Prying Open Pandora's Box: KCI Attacks against TLS

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USENIX WOOT 2015

RISE
Research Industrial Systems Engineering

Outline of this Talk

- Authenticated Key Agreement and KCI
- TLS is vulnerable to KCI
- KCI and TLS in practice
- Conclusion and Mitigation

Key Compromise Impersonation (KCI)

Weakness of Authenticated Key Agreement protocol

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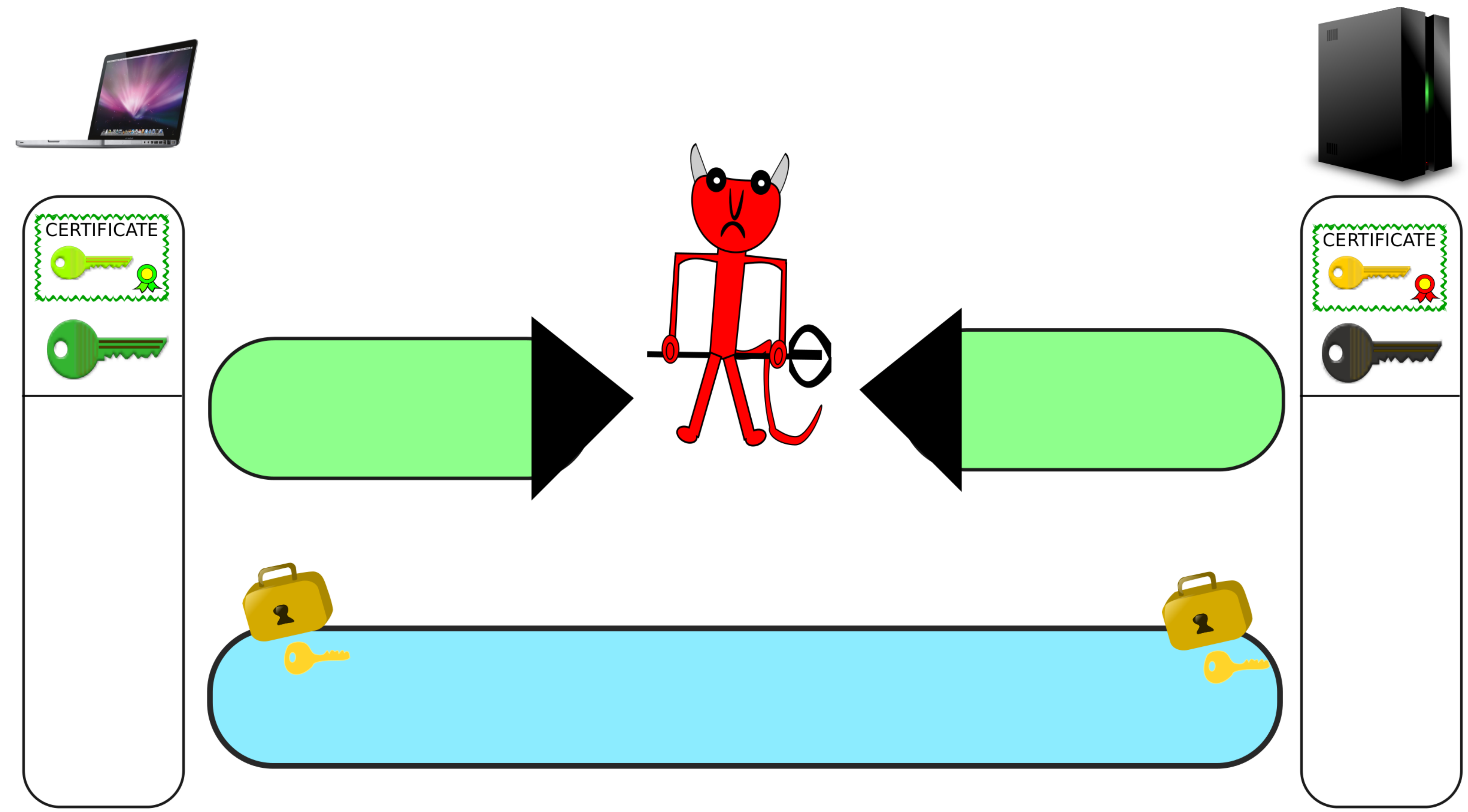
Weakness of Authenticated Key Agreement protocol

Authenticated Key Agreement

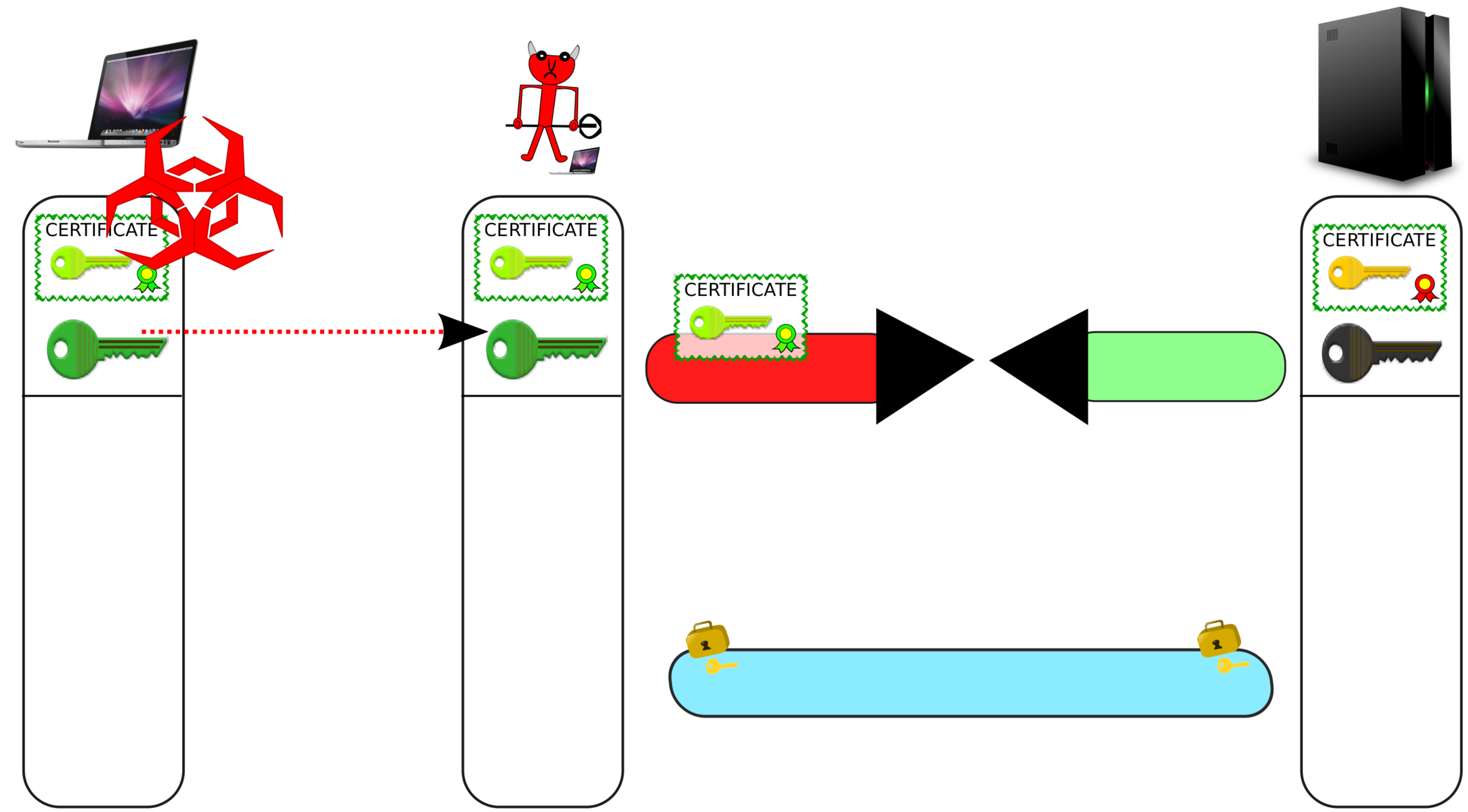
- 2 parties exchange messages
- Over an adversarial network
- To derive a shared secret (session key)



Key Compromise Impersonation (KCI)

Weakness of Authenticated Key Agreement protocol

- Compromise of long-term secret allows to trivially impersonate the compromised party
- KCI – reverse situation: Impersonate an uncompromised party to the compromised party
- KCI allows for MitM attacks



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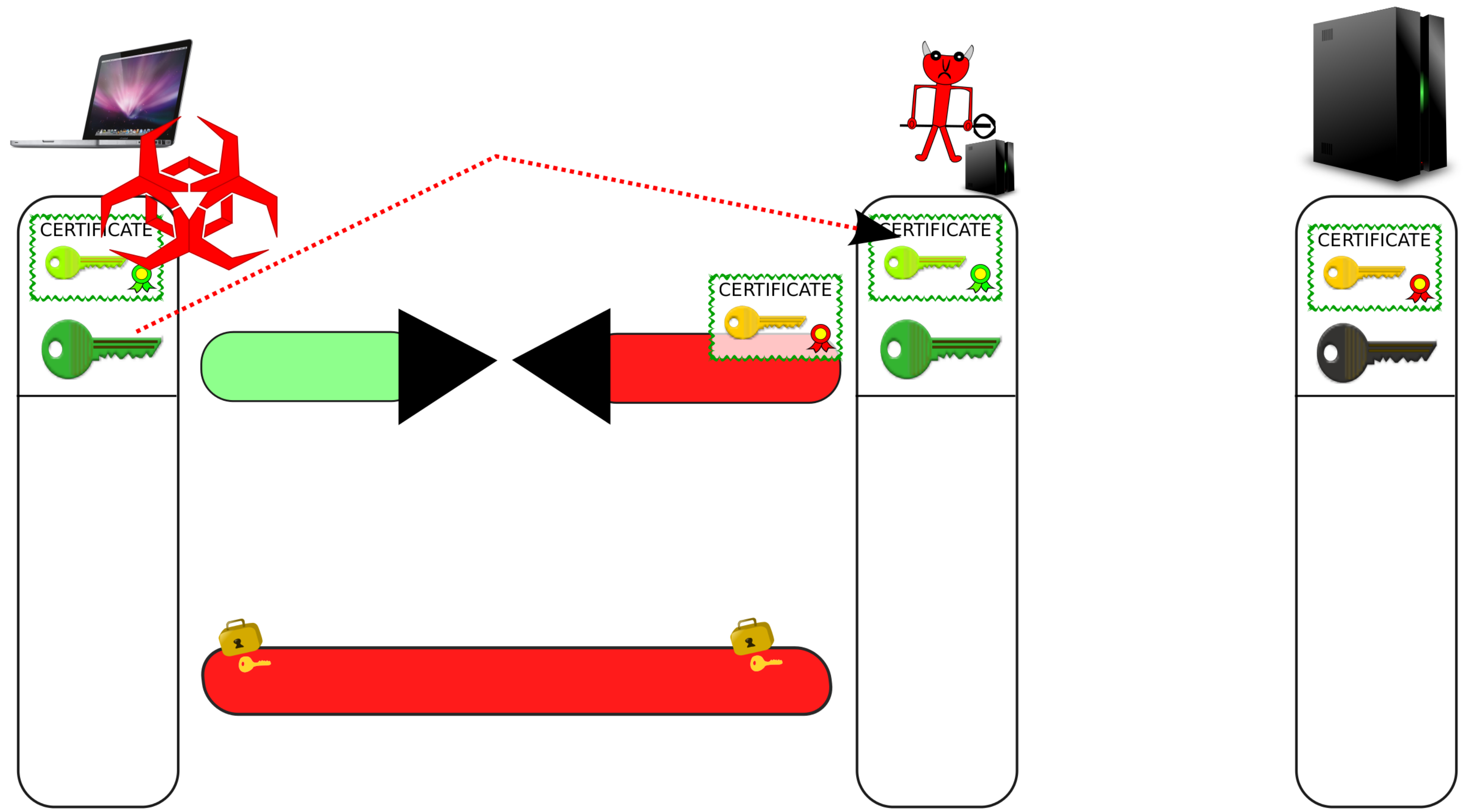

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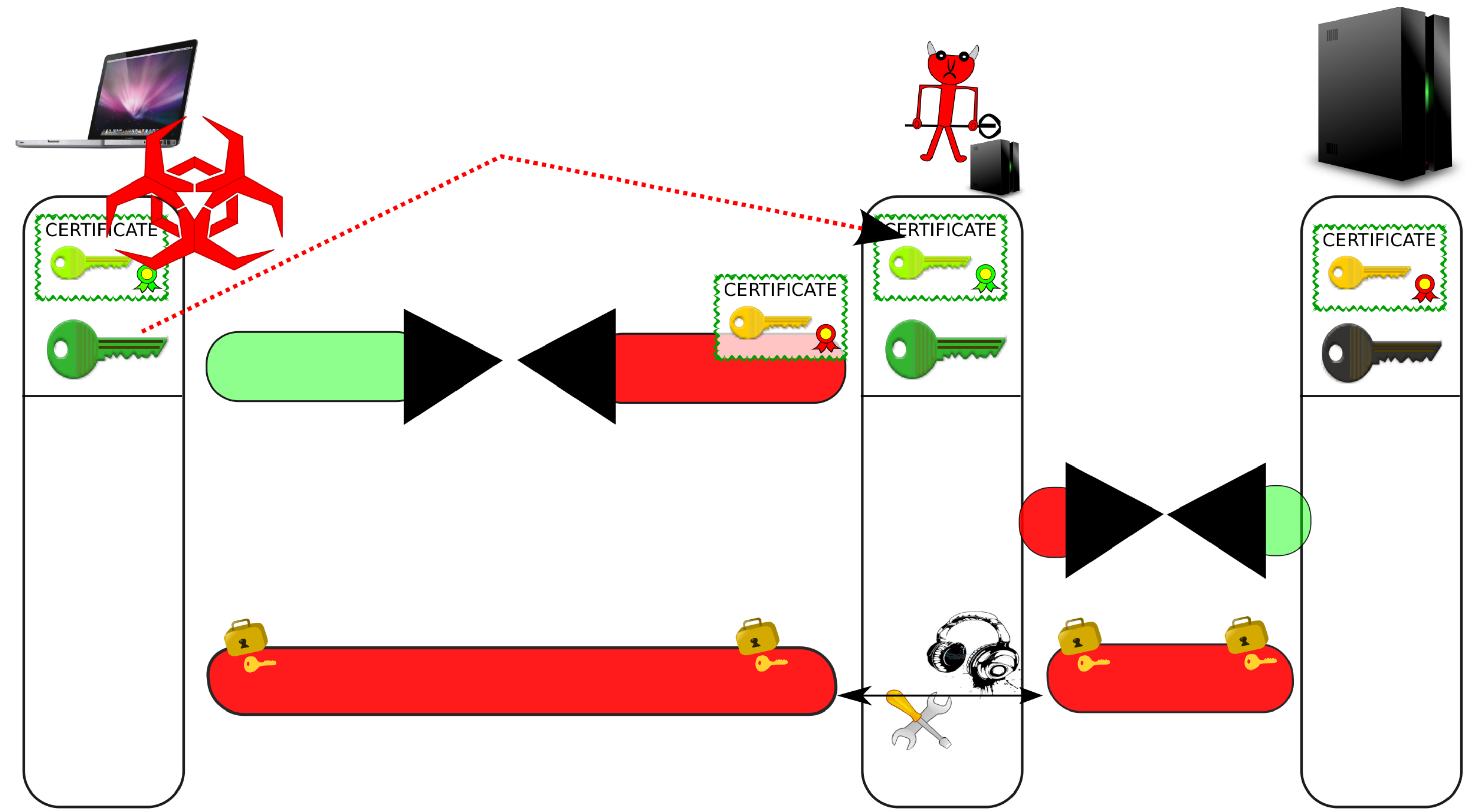

TLS protocol is vulnerable to KCI

Non-ephemeral Diffie-Hellman key exchange with fixed Diffie-Hellman client authentication

- $\mathbb{Z}_p$ as well as EC
- In all TLS versions
- Client indicates support in `ClientHello` message
- Server requests `fixed_(ec)dh` authentication
- Session key is derived from static DH values:

  client: $PRF((g^s)^c, rand_c || rand_s)$

  server: $PRF((g^c)^s, rand_c || rand_s)$

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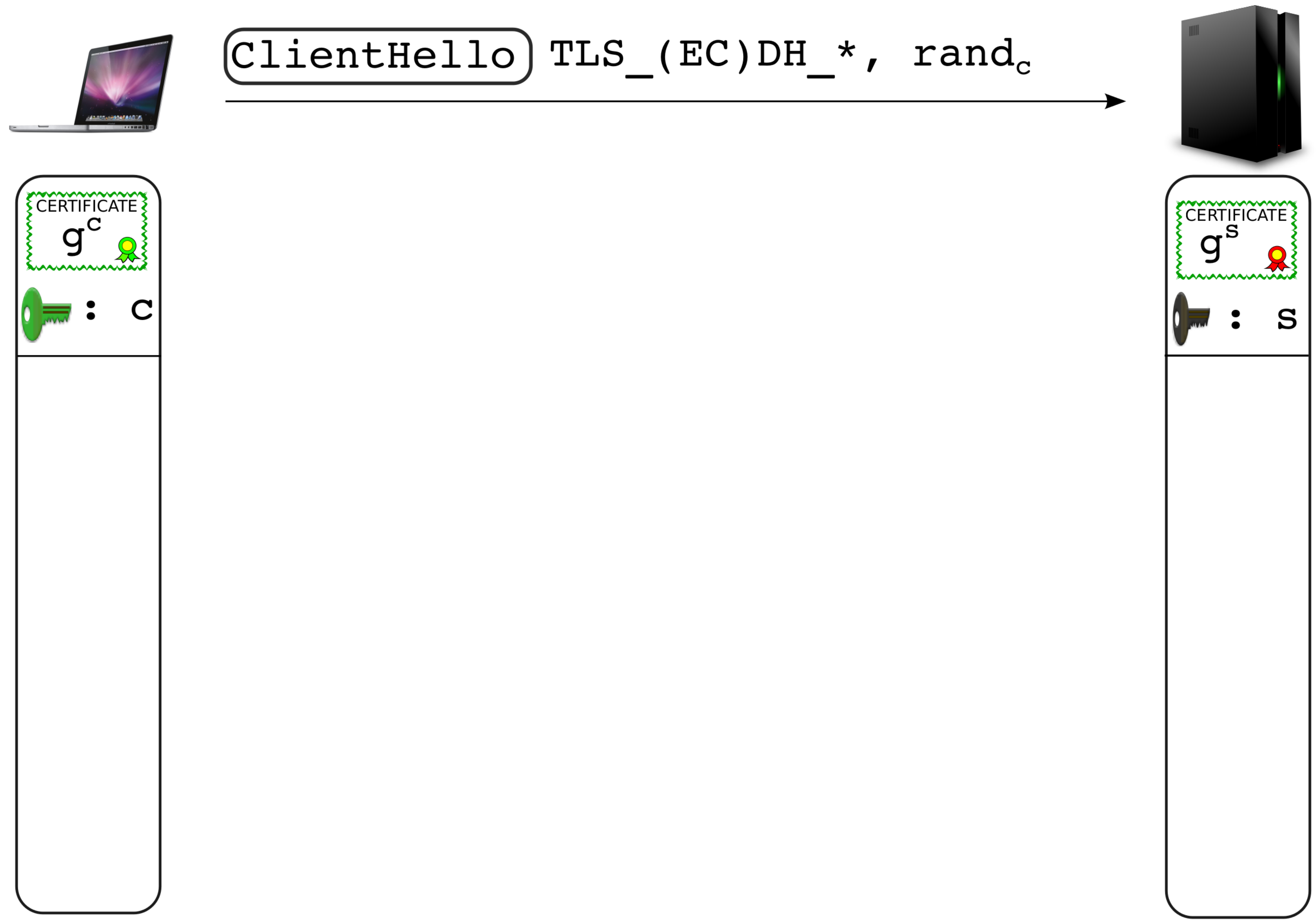

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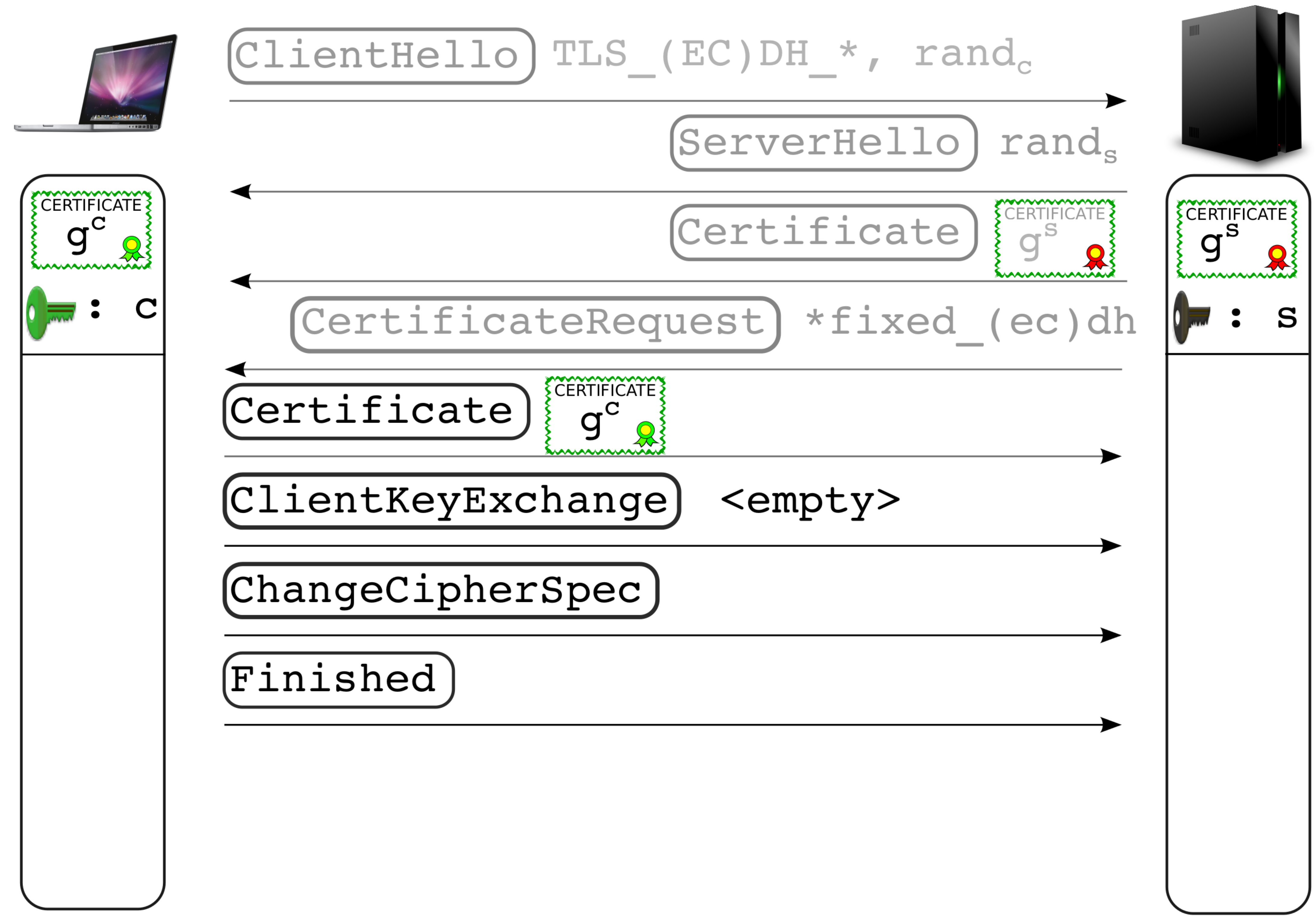

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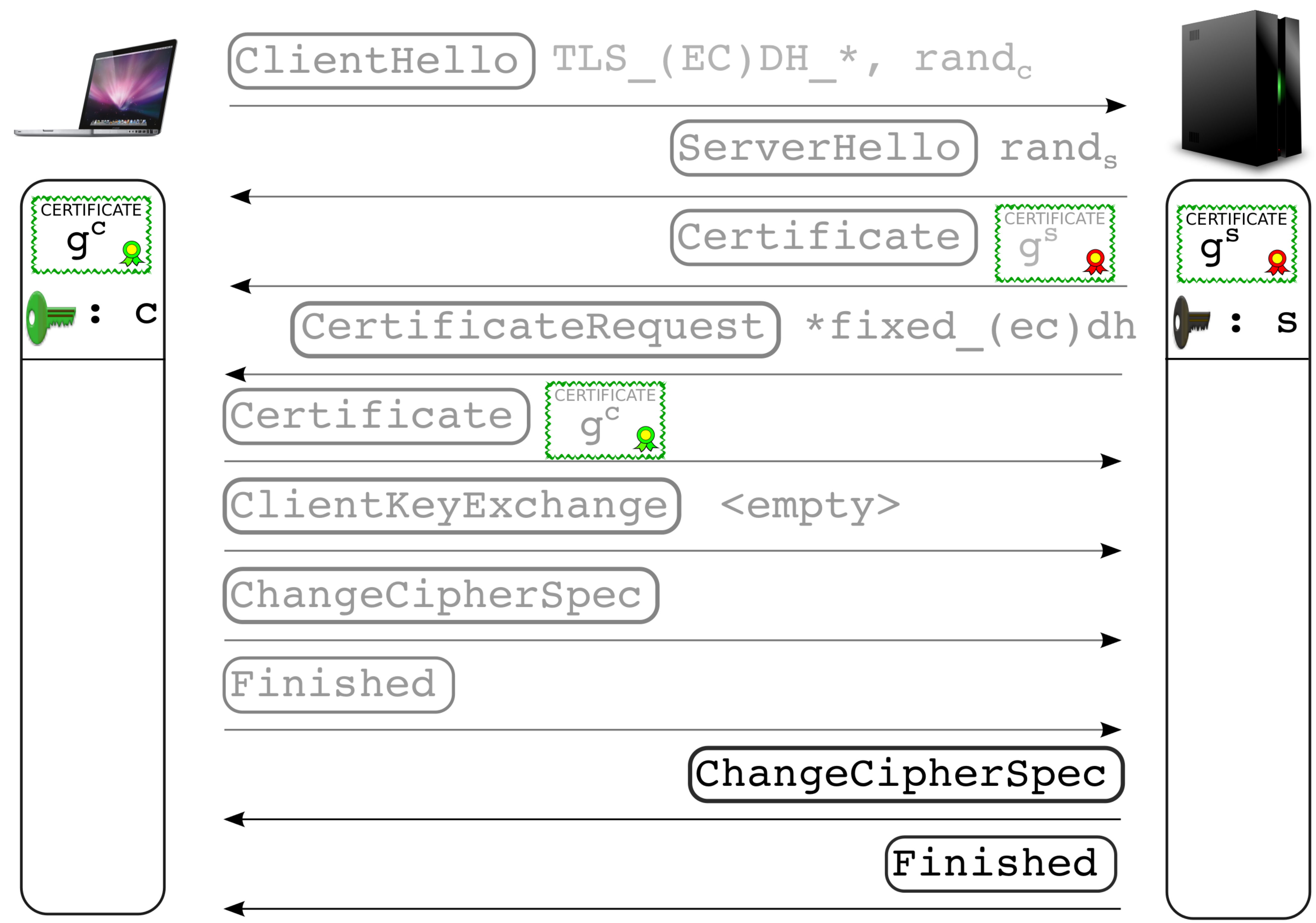
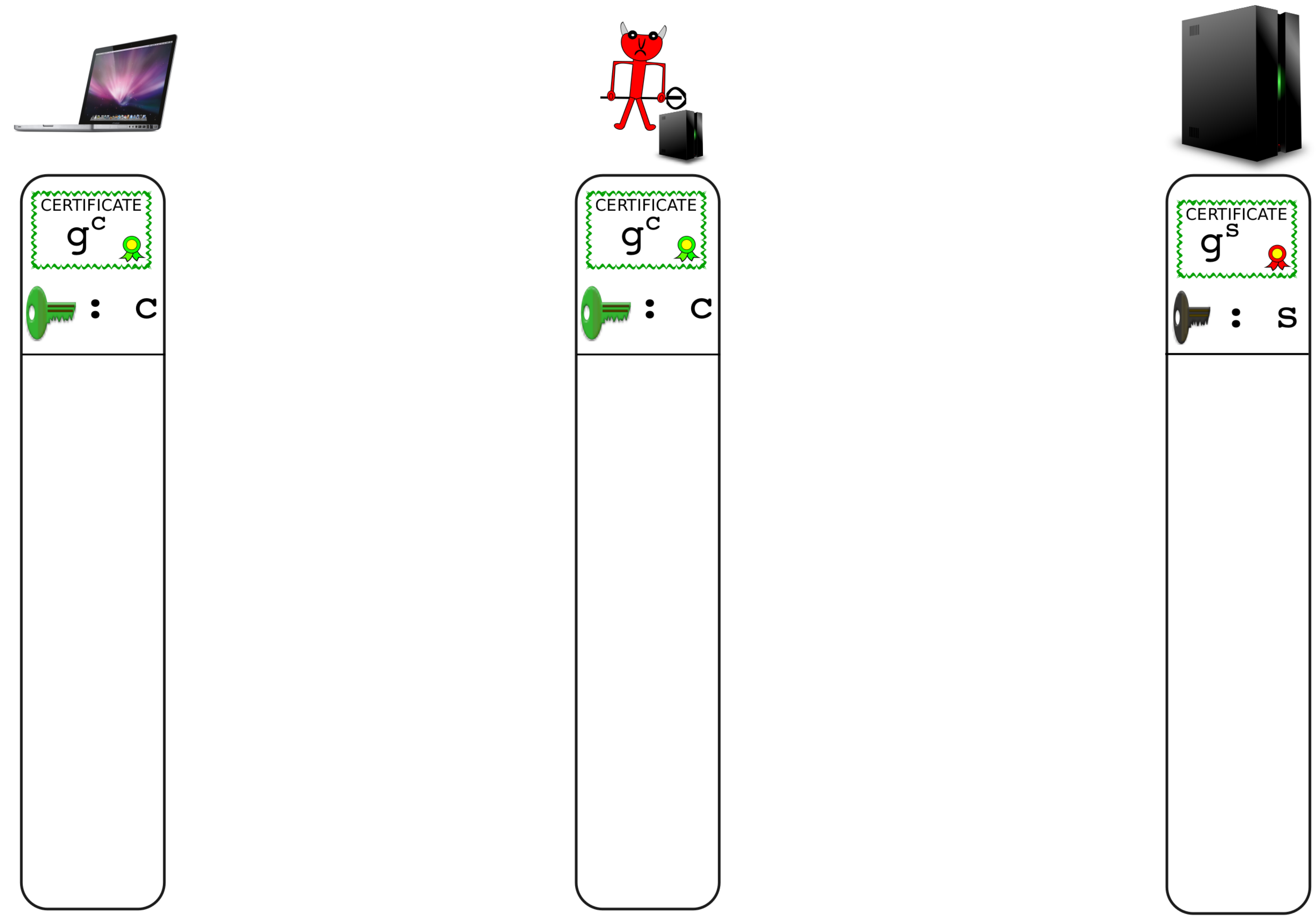


TLS protocol is vulnerable to KCI

Man-in-the-Middle attack against TLS using KCI

- Block connection to server
- Send server cert
- Request fixed (EC)DH
- Request compromised cert via Distinguished Name in `CertRequest`
- Both attacker and client do the same session key computation: $PRF((g^s)^c, rand_c||rand_s)$
- Connect to server



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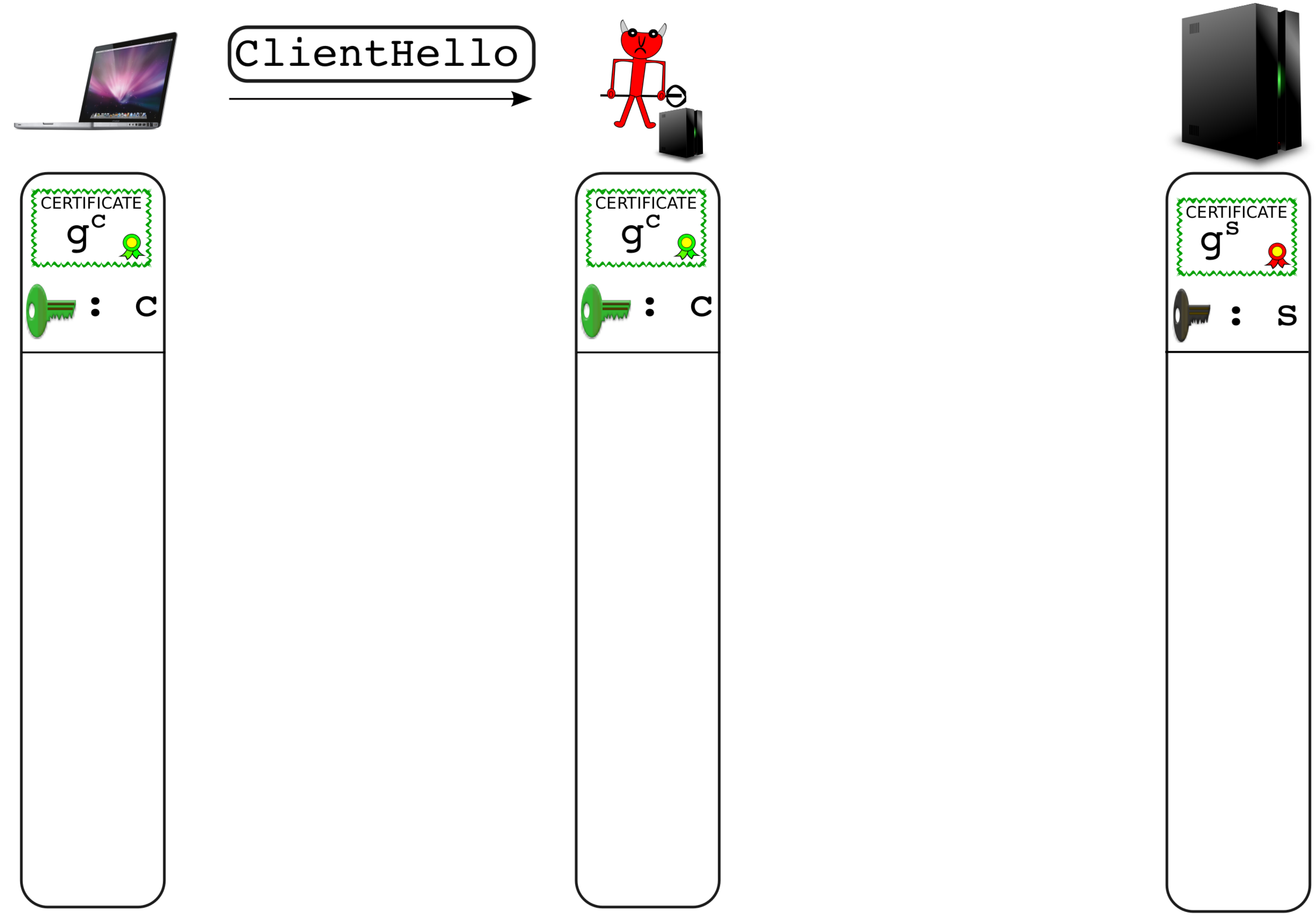

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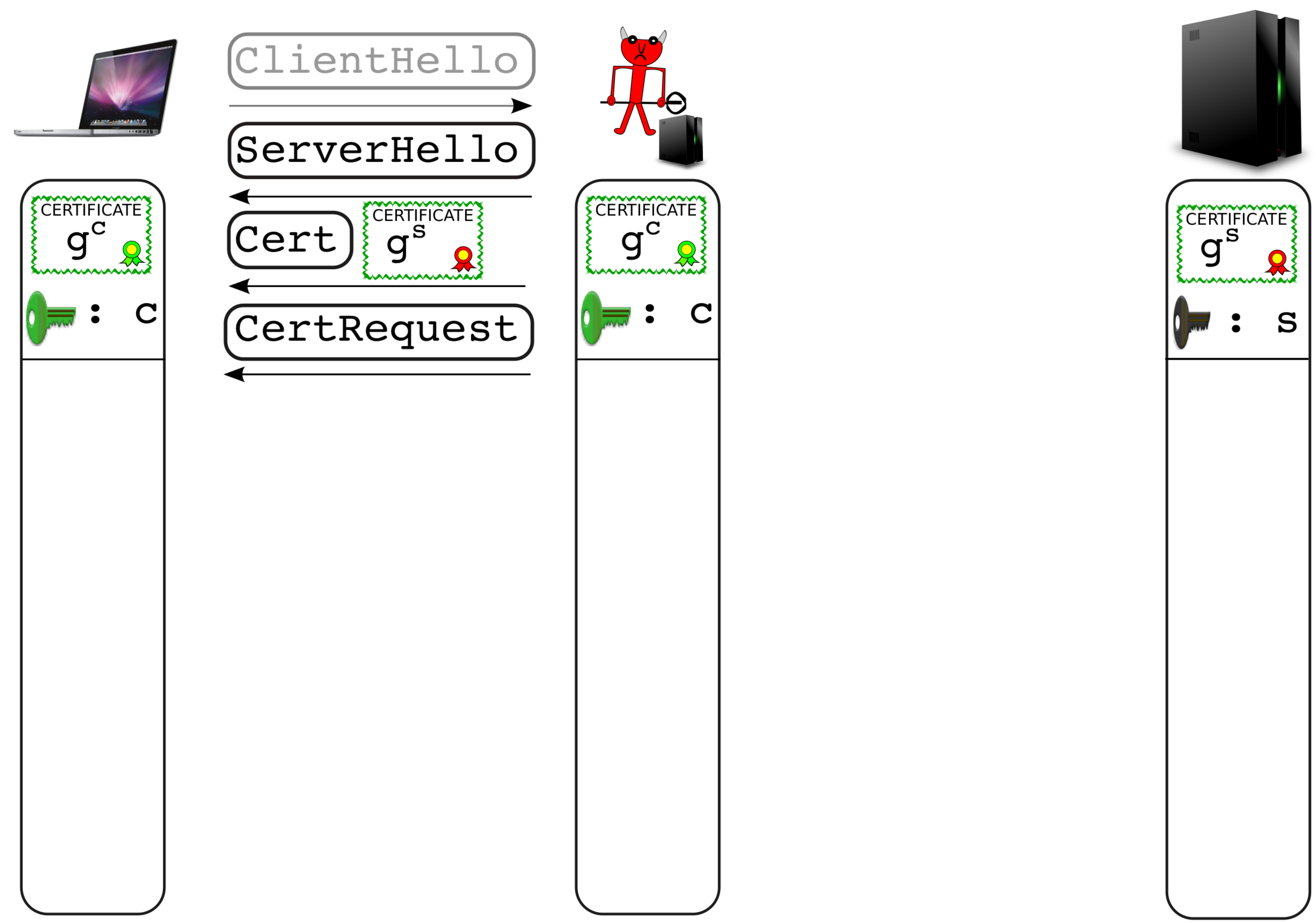

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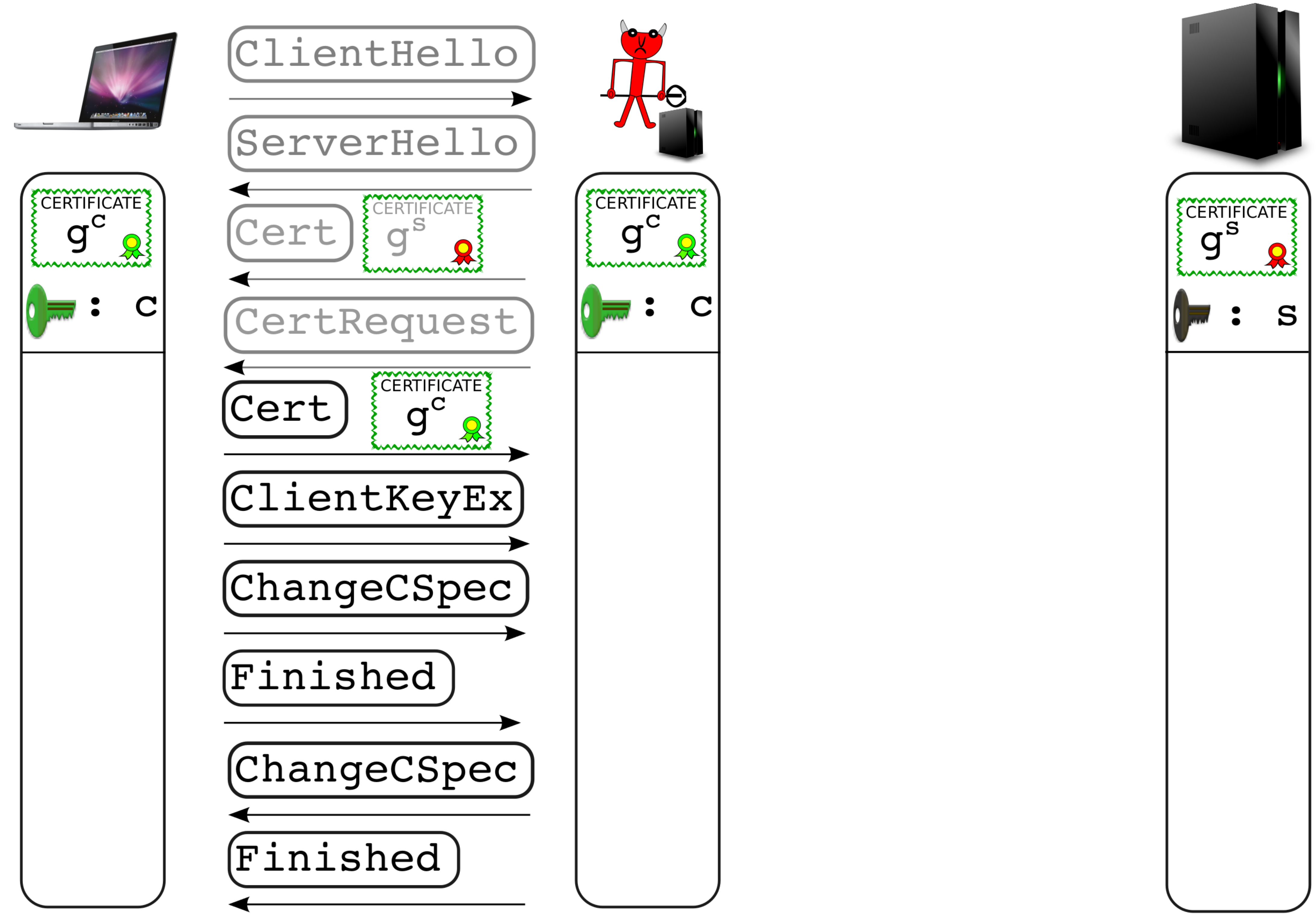

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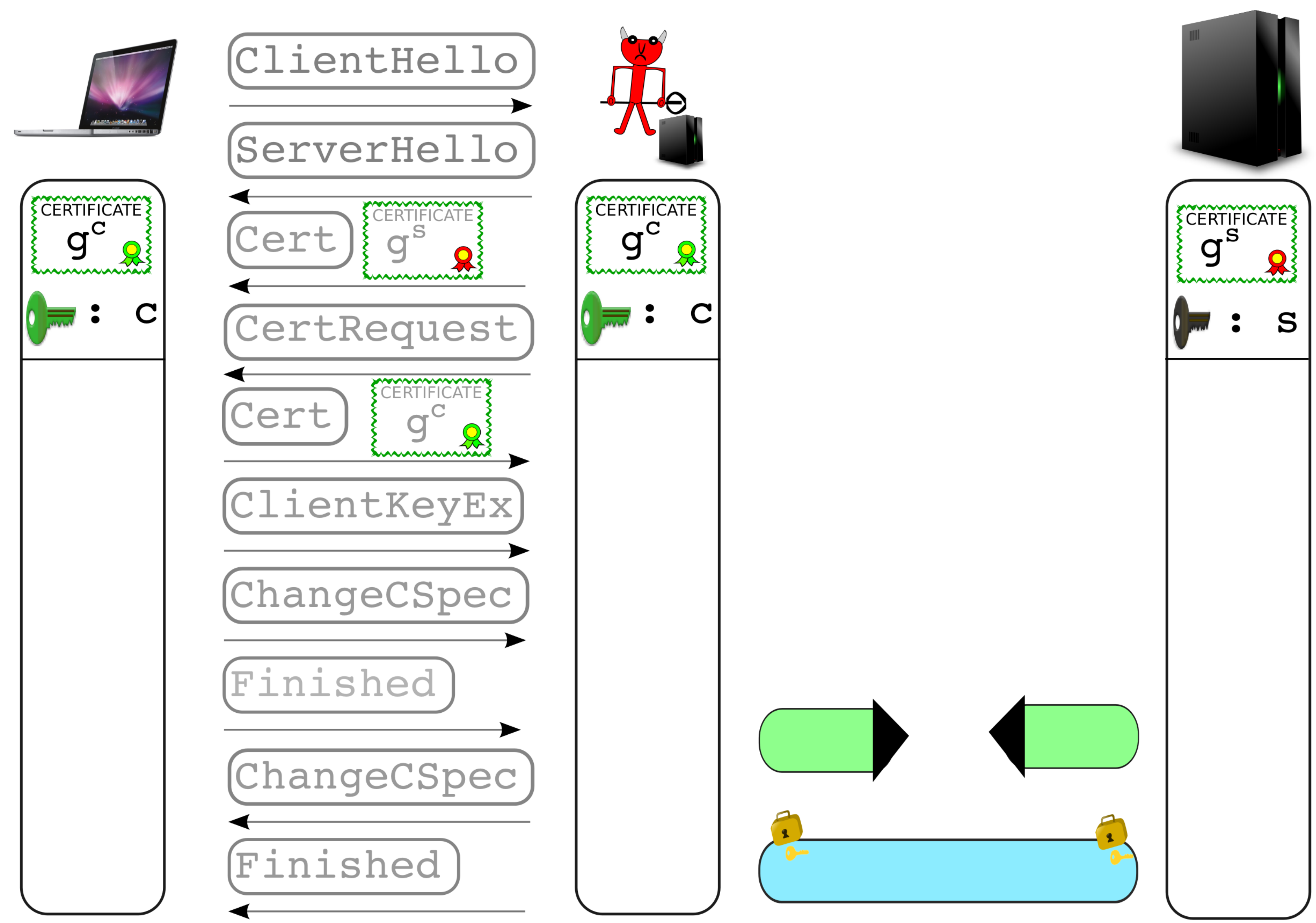

Prerequisites KCI attacks against TLS

1. Victim client support: must implement non-ephemeral Diffie Hellman with fixed client authentication handshake
   - `rsa_fixed_dh`
   - `dss_fixed_dh`
   - `rsa_fixed_ecdh`
   - `ecdsa_fixed_ecdh`
2. Victim server support: must have matching certificate
3. Compromised client certificate's secret:
   - Stolen private key
   - Client cert foisted on victim (various vectors)

Foisting client cert on victim: Social engineering

- Secure ways for generating client certs exist
- Common practice: send pre-generated client certs with secret key to user
- Insecure OS mechanisms to install client certs
- Attacker / malicious admin coax victim to install client certificate for network X, then use it to exploit connections to all vulnerable servers

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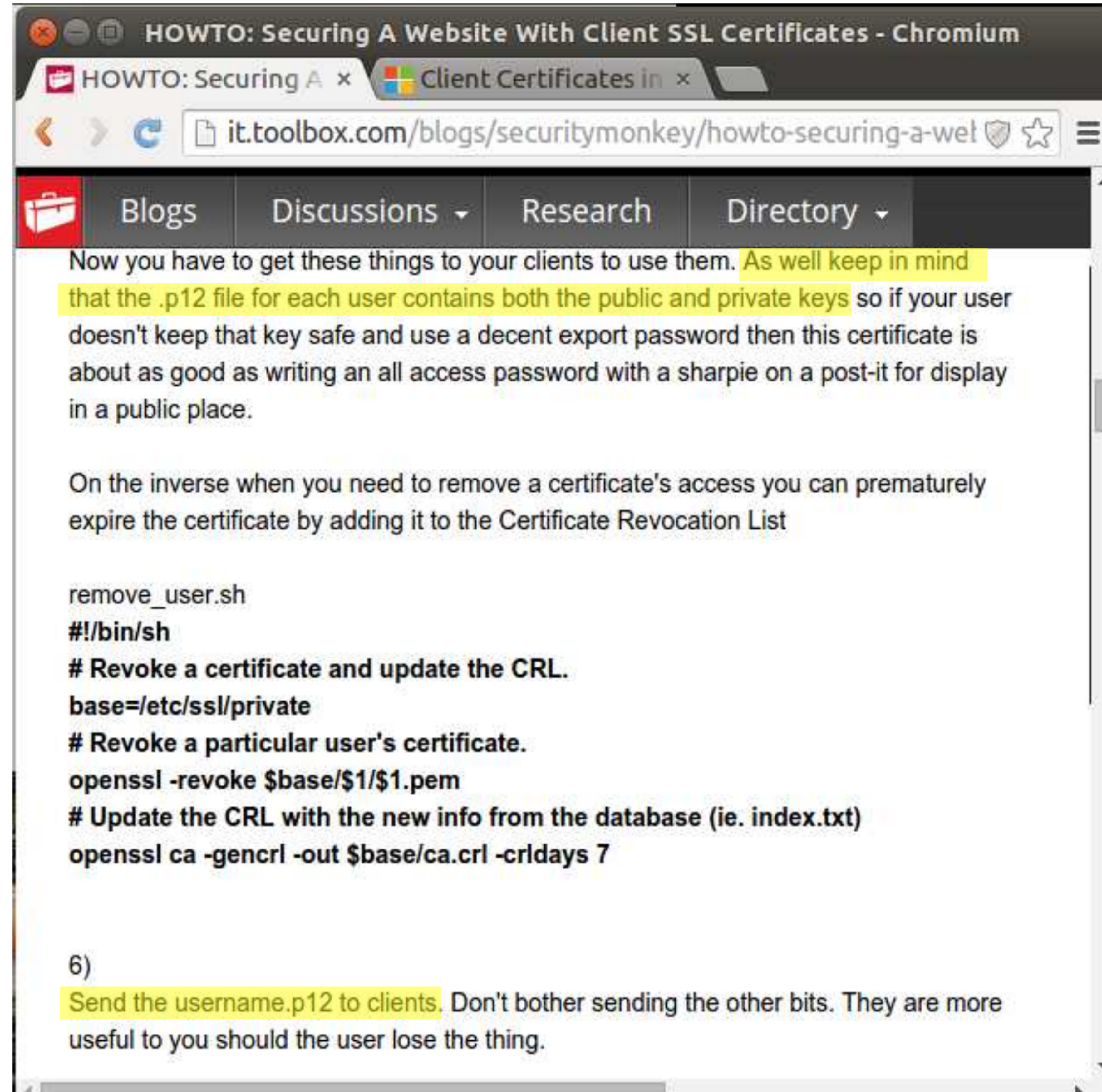

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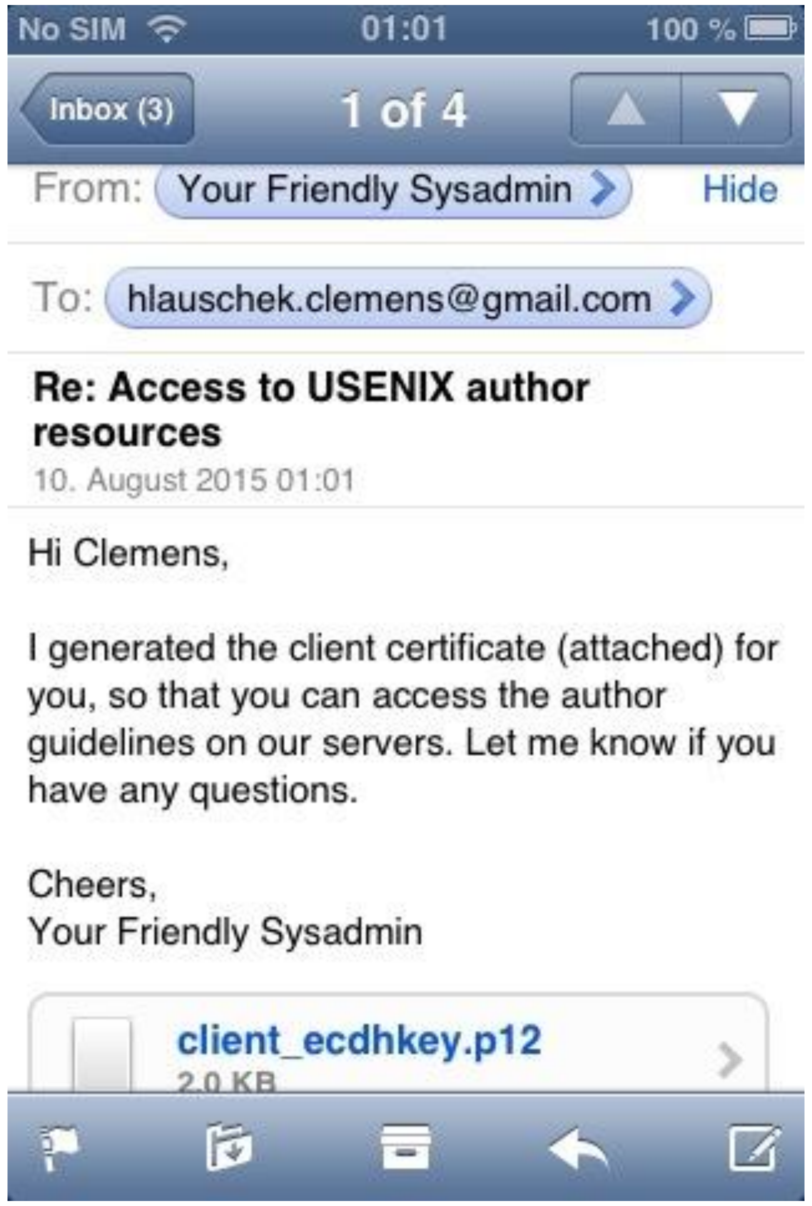

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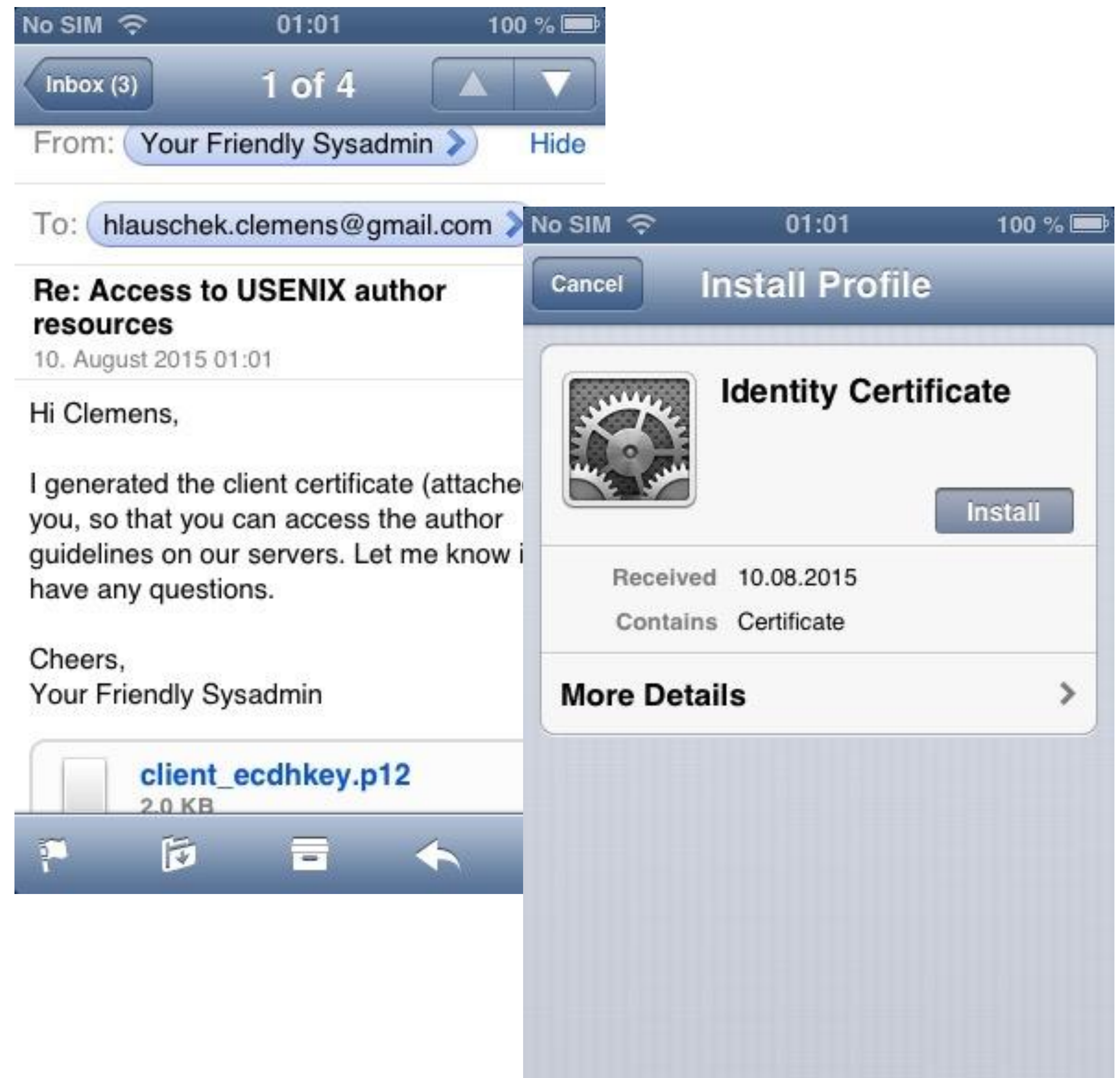

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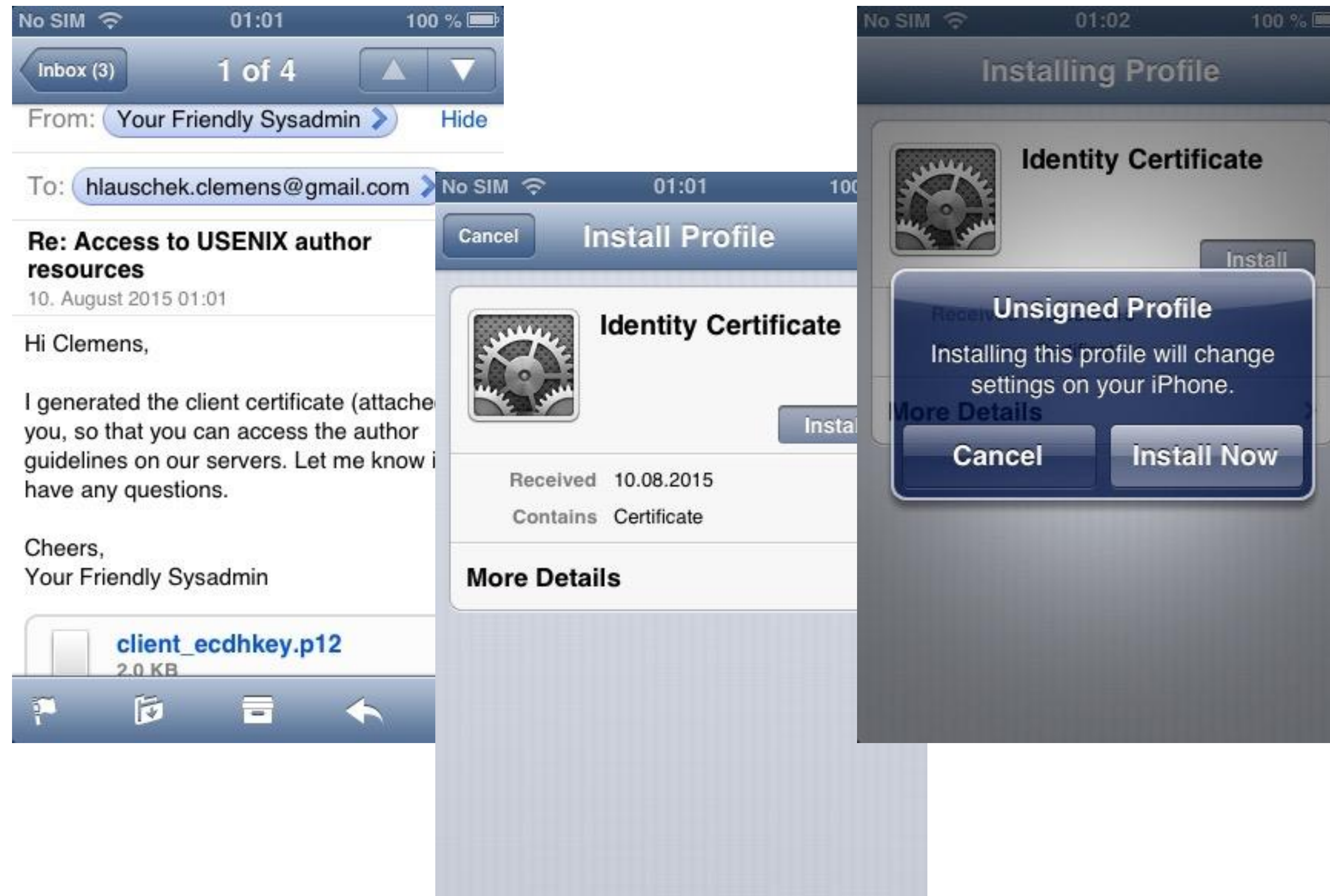

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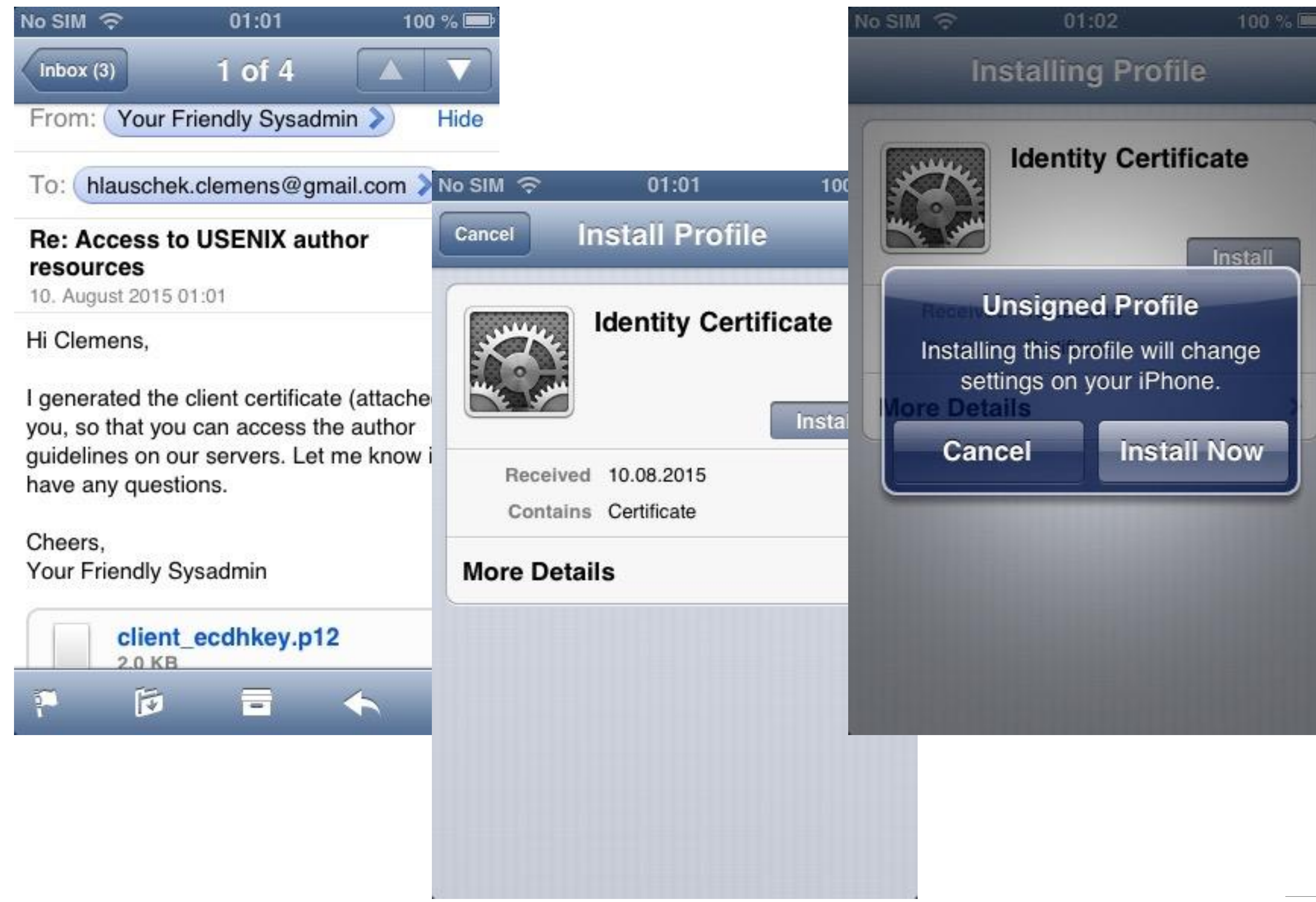
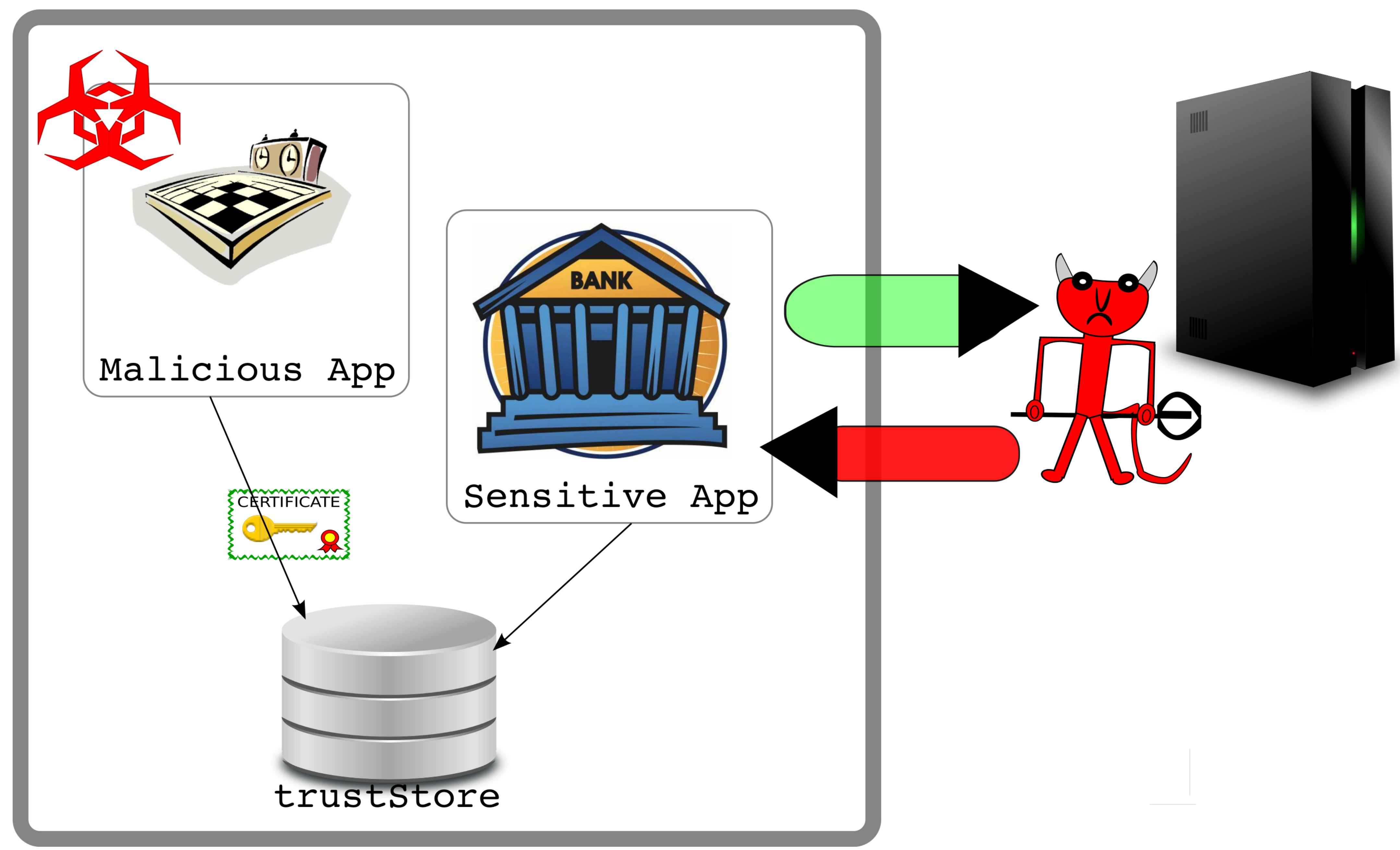


Foisting client cert on victim: Install in certificate store

For example (hypothetically): Abusing the `trustStore` on Android devices

- A user installs a malicious, but benign looking app
- Malicious app installs client certificate in system `trustStore`
- Targeted app makes TLS connection
- MitM forces targeted app to use client authentication, using the previously installed cert
- User confirms client authentication



Foisting client cert on victim: Vendor backdoor

A malicious vendor or distributor might install a backdoor in form of a client certificate

- Superfish-MitM: Inject own CA certificate
- KCI-Backdoor:
  - Implementation fully spec-conform
  - Server certs do not change

Victim server support: Matching Certificate

Server must either

- Support a non-ephemeral (EC)DH handshake
- Have an ECDSA certificate ($< 10\%$)
  - ECDH and ECDSA cert same structure
  - If X509 KeyUsage extension is used
    - `KeyAgreement` Bit must be set
    - But client may not check KeyUsage extension
  - KeyUsage extension not mandatory

Victim client support

Vulnerable client software

- Programs using BouncyCastle might be vulnerable
- Apple SecureTransport on older versions of Mac OS X (Safari)
- OpenSSL
  - Recently added support (1.0.2 branch) for fixed DH ($\mathbb{Z}_p$) client authentication
  - TODOs in the source code for fixed ECDH client authentication
- RSA Bsafe(?): support for non-ephemeral ECDH (according to API documentation)

Conclusion and Mitigation

- Clients should disable KCI-vulnerable cipher suites
- ECDSA server certificates should not set `KeyAgreement` bit in X509 KeyUsage extension
- Industry best-practice guides (e.g., RFC 7572) should warn against KCI-vulnerable cipher suites
- Secure generation of client certificates (private key does not leave user's computer) should become common practice

Although we managed to attack prestigious targets (Safari – Facebook), both client and server support are rather rare, currently. Hopefully, this work prevents the issue from ever becoming more widespread:

- OpenSSL only very recently added support for fixed DH client authentication
- ECDSA certificates are probably becoming more widespread in the future