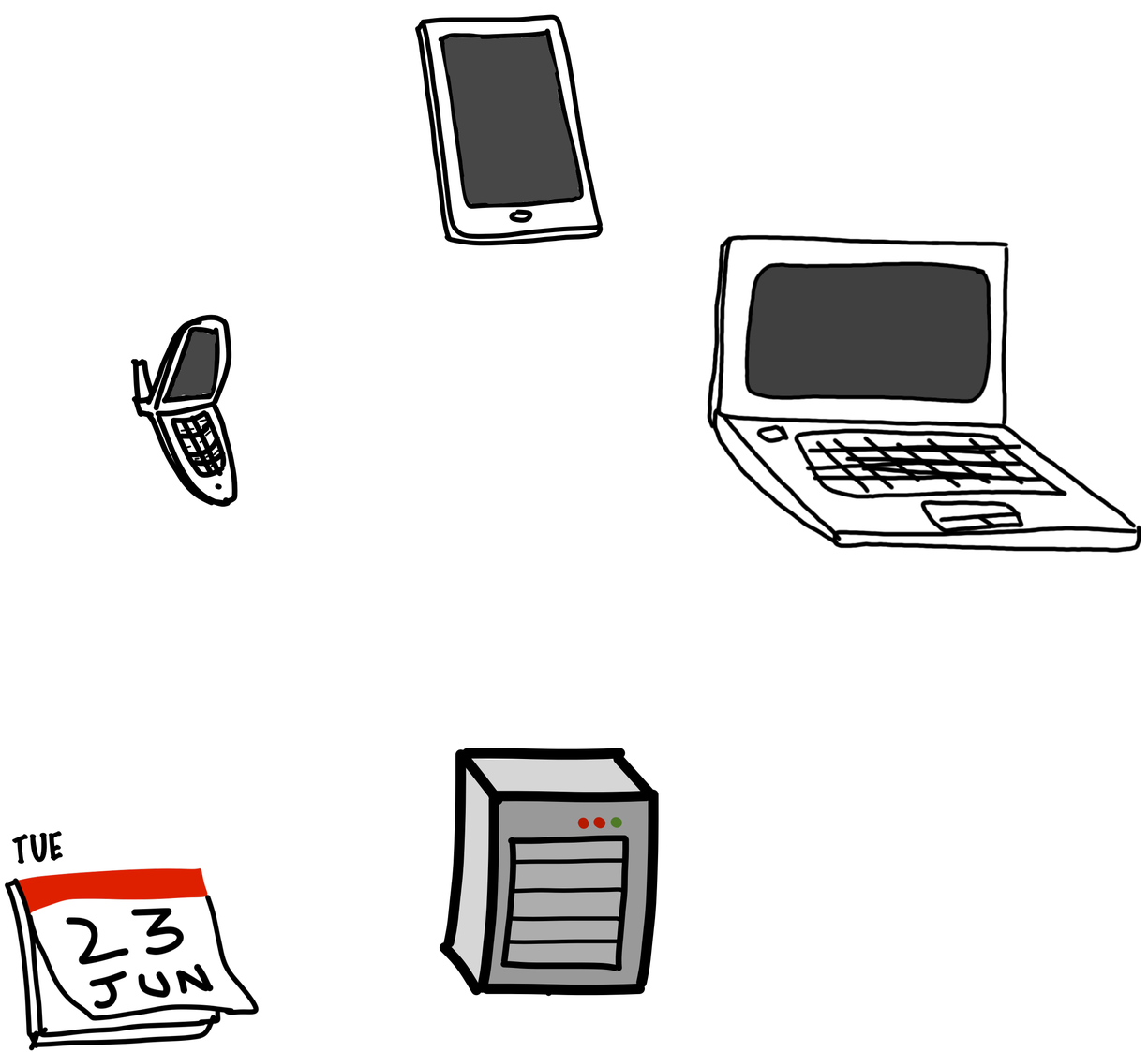

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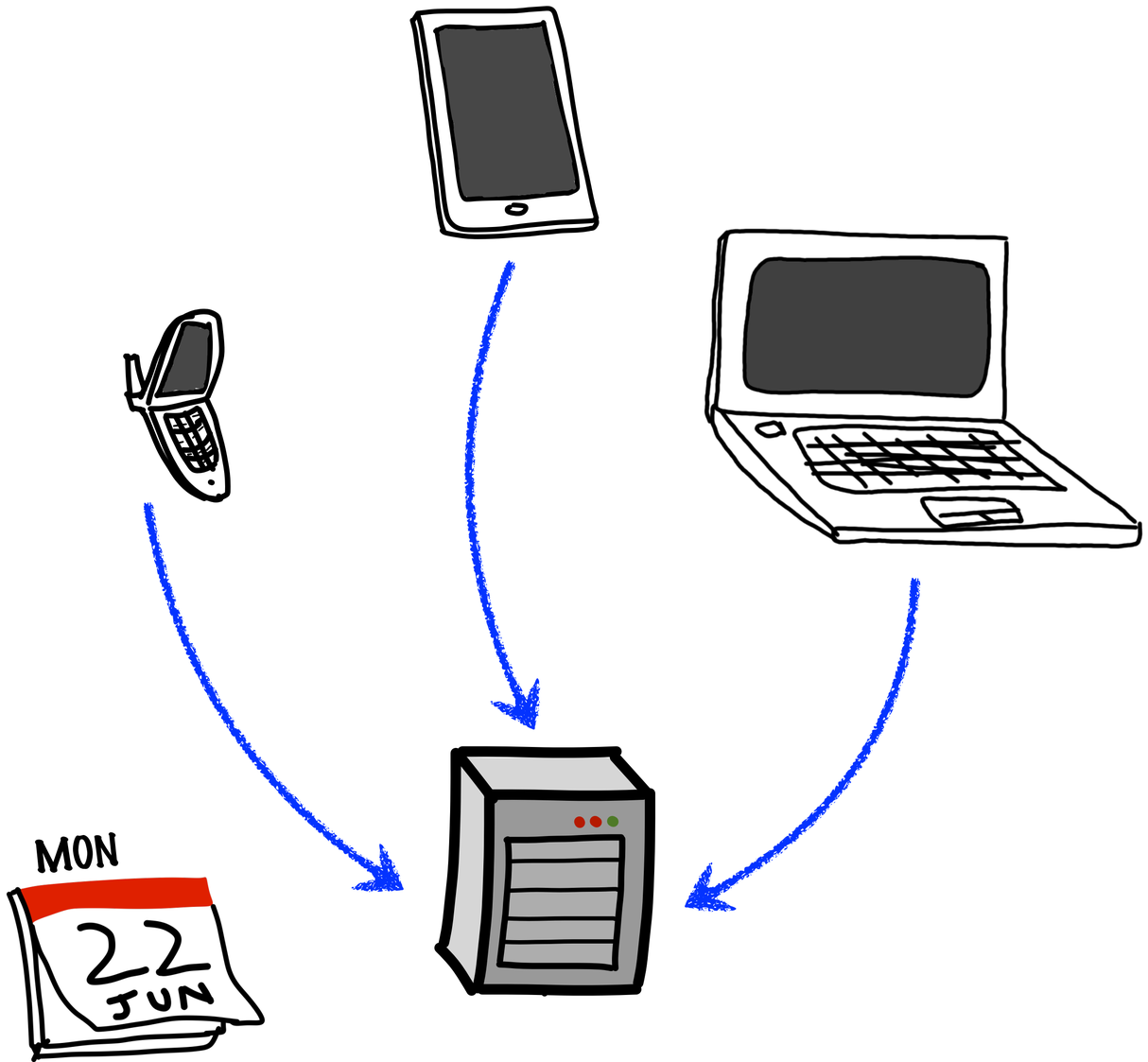

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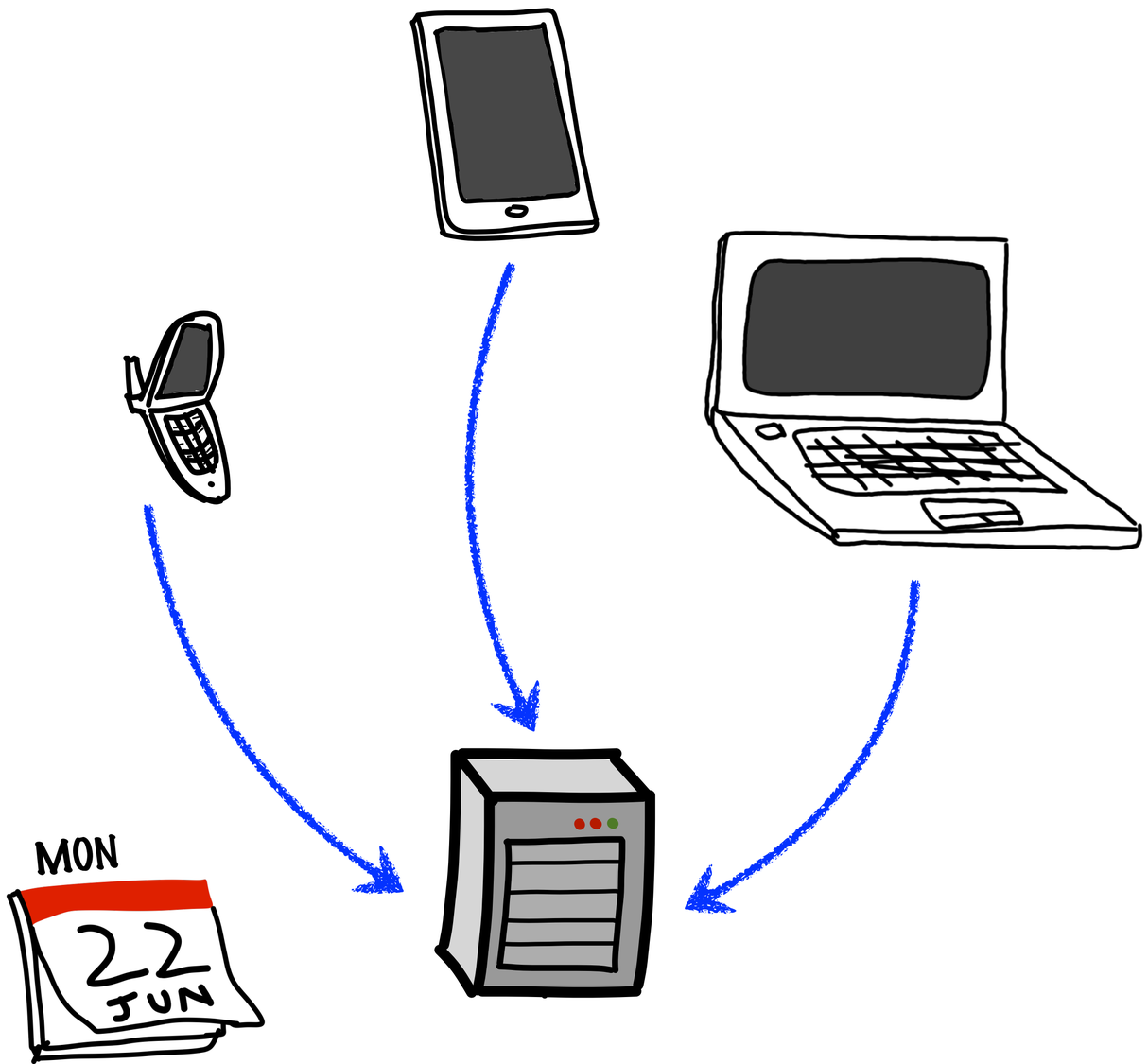

Assumption:
secure against corruption
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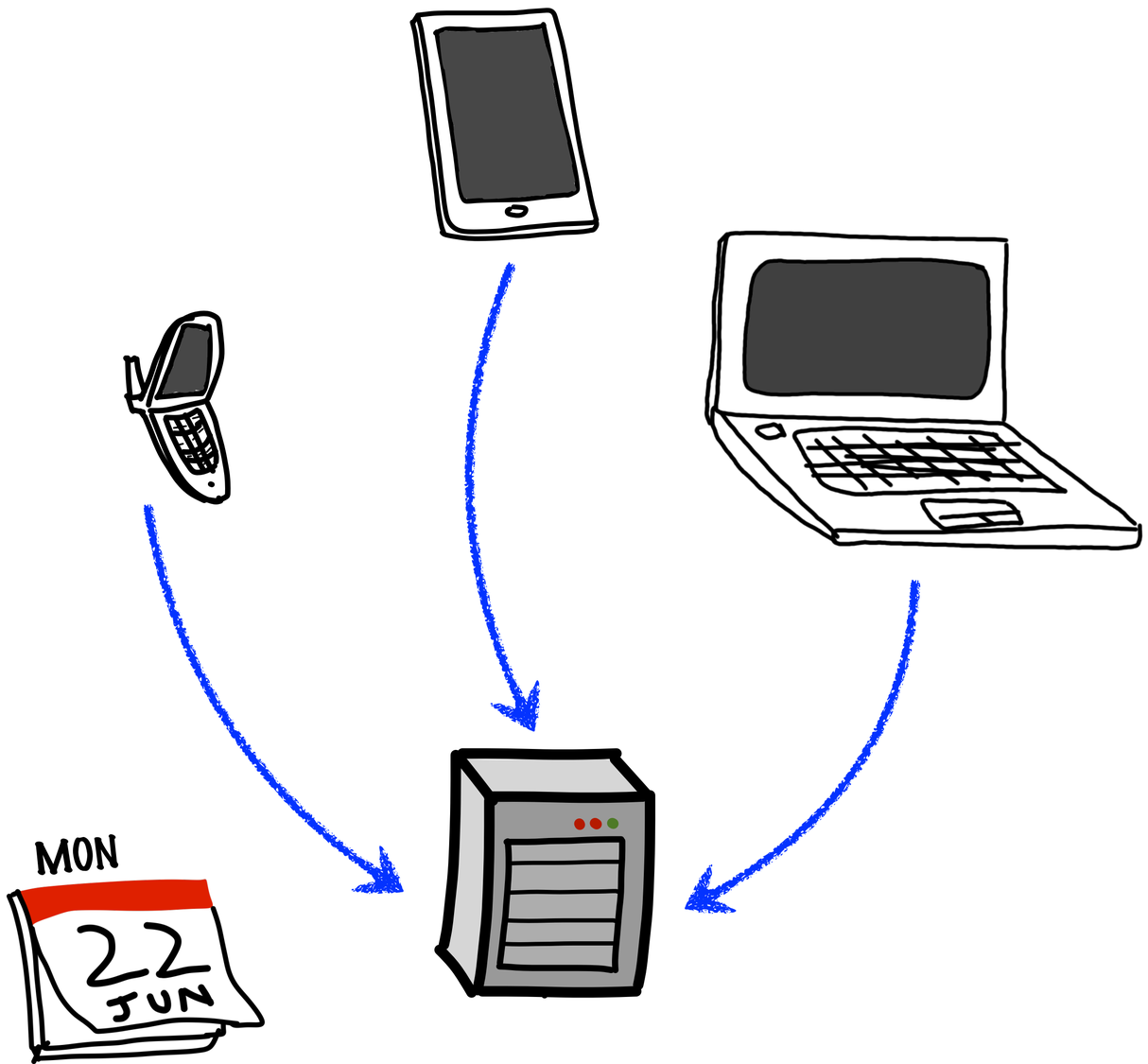

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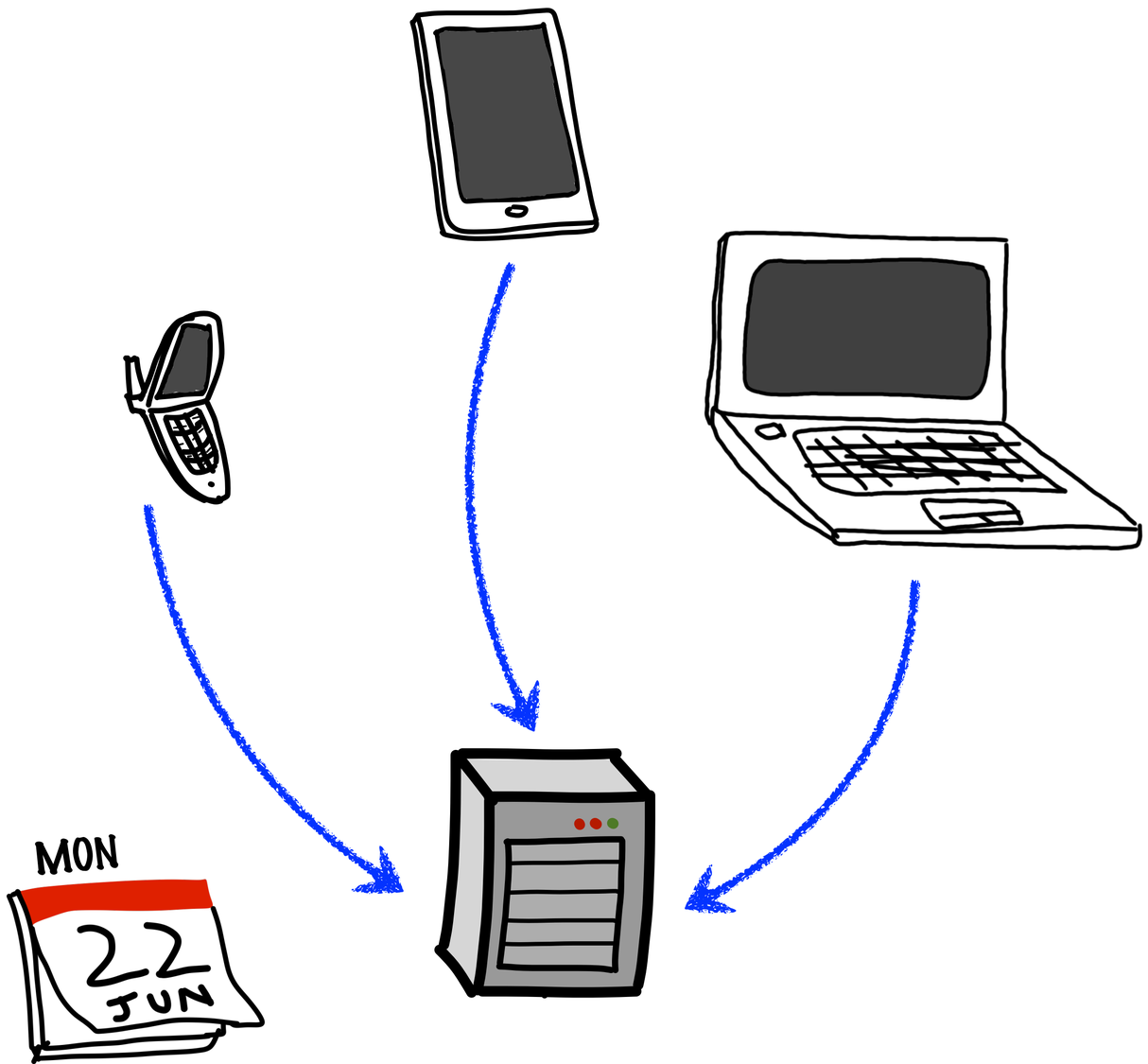

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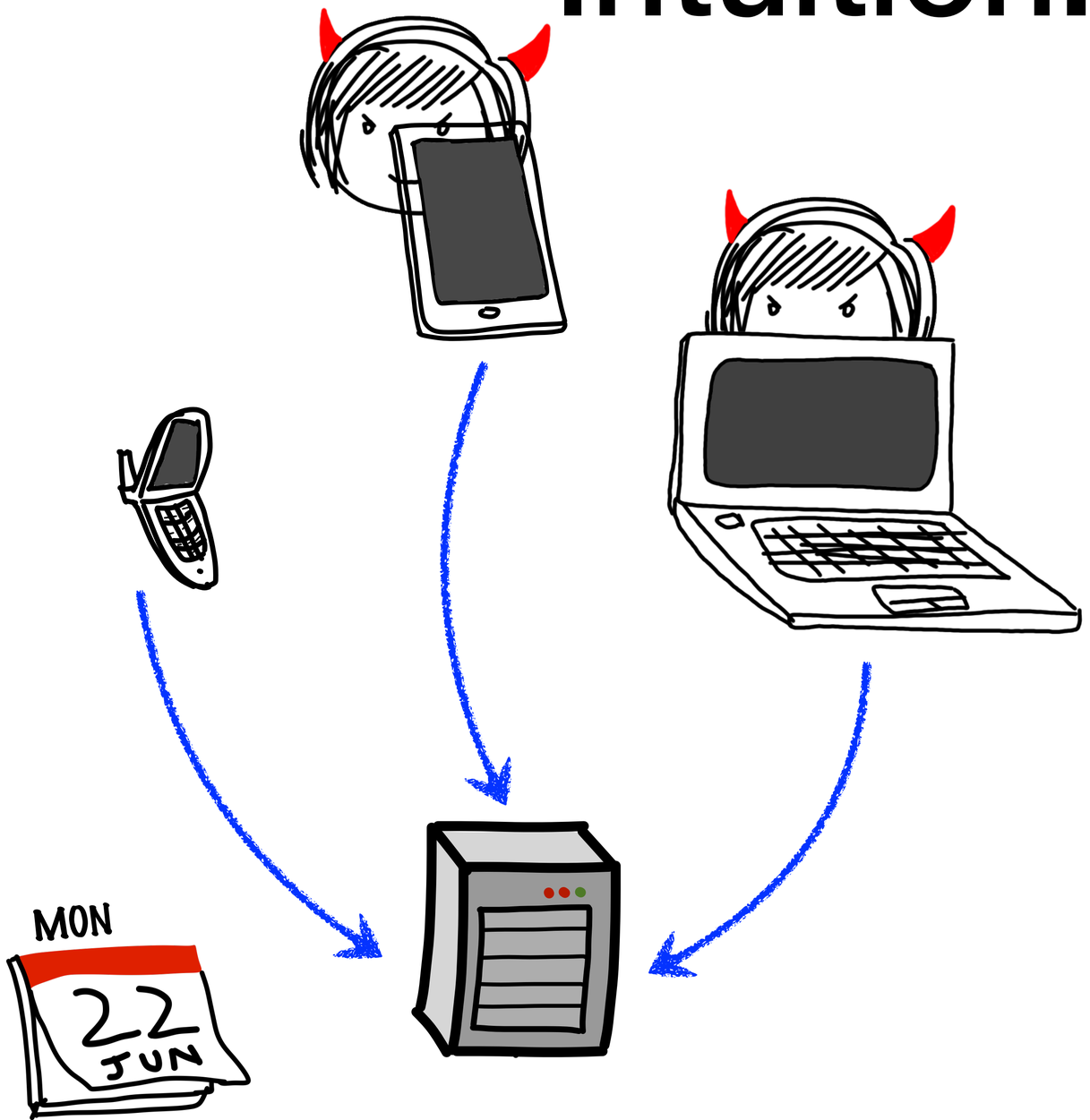

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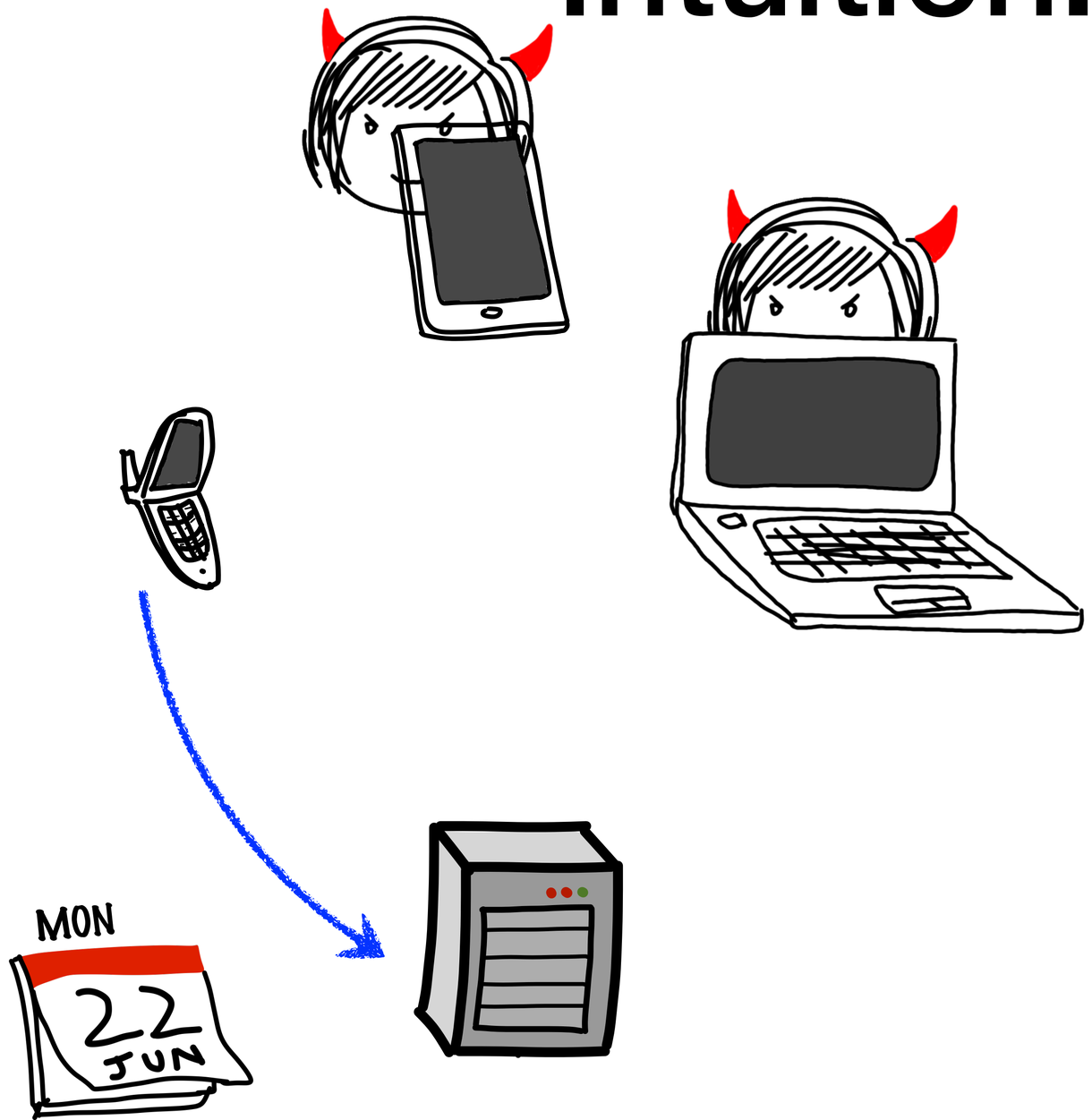

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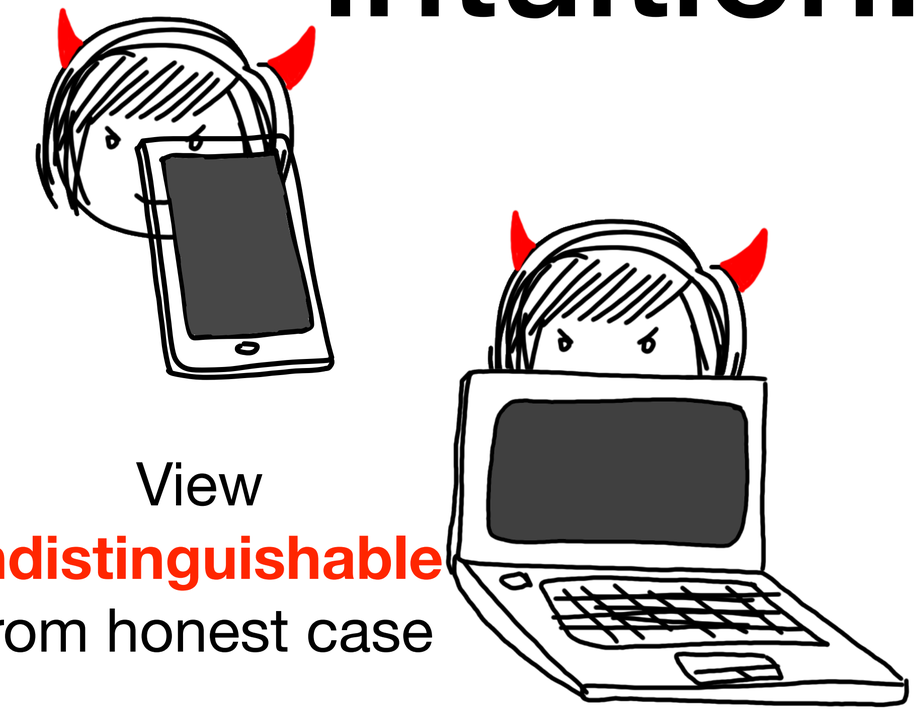

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View
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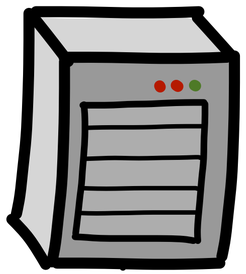
SUCCESS



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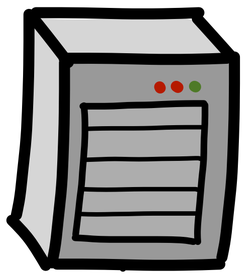

SUCCESS

By unanimous erasure

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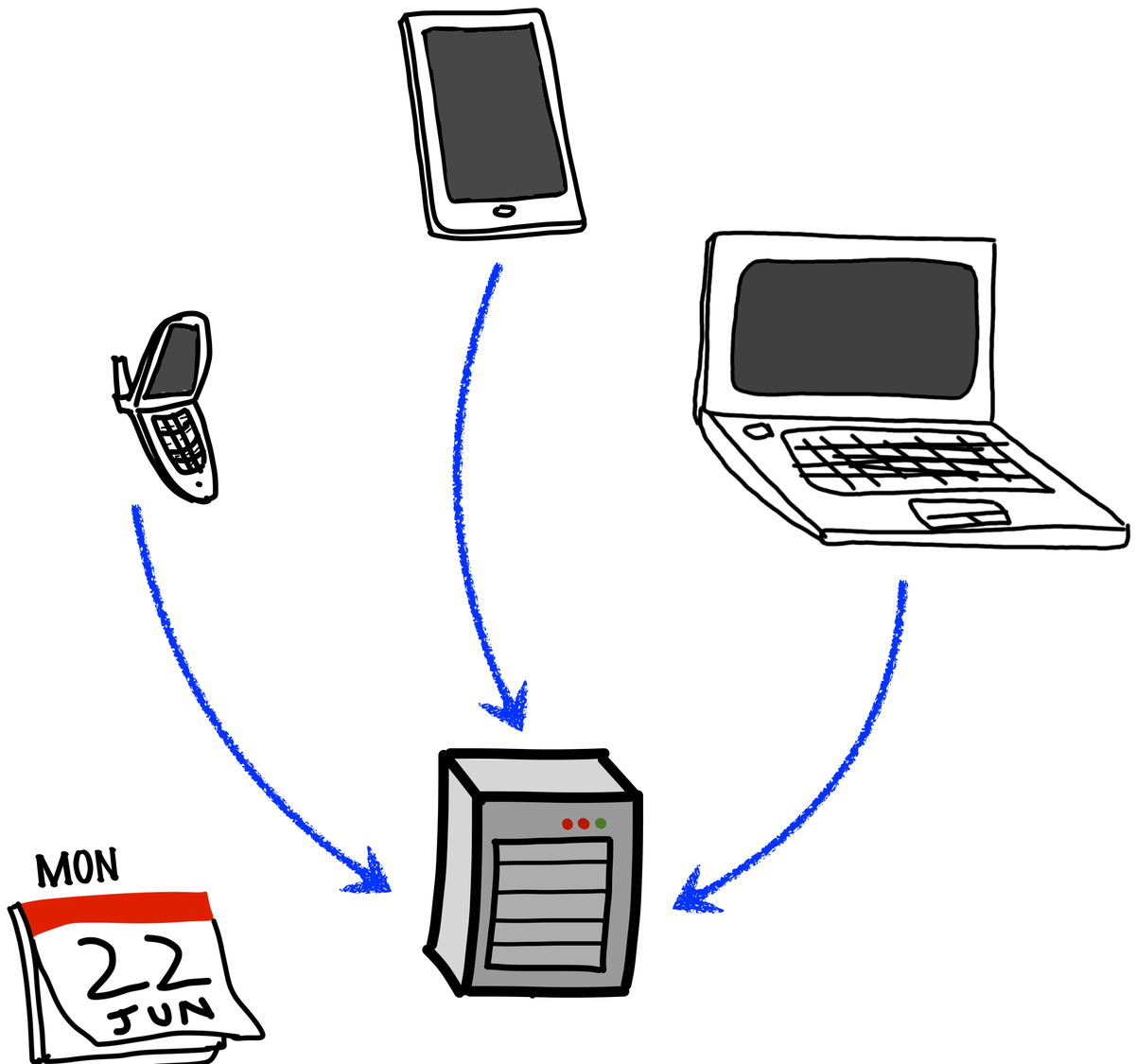

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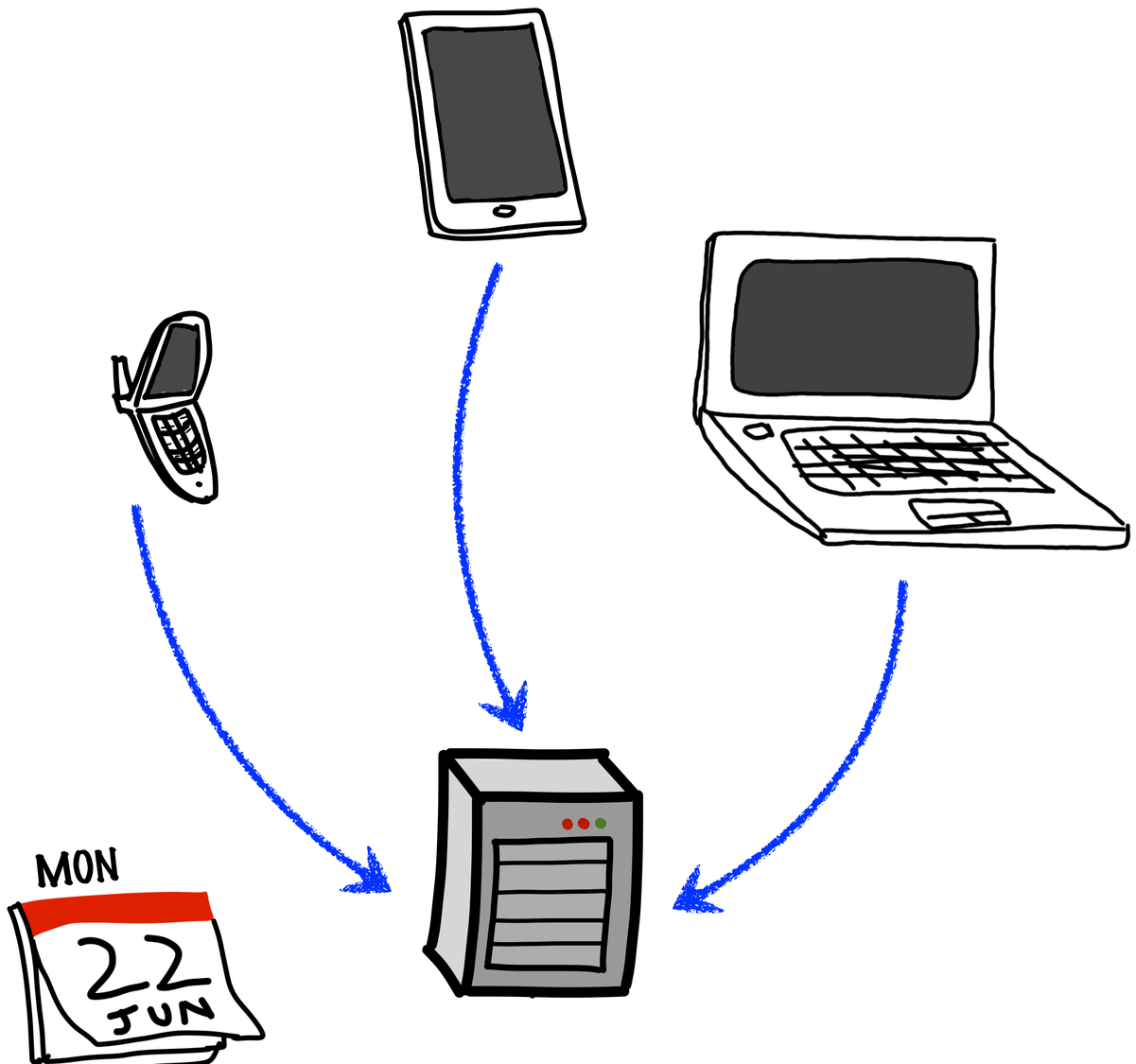

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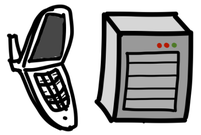
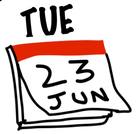
Corollary:

Corrupting  on 

Gives secrets of  on 

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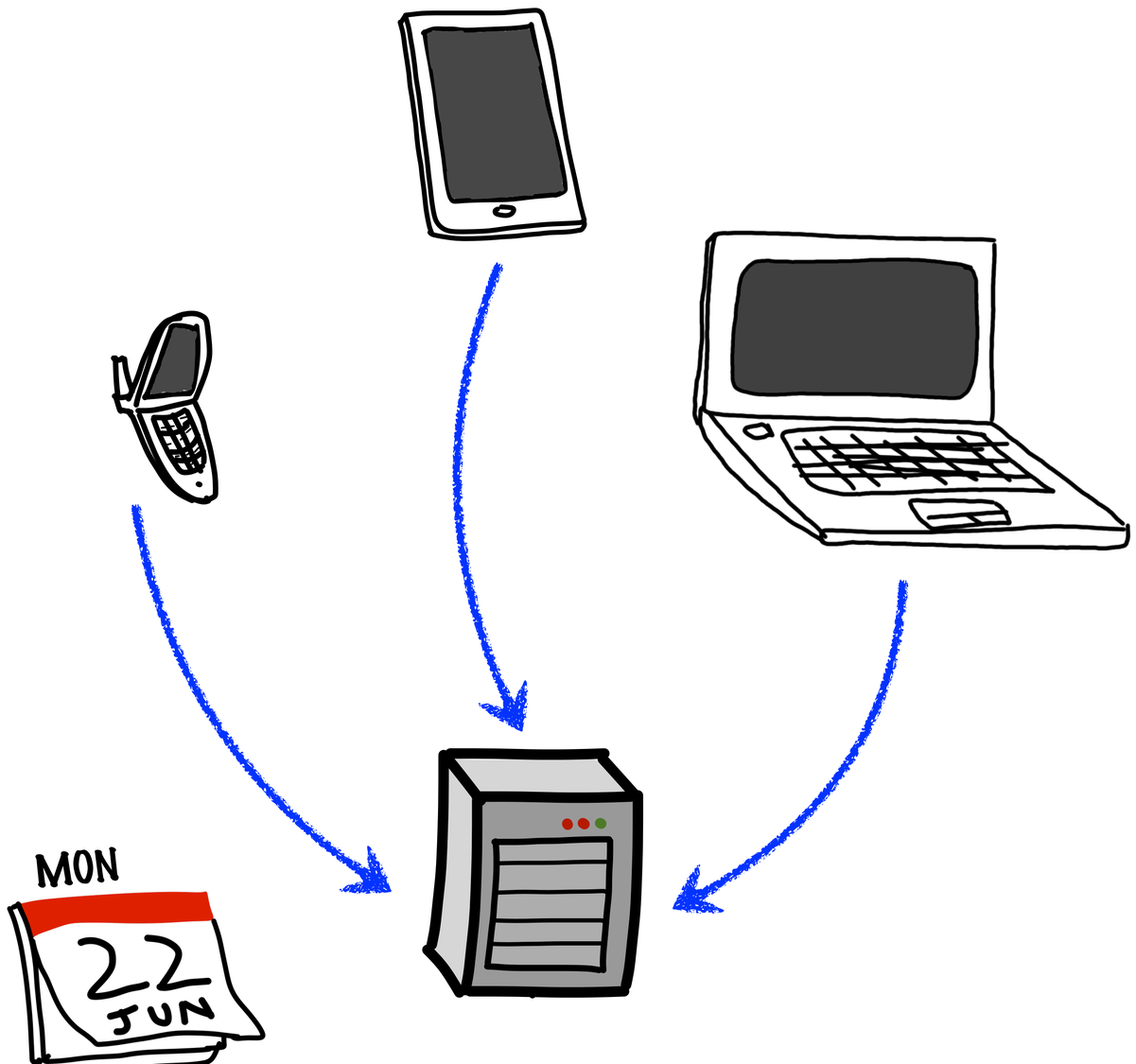

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View of  has enough info
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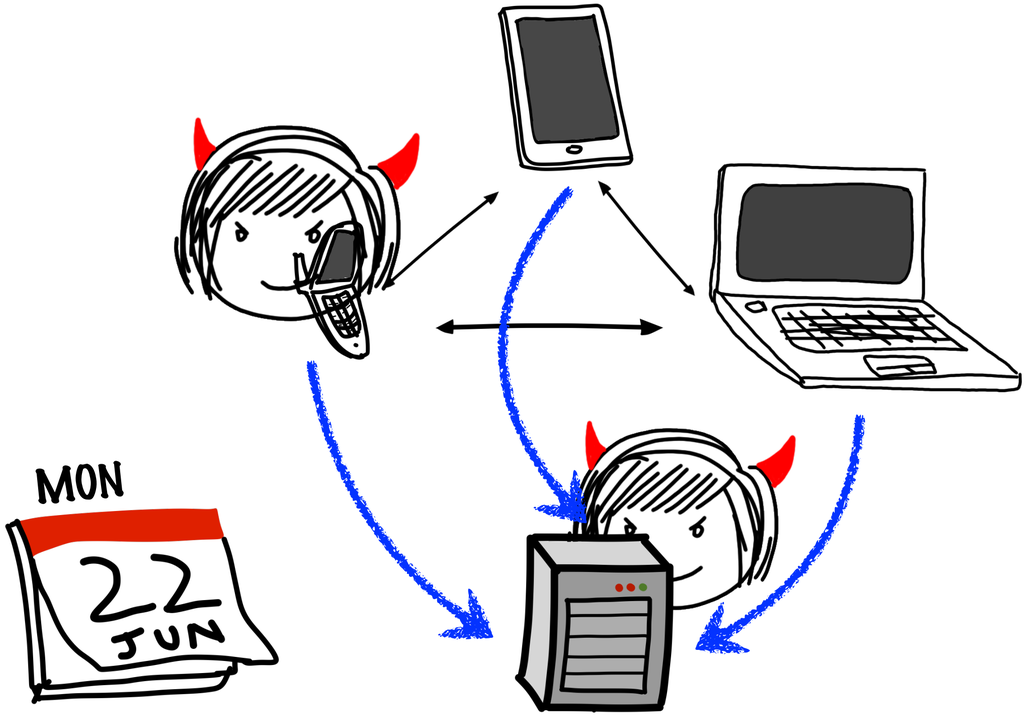
Corollary:

Even after uncorruption

Corrupting  on 

Gives secrets of  on 

General Attack Strategy



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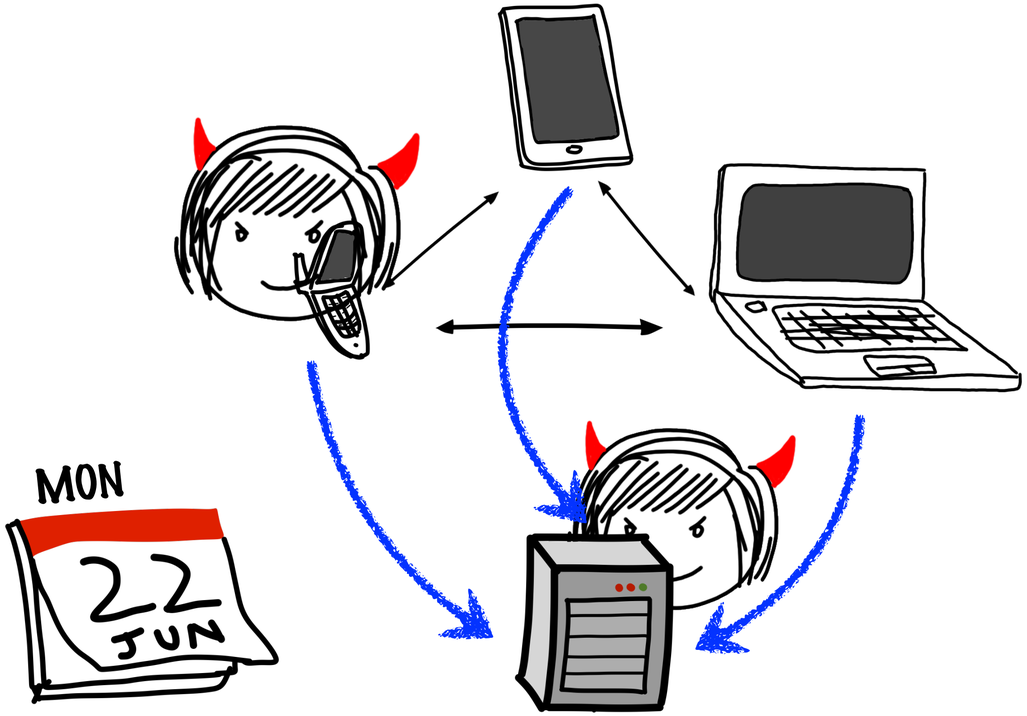

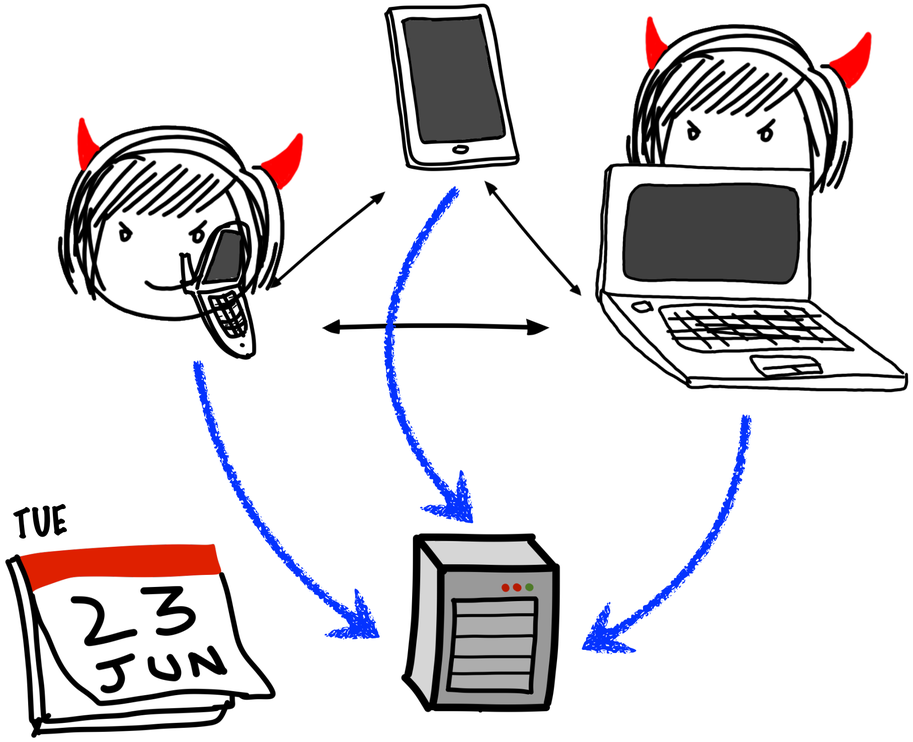

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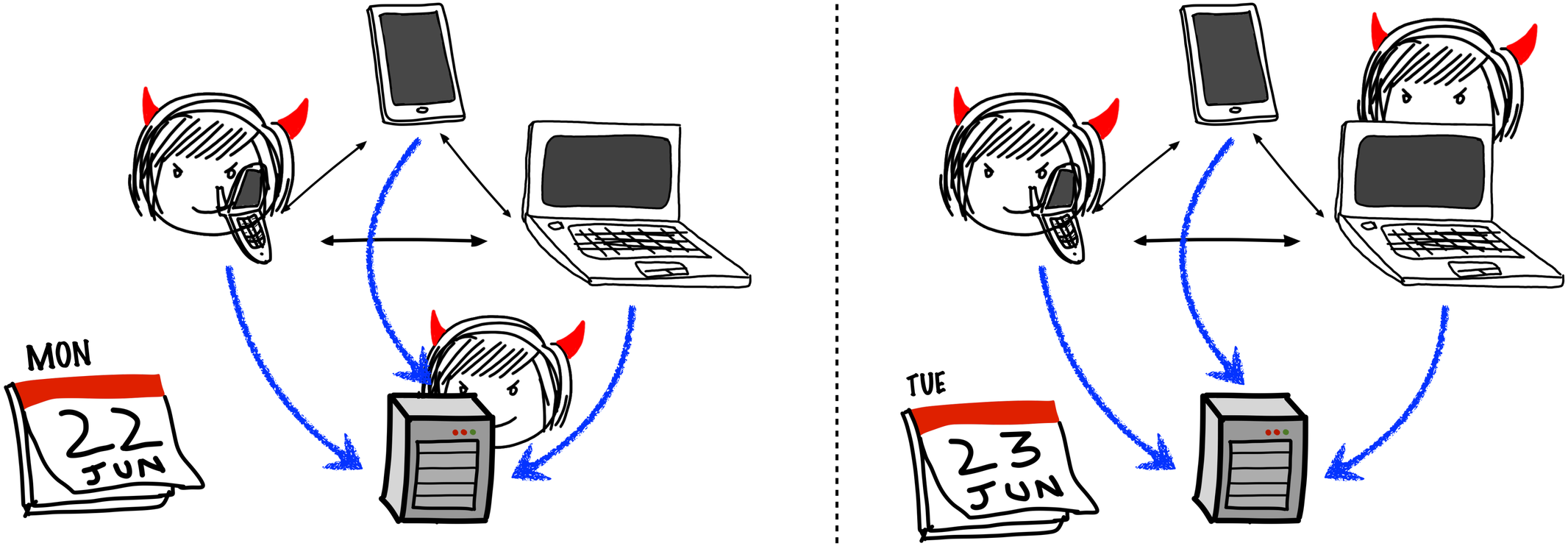

Can derive state of  on TUE even ***after*** refresh

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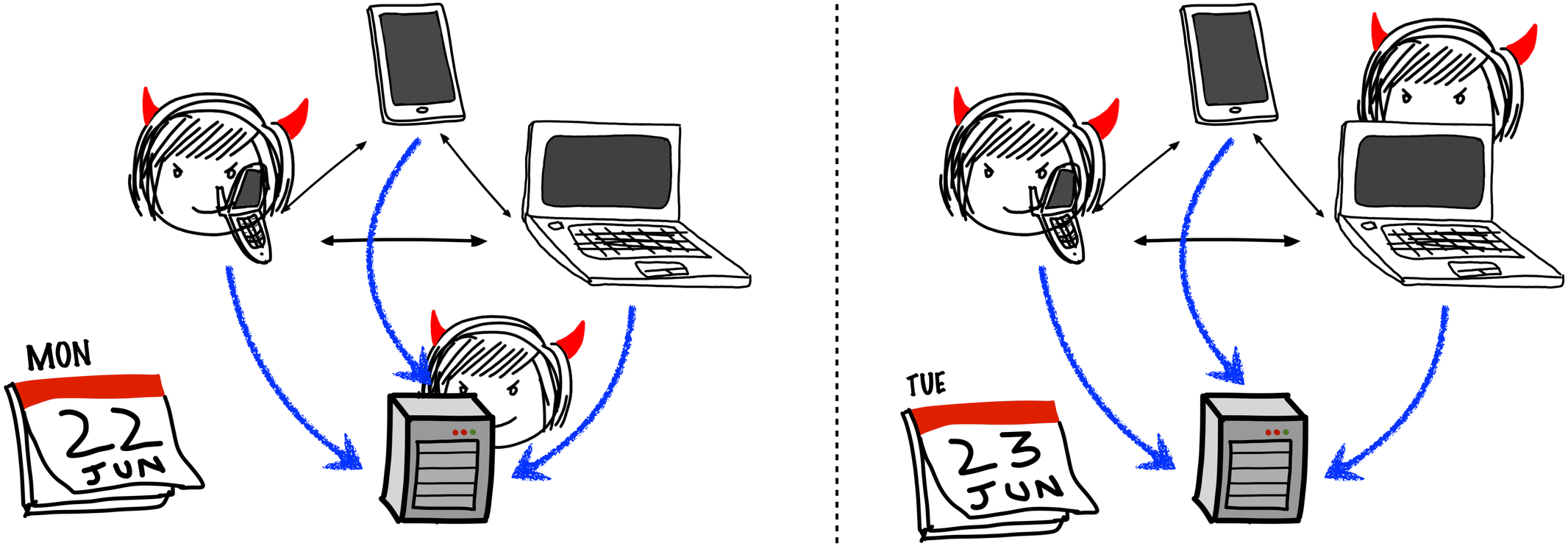

Can derive state of  on TUE even ***after*** refresh

Two corrupt parties + 1 derived state = (3,4) broken

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Thanks Jack Doerner!

- Discussions of definition, full proofs

Thanks!

eprint.iacr.org/2019/1328

Thanks **Eysa Lee** for