Karlsruhe Institute of Technology

Practical and Robust Secure Logging from Fault-Tolerant Sequential Aggregate Signatures

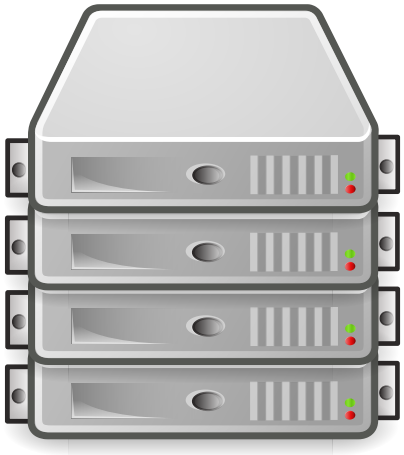
ProvSec 2017 | Gunnar Hartung, Björn Kaidel, Alexander Koch, Jessica Koch, Dominik Hartmann

DEPARTMENT OF INFORMATICS, INSTITUTE OF THEORETICAL INFORMATICS


```
[   18.800138] init: cups main process (921) killed by HUP signal
[   18.800168] init: cups main process ended, respawning
[   19.277716] r8169 0000:03:00.0 eth1: link down
[   19.277736] r8169 0000:03:00.0 eth1: link down
[   19.277807] IPv6: ADDRCONF(NETDEV_UP): eth1: link is not ready
[   19.278090] IPv6: ADDRCONF(NETDEV_UP): eth1: link is not ready
[   19.454410] audit_printk_skb: 21 callbacks suppressed
[   19.454414] type=1400 audit(1452086079.075:19): apparmor="STATUS" operation="profile_replace" profile="unconfined" name="/sbin/dhclient" pid=1007 comm="apparmor_parser"
[   19.454421] type=1400 audit(1452086079.075:20): apparmor="STATUS" operation="profile_replace" profile="unconfined" name="/usr/lib/NetworkManager/nm-dhcp-client.action" pid=1007 comm="apparmor_parser"
[   19.454426] type=1400 audit(1452086079.075:21): apparmor="STATUS" operation="profile_replace" profile="unconfined" name="/usr/lib/connman/scripts/dhclient-script" pid=1007 comm="apparmor_parser"
[   19.454742] type=1400 audit(1452086079.075:22): apparmor="STATUS" operation="profile_load" profile="unconfined" name="/usr/lib/x86_64-linux-gnu/lightdm-remote-session-freerdp/freerdp-session-wrapper" pi
d=1005 comm="apparmor_parser"
[   19.454751] type=1400 audit(1452086079.075:23): apparmor="STATUS" operation="profile_load" profile="unconfined" name="chromium" pid=1005 comm="apparmor_parser"
[   19.454776] type=1400 audit(1452086079.075:24): apparmor="STATUS" operation="profile_replace" profile="unconfined" name="/usr/lib/NetworkManager/nm-dhcp-client.action" pid=1007 comm="apparmor_parser"
[   19.454781] type=1400 audit(1452086079.075:25): apparmor="STATUS" operation="profile_replace" profile="unconfined" name="/usr/lib/connman/scripts/dhclient-script" pid=1007 comm="apparmor_parser"
[   19.454866] type=1400 audit(1452086079.075:26): apparmor="STATUS" operation="profile_load" profile="unconfined" name="/usr/lib/lightdm/lightdm-guest-session" pid=1004 comm="apparmor_parser"
[   19.454870] type=1400 audit(1452086079.075:27): apparmor="STATUS" operation="profile_load" profile="unconfined" name="chromium" pid=1004 comm="apparmor_parser"
[   19.454977] type=1400 audit(1452086079.075:28): apparmor="STATUS" operation="profile_replace" profile="unconfined" name="chromium" pid=1005 comm="apparmor_parser"
[   20.269329] vboxdrv: module verification failed: signature and/or  required key missing - tainting kernel
[   20.272462] vboxdrv: Found 4 processor cores.
[   20.272850] vboxdrv: fAsync=0 offMin=0x4bd offMax=0x37a5
[   20.272936] vboxdrv: TSC mode is 'synchronous', kernel timer mode is 'normal'.
[   20.272937] vboxdrv: Successfully loaded version 4.3.34_Ubuntu (interface 0x001a000b).
[   20.288317] vboxpci: IOMMU not found (not registered)
[   20.968583] r8169 0000:03:00.0 eth1: link up
[   20.968594] IPv6: ADDRCONF(NETDEV_CHANGE): eth1: link becomes ready
[   22.513738] init: plymouth-upstart-bridge main process ended, respawning
[   22.526708] init: plymouth-upstart-bridge main process ended, respawning
[   48.266900] NFS: Registering the id_resolver key type
[   48.266913] Key type id_resolver registered
[   48.266915] Key type id_legacy registered
```

(Seal CC-0 by Tango Desktop Project)

Secure Logging – Motivation/First Try



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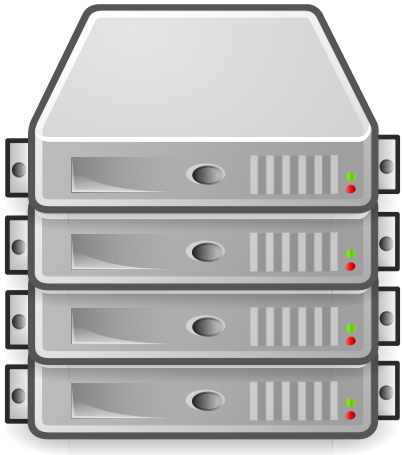
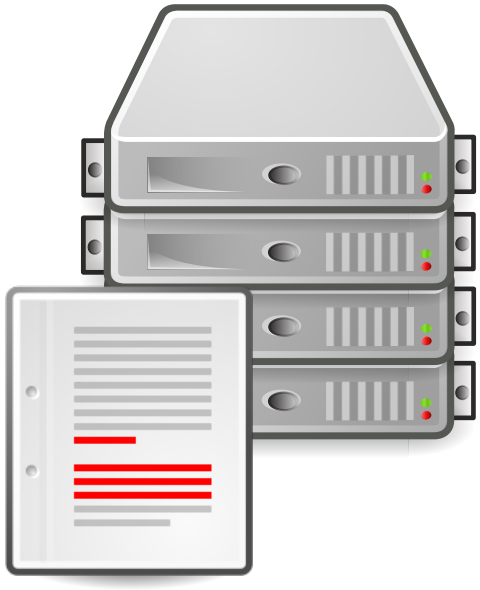


attacks stealthy

learns secrets

System under attack

Secure Logging – Motivation/First Try



attacks stealthy

learns secrets

We can use a log file to detect an attack later

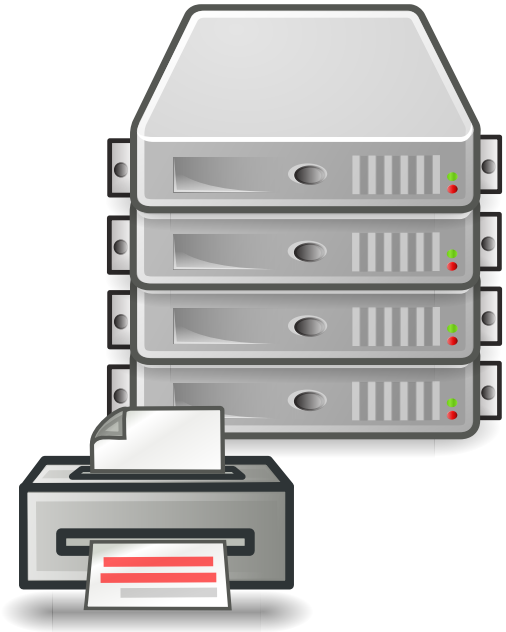
Secure Logging – Motivation/First Try

attacks stealthy

learns secrets

But the attacker may modify the log file to cover his traces!

Secure Logging – Motivation/First Try



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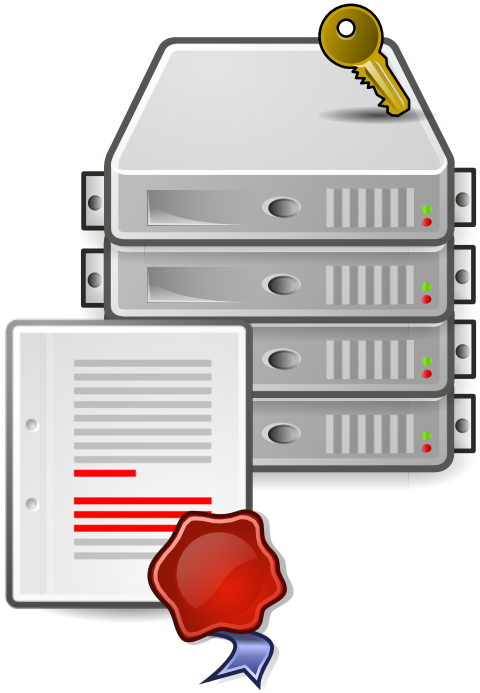
learns secrets

Hardware-solutions are costly, want to use crypto.

Secure Logging – Motivation/First Try

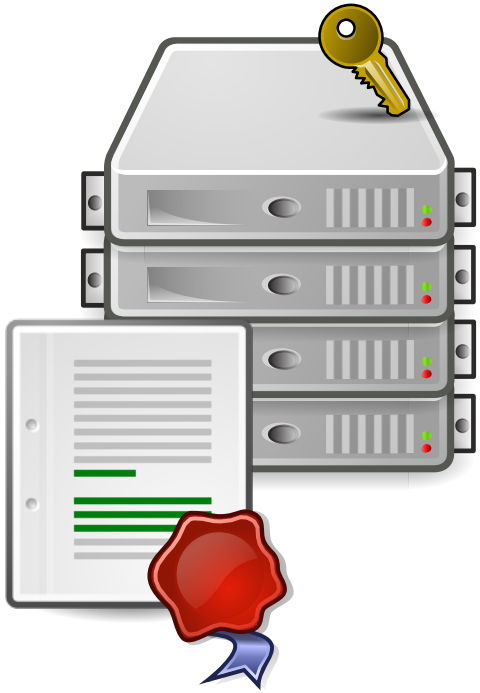


attacks stealthy

learns secrets

Lets use a signature to protect the log file.

Secure Logging – Motivation/First Try



attacks stealthy

learns secrets

But the attacker may retrieve the signing key and just re-sign!

Secure Logging – Motivation/First Try

“I am scared!”

Aim: We want a provably secure logging scheme that features

1. forward-security
2. truncation-resistance
3. robustness (while retaining space-efficiency)

Forward-Secure Model

Idea: Sign log entries using forward-secure signatures [BM99]

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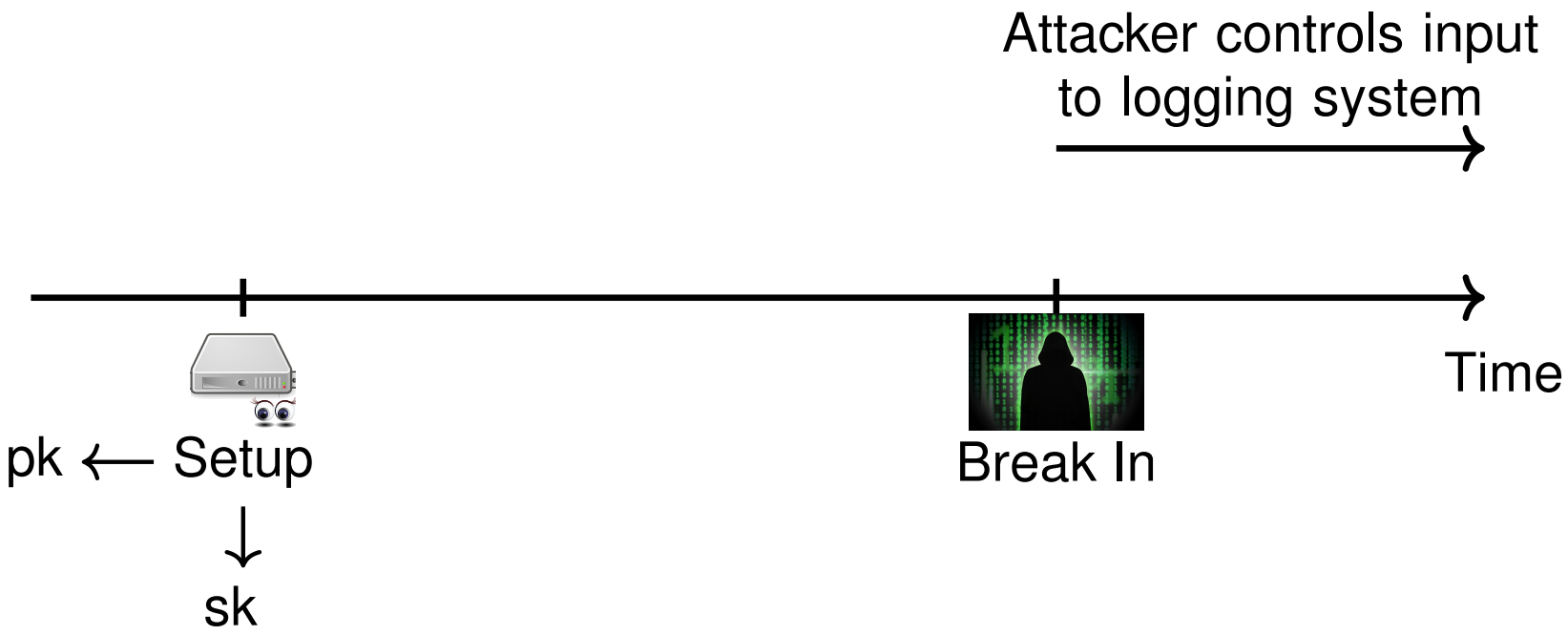

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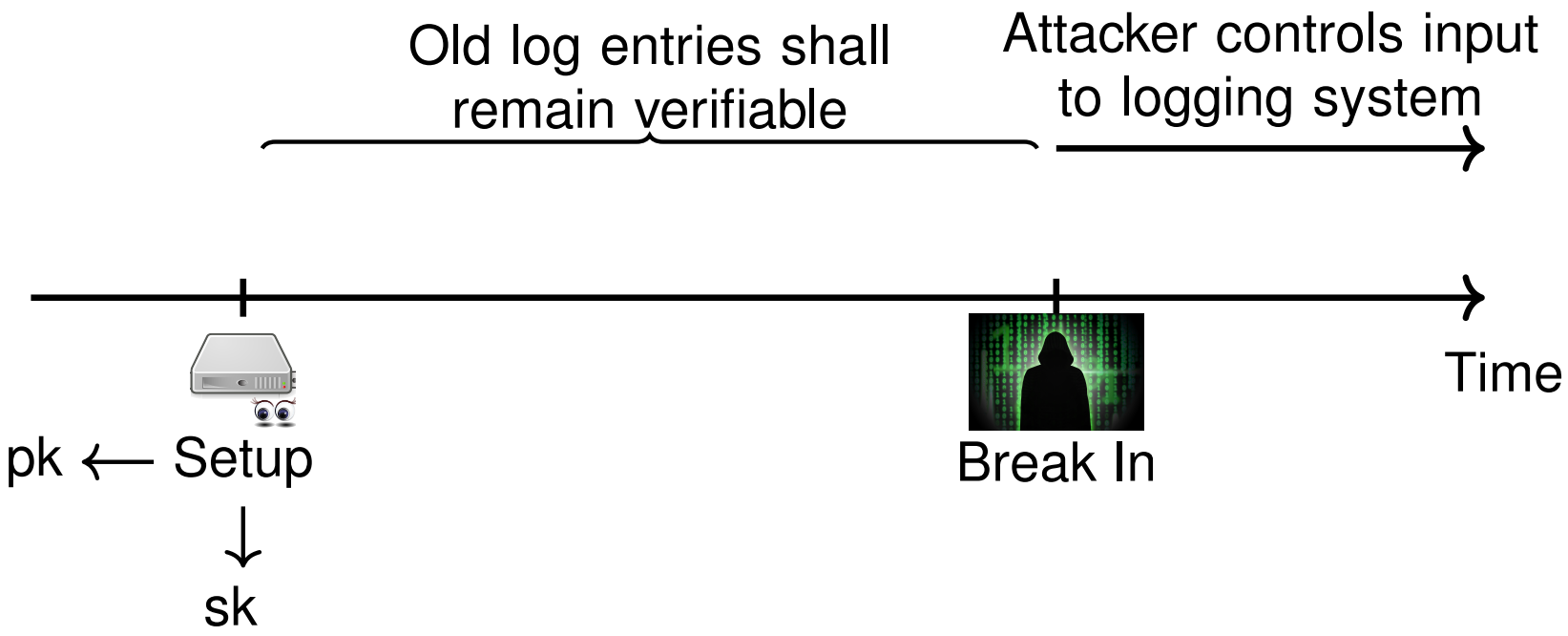

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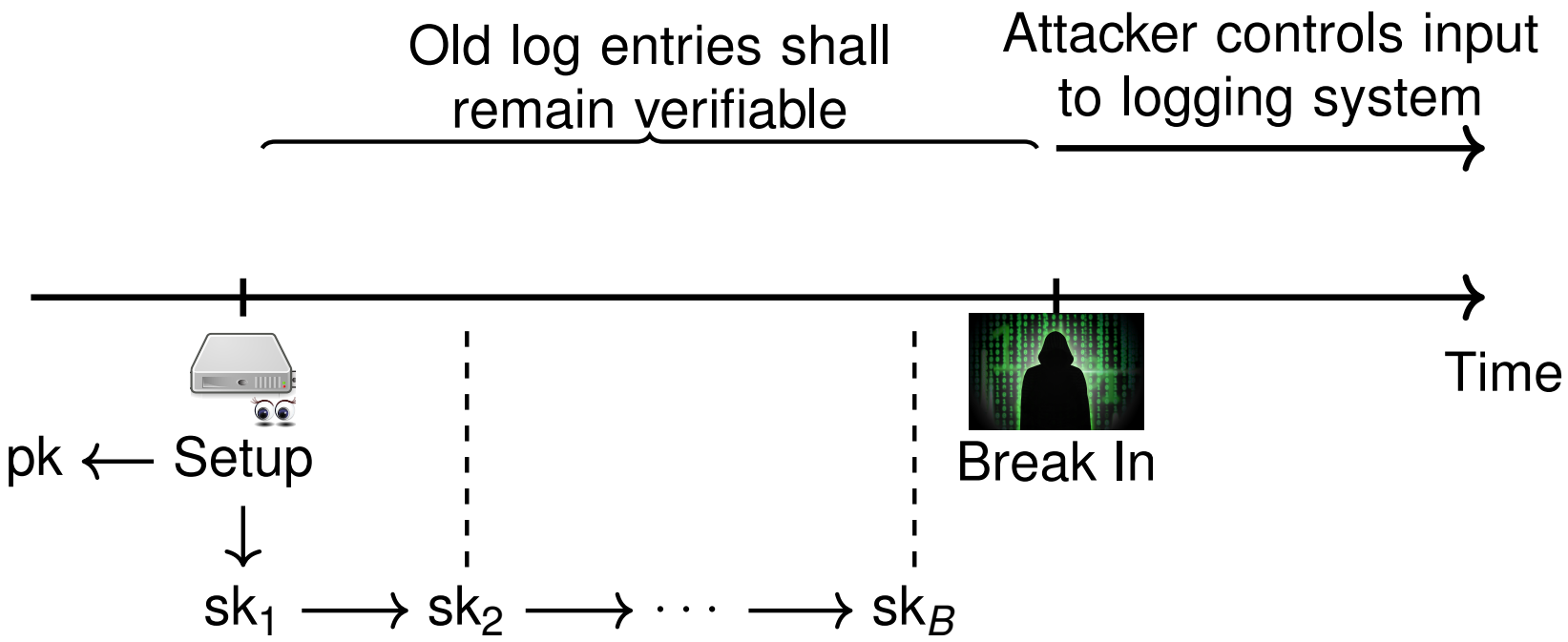

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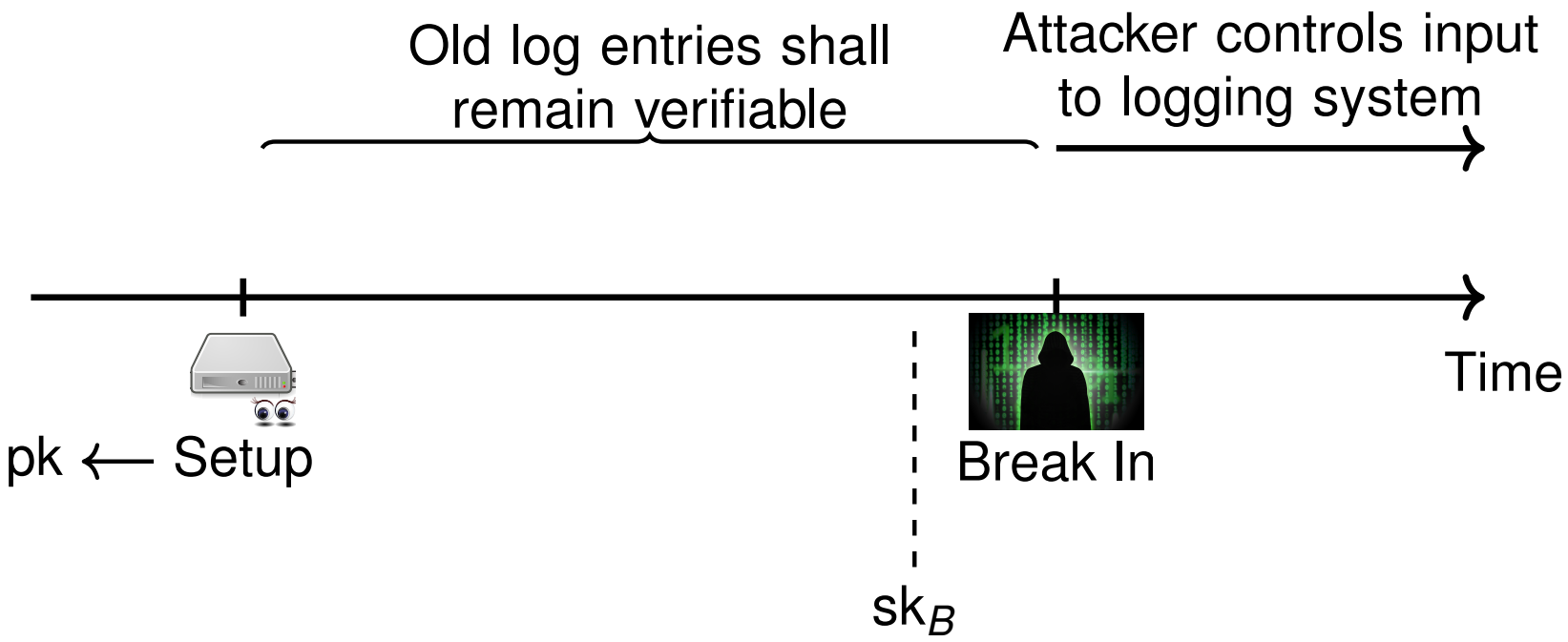
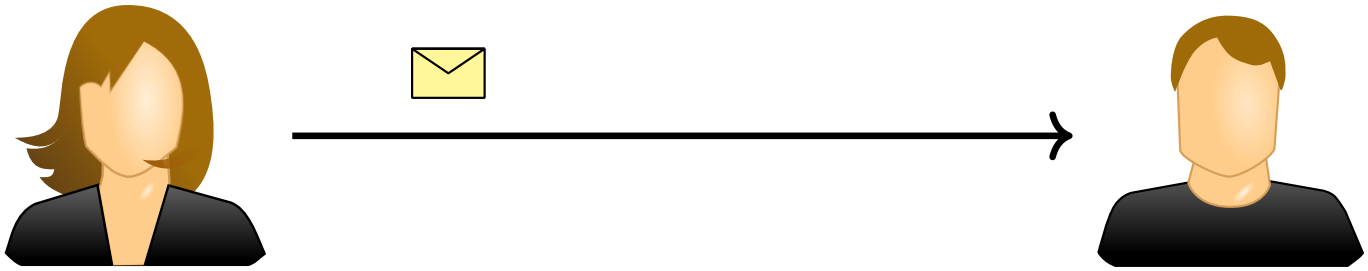


Achieving truncation-resistance [MT08]

W/ [forward-secure sequential] aggregate signatures [Bon+03]



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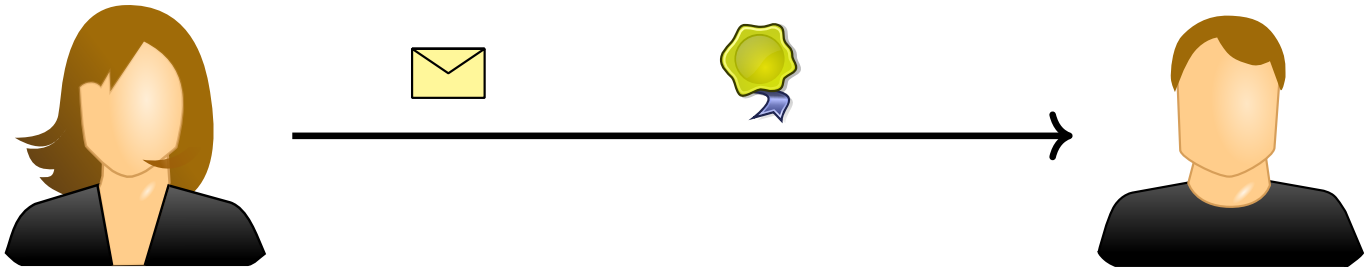

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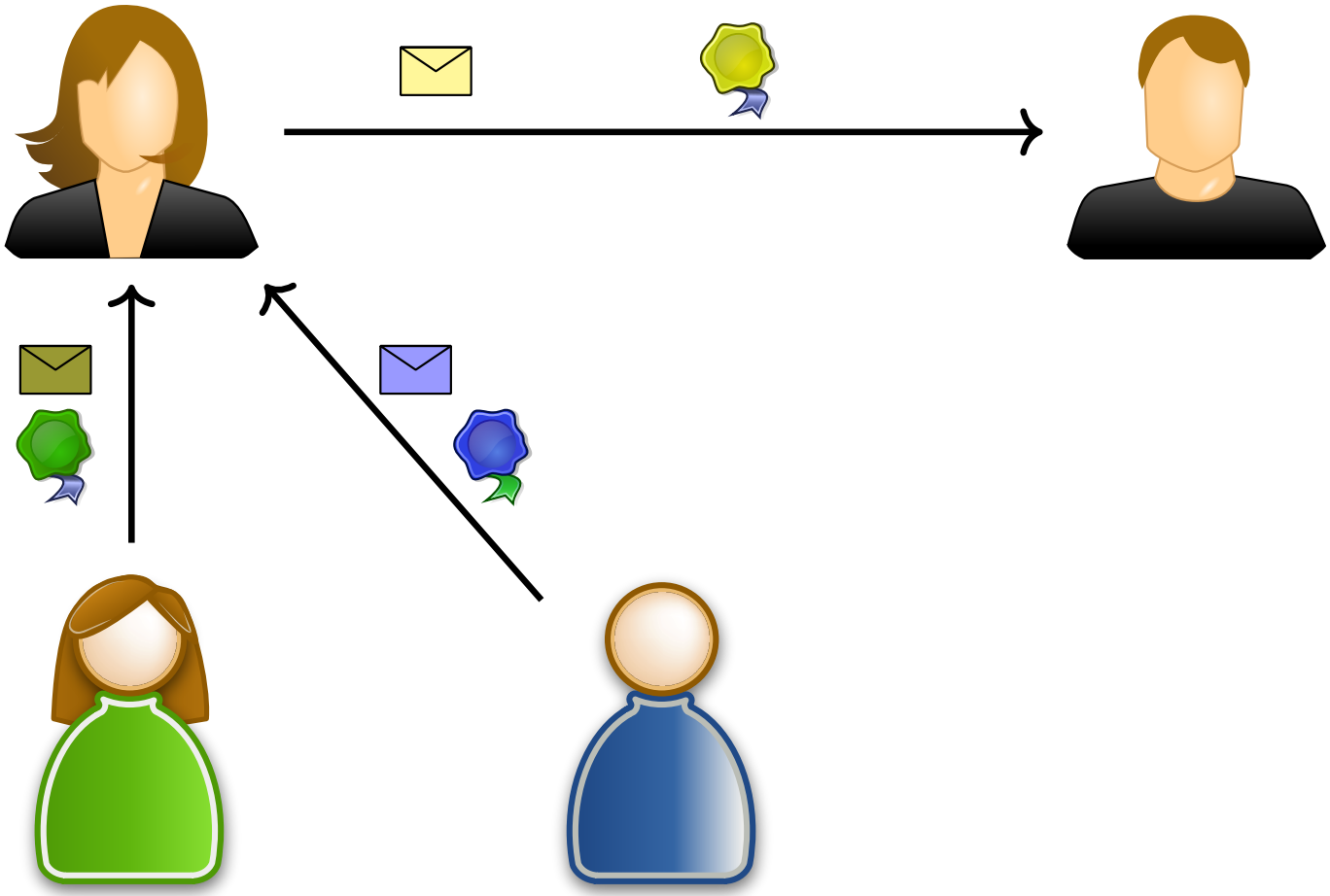

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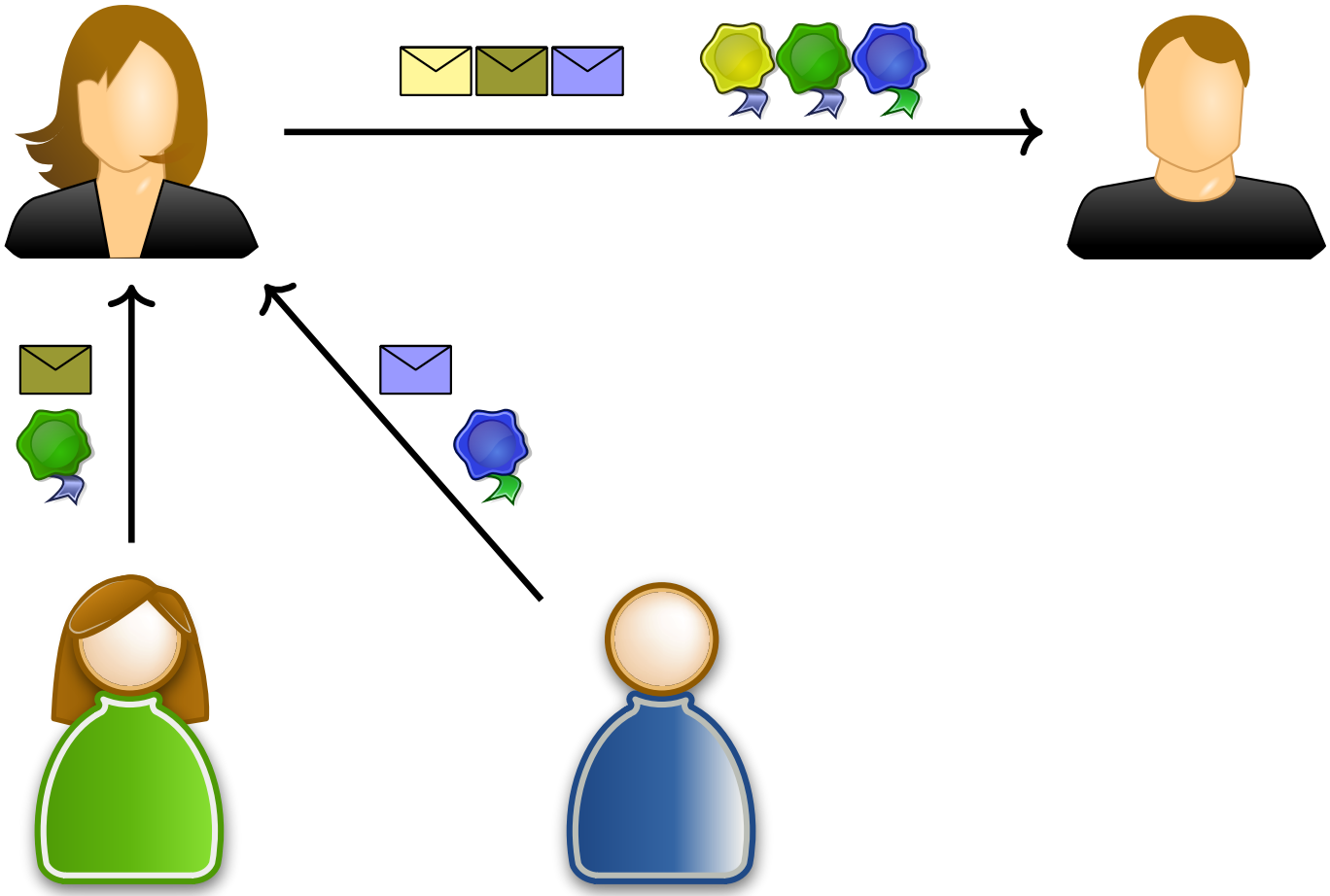

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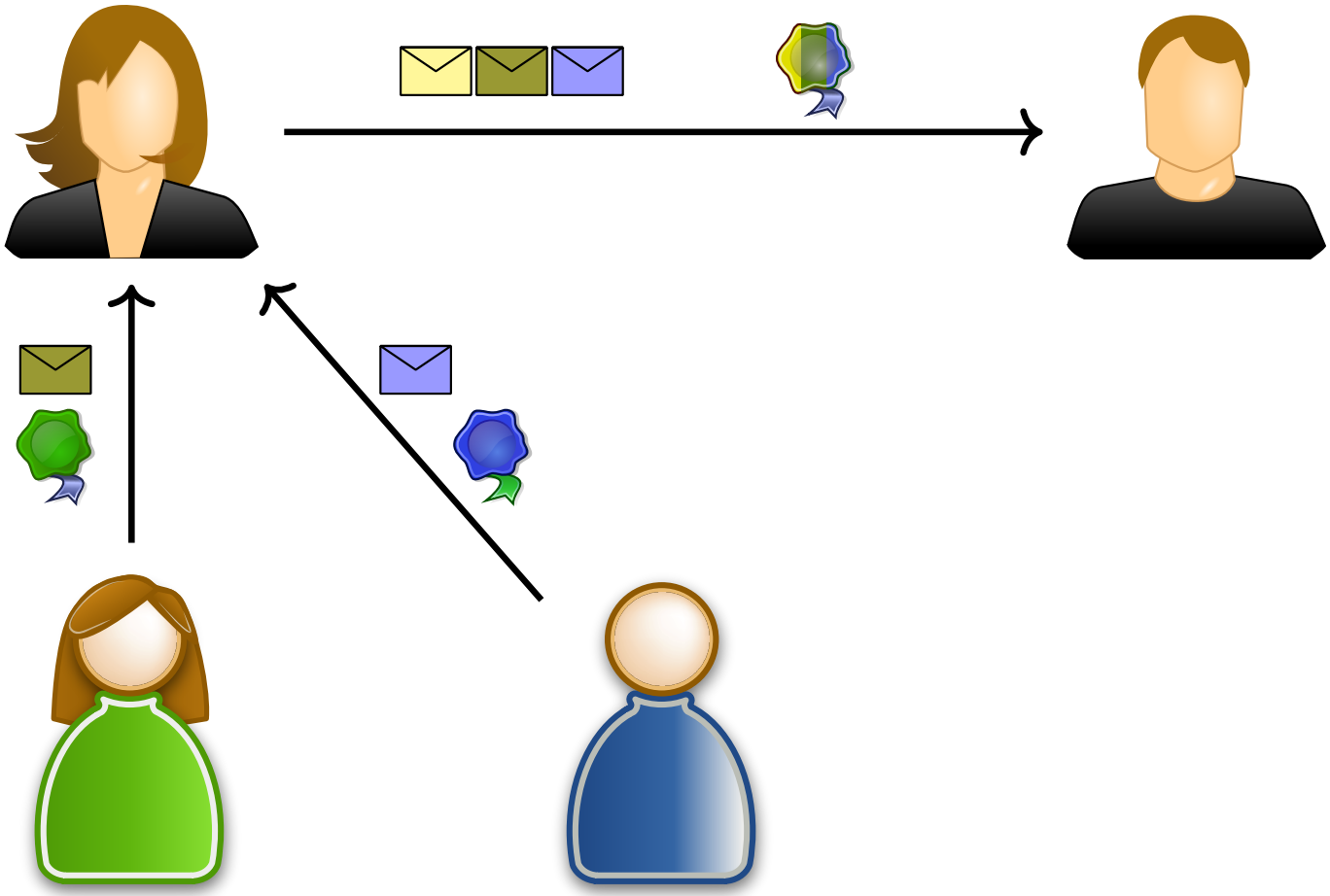

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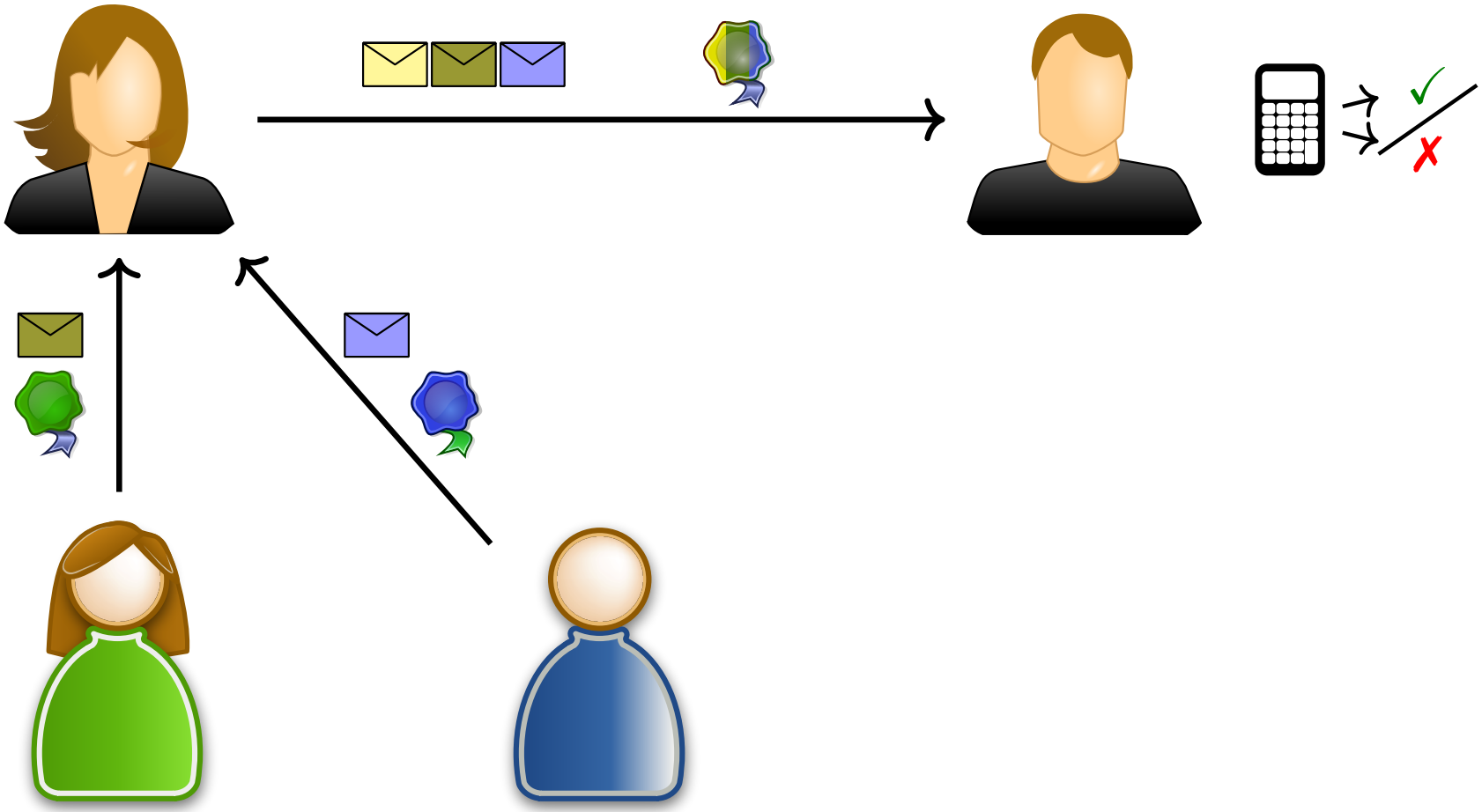

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Robustness for Aggregate Signatures

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What happens if verification fails?

Robustness for Aggregate Signatures

What happens if verification fails?

Bob doesn't know which/how many messages are invalid

$\Longrightarrow$ If we have an invalid aggregate signature for our logfile, everything is untrusted! This makes it very non-robust to log-modifications

Possible fix: Save all log entry signatures also.

Robustness for Aggregate Signatures

What happens if verification fails?
Bob doesn't know which/how many messages are invalid
$\Longrightarrow$ If we have an invalid aggregate signature for our logfile, everything is untrusted! This makes it very non-robust to log-modifications

Possible fix: Save all log entry signatures also.

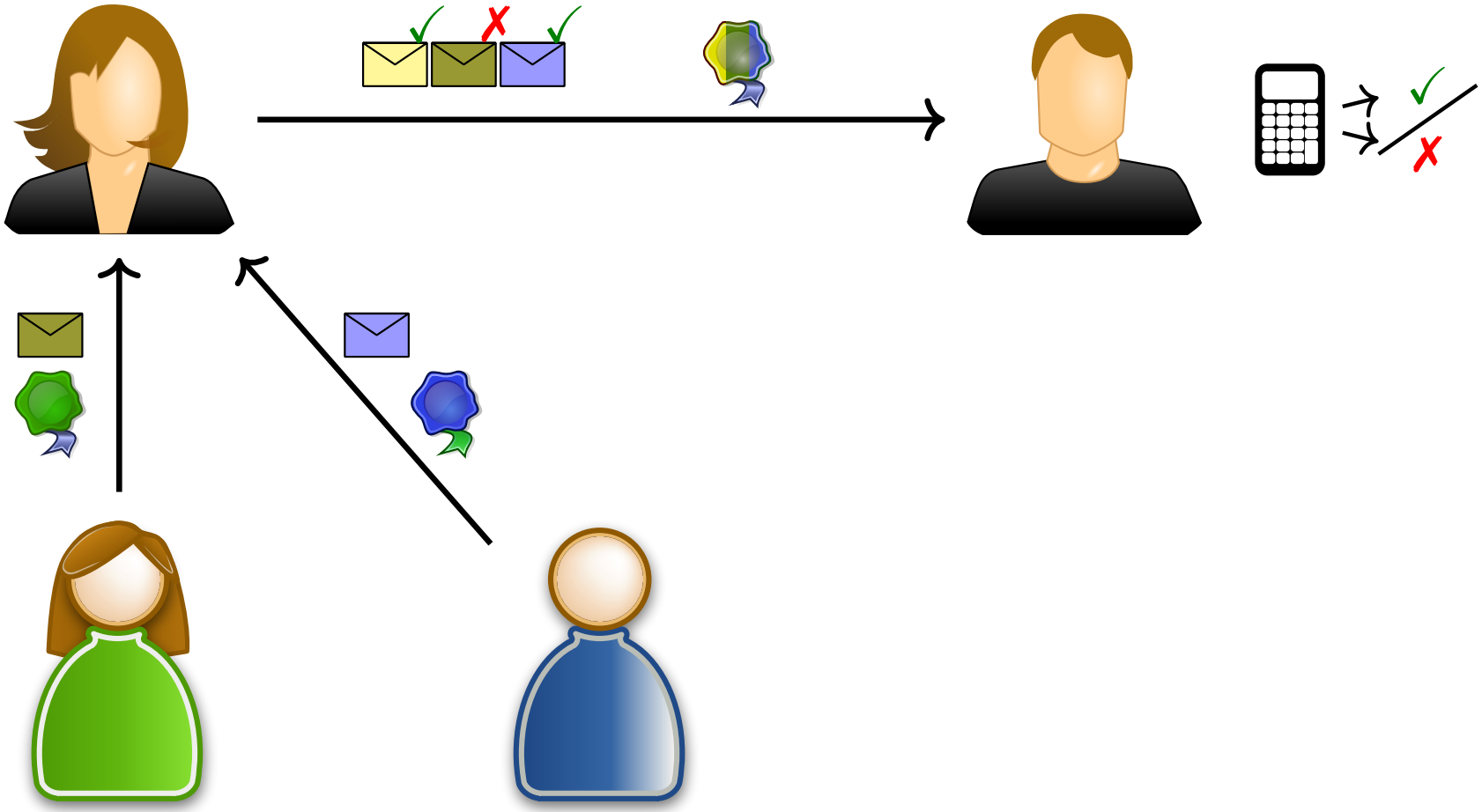
However, this is

- not space-efficient (uses n sigs, want: $\log(n)$)
- it might hinder truncation-security!
  For general aggregation: adversary just reaggregates all sigs excluding the entries to be truncated

We can do better :-)

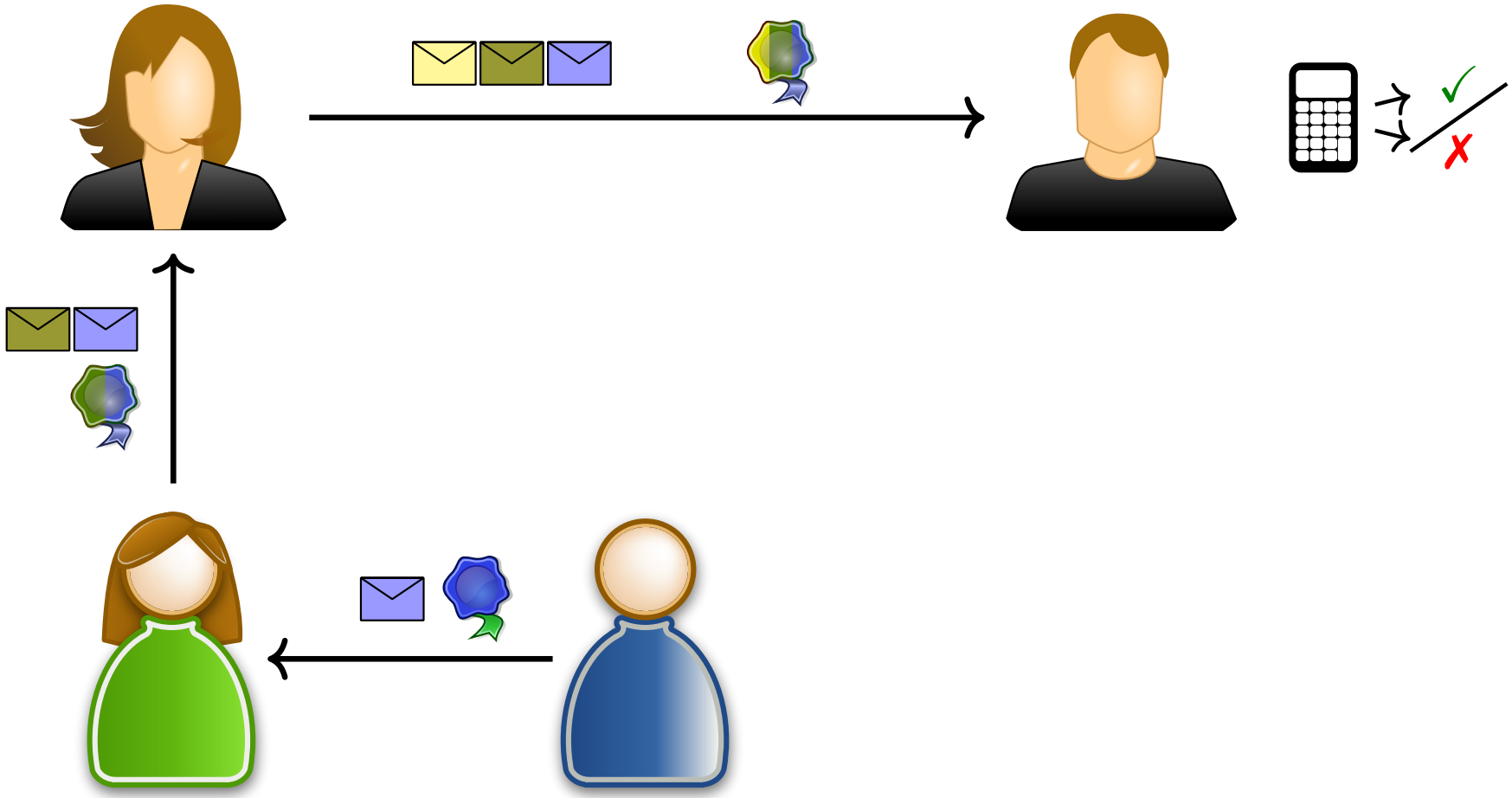
Adding Robustness to Aggregate Signatures

Hartung et al. [Har+16]



Relaxed: Sequential Aggregate Signatures

Lysyanskaya et al. [Lys+04]



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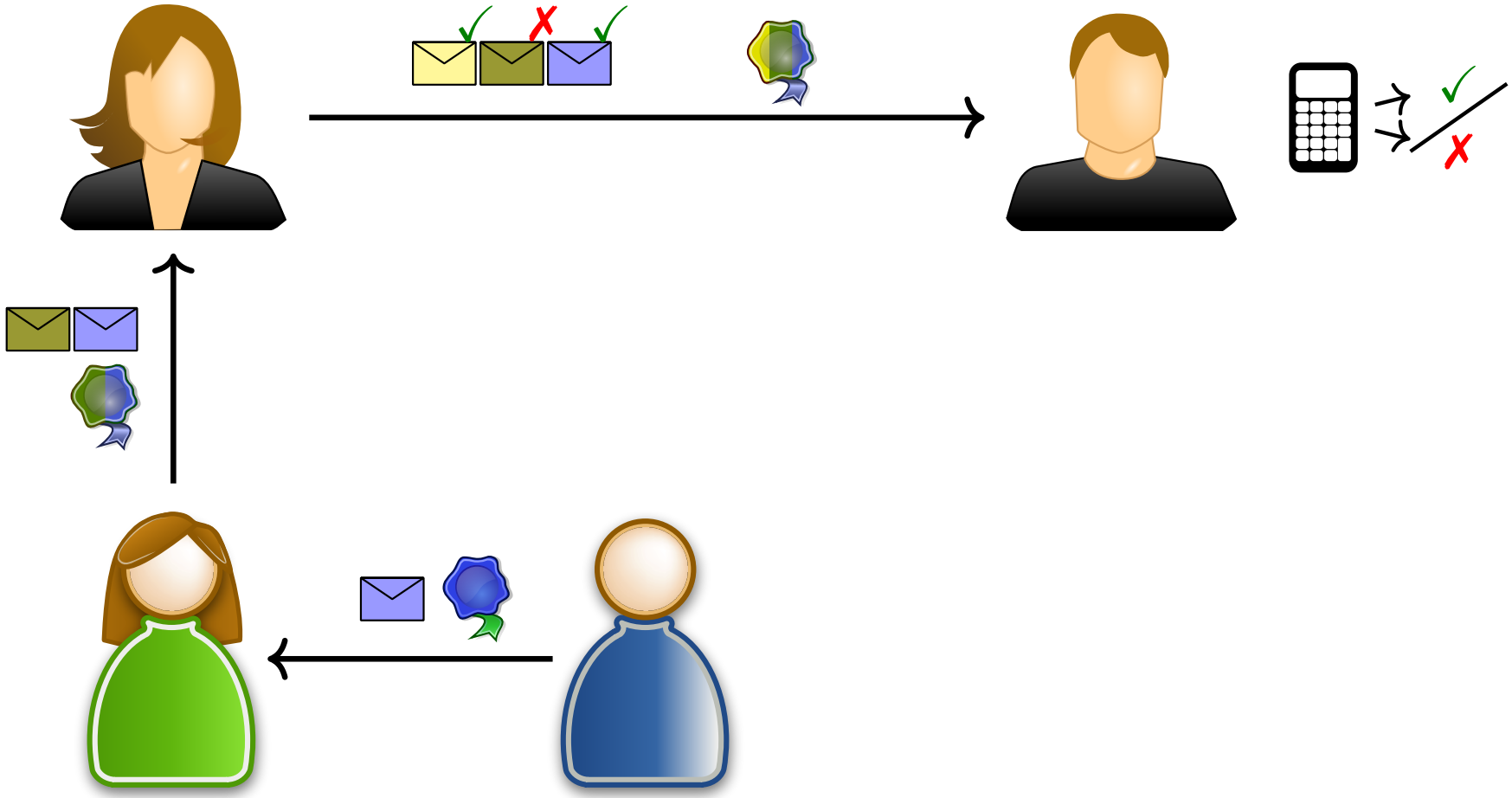
Lysyanskaya et al. [Lys+04], New: Adapt Robustness



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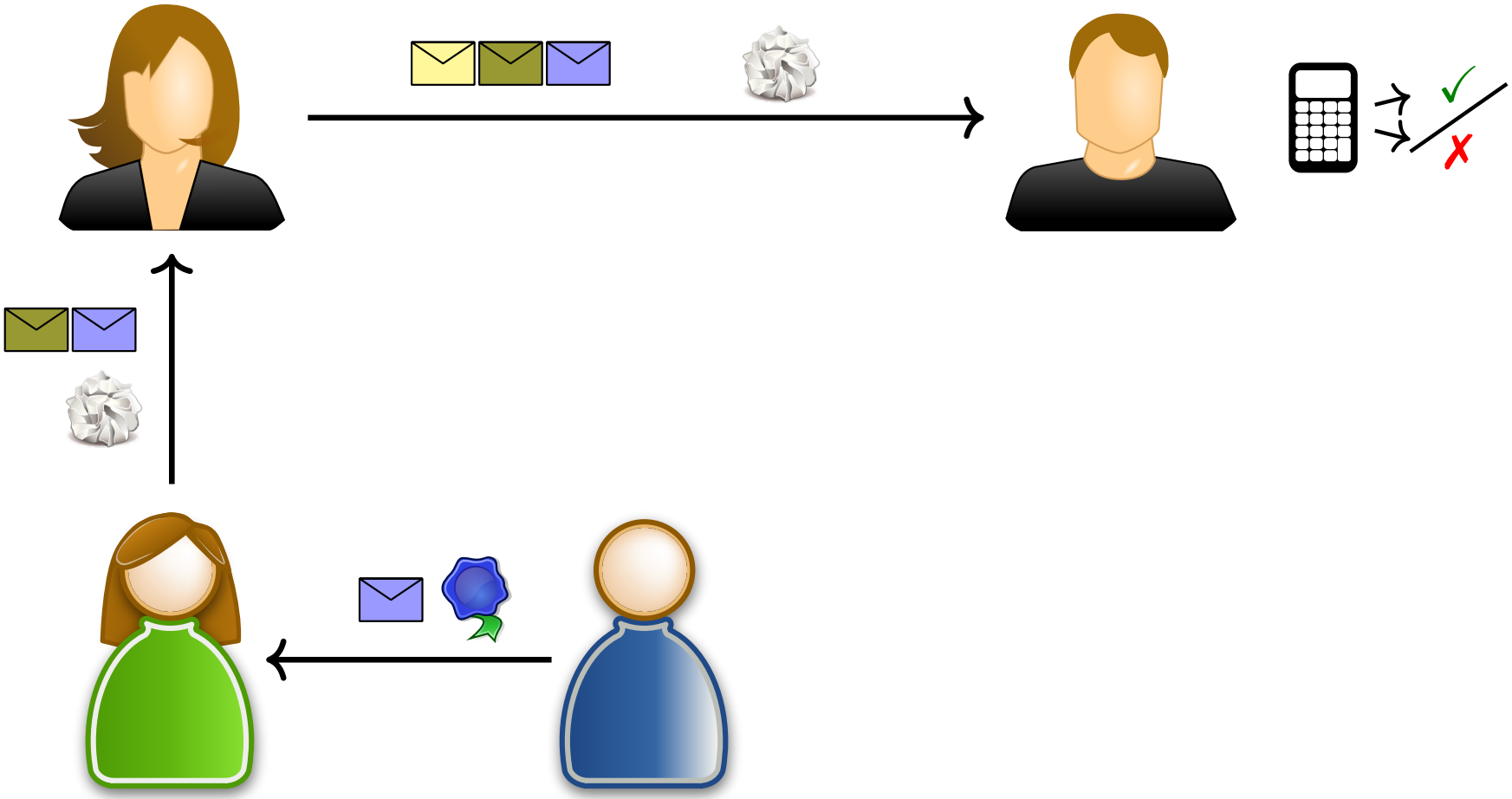

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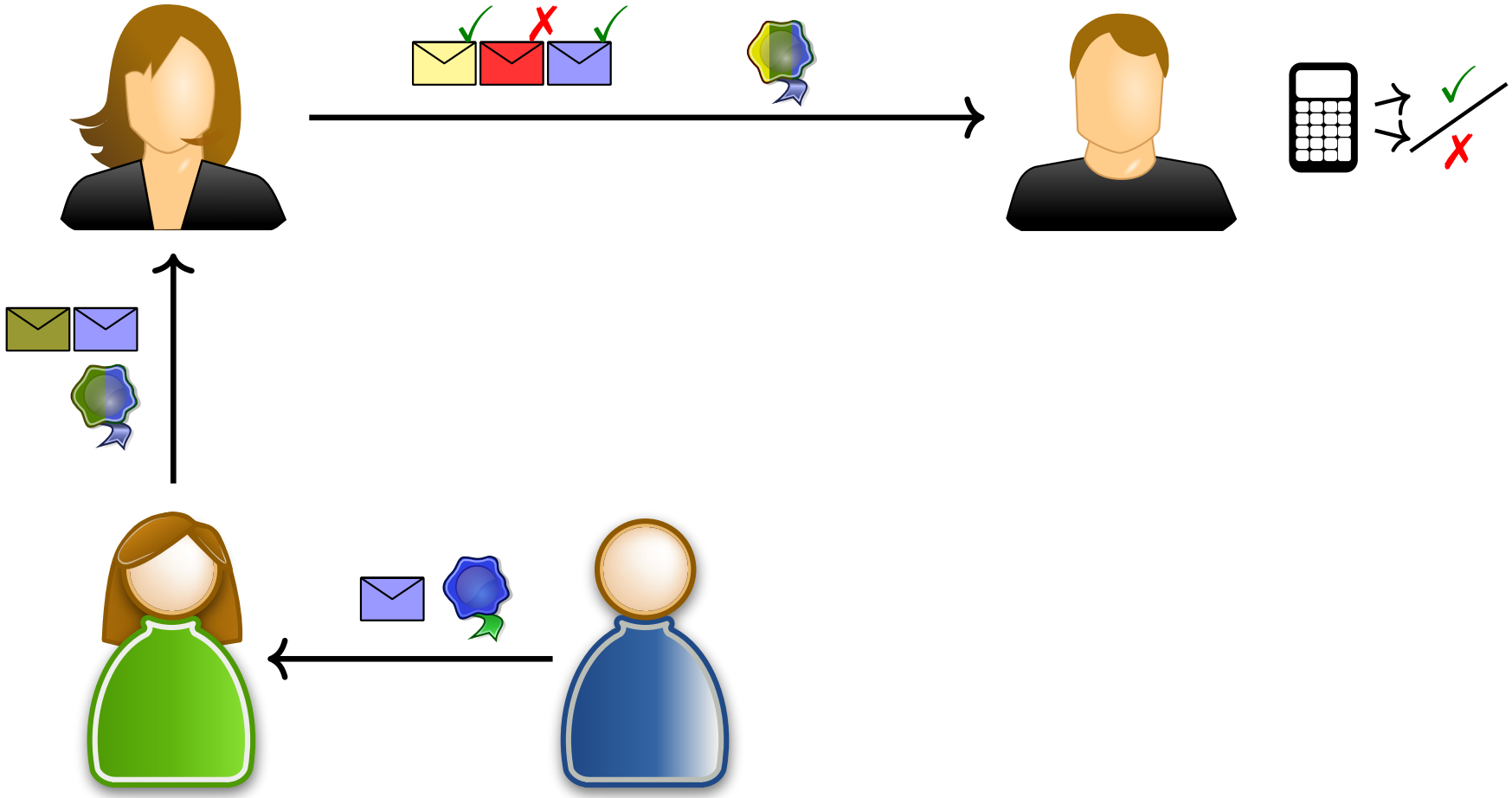

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Robustness/Fault-Tolerance

Adapted from Hartung et al. [Har+16]

- The verification algorithm outputs a list of valid messages.
- A message seq. C is regular for σ, if σ is a generated sig for C.

Definition: Fault-Tolerance (informal)

A sequential aggregate signature scheme is d-fault-tolerant, iff

- for any C, σ as above, any C' with distance $\leq d$ from C (of possibly different length)
- Verify(C', σ) outputs (at least) all valid messages from C'.

Review: Approach from [Har+16]

- signature $\hat{=}$ vector of signatures of underlying scheme

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$$\begin{pmatrix} 1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{pmatrix} \rightsquigarrow \begin{pmatrix} \quad \end{pmatrix}$$

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$$\begin{pmatrix} \sigma_1 & 0 & 0 & \sigma_4 & 0 & \sigma_6 \\ \sigma_1 & \sigma_2 & 0 & 0 & \sigma_5 & 0 \\ 0 & \sigma_2 & \sigma_3 & \sigma_4 & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 & \sigma_5 & \sigma_6 \end{pmatrix} \rightsquigarrow \begin{pmatrix} \\ \\ \\ \end{pmatrix}$$

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Why does this work?

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$$\begin{pmatrix} \sigma_1 & 0 & 0 & \sigma_4 & 0 & \sigma_6 \\ \sigma_1 & \sigma_2 & 0 & 0 & \sigma_5 & 0 \\ 0 & \sigma_2 & \sigma_3 & \sigma_4 & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 & \sigma_5 & \sigma_6 \end{pmatrix} \rightsquigarrow \begin{pmatrix} \mathrm{Agg}(\sigma_1, \sigma_4, \sigma_6) & \text{✗} \\ \mathrm{Agg}(\sigma_1, \sigma_2, \sigma_5) & \text{✓} \\ \mathrm{Agg}(\sigma_2, \sigma_3, \sigma_4) & \text{✗} \\ \mathrm{Agg}(\sigma_3, \sigma_5, \sigma_6) & \text{✓} \end{pmatrix}$$

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No single column “covers” any other column.

Review: Approach from [Har+16]

- signature $\hat{=}$ vector of signatures of underlying scheme
- columns $\hat{=}$ individual signatures

$$\begin{pmatrix} \sigma_1 & 0 & 0 & \sigma_4 & 0 & \sigma_6 \\ \sigma_1 & \sigma_2 & 0 & 0 & \sigma_5 & 0 \\ 0 & \sigma_2 & \sigma_3 & \sigma_4 & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 & \sigma_5 & \sigma_6 \end{pmatrix} \rightsquigarrow \begin{pmatrix} \mathrm{Agg}(\sigma_1, \sigma_4, \sigma_6) & \text{✗} \\ \mathrm{Agg}(\sigma_1, \sigma_2, \sigma_5) & \text{✓} \\ \mathrm{Agg}(\sigma_2, \sigma_3, \sigma_4) & \text{✗} \\ \mathrm{Agg}(\sigma_3, \sigma_5, \sigma_6) & \text{✓} \end{pmatrix}$$

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Why does this work?
No single column “covers” any other column. (But 2 do!)

Incidence matrices of cover-free families [KRS99] allow for more (d) invalid signatures. Caveat: compression ratio is $\Omega(\log_2(n))$

Security Experiment

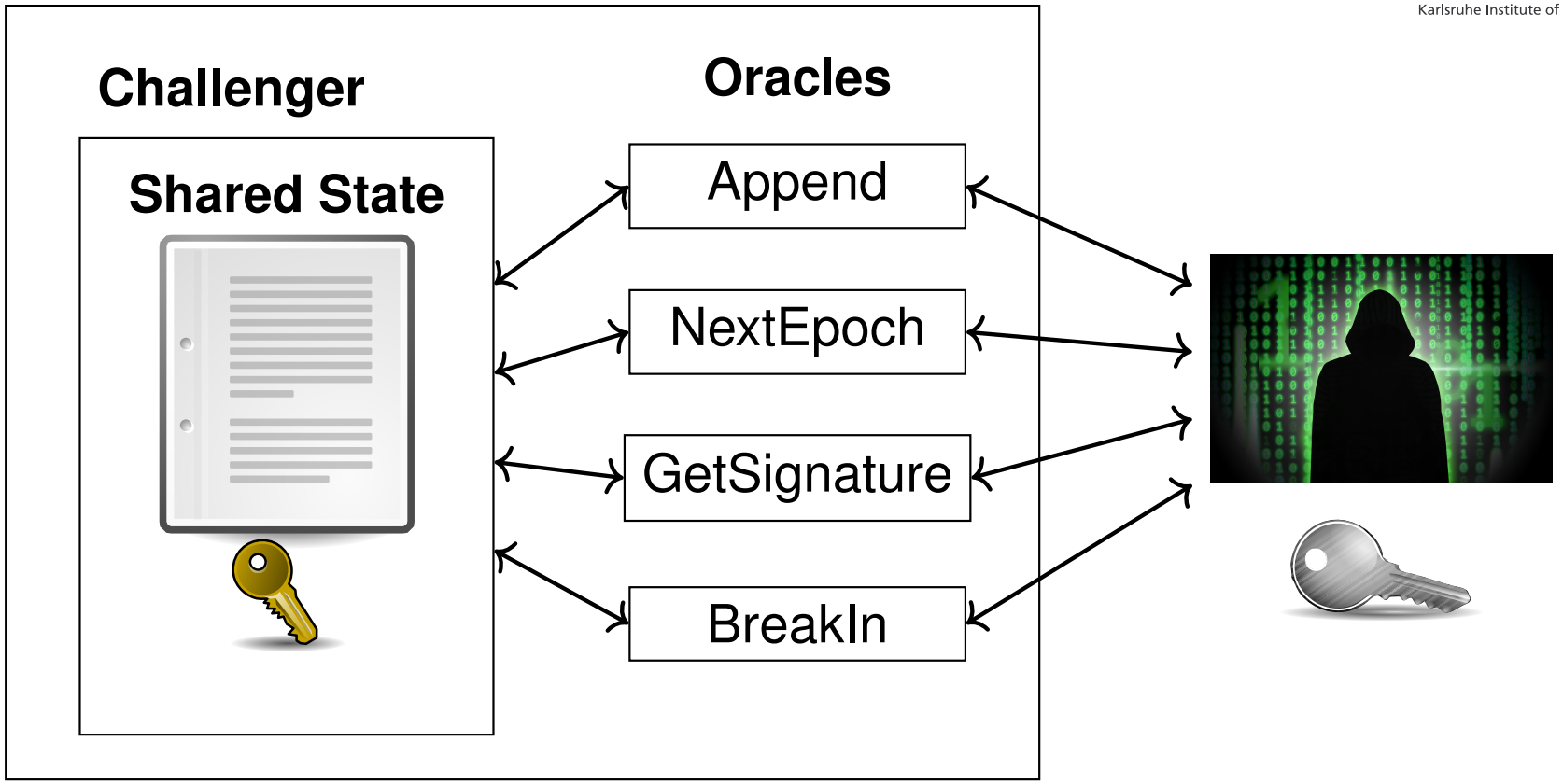
Karlsruhe Institute of Technology

Challenger

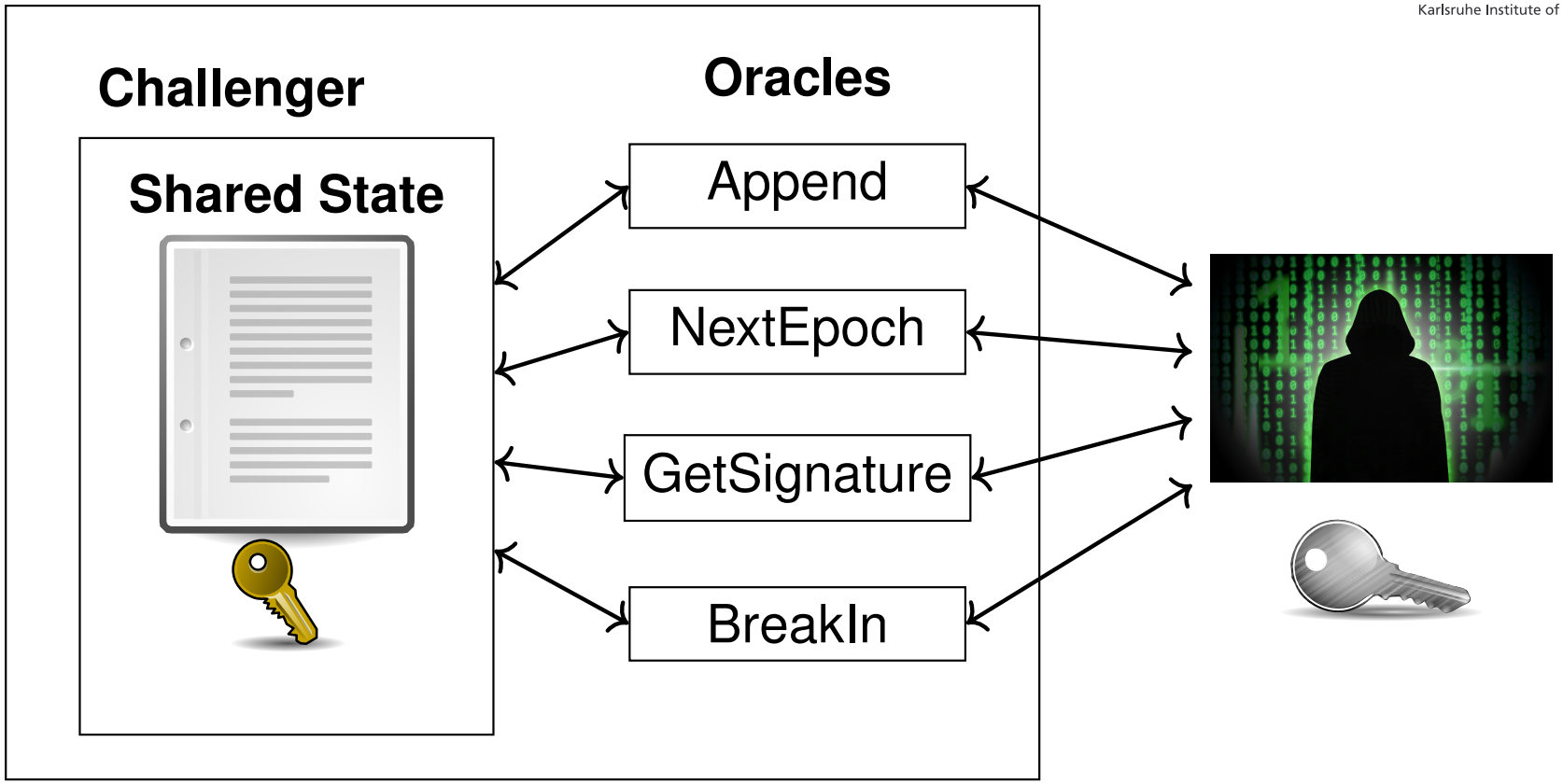
Oracles

Shared State

Security Experiment



Security Experiment



A forgery σ^* is error-free, i.e. $\text{VerifyLog}(C^*, \sigma^*) \cap \{\perp_{\text{sig}}, \perp_{\text{len}}, \perp_{\text{em}}\} = \emptyset$.

Trivial Forgeries: log states from signatures requested from $\mathcal{A}$'s GetSignature oracle or (if there has been a break in) any continuations of these using signatures from/after the break in epoch. (excl. empty log)

Our generic construction

Ingredients:

- A forward-secure sequentially aggregate signature scheme FSSAS (for creating a aggregate signature over the log across epochs)
- A forward-secure signature scheme FS (as a signature on the current log length, to be securely erased after append)
- A cover-free family CFF (for robustness)

Theorem (Informal)

Our log scheme is secure, if FSSAS and FS are secure respectively.

Proof Technique: We split the event space of what happens (whether the length signature or the log aggregate signature was forged) in two and reduce to the respective security experiments.

Implementation Benchmark

BGLS-based FSSAS (160bit), Bellare-Miner-based FS (80bit)

Algorithm	**Parameter**	ℓ	**avg** [ms]	**STD** [ms]
KeyGen	$T = 10\,000$		38 053	241
Update	$T = 10\,000$		18.6	0.033
AggSign + Update	$n = 1000$	10	67.5	0.014
	$n = 1000$	100	60.4	0.048
	$n = 1000$	1000	59.7	0.019
Verify	$n = 1000$	10	271	2.05
	$n = 1000$	100	227	1.87
	$n = 1000$	1000	22.5	0.15

On a laptop w/ Intel Core i5-2430M CPU with 2.4 GHz, equipped with 5.7 GiB of RAM. Using Shoups NTL library for BM-FSS, PBC library for BGLS-FS-SAS.

T: max. nr of epochs supported

n: nr. of messages

ℓ: nr. of messages per epoch

avg: average runtime for algorithm (STD: standard deviation)

Summary/Conclusion

- Secure logging is important. Provable Security also.
- Secure logging is hard. Mostly because of truncation.

Contribution

- We adapt the notion of fault-tolerance from [Har+16] to sequential aggregate signatures, adapt their generic construction and prove its security and fault-tolerance,
- we give a strong security notion capturing truncation attacks,
- we give a generic space-efficient construction of a publicly-verifiable robust secure logging scheme, which has a tight reduction,
- we benchmark an implementation of our scheme.

Future work: Find a forward-secure sequential aggregate signature scheme without pairings (i.e. that is not already fully aggregatable).

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