PKI-101

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Intro to PKI, crypto and certificates

aka "*When Alice met Bob*"

Instructional goals

- Understand **cryptography fundamentals**.
- Know why proper **key management** is important.
- Know what **certificates** are and their purpose.
- Understand the **infrastructure** for PKI.
- Have a small set of **best practices**.

Required knowledge

- Basic computer networking,
  - "*How do computers talk to each other?*"
  - "*What is a server? What is a client?*"

- DNS, hostnames, URLs
  - "*How do I get from google.com to 144.89.33.10?*"

Alice and Bob and the CIA

- Alice and Bob have come a long way
  - https://cryptocouple.com

- InfoSec says, things worth protecting:
  - Confidentiality
  - Integrity
  - Availability

Alice and Bob and the CIA

- Cryptography helps us with C and I.
  - Confidentiality by enciphering.
  - Integrity by hashing.

- … But it can hurt A!
  - Losing access to data.

Alice and Bob and the CIA

- Challenge: how to prove identity?
  - How does Alice know she's talking to Bob,
  - And not to some hacker?

- That's the point of PKI:
  - Assuring trust.

What could go wrong?

- If you don't follow guidelines and best practices:
  - Key compromise
  - Bad cryptographic implementations

- Leading to:
  - Data leaks or falsification
  - Impersonation and credential theft

Encryption basics

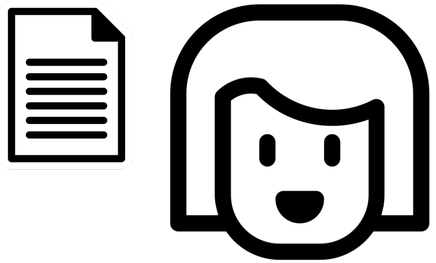
The dry definition

"[…] encryption is the process of ***encoding a message or information*** *in such a way that* ***only authorized parties can access it*** *and those who are not authorized cannot. Encryption does not itself prevent interference, but denies the intelligible content to [interceptors]"*

- Wikipedia

Symmetric key encryption

- Both parties use a shared secret.



Symmetric key encryption

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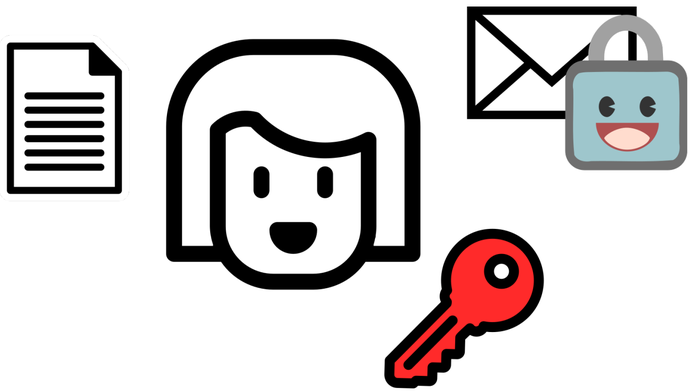

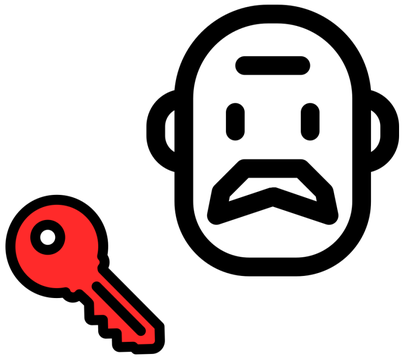

Symmetric key encryption

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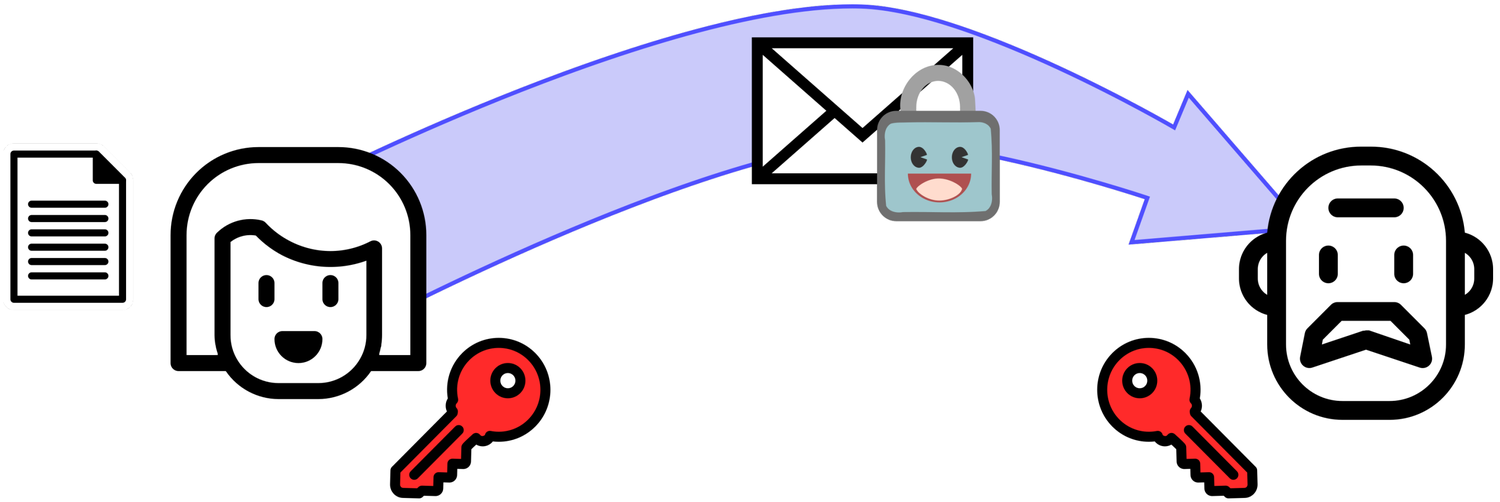


Symmetric key encryption

- Both parties use a shared secret.

- Confidentiality, but how to share the key?

Key exchange

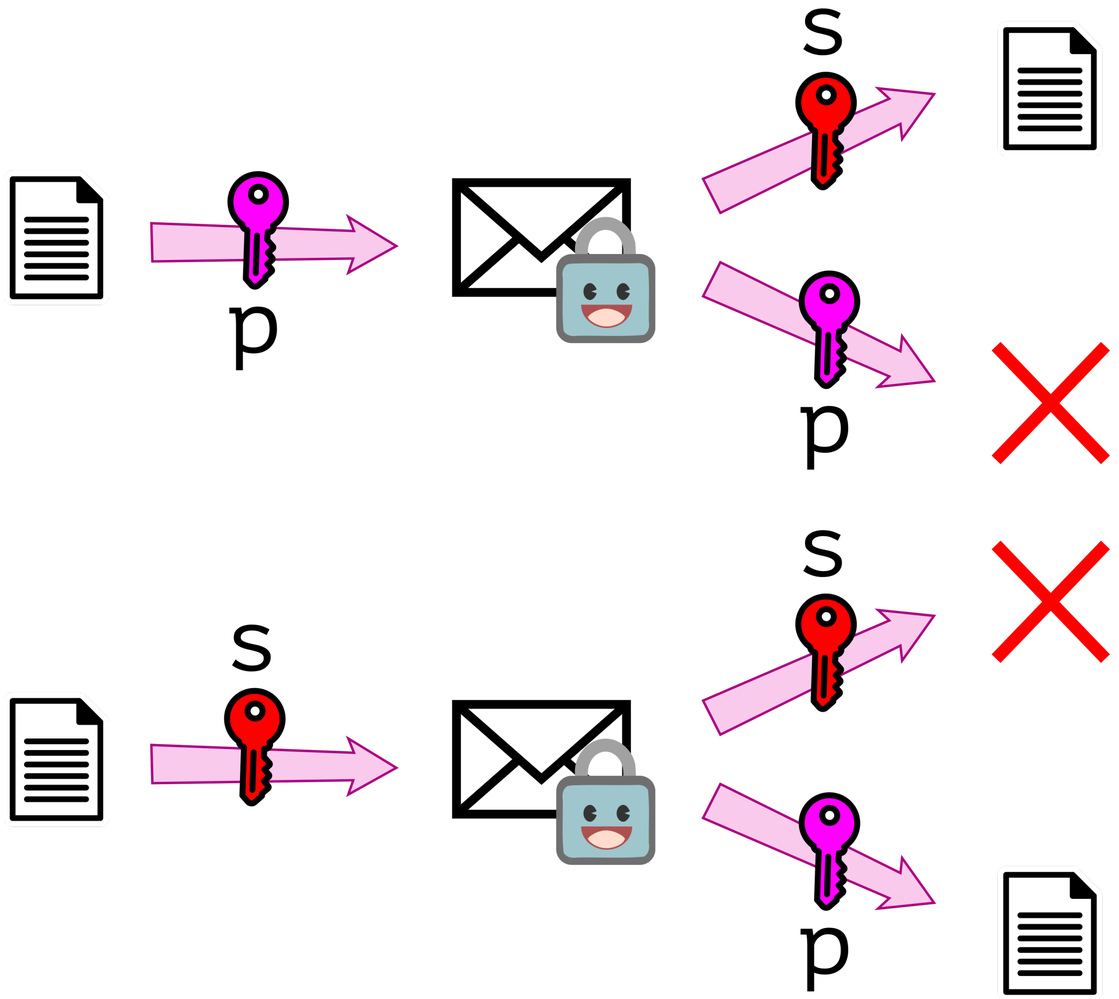
- Symmetric crypto is fast. We want that!
- But how to safely agree on a shared key?
  - Diffie Hellman, open-air mutual agreement
  - RSA / public-key encryption

See also: Venafi - Diffie-Hellman vs RSA

Asymmetric encryption

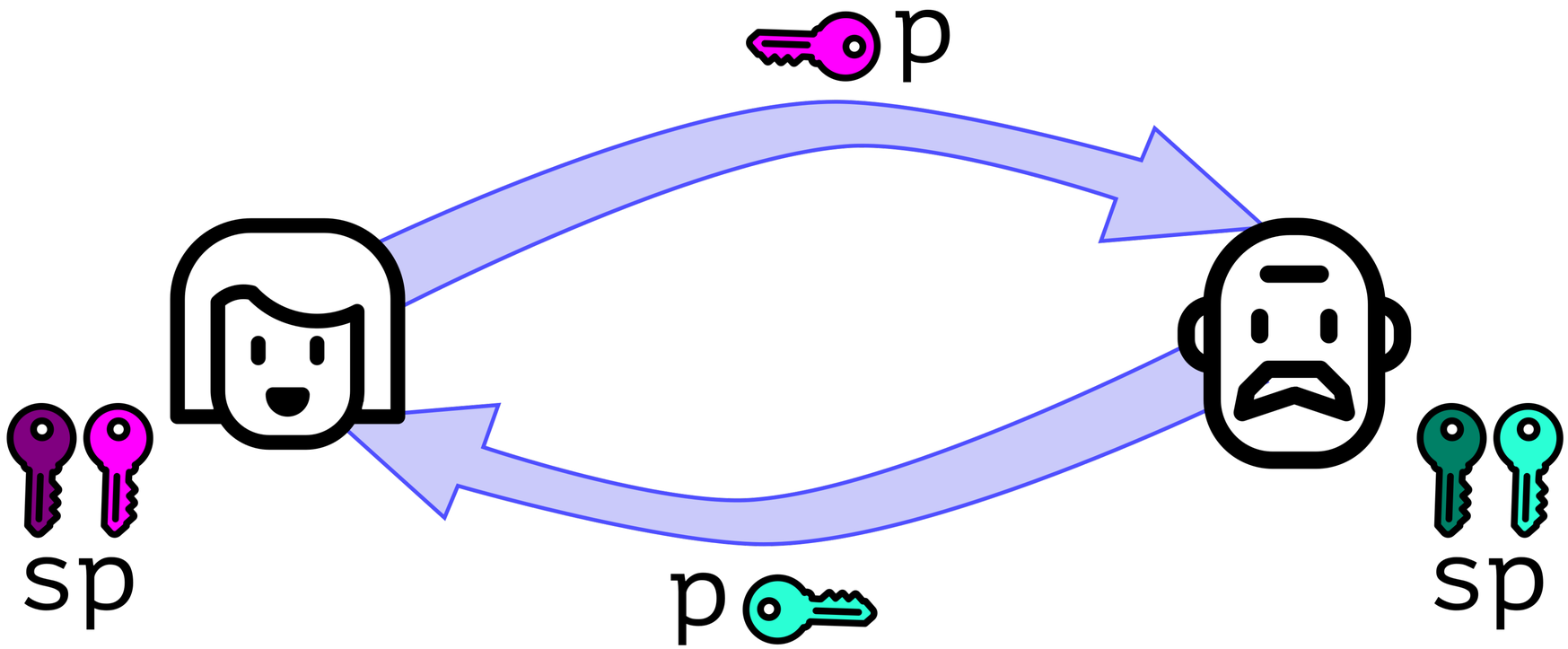
- Both parties have a pair of keys.
- One-way trapdoor math!
- What you encrypt with the one key,
  - Can only be recovered with the other.
  - And vice versa…

Asymmetric encryption



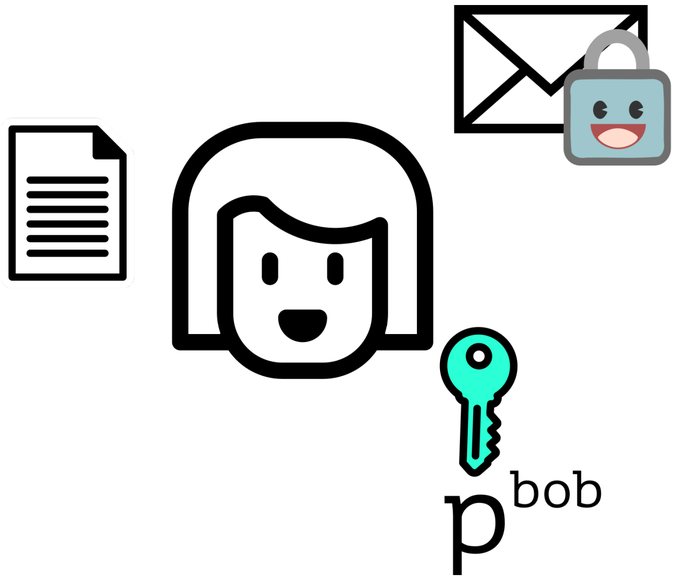
Asymmetric encryption

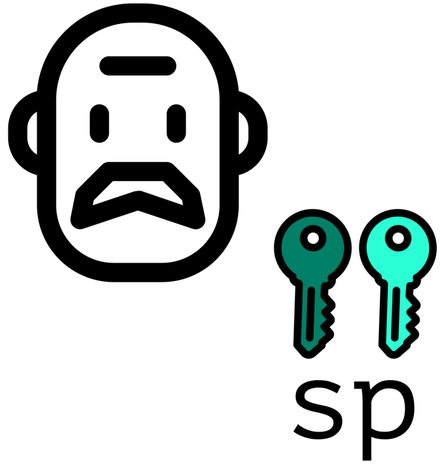
- Exchange public keys



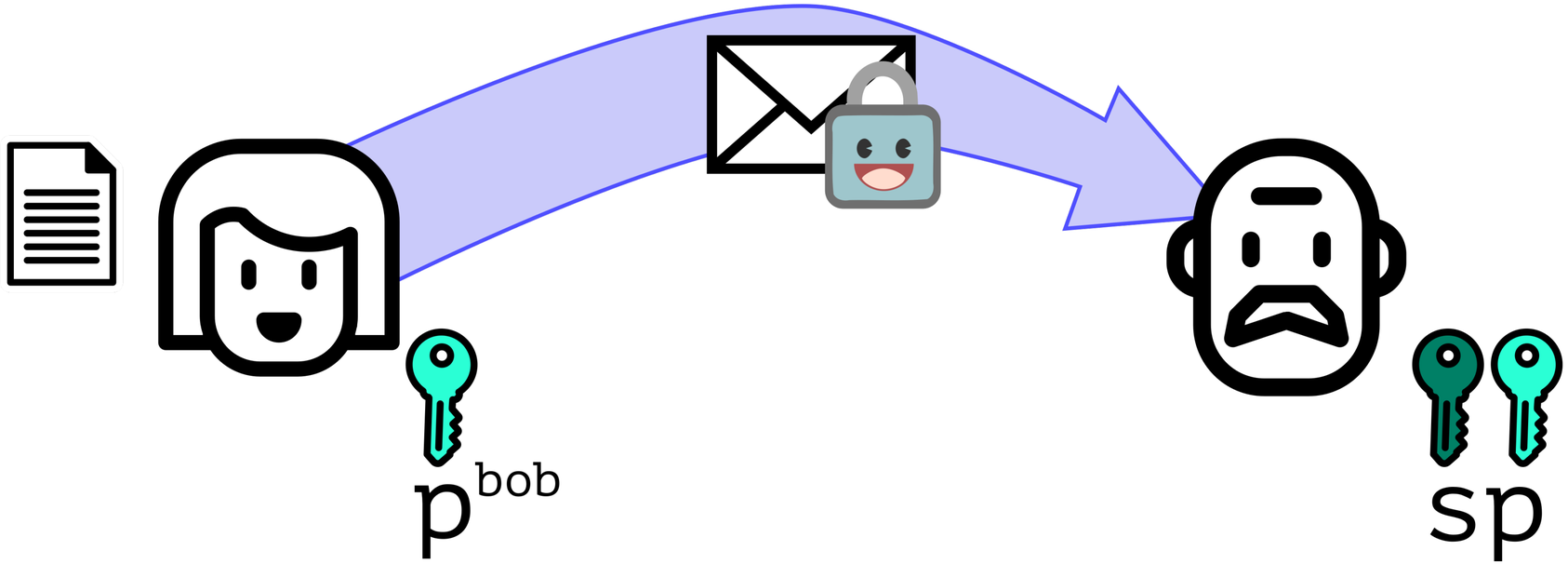
Asymmetric encryption

- Sender encrypts with recipient's public key.



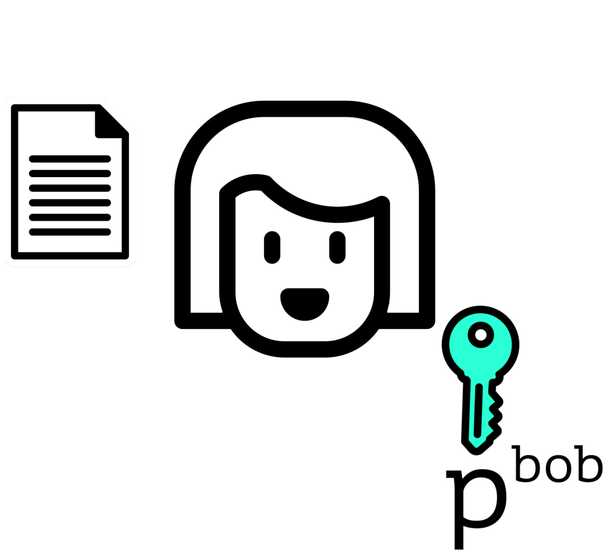


Asymmetric encryption



Asymmetric encryption

- Recipient decrypts with their private key.



Asymmetric encryption

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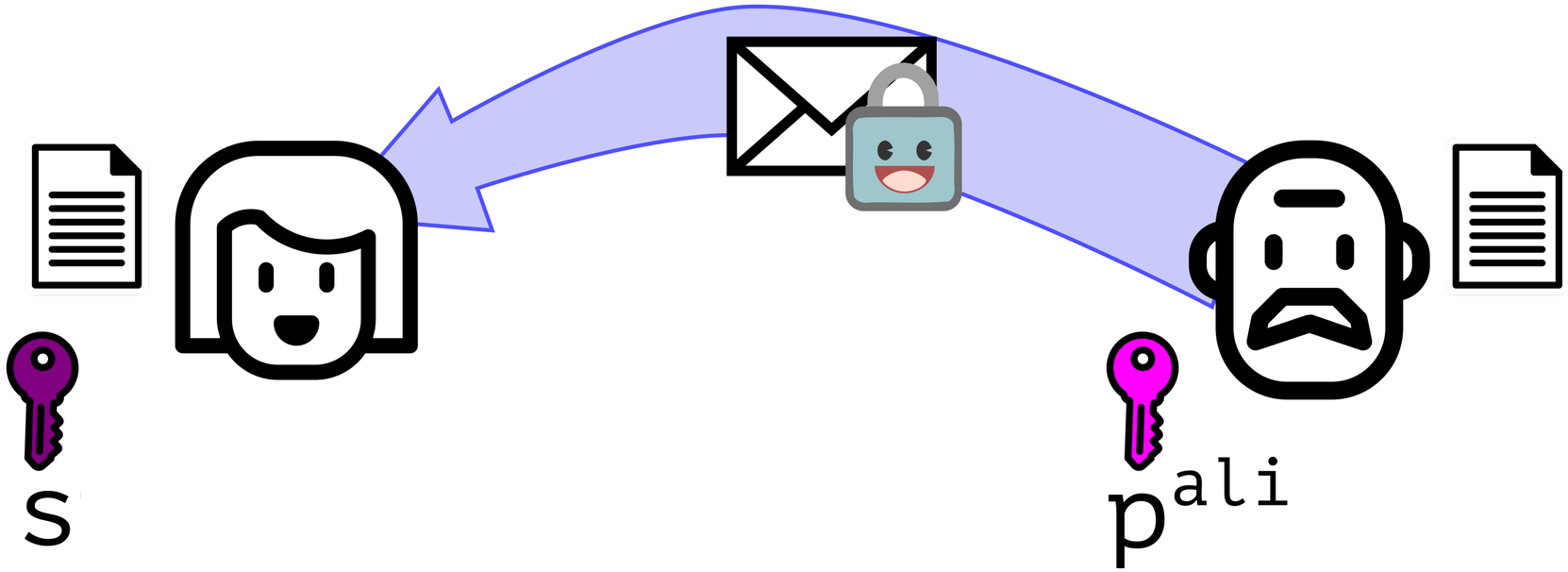
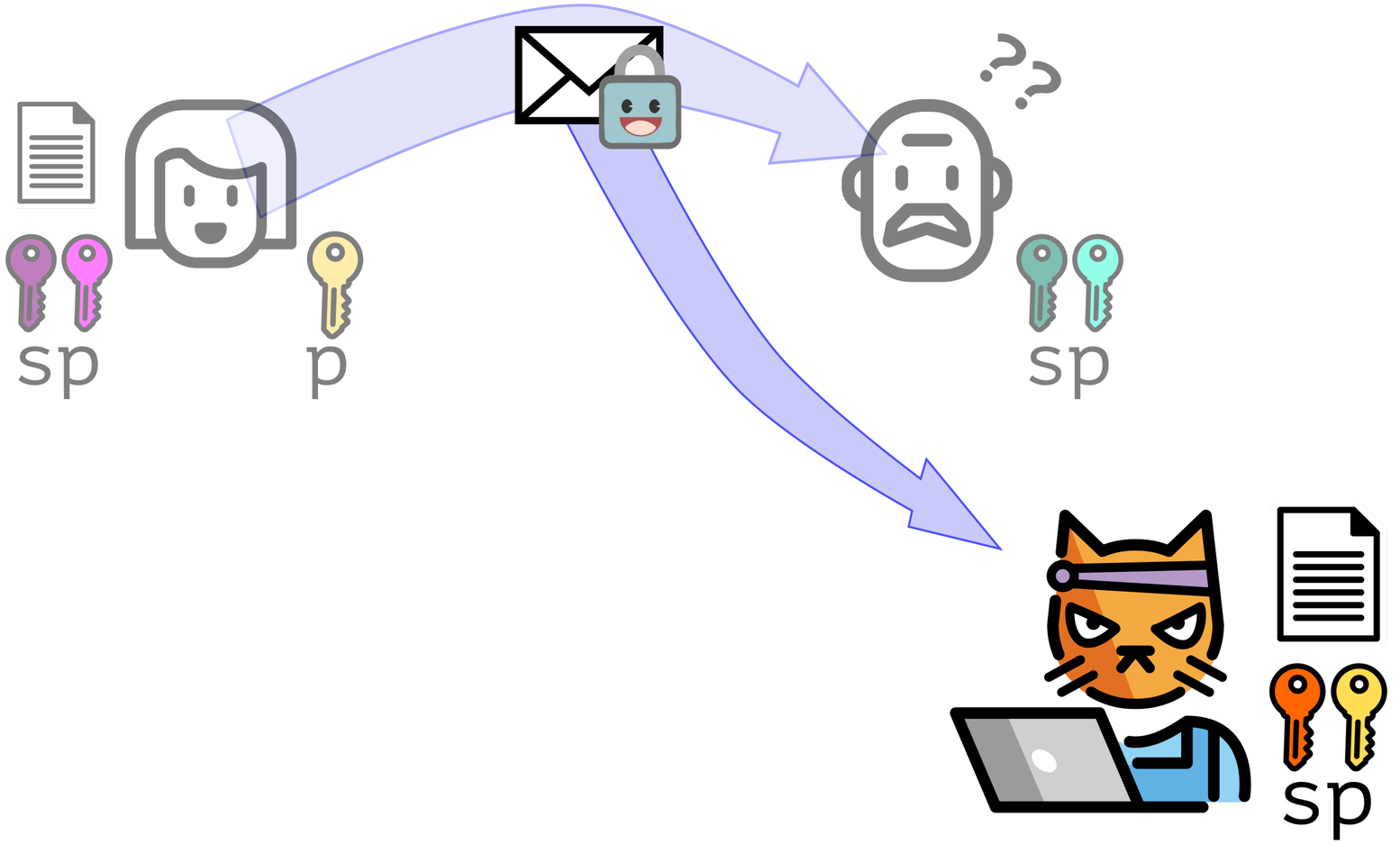


Asymmetric encryption

- BOOM! Confidentiality!
  - Without the worries of key-distribution.

- Daily usage:
  - SSH & TLS: key exchange
  - PGP: email encryption

The next challenge: identity



The next challenge: identity

- Let's add something!
  - *Hashing*, to guarantee integrity.
  - *Signing*, to enable non-repudiation.

- Non-*repudiwhatnow*? 😲
  - You can 100% prove someone did something.

Cryptographic hashing

- Maths which creates a quasi-unique string.
  - The string is derived from the input data.

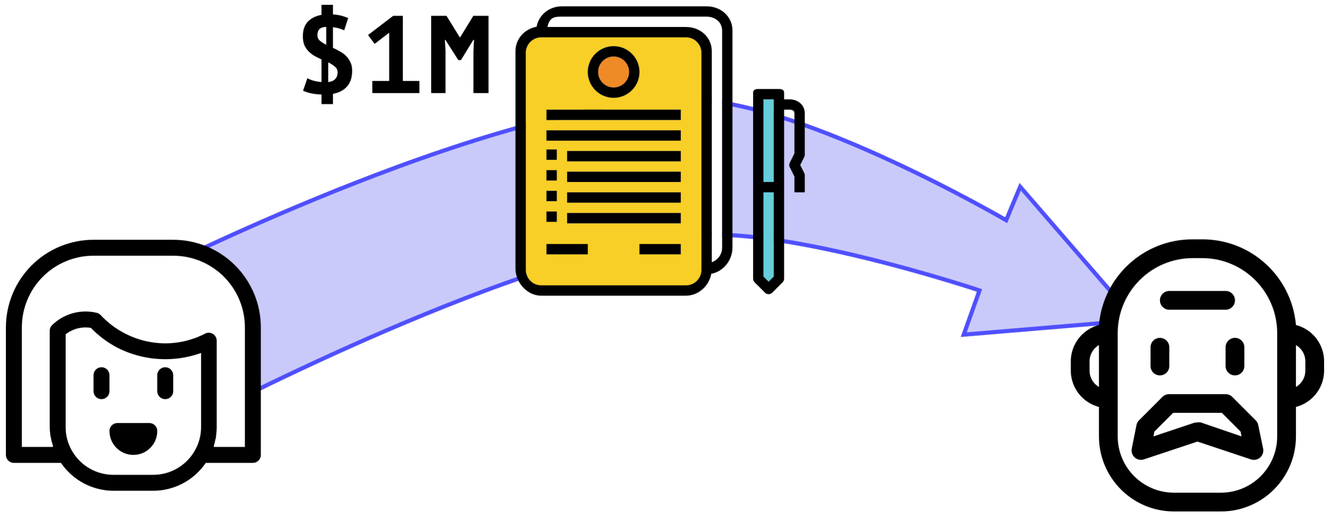
- The same input, will always make the same output.
  - The smallest change, will make big differences.

Signing

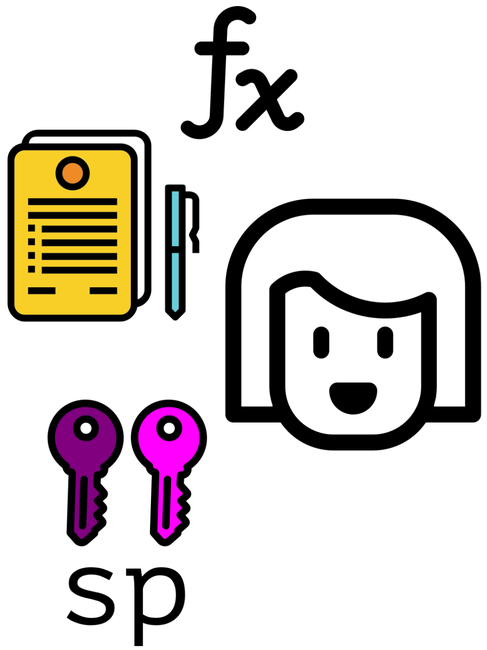
- Calculate your message’s hash.
- Encrypt the hash with your private key.

- Integrity and non-repudiation!
  - Recipient decrypts the hash with your public key.
  - And verifies message integrity.

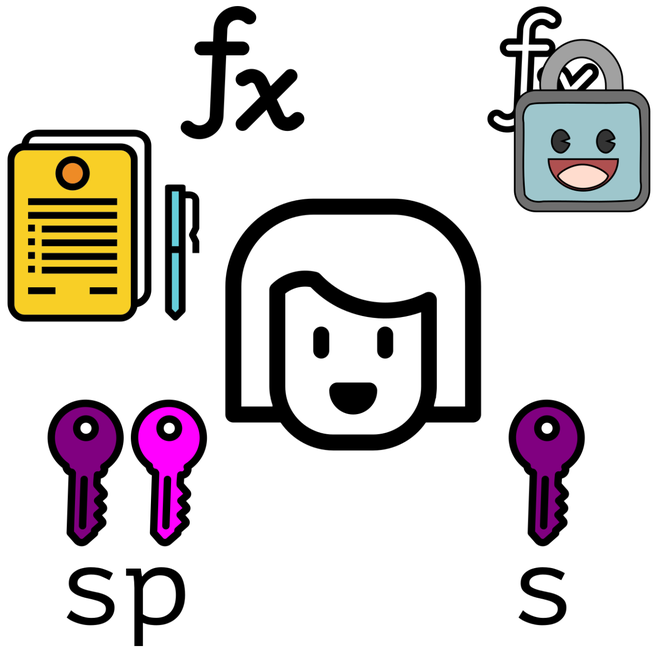
Hashing and signing



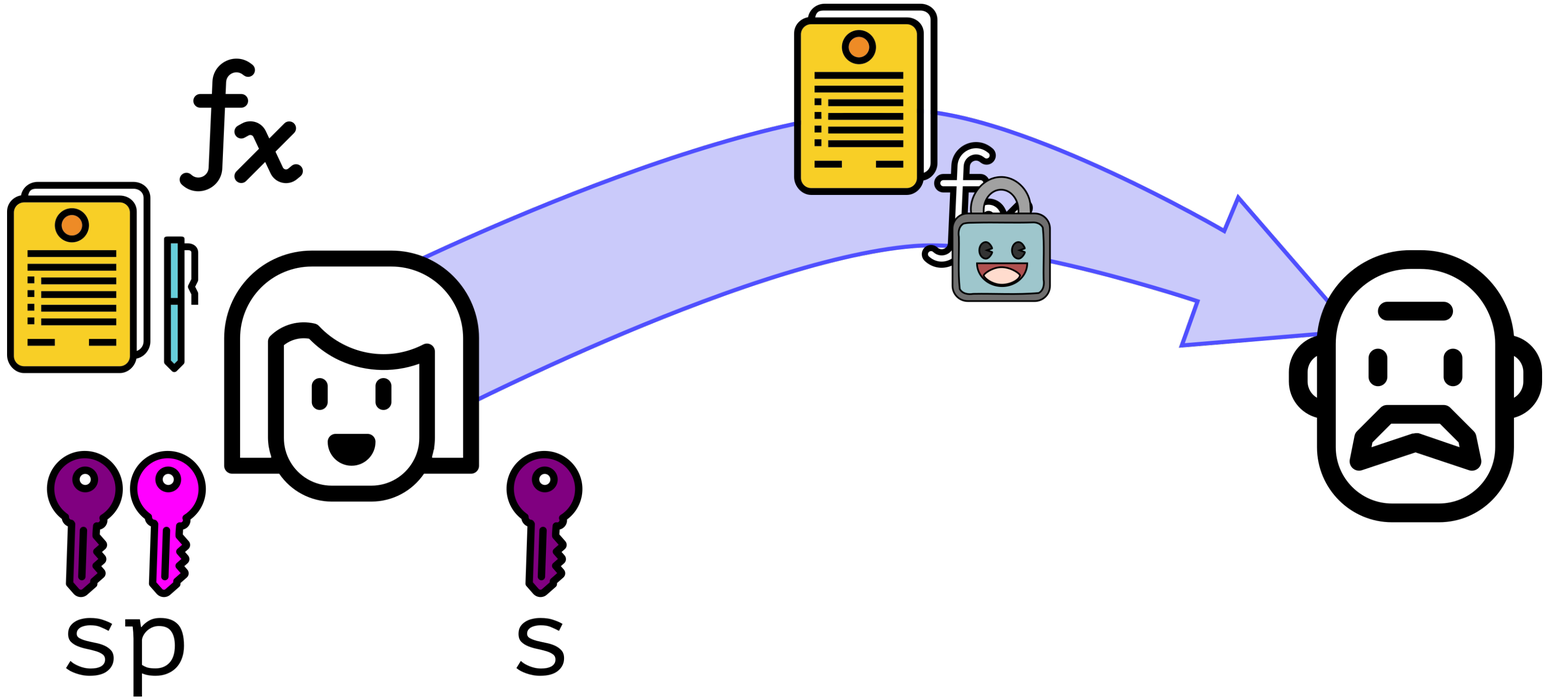
Hashing and signing



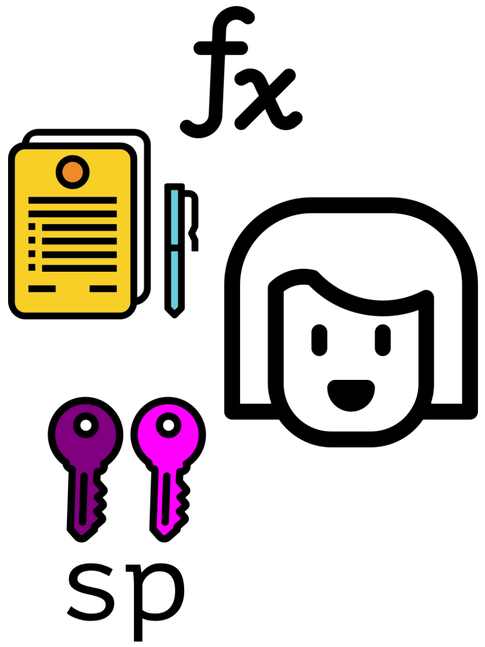
Hashing and signing

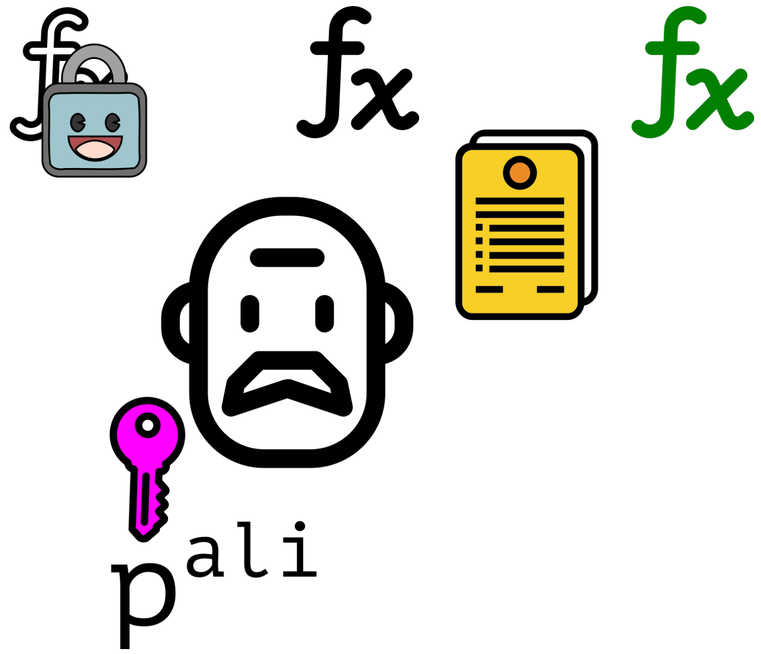


Hashing and signing



Hashing and signing





Certificates

Certificates

- What do we call it when:
  - Someone signs someone else's public key?

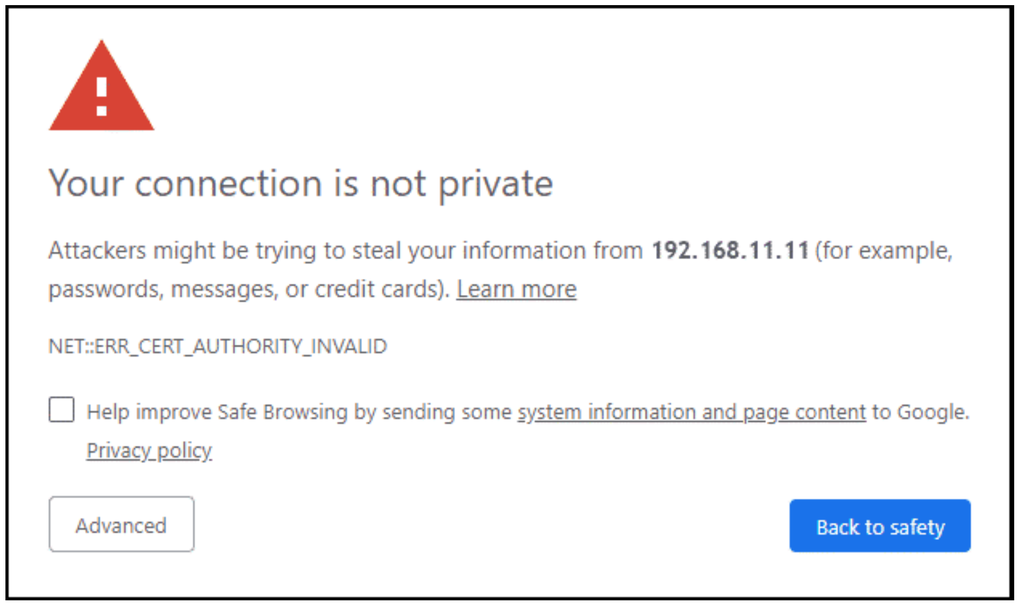
CERTIFICATION

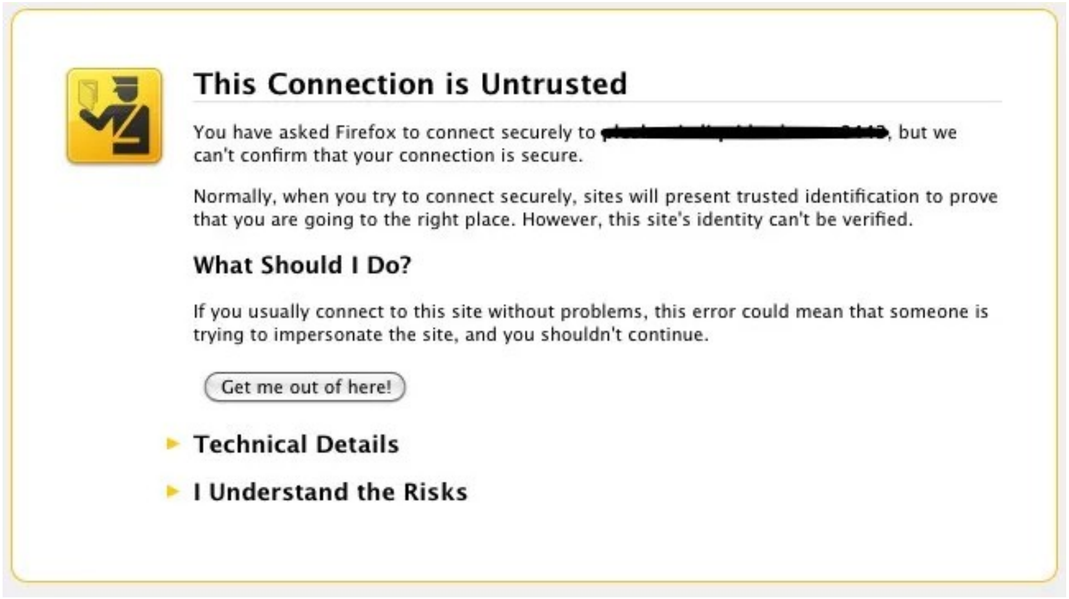
Certificates

- Self-signed certificate
  - Subject states that they are themselves
  - Anybody can make these!

Certificates

- Self-signed certificate





Certificates

- Someone else signs your certificate
  - Another party confirms the identity
  - Still, anybody can make these…

- How do we get to "trust"?

PKI: Public Key Infrastructure

Possible solutions to PKI

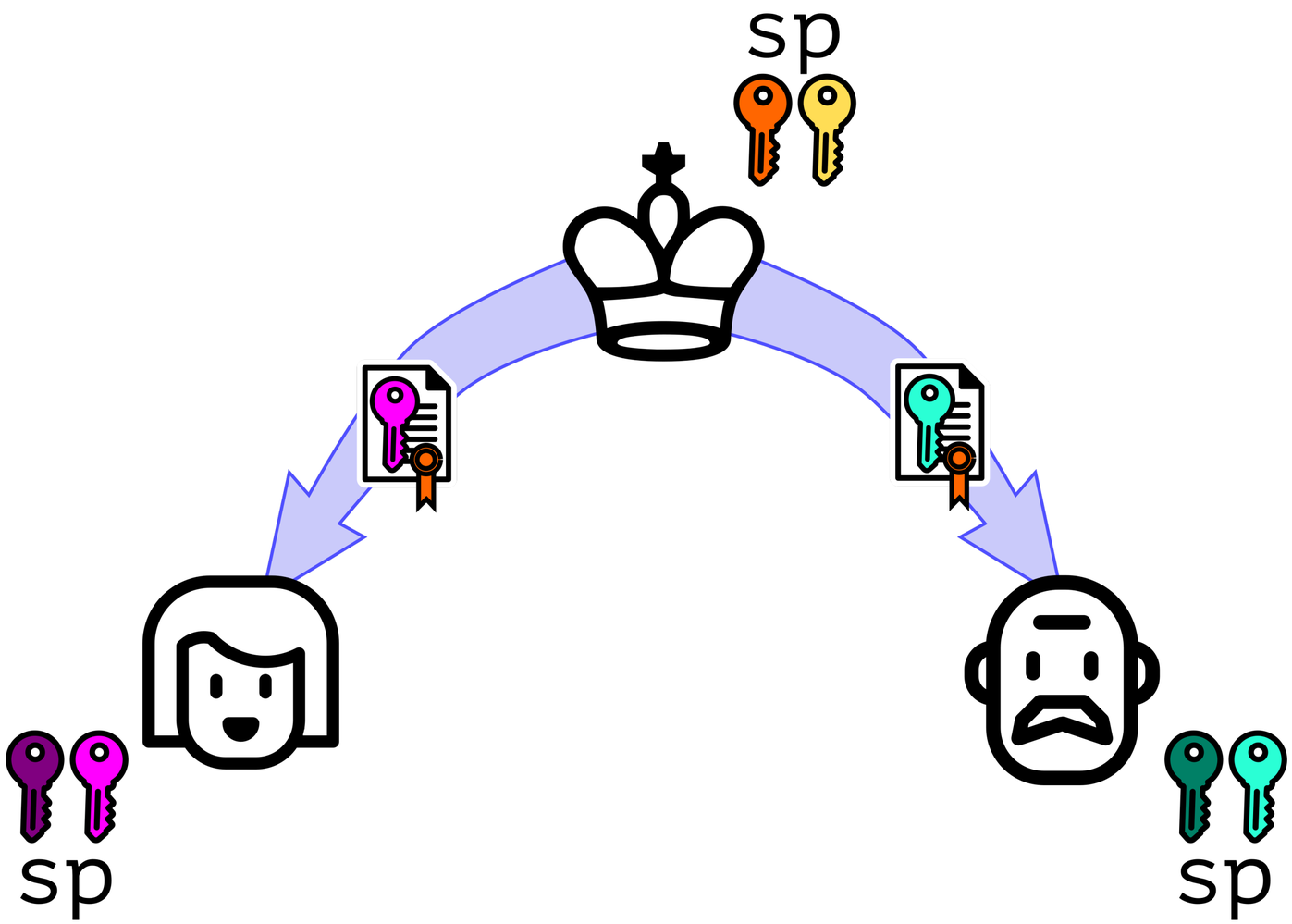
- Certificate Authority (syn. “PKI”)
- Web of trust (e.g. PGP)
- Blockchain

Certificates

- A trusted certificate consists of:
  - A public key,
  - Identifying information and
  - Meta-data

- And is signed by a trusted third party.

Certificate Authority



A Trusted Third Party

- Called a “Certificate Authority”.
- Lots of TTPs: commercial, government, open source
  - *VeriSign, GlobalSign, Let’s Encrypt!, KPN*
  - *Staat der Nederlanden, Department of Defense*

- But you can build your own as well!

A Trusted Third Party

- We trust TTPs because they:
  - Offer guarantees about security
  - Offer guarantees about vetting
  - Offer guarantees about availability

- https://cabforum.org
- https://casecurity.org

Does this ever go wrong?

- YES! Sometimes horribly:
  - *DigiNotar* (GMail attack by Iran)
  - *Comodo* (GlobalTrust)

- Rogue certificates:
  - "*Certificate transparency*" is a must,
  - And so is "*CAA*": CA Authorization

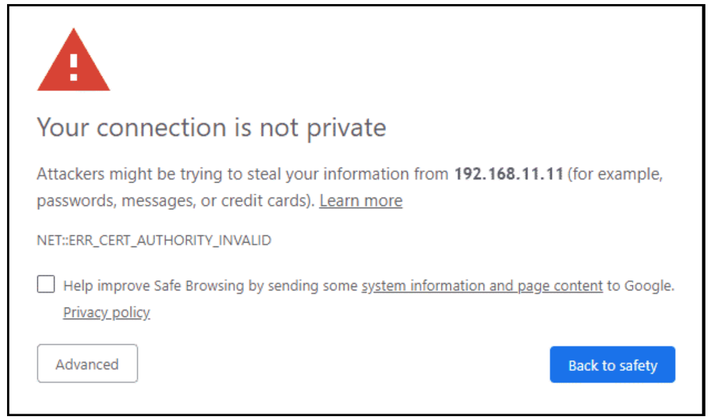
Assuring trust

Trust store

- There isn't ONE standard solution.
  - Most OSes offer a central trust store.
    - *Keychain Access*, *CertMgr.msc*, */etc/tls/certs*
  - Most browsers have their own trust store.
  - Many applications also have their own!

Trust store

- If your trust store isn't complete?
  - Then TLS will refuse to connect.




```
curl: (60) SSL certificate problem: unable to get local issuer
certificate

Exception: javax.net.ssl.SSLHandshakeException:
sun.security.validator.ValidatorException: PKIX path validation
failed:
```

When to trust a certificate

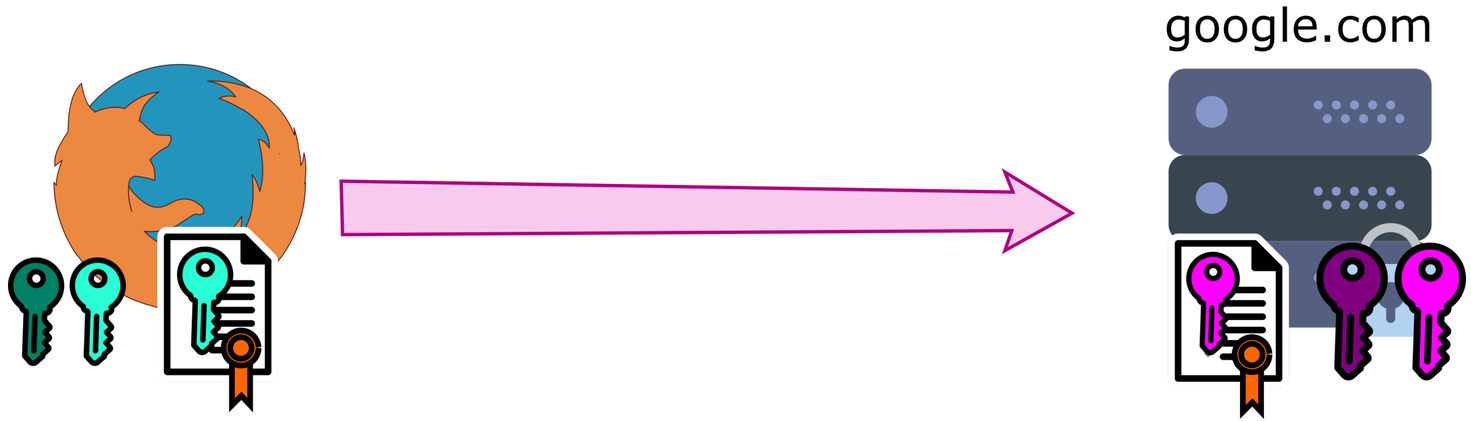
- When it matches our **counterpart**.
- When we actively **trust** the CA.
- When it hasn’t **expired**.
- When it hasn’t been **revoked**.
- When the “**chain**” is valid.

What is a chain?

- A series of valid, trusted certificates.
  - That link the subject,
  - Via the issuing CA(s),
  - To the "trust anchor", the "root CA".

Bringing it all together

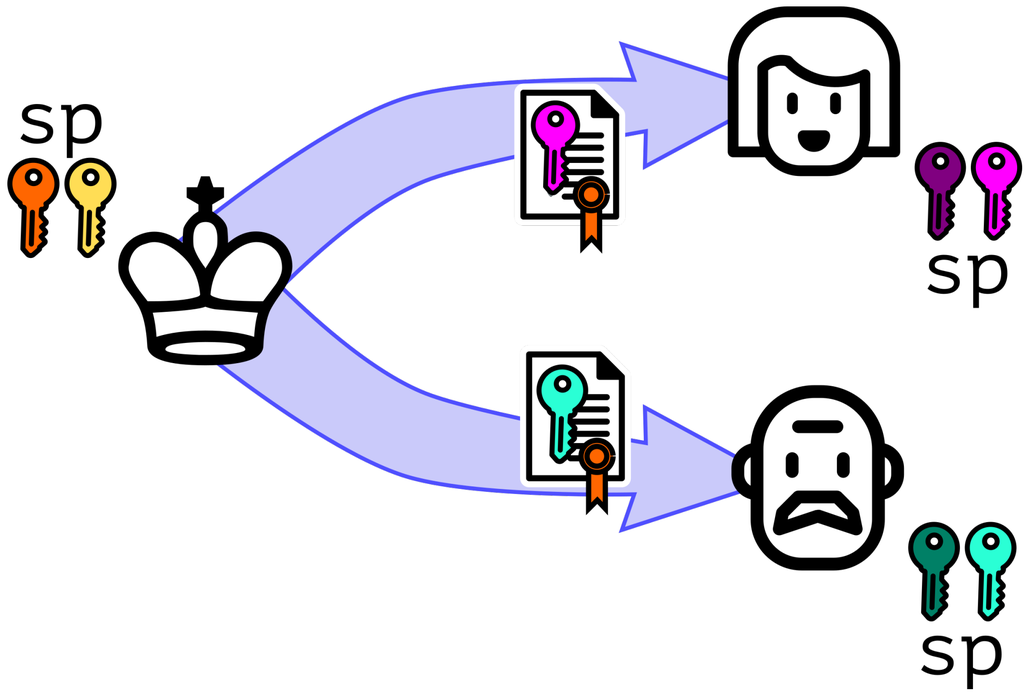
- HTTPS uses asymmetric crypto for key exchange.
  - Allows us to safely setup fast, symmetric crypto.



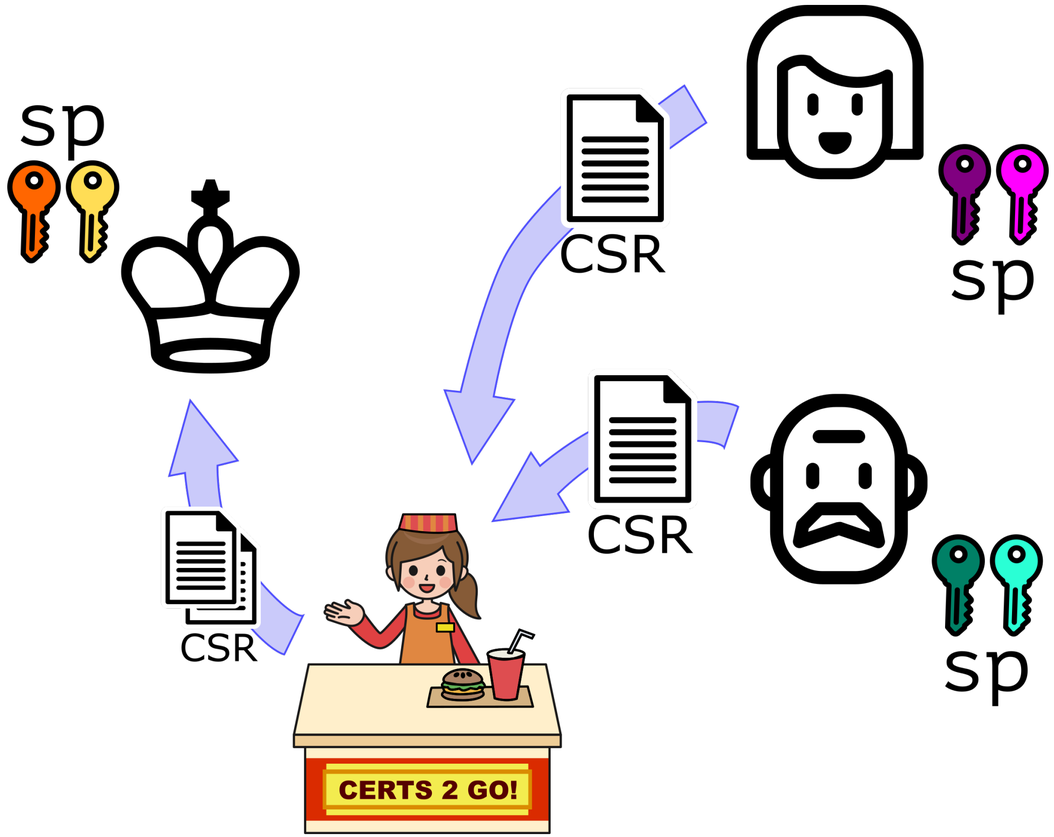
See: How does TLS work? and The illustrated TLS connection

PKI Anatomy

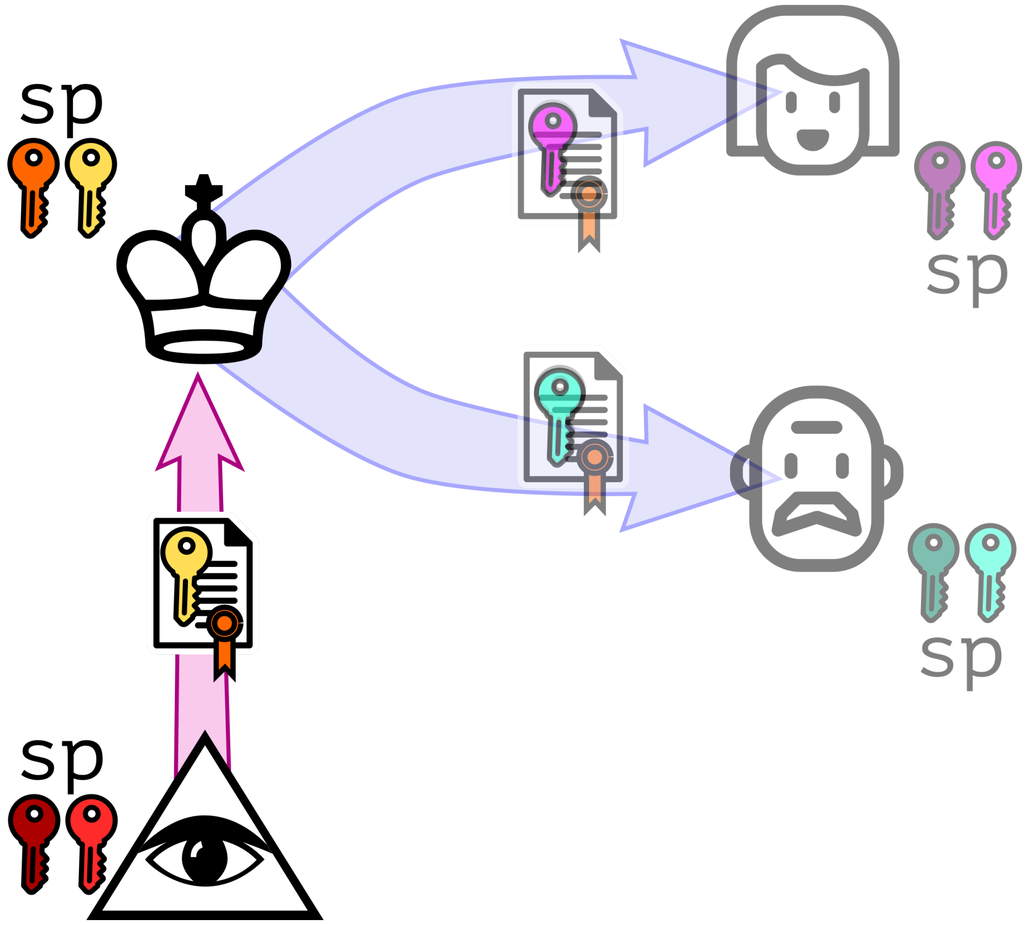
Subjects, Issuing CA



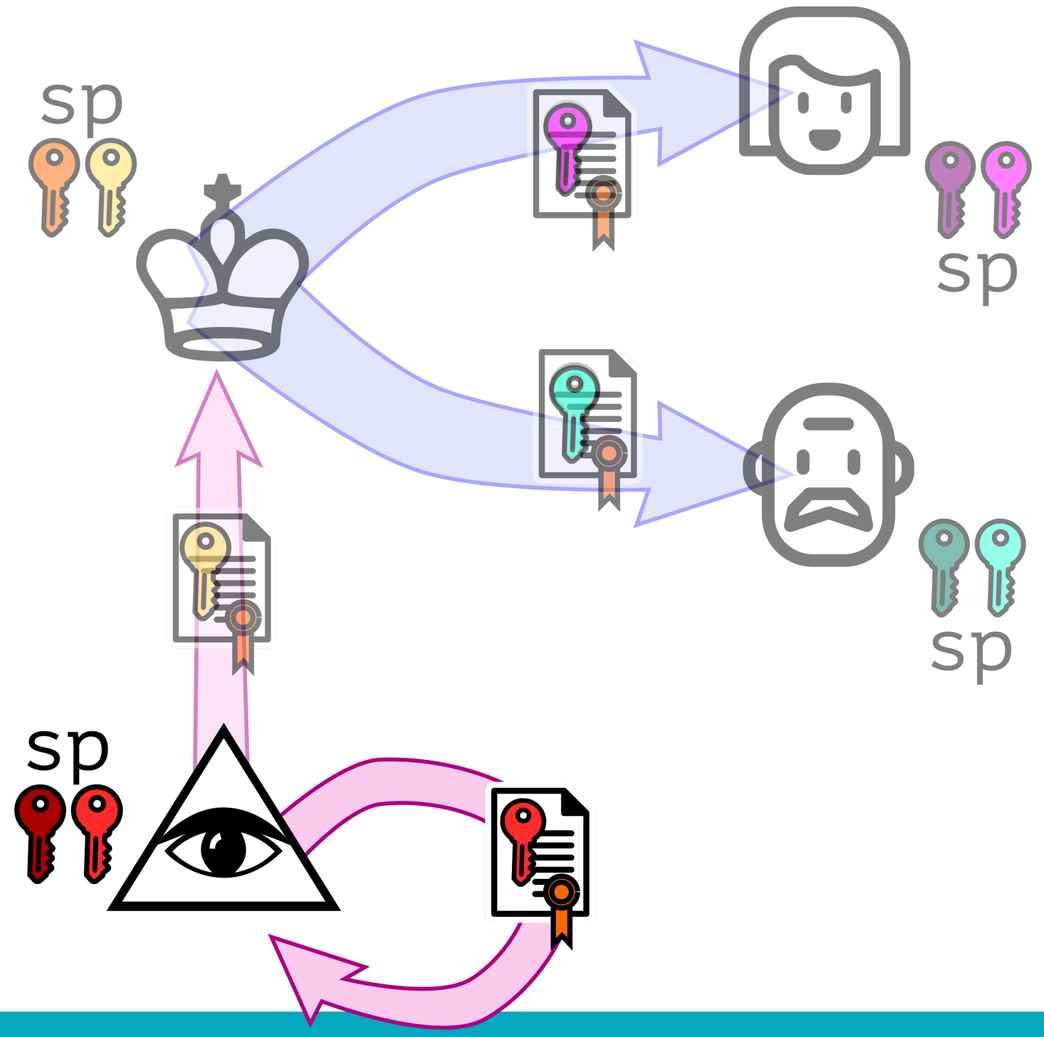
Registration Authority



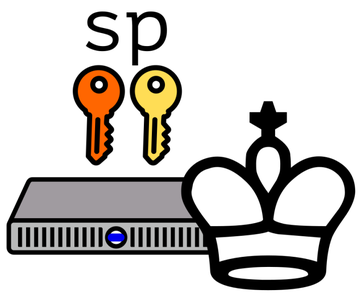
Root CA

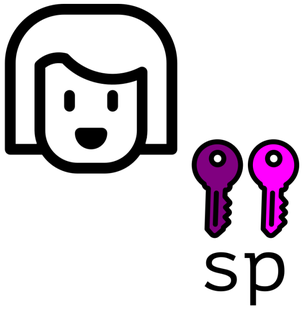


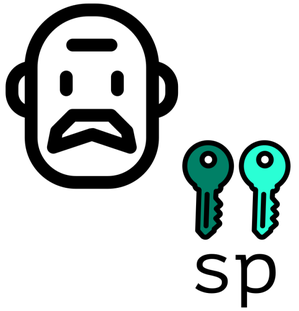
Root CA

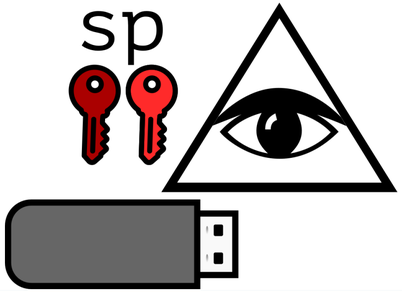


Hardware Security Module

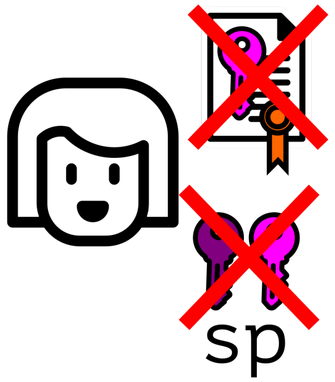


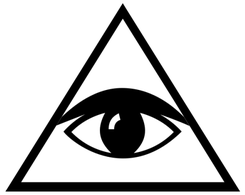






Validation Authority





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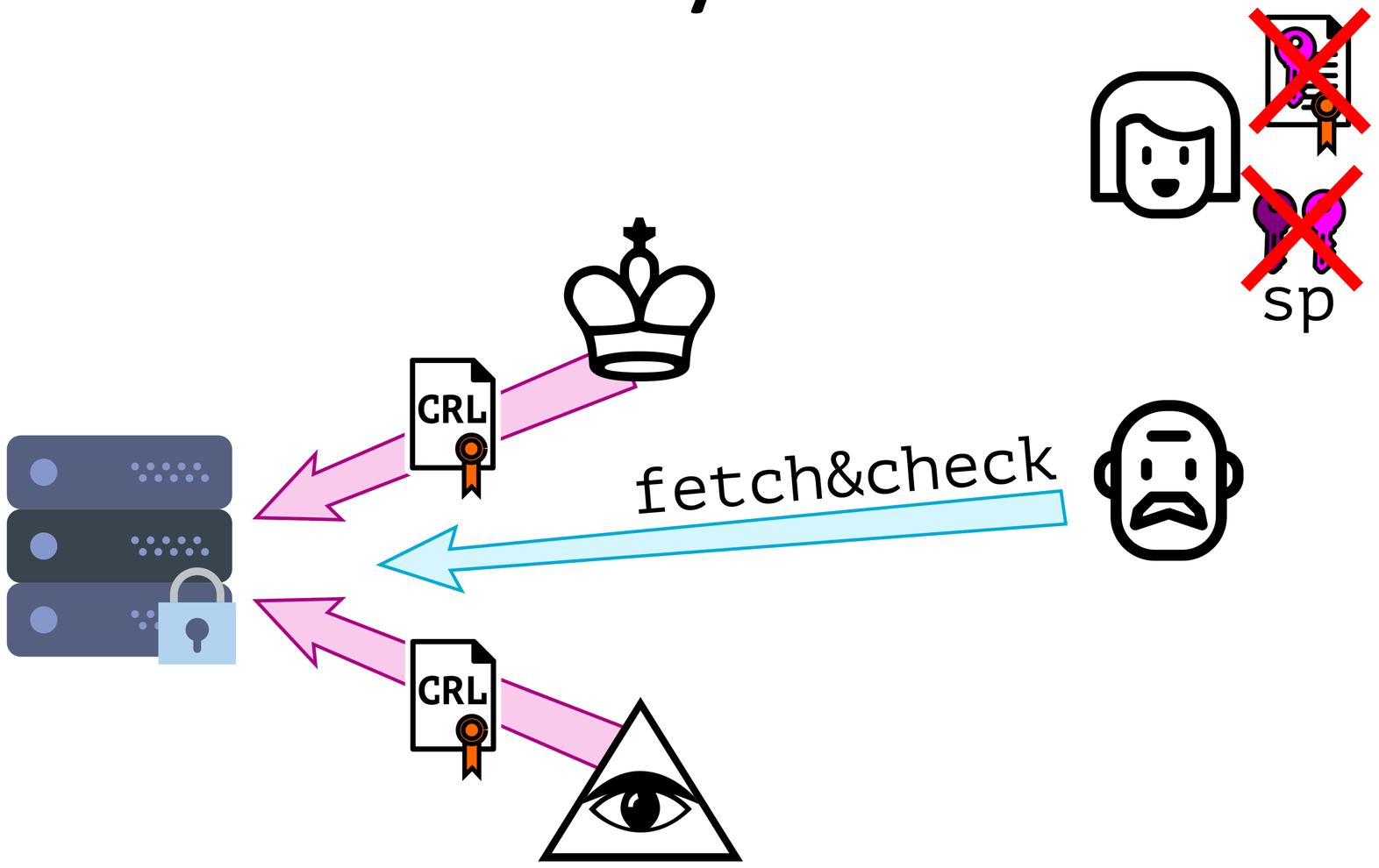
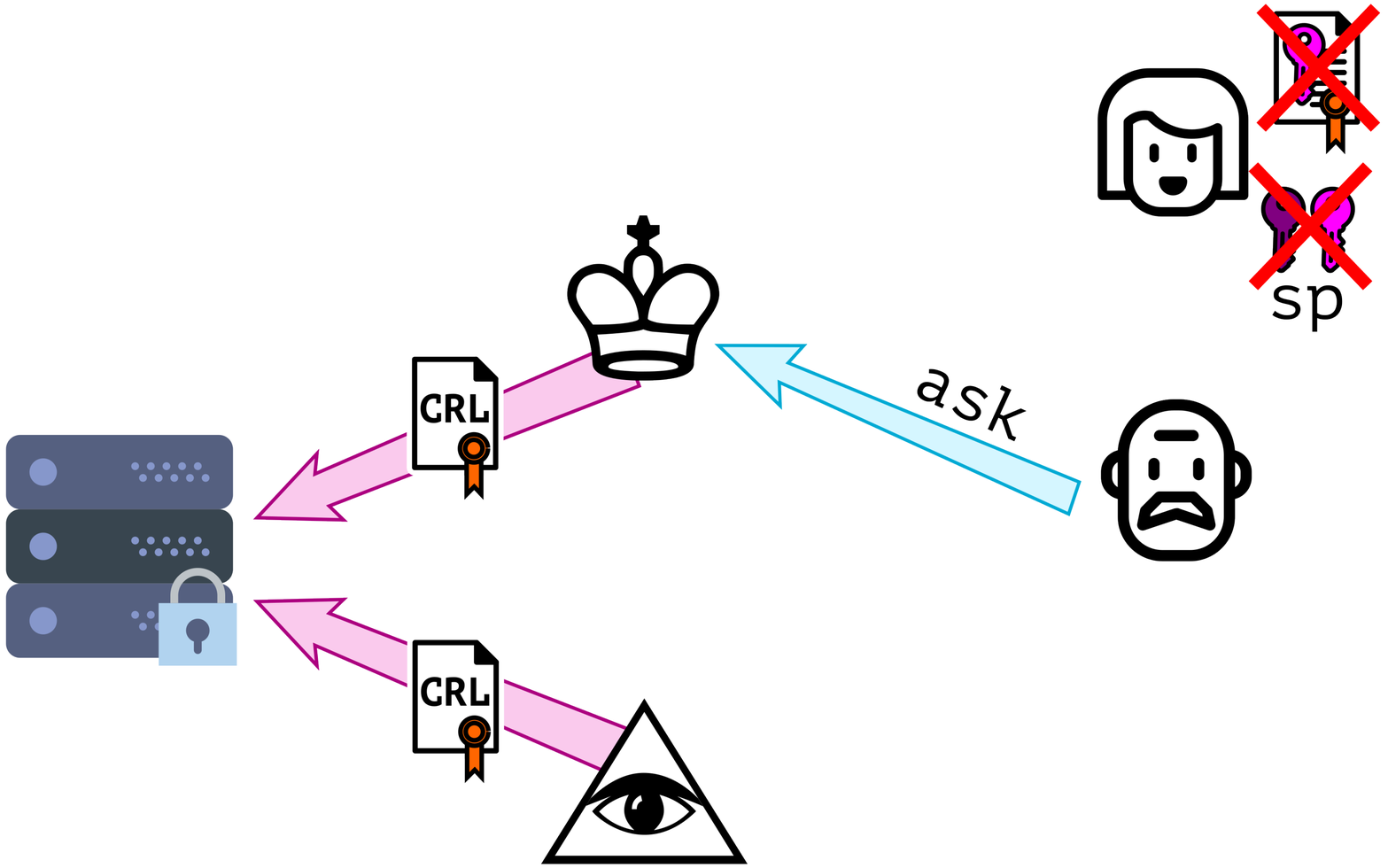
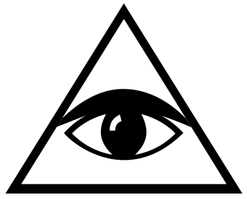
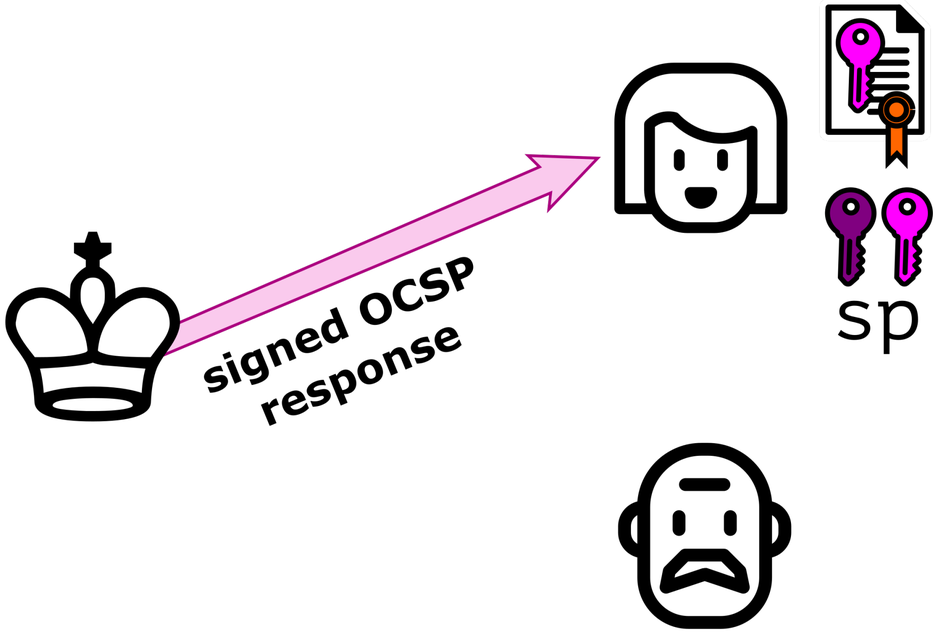


OCSP



OCSP stapling





How can it fail?

- Scott Helme: “*Revocation is broken.*”
  - OCSP breaks privacy.
  - CRL and OCSP can be blocked.
  - Many browsers soft-fail.
  - Many apps hard-fail.

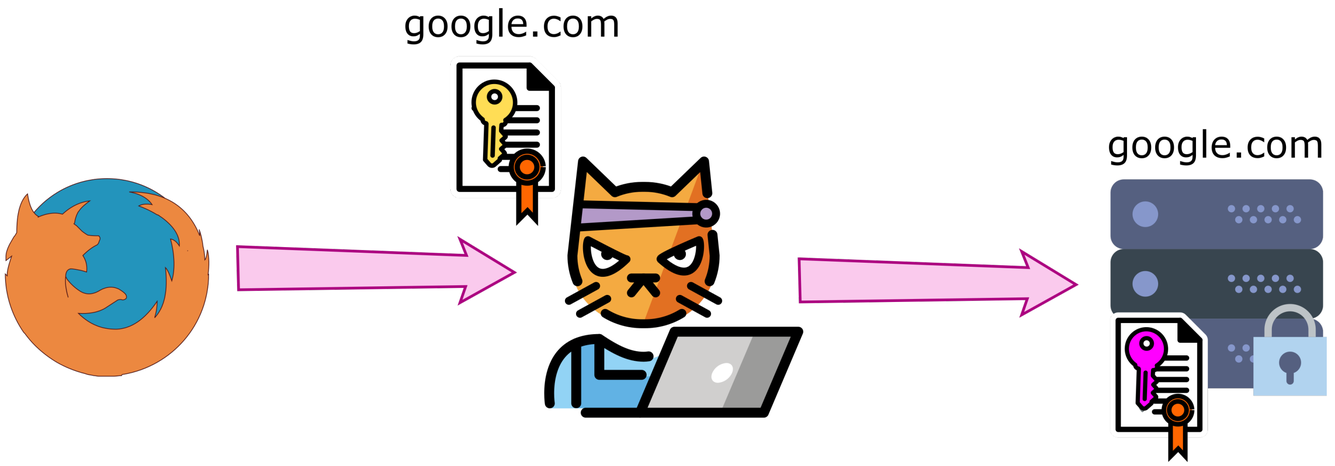
- There are workarounds and fixes.

And why do we trust these?

- Because the ones running the PKI:
  - Offer guarantees about security
  - Offer guarantees about vetting
  - Offer guarantees about availability

Attack Scenarios

On-path, no cert validation

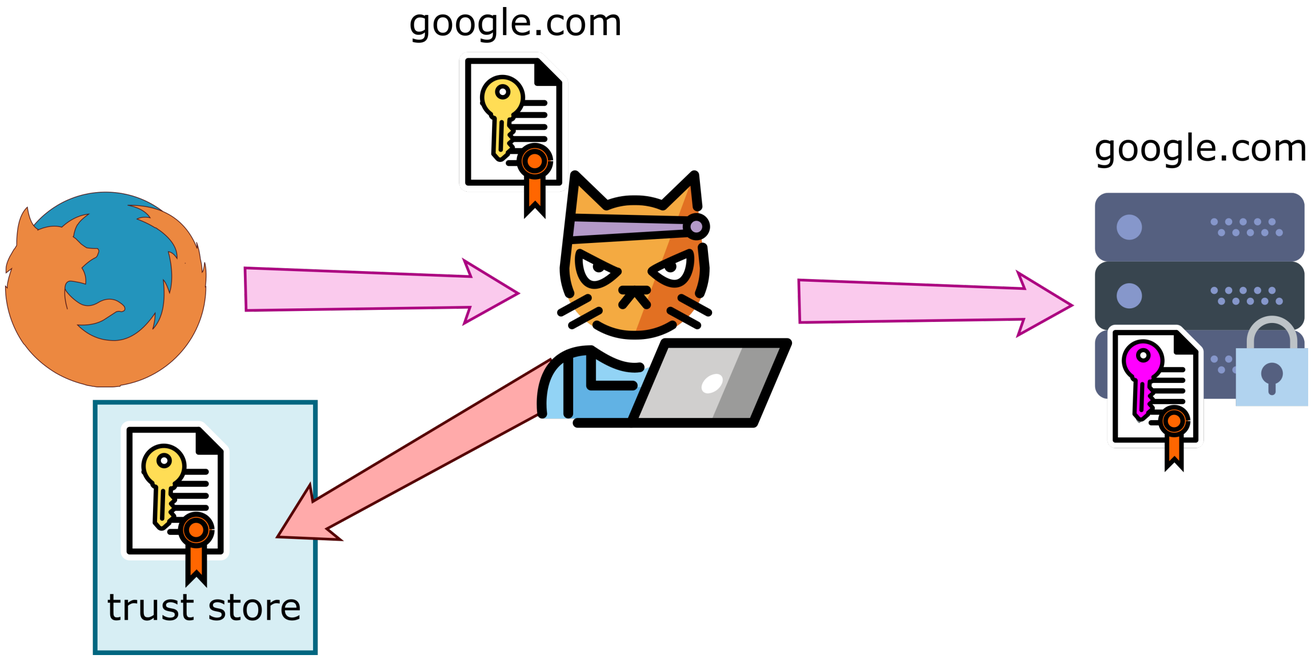



```
curl -k https://www.google.com
```

On-path, no cert validation

- When?
  - Every StackOverflow solution ...
  - Every tutorial ...
  - Every default demo project ...
  - That says: "*just disable TLS validation*".

On-path, breached trust store

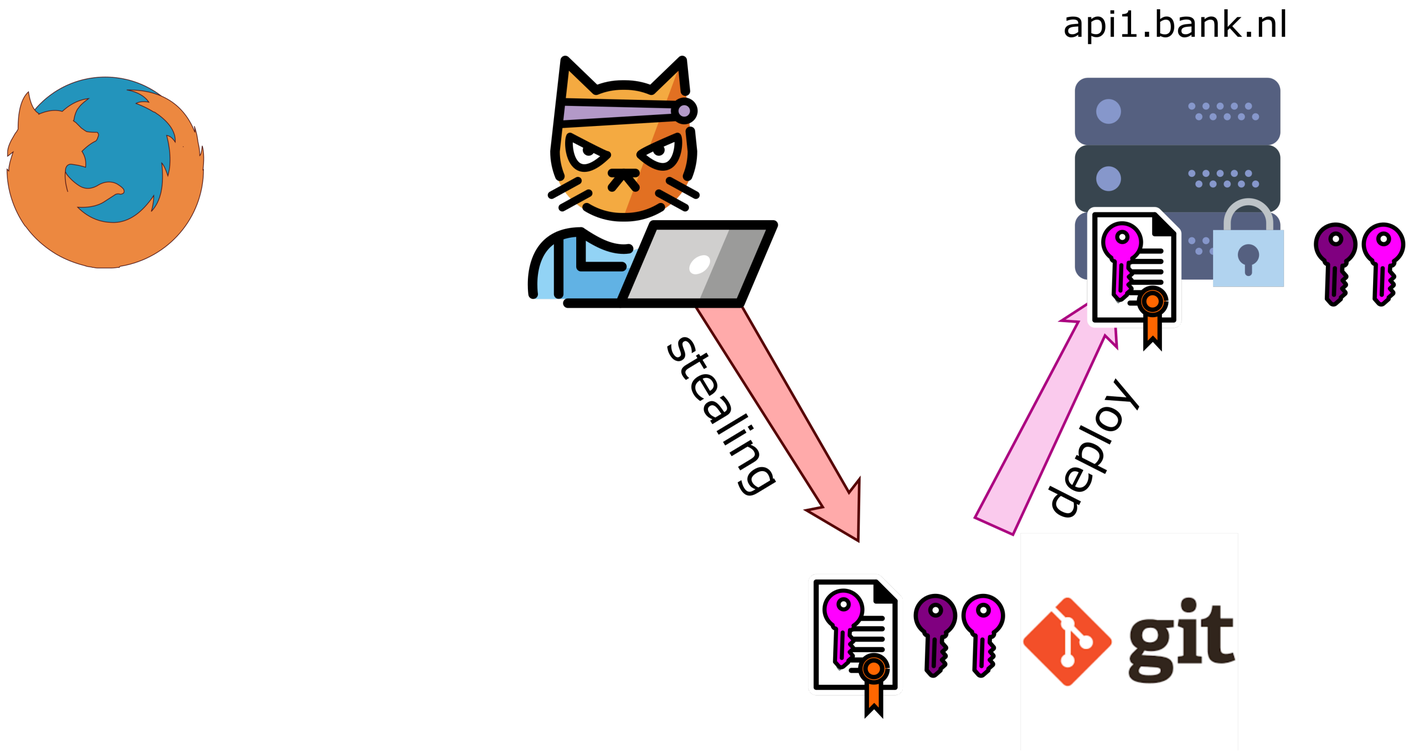


On-path, breached trust store

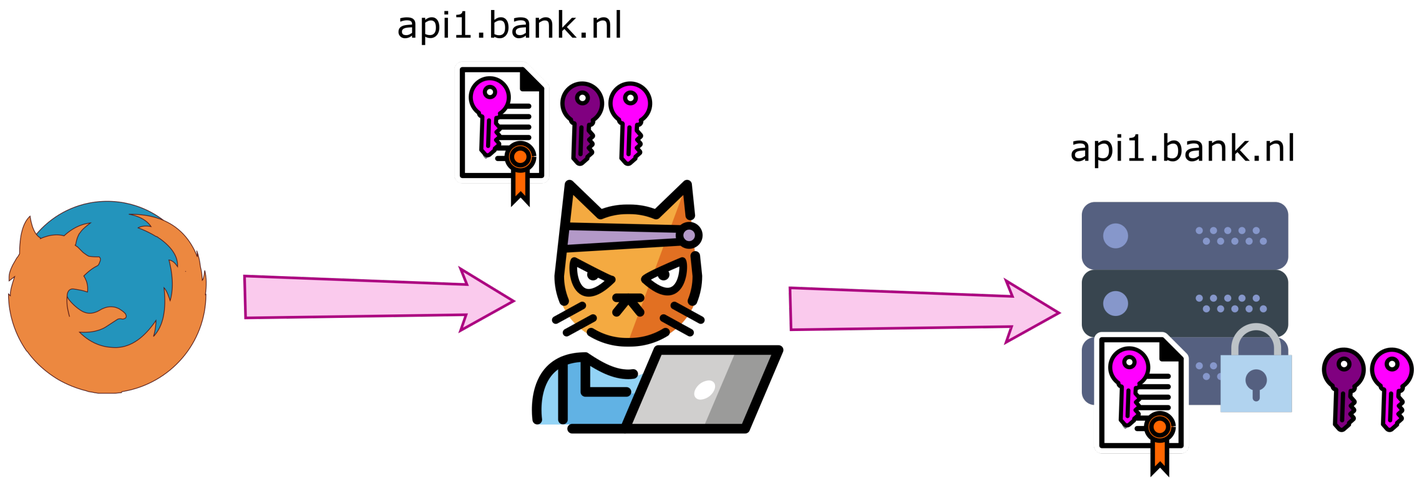
- Lenovo and Kazakhstan did this.

- When?
  - Malware
  - Internet inspection proxy servers
  - Government oversight

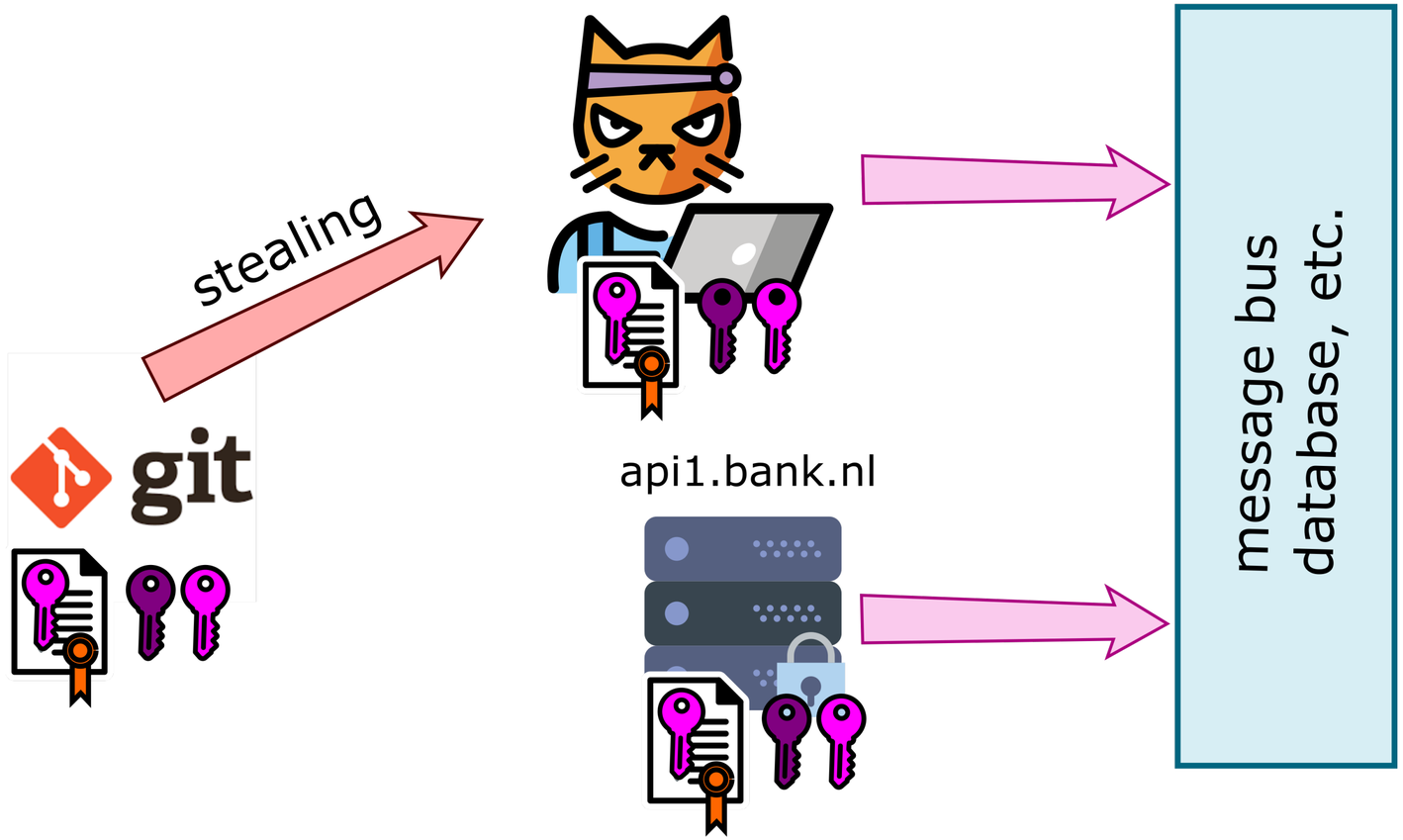
On-path, stolen keys+cert



On-path, stolen keys+cert



Impersonation

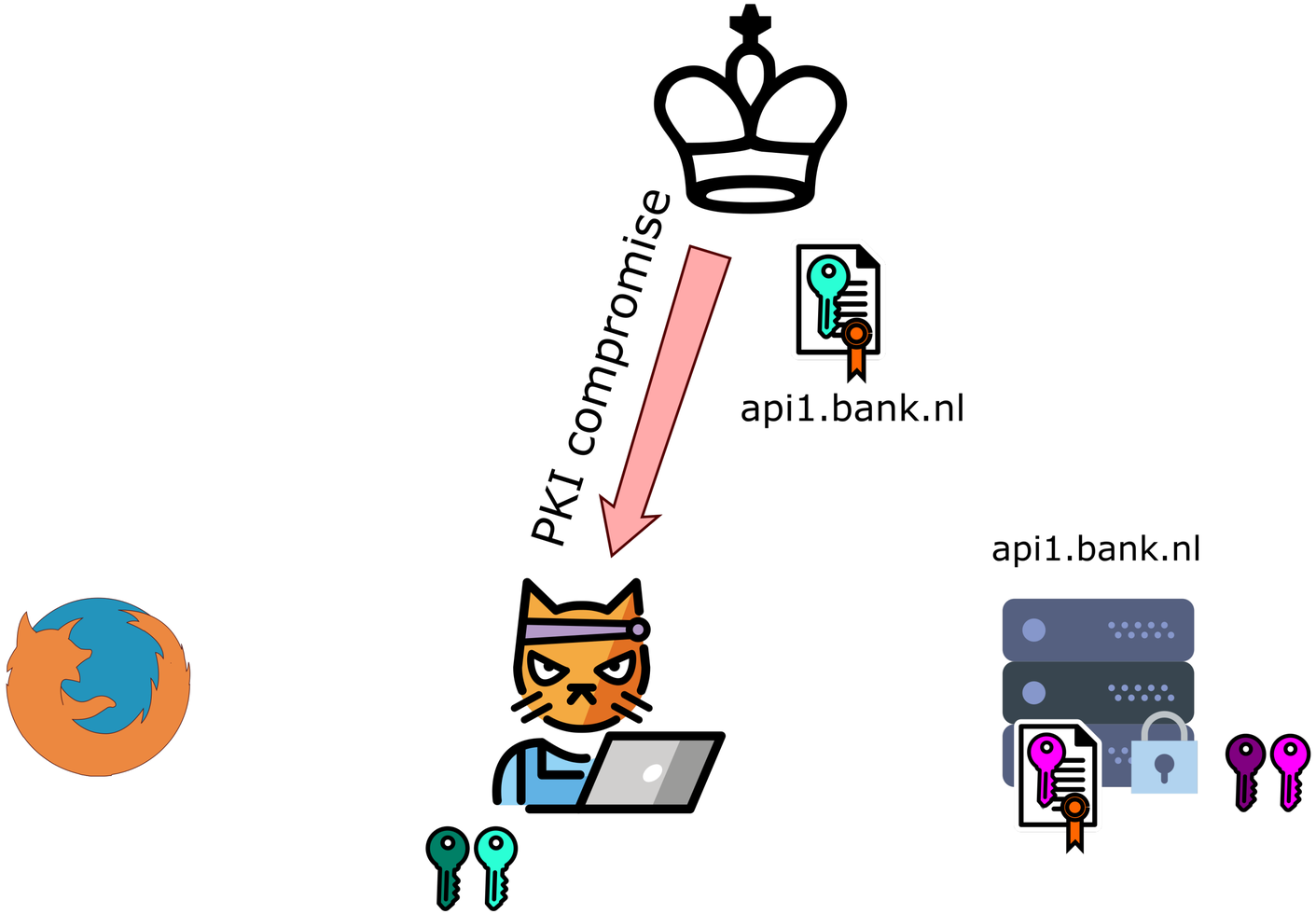


On-path, stolen keys+cert

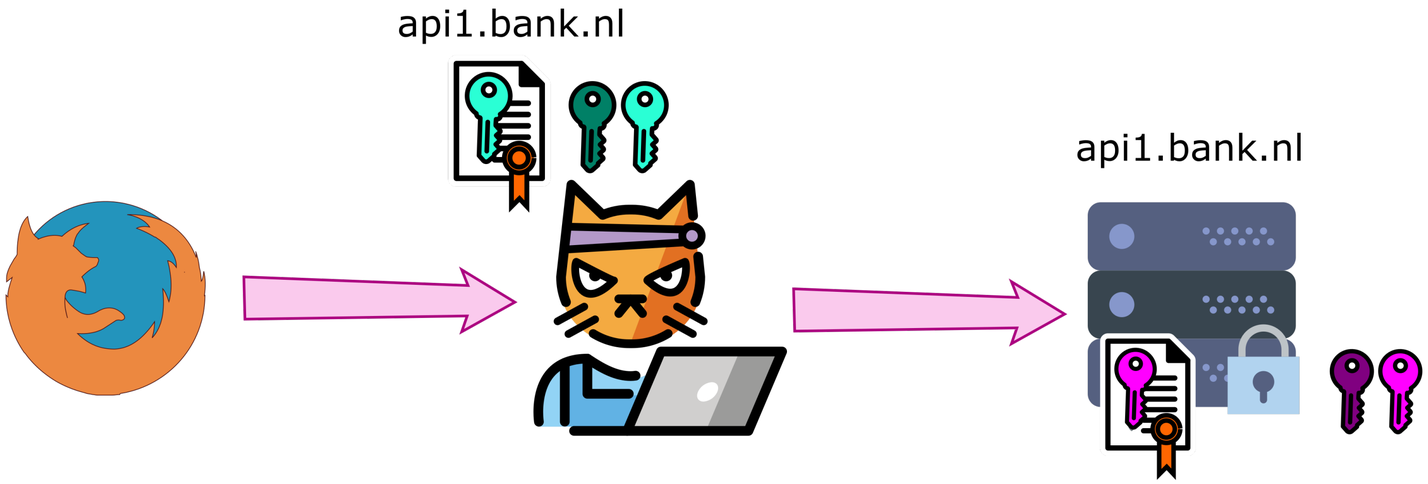
- This happened to Microsoft and Github!

- When?
  - Malware
  - APT: *Advanced Persistent Threat*
  - Criminal gangs

On-path, forged certificate



On-path, forged certificate



On-path, forged certificate

- This happened to Diginotar!

- When?
  - Malware
  - APT: *Advanced Persistent Threat*

Best practices

Your product MUST

- Trust your company's PKI.
- Validate and verify all certificates.
- Have its own, valid certificates.
- Store its keys securely.
- Use approved algorithms and libraries.

Your product must NOT

- Trust random CAs, have a writable trust store.
- Ignore certificate validation.
- Use self-signed or bogus certificates.
- Store keys in Git, file shares or outside the server.
- Use outdated crypto.
- "Roll your own" crypto. Never!