# Passive SSH Key Compromise via Lattices

Keegan Ryan[1], Kaiwen He[2], George Arnold Sullivan[1], Nadia Heninger[1]

[1] UC San Diego

[2] UC San Diego, MIT

ACM CCS, November 2023

# Overview

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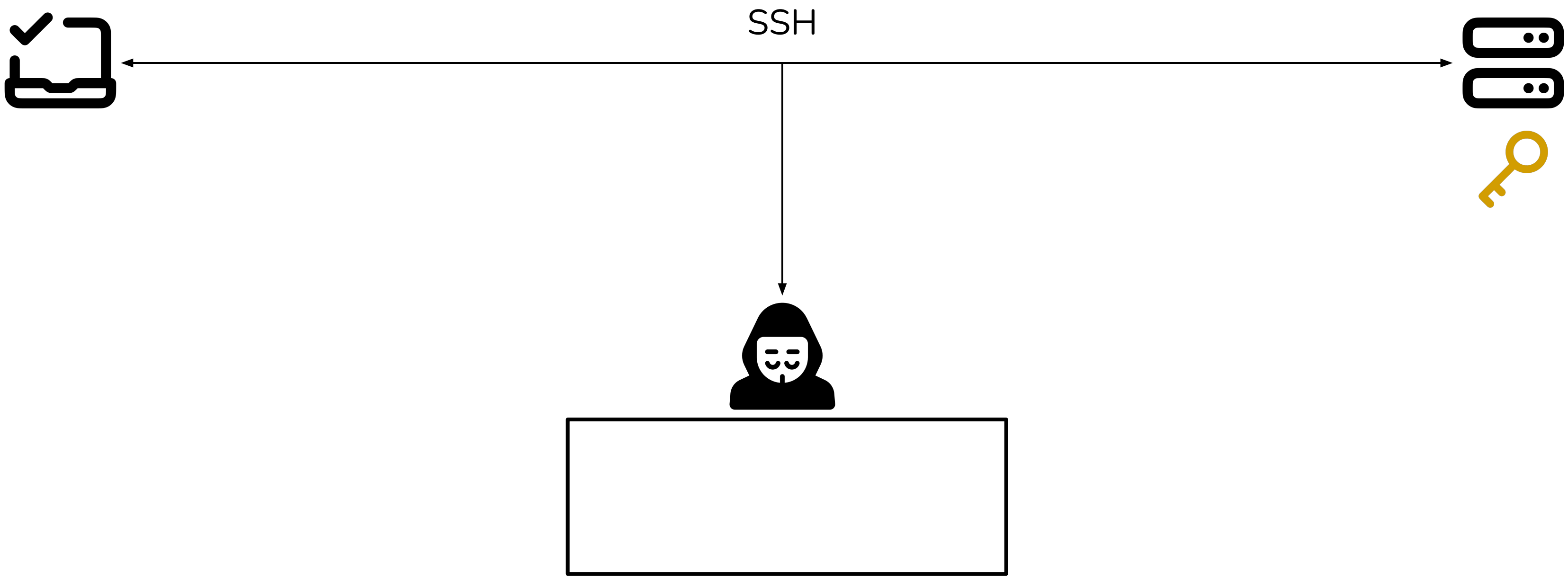

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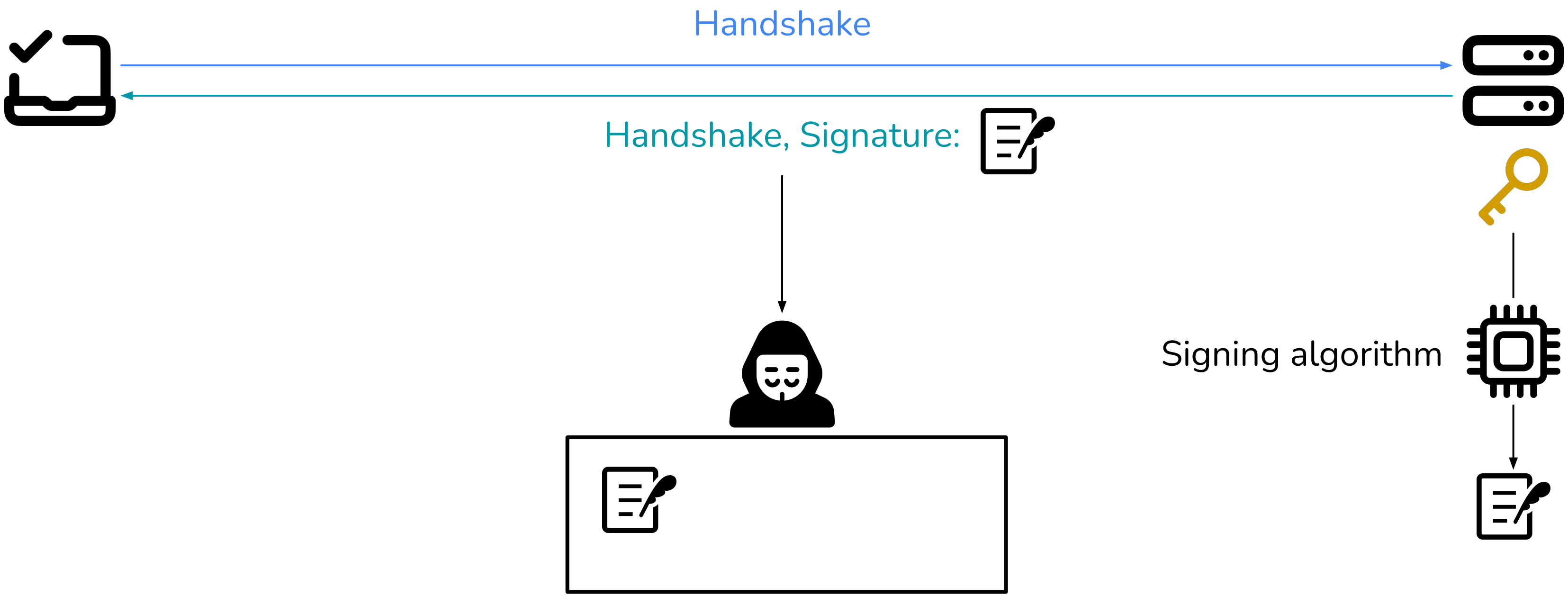

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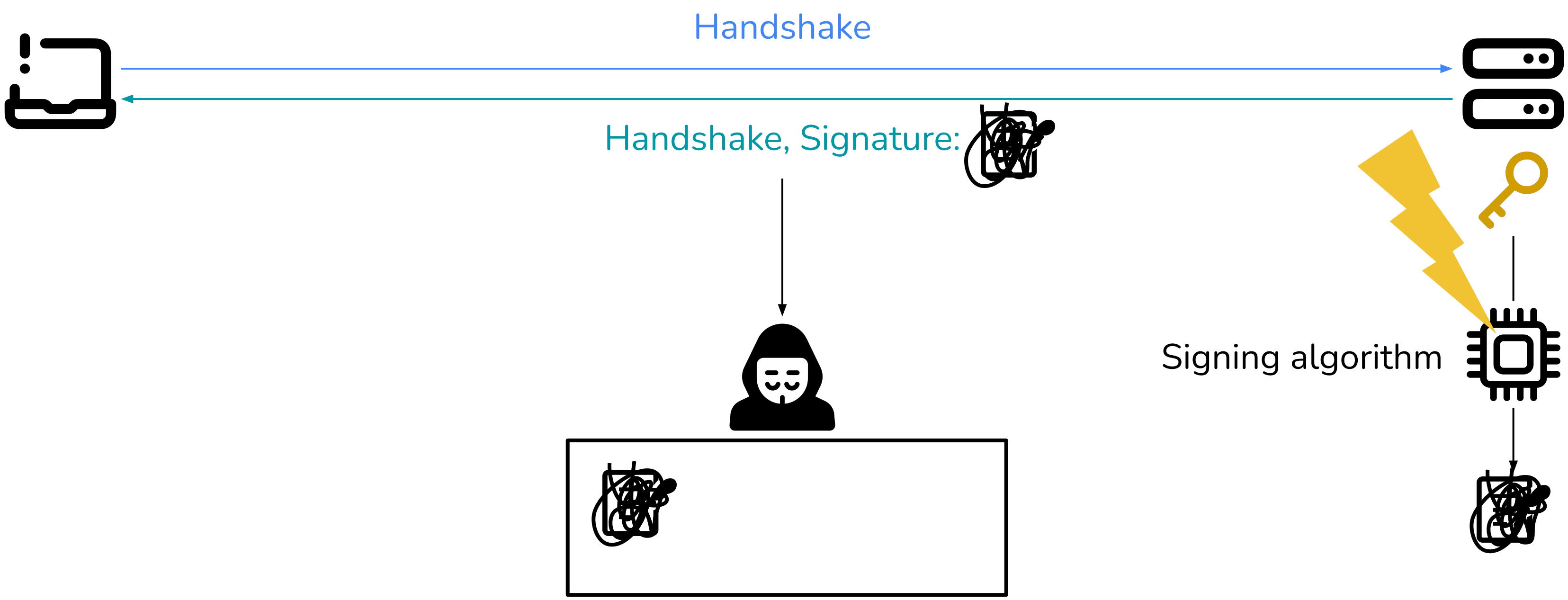

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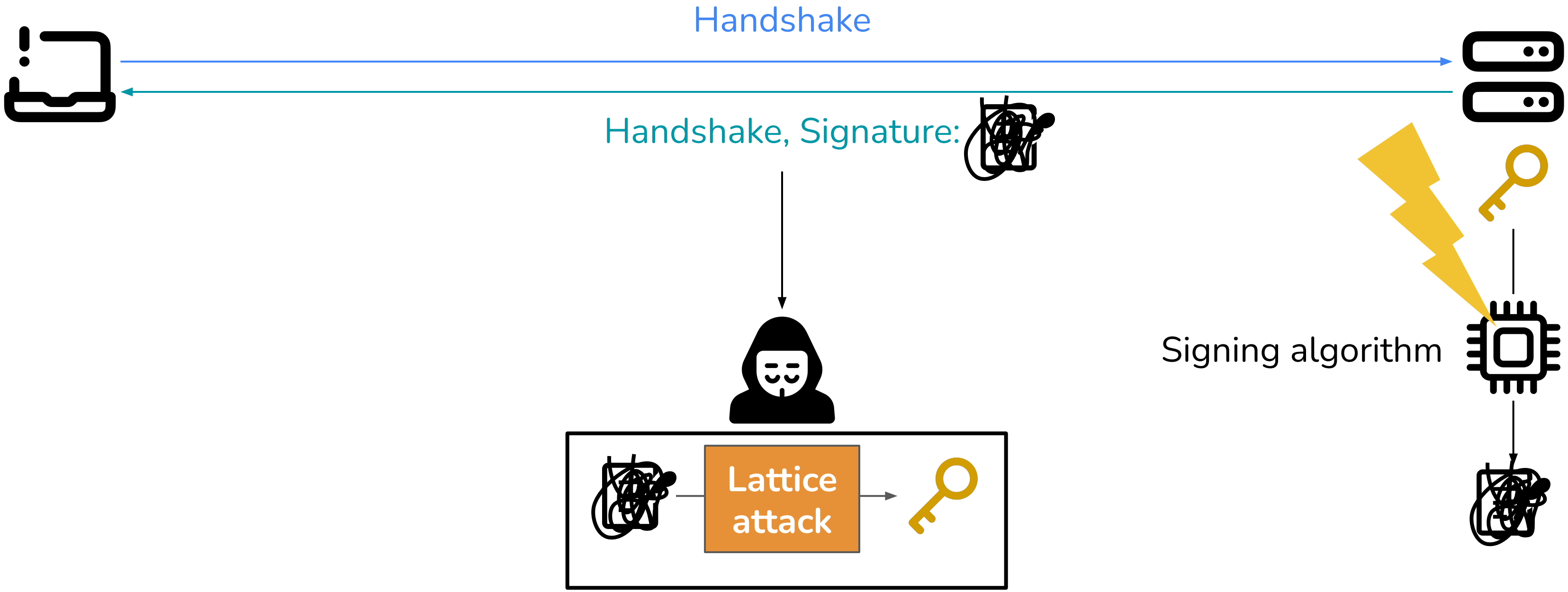
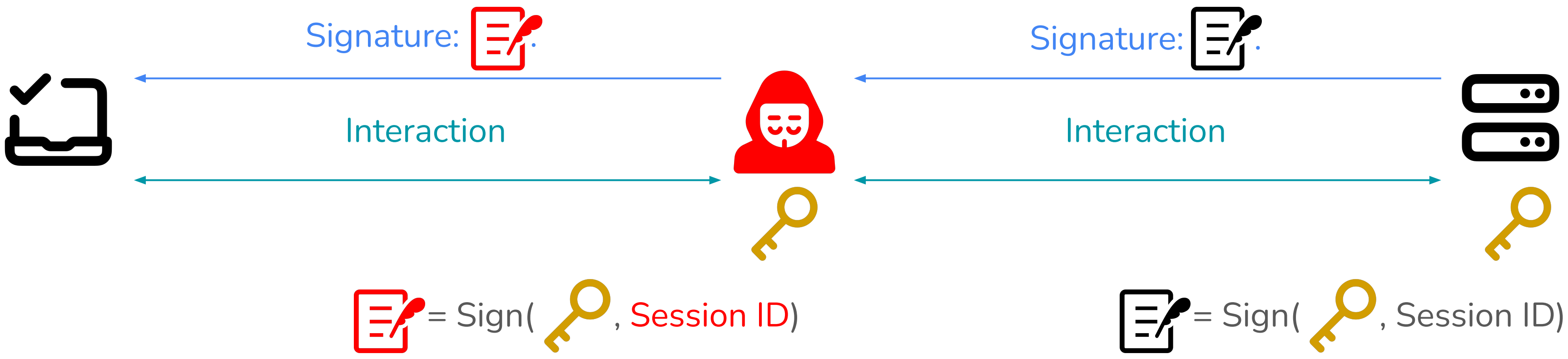


# Implications of host key compromise

Active attacker with the key can impersonate the server

- Can then intercept and arbitrarily tamper with connection



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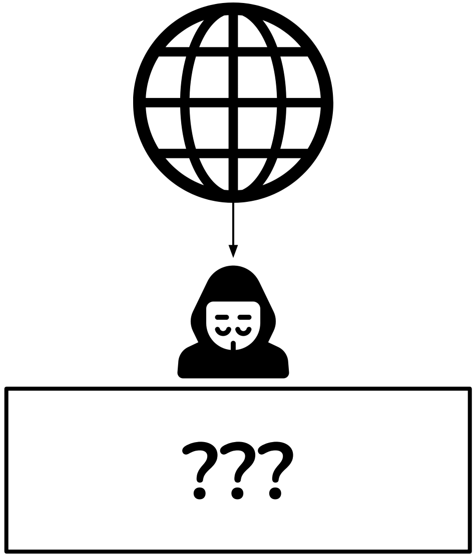

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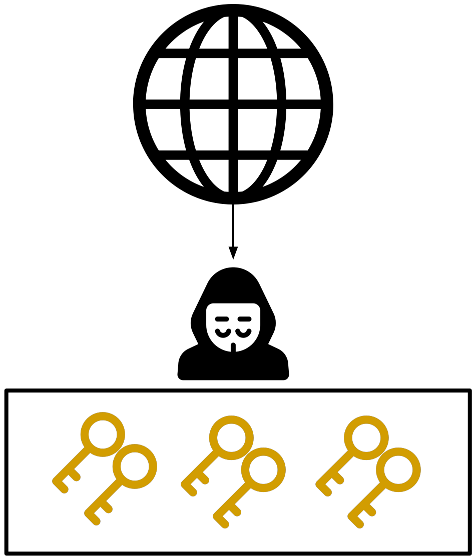
We analyzed **3.2 billion** SSH signatures on the internet

(1.2 billion *RSA signatures*)

**4,962** signatures: Revealed **private keys**



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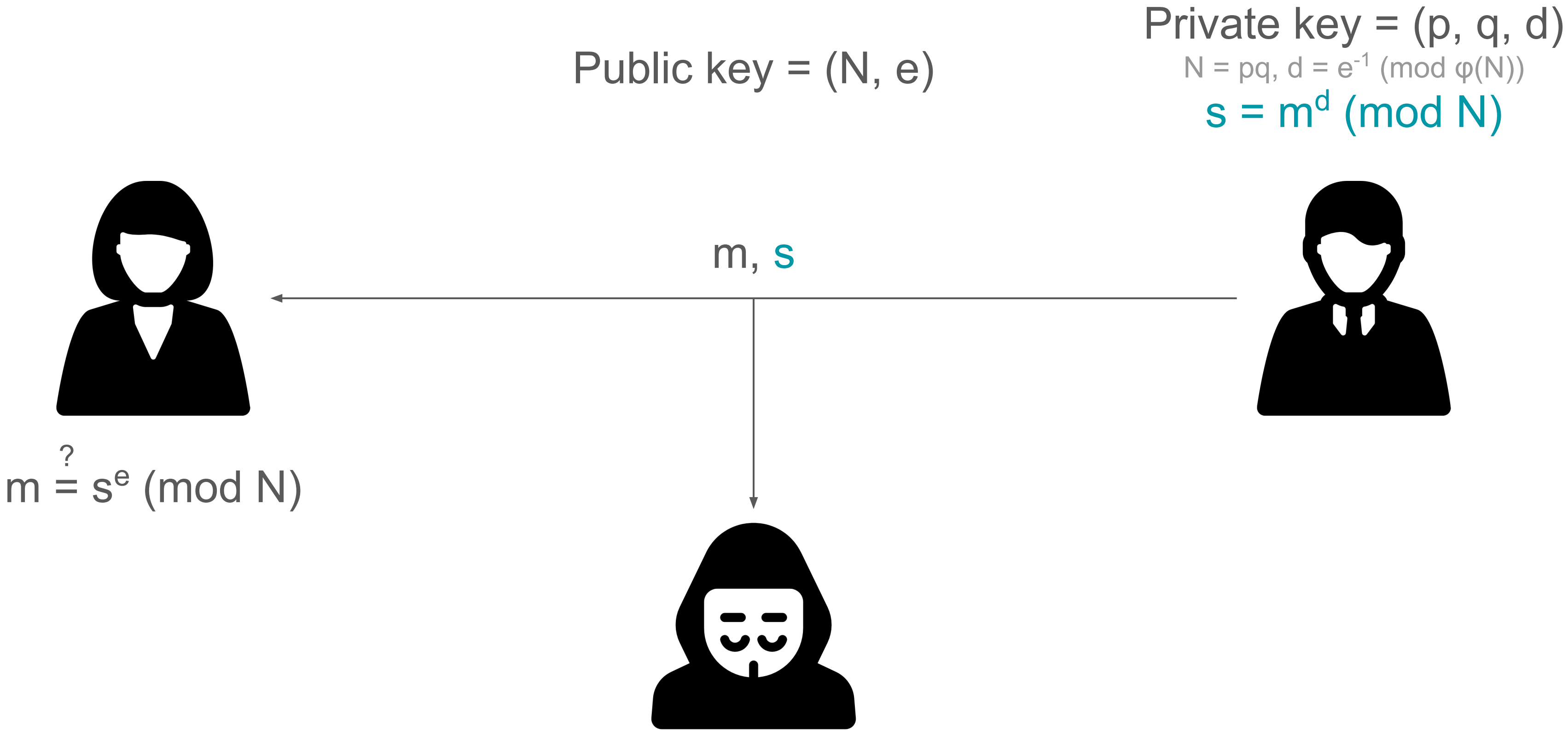
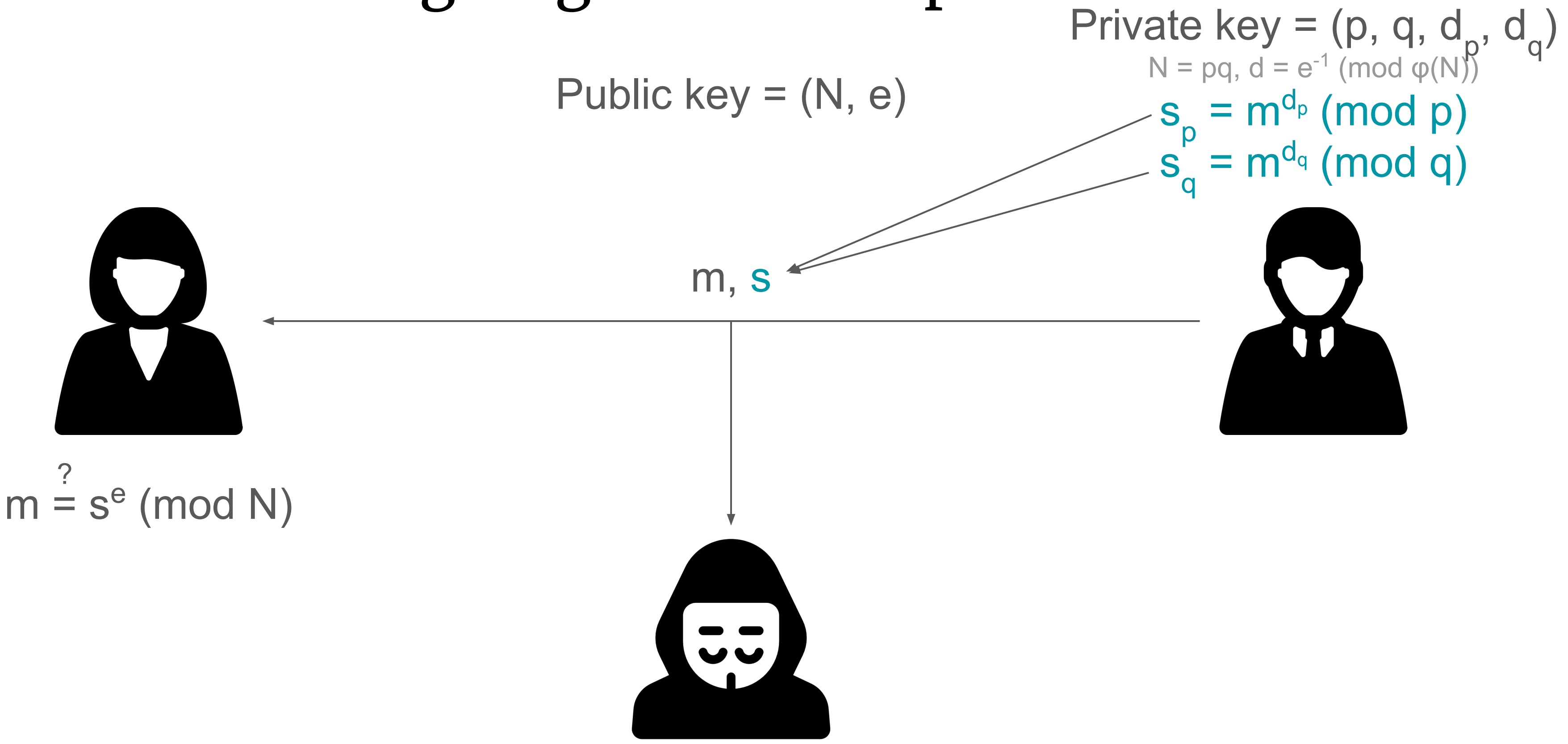
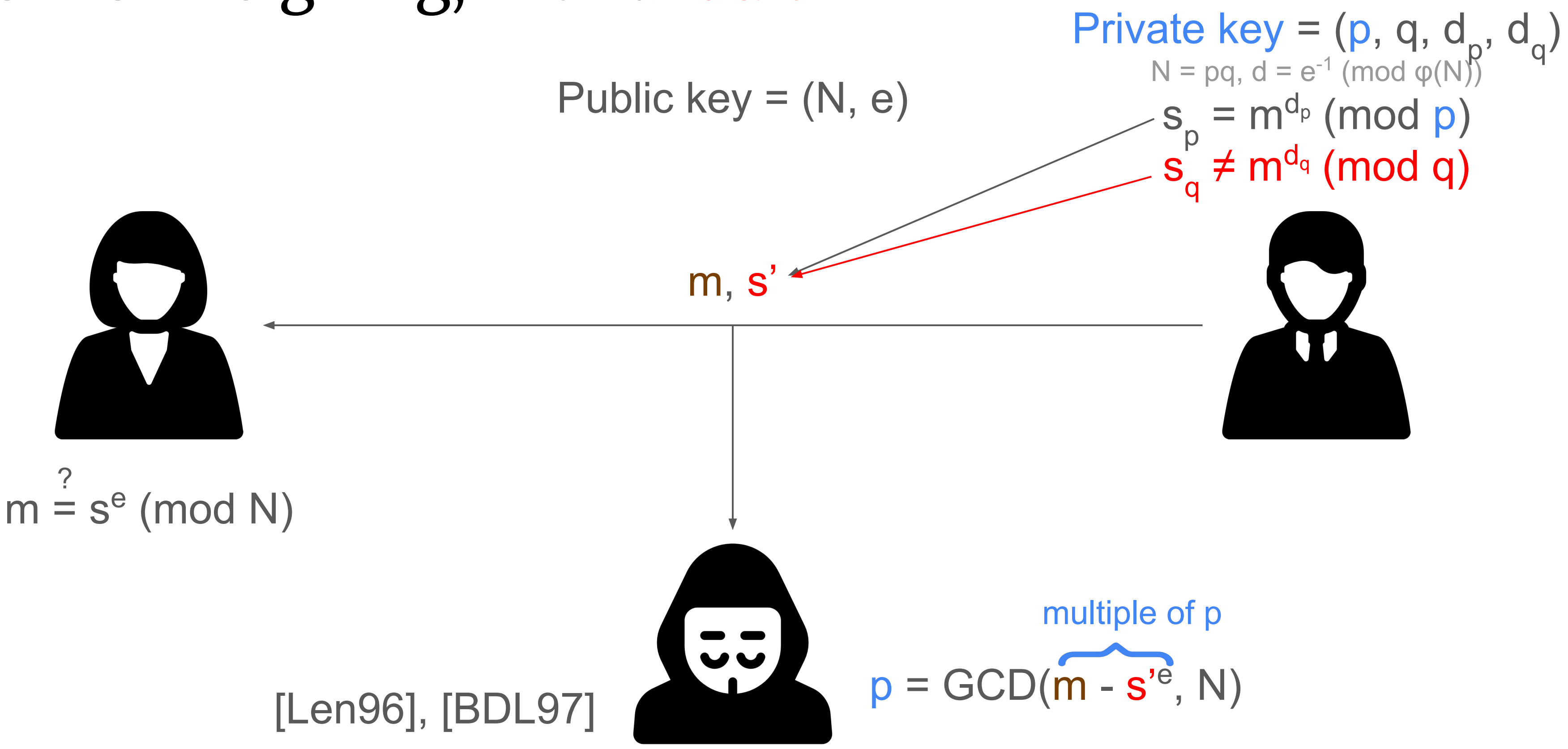
# Textbook RSA signing



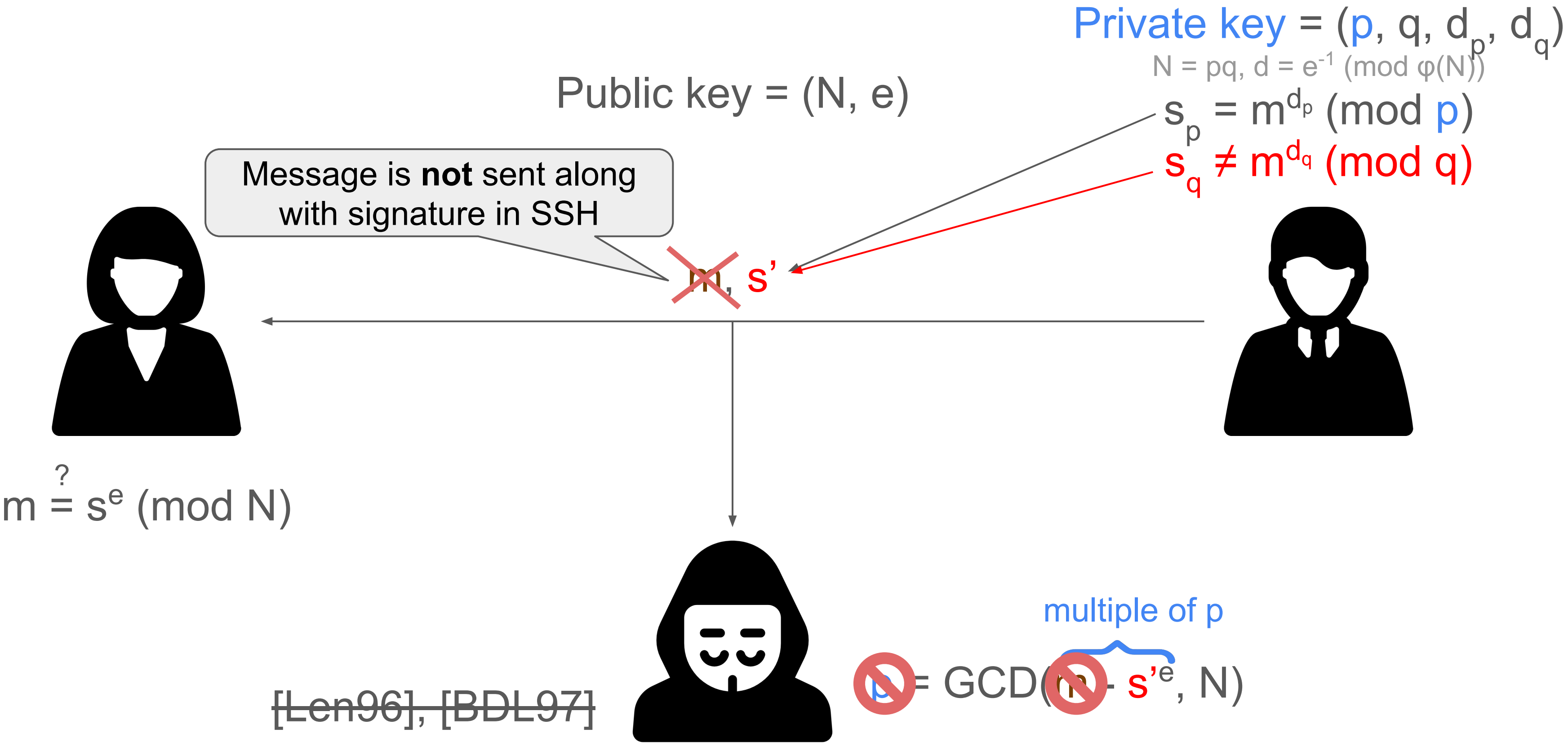
# Textbook RSA signing with CRT optimization



# RSA-CRT signing, with a fault



# RSA-CRT fault in SSH



# PKCS#1 v1.5 RSA signature padding

Message format for SSH:
m = 0x0001FF…FF00 {hash algorithm} {hash}

- Padding is deterministic and known to the attacker
- Attacker knows almost all of message m, except for the hash

# RSA-CRT fault in SSH, passive attack

Private key = $(p, q, d_p, d_q)$

$N = pq,\ d = e^{-1} \pmod{\varphi(N)}$

Public key = $(N, e)$

$s_p = m^{d_p} \pmod{p}$

$s_q \neq m^{d_q} \pmod{q}$

$s'$

Message format for SSH: (PKCS#1 v1.5)

m = 0x0001FF…FF00 {algorithm} {hash}

[CJK+09]

Knows that $m = \overbrace{a}^{\text{known}} + \overbrace{r}^{\text{small unknown}}$

$p$ = **Approx**-GCD$(a - s'^e, N)$

# Lattice attack

Message format for SSH: (PKCS#1 v1.5)
m = 0x0001FF…FF00 {hash algorithm} {hash} < N

Experimented with attacking faulty SSH signatures:

- Generated instances that correspond to SSH parameter choices
    - e.g., RSA-2048, SHA-256

For all common parameter choices (RSA modulus length > 4 × hash length):

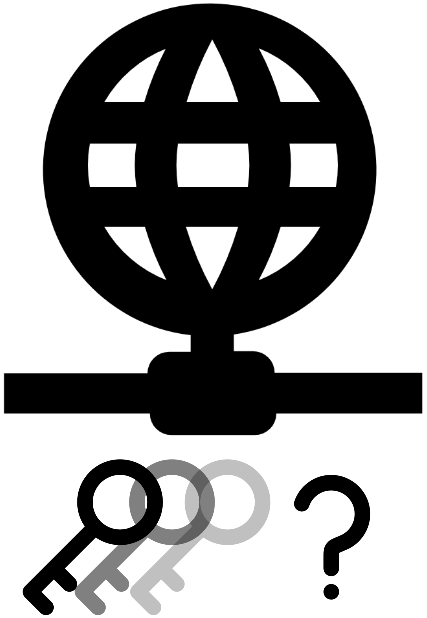
- Attack averages under 0.2 seconds per signature
- Recovers correct key for every generated signature

# Key leakage in the wild

How frequently do keys leak on the internet?

We analyzed data from:

- Zmap scans performed at UCSD
- Passive network traffic through UCSD
- Censys
- University of Michigan



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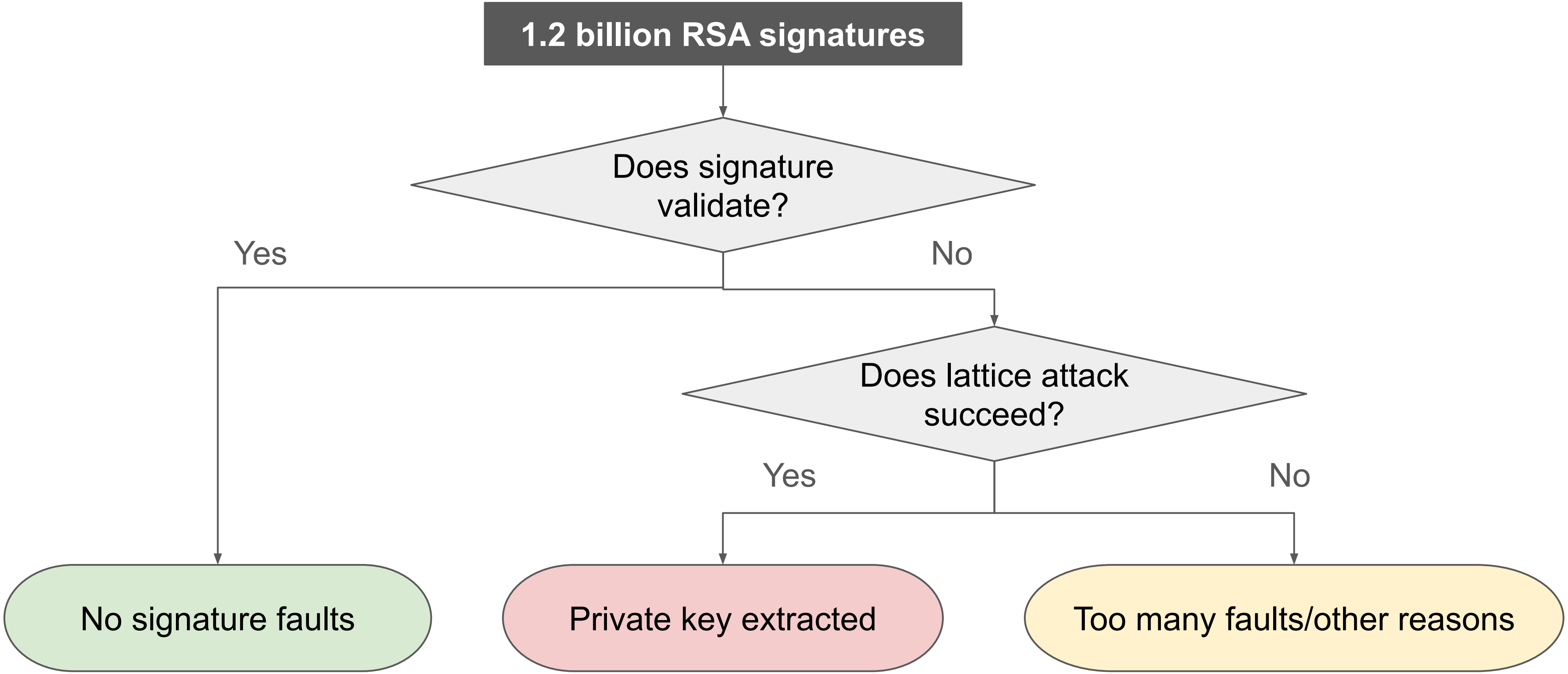

1.2 billion RSA signatures
Does signature validate?
Yes
No
Does lattice attack succeed?
Yes
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No signature faults
Private key extracted
Too many faults/other reasons

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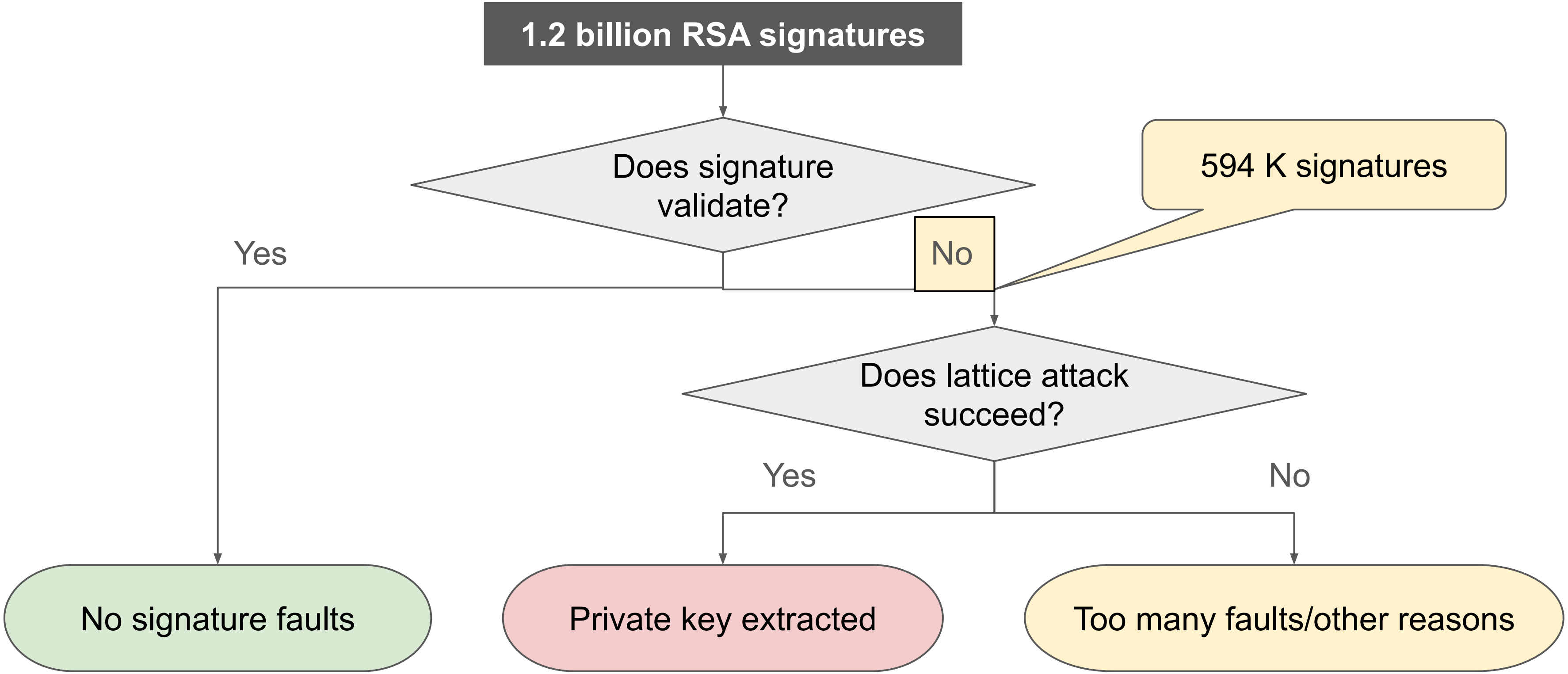

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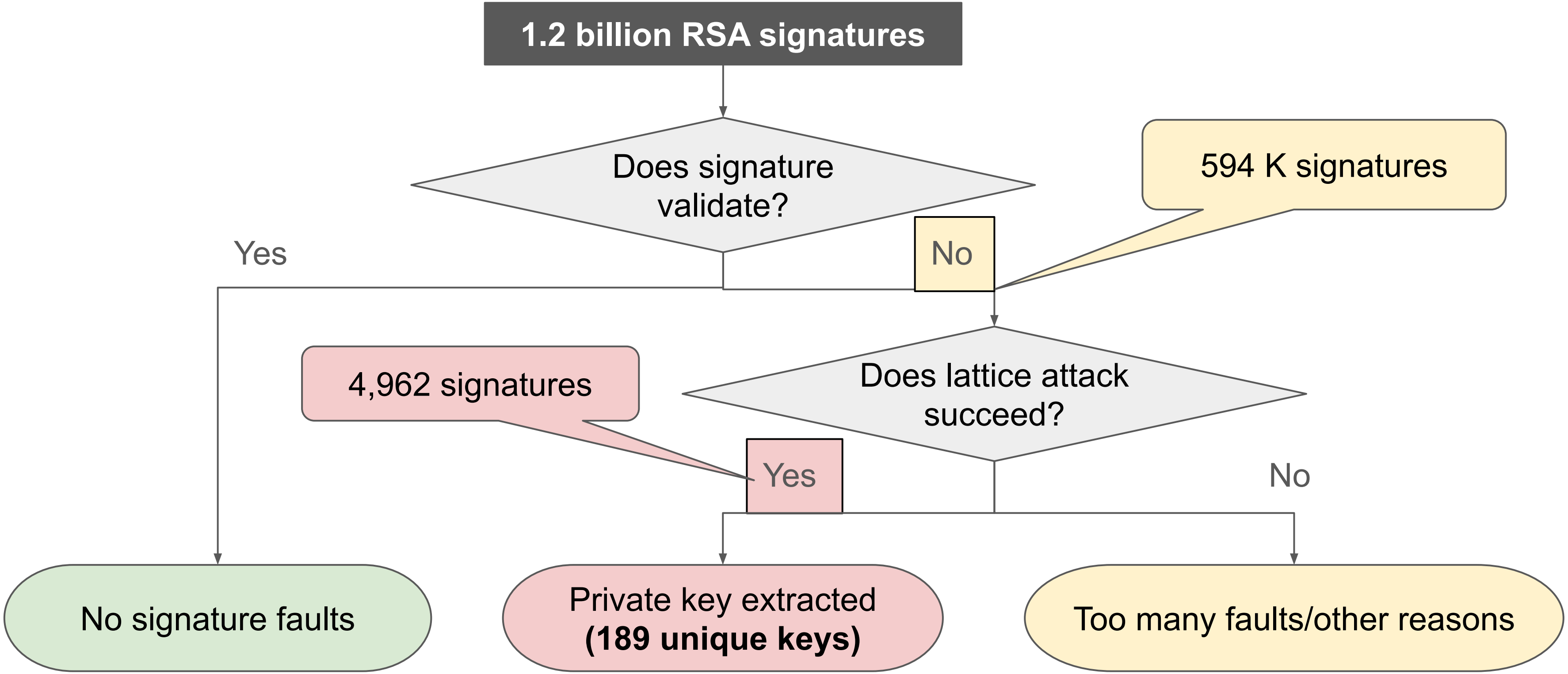
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(189 unique keys)
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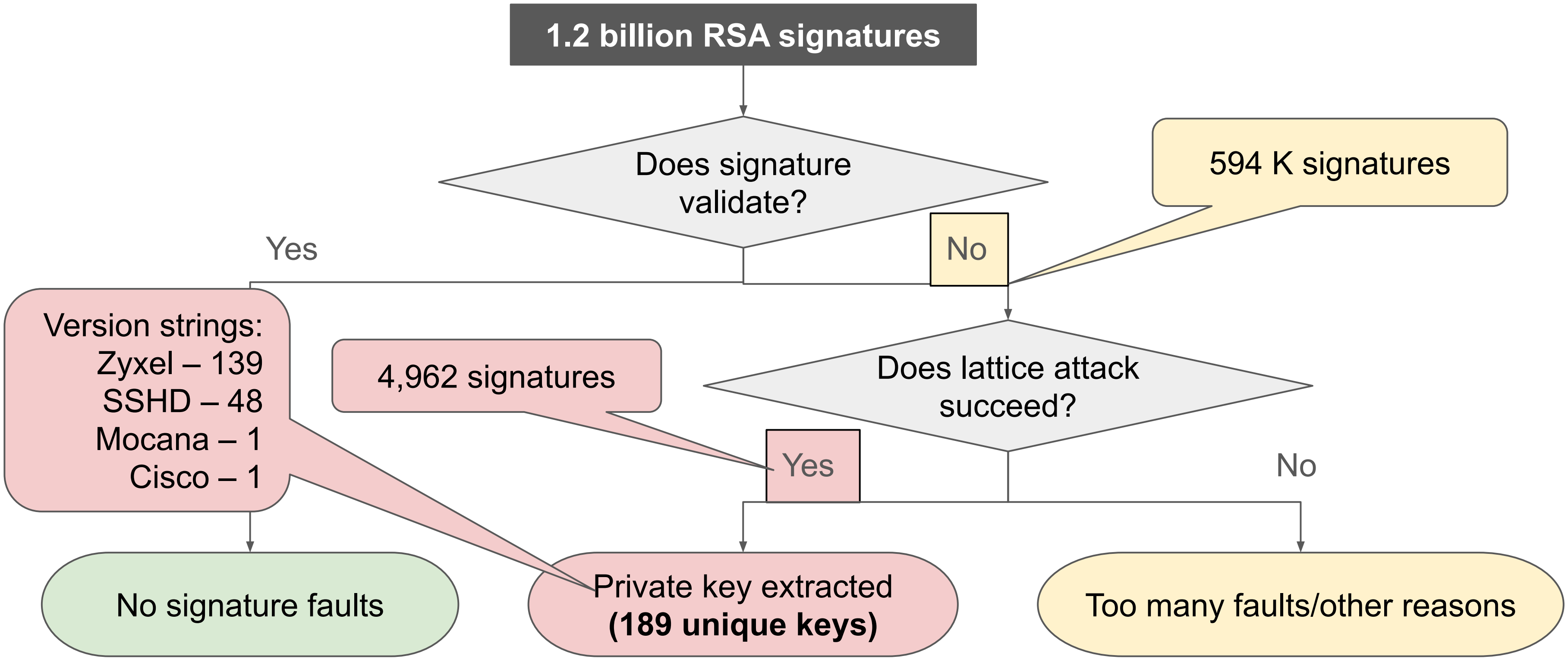
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Version strings:
Zyxel – 139
SSHD – 48
Mocana – 1
Cisco – 1
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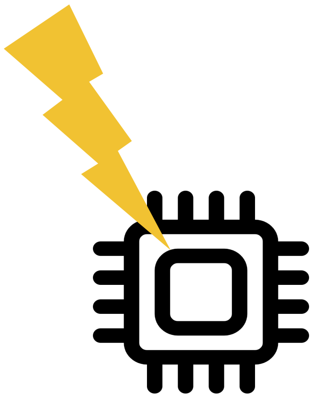
# Lessons



Hypothesis: signature faults originate from hardware failures

Include random hardware faults in the threat model

**Countermeasure**: Validate signatures before sending

- OpenSSL and derivatives include this check
- Vulnerable implementations we observed do not have this countermeasure

# Future directions

- SSH: Collect `rsa-sha2-*` signatures
  - Potentially more vulnerable hosts are out there
- Collect more data passively
- Study similar key leaks on IPsec
  - Our visibility into IPsec hosts is limited

# Summary

**A single faulty signature reveals the private SSH host key to eavesdroppers**

- Private host key allows attacker to later impersonate server
- About 1 out of 1 million analyzed signatures on the internet are vulnerable

We disclosed the vulnerability to device vendors:

- Mitigations confirmed for Cisco, Zyxel, and Hillstone Networks
- Unable to contact Mocana

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https://ia.cr/2023/1711

Keegan Ryan[1] kryan@ucsd.edu
Kaiwen He[2] khe01@mit.edu
George Arnold Sullivan[1] gsulliva@ucsd.edu
Nadia Heninger[1] nadiah@cs.ucsd.edu

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# References

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