WebPKI and Trust

CS249i: The Modern Internet

November 10, 2021

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Authentication

Definition: proving/verifying the identity of something

Keystone network security goal: confidentiality/privacy is meaningless without authentication

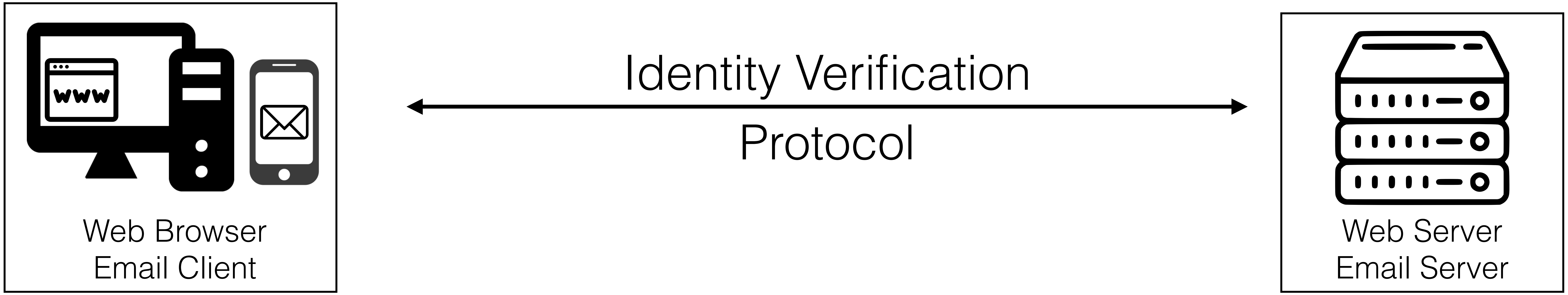
What something? What identifier? How to prove/verify?

Authentication

Definition: proving/verifying the identity of something

Something	Identifier	Proof Method	Proof Type
Person	Blood type	Blood test	Direct: functional test
Person	Name	ID card	Indirect: trusted entity
Client/User	Email address	Confirmation email	Direct: Request + Response
Client/User	Account owner	Password	Direct: Shared secret
Server	DNS Name	?	?

Web Server Auth #1: Direct



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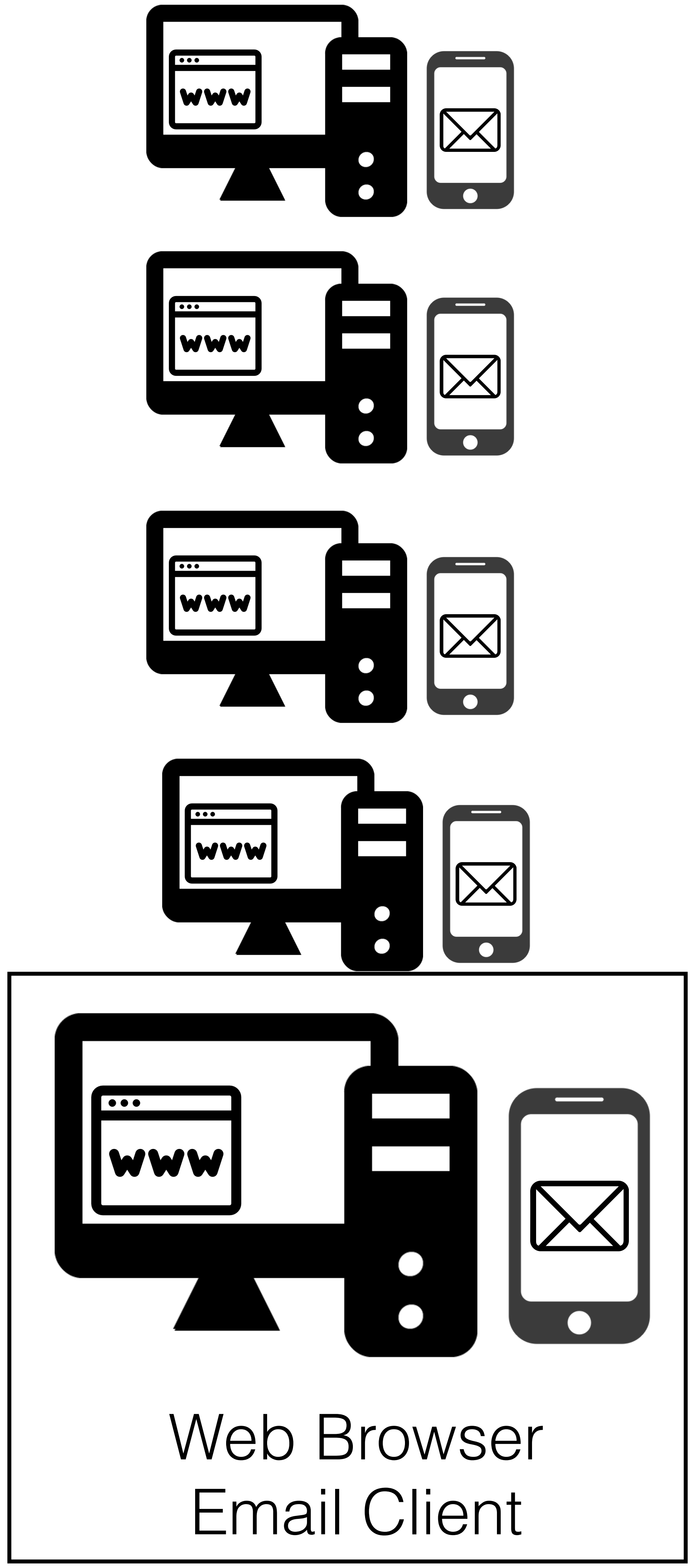

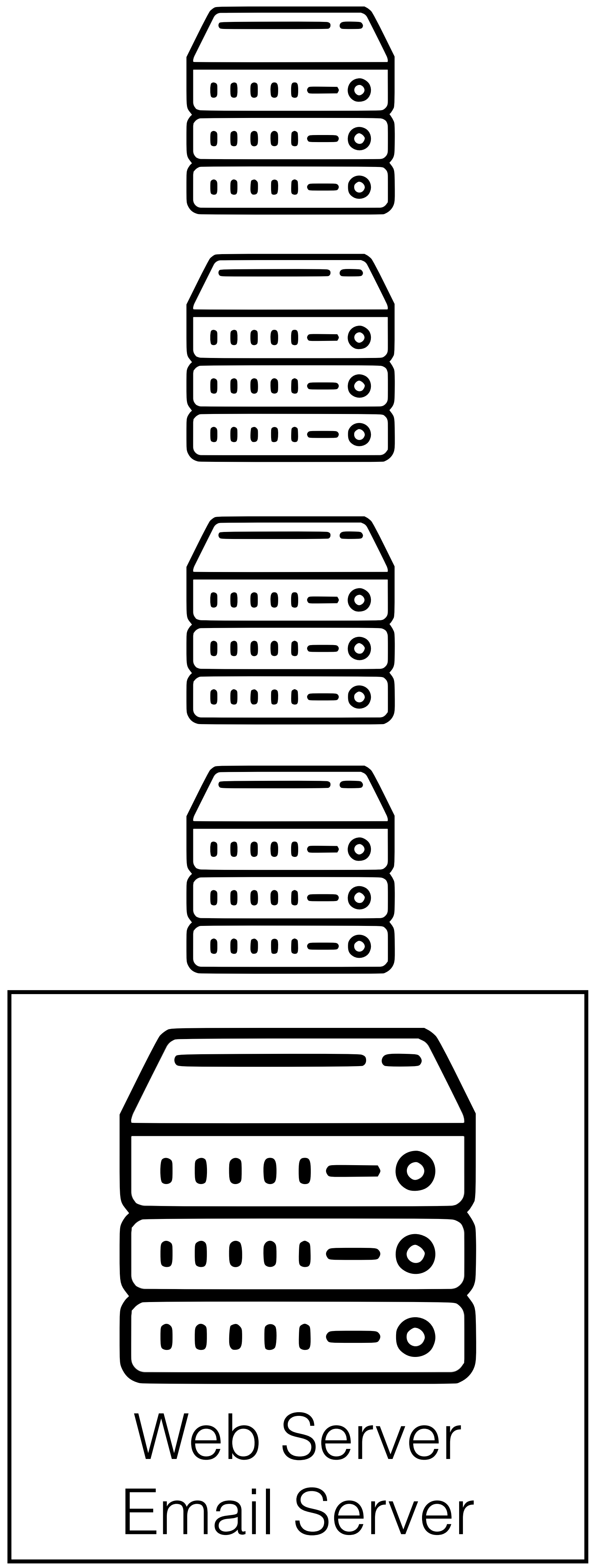

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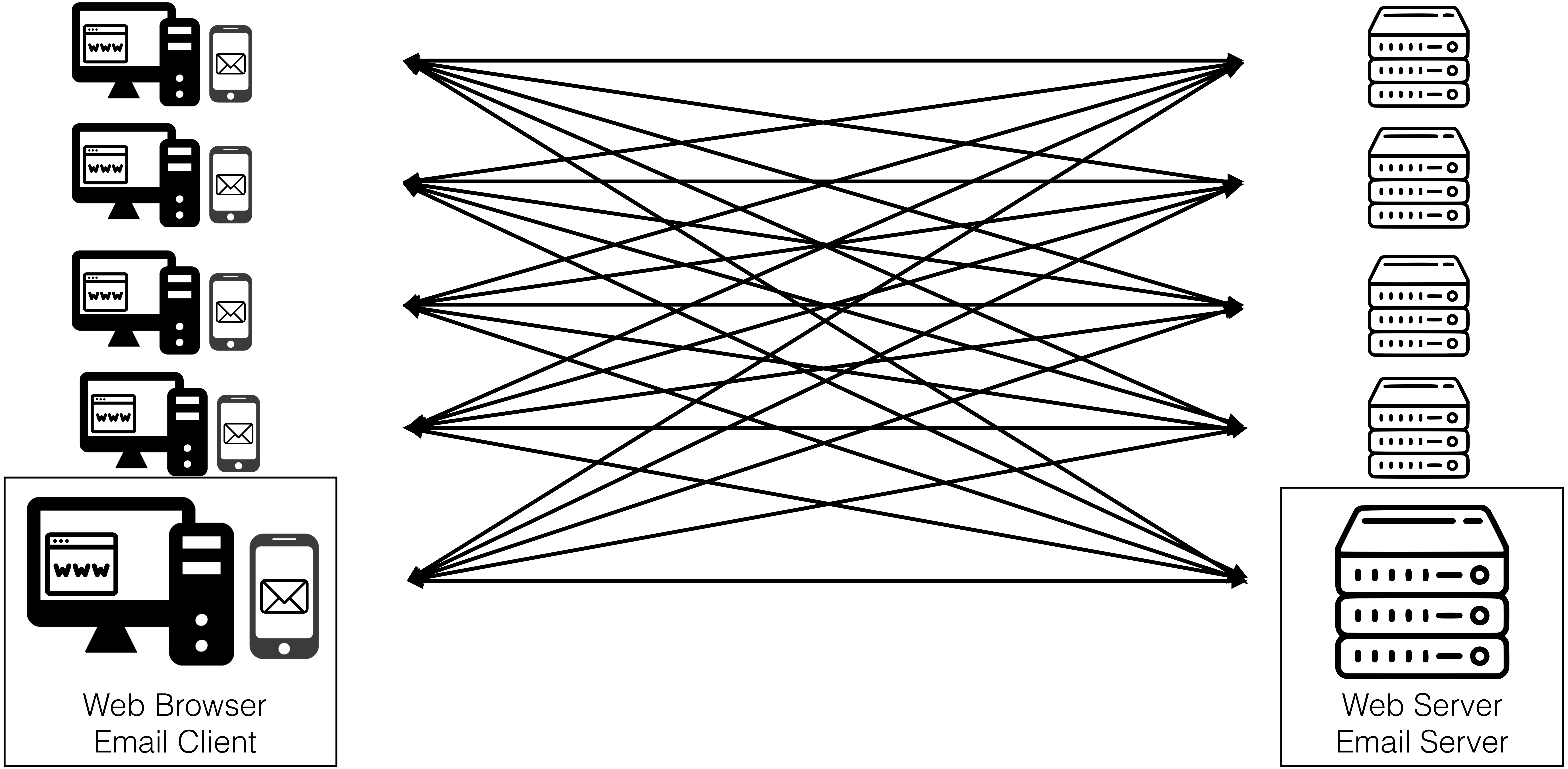

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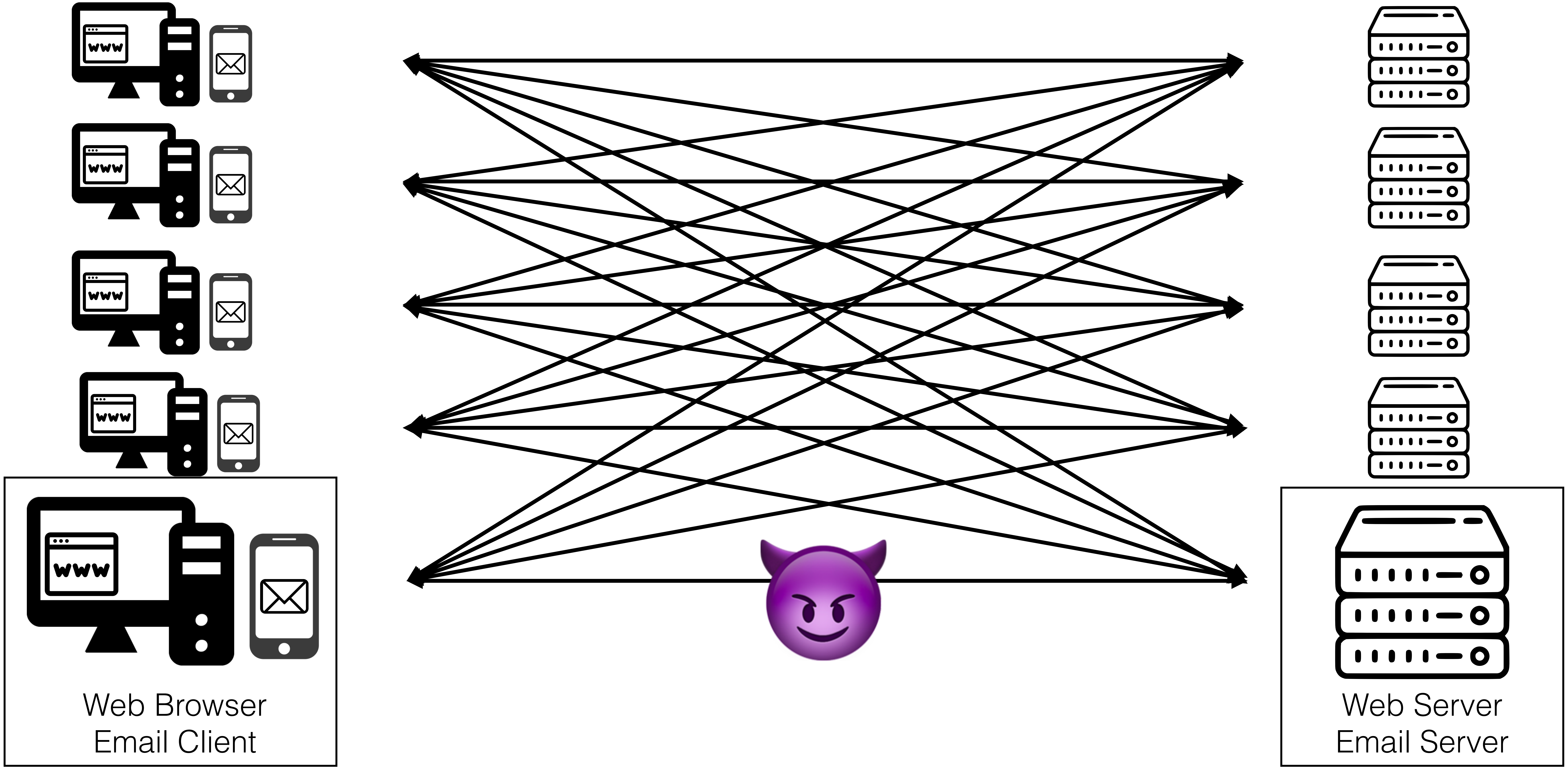
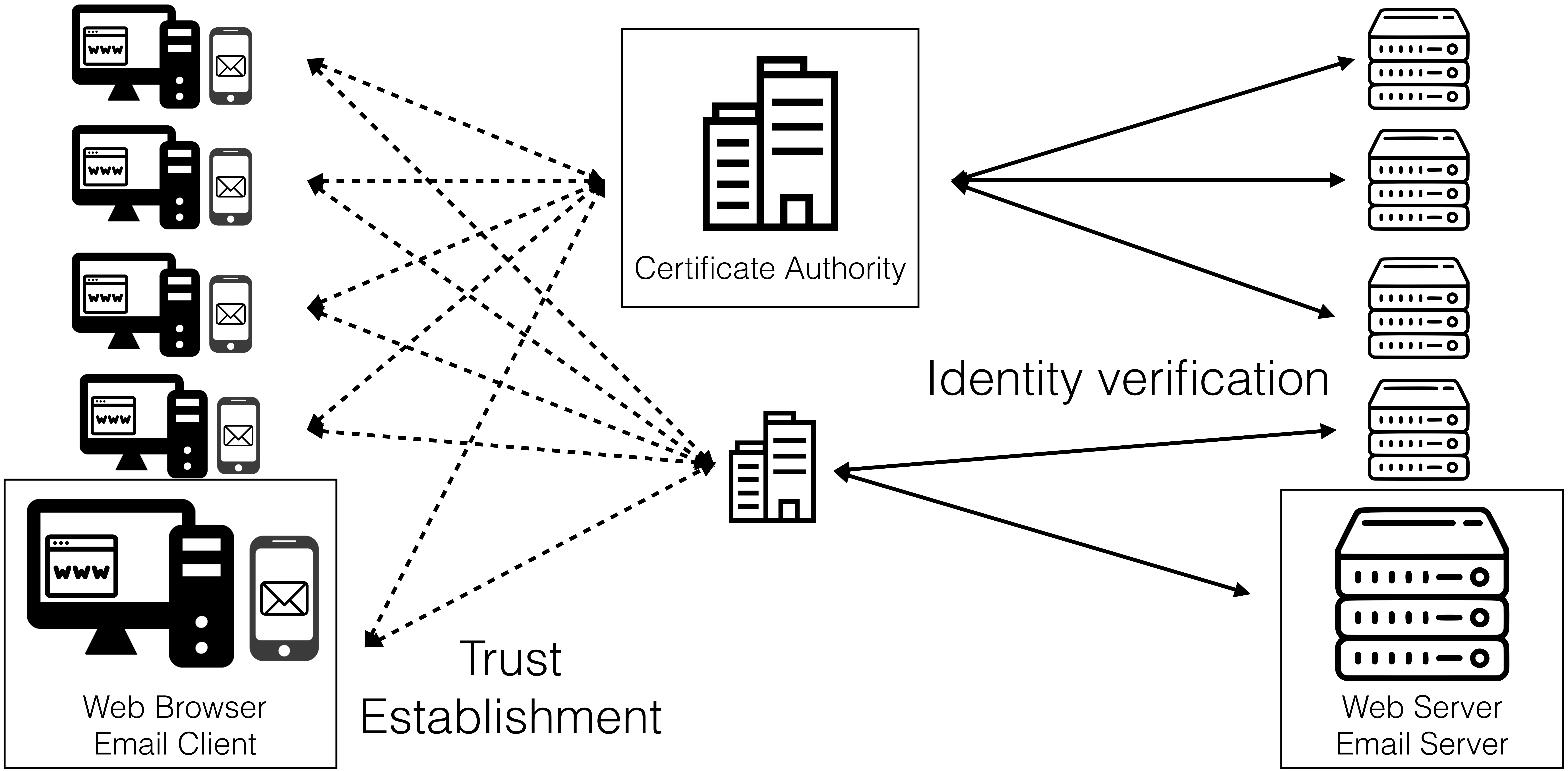
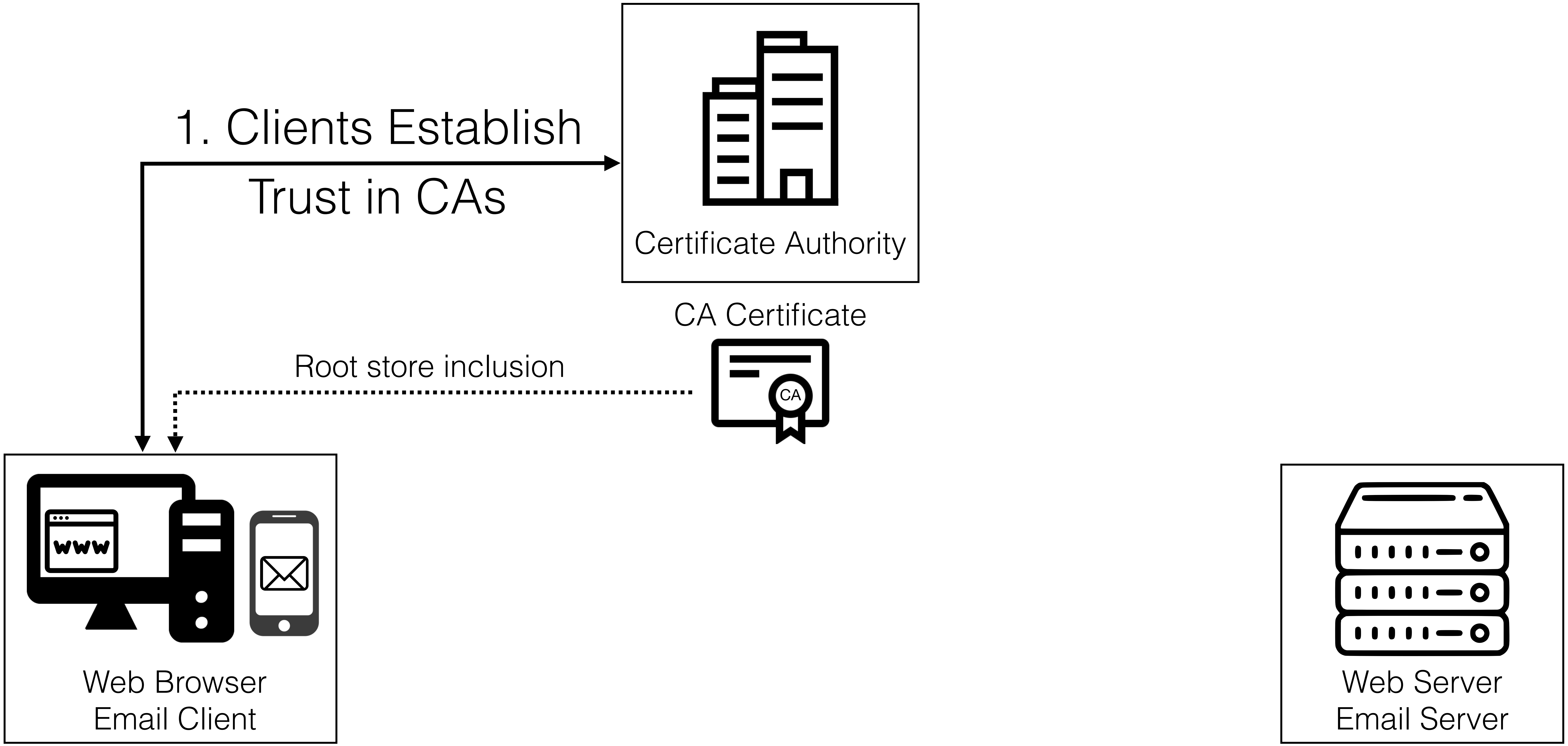


Web Server Auth #2: Indirect



TLS + Web PKI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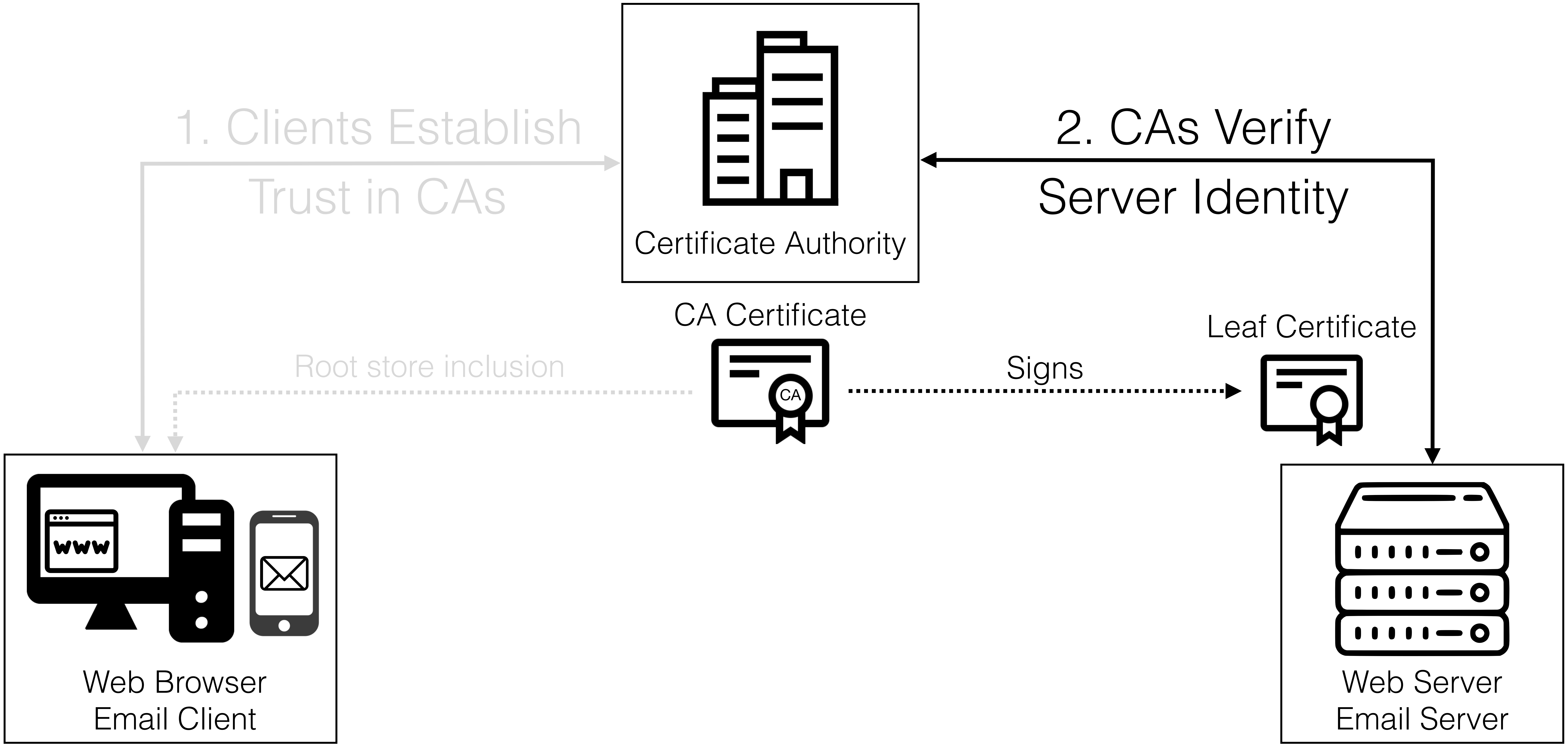
Trust in CAs
Certificate Authority
CA Certificate
Root store inclusion
CA
www
Web Browser
Email Client
Web Server
Email Server

TLS + Web PKI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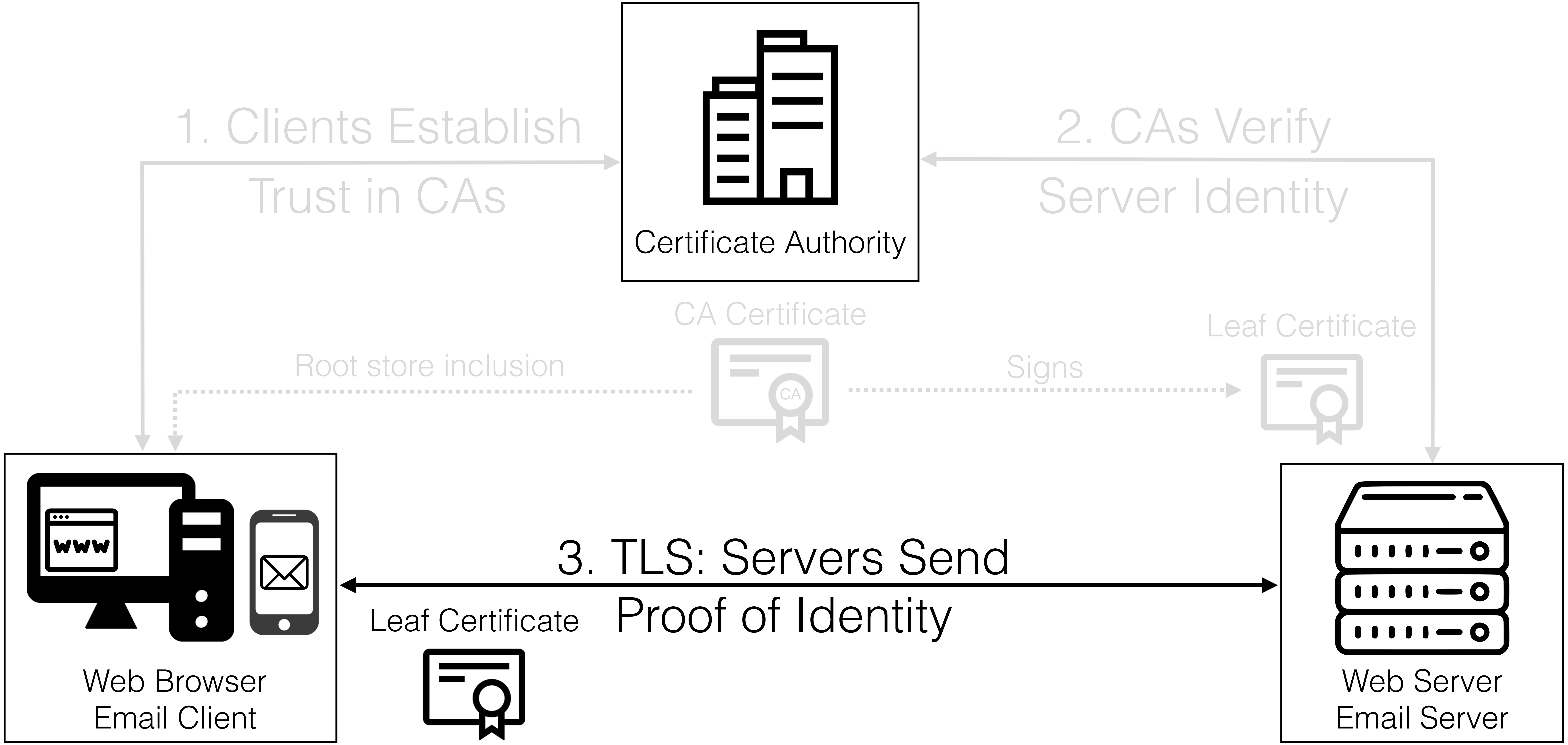
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3. TLS: Servers Send Proof of Identity
Leaf Certificate
Web Browser
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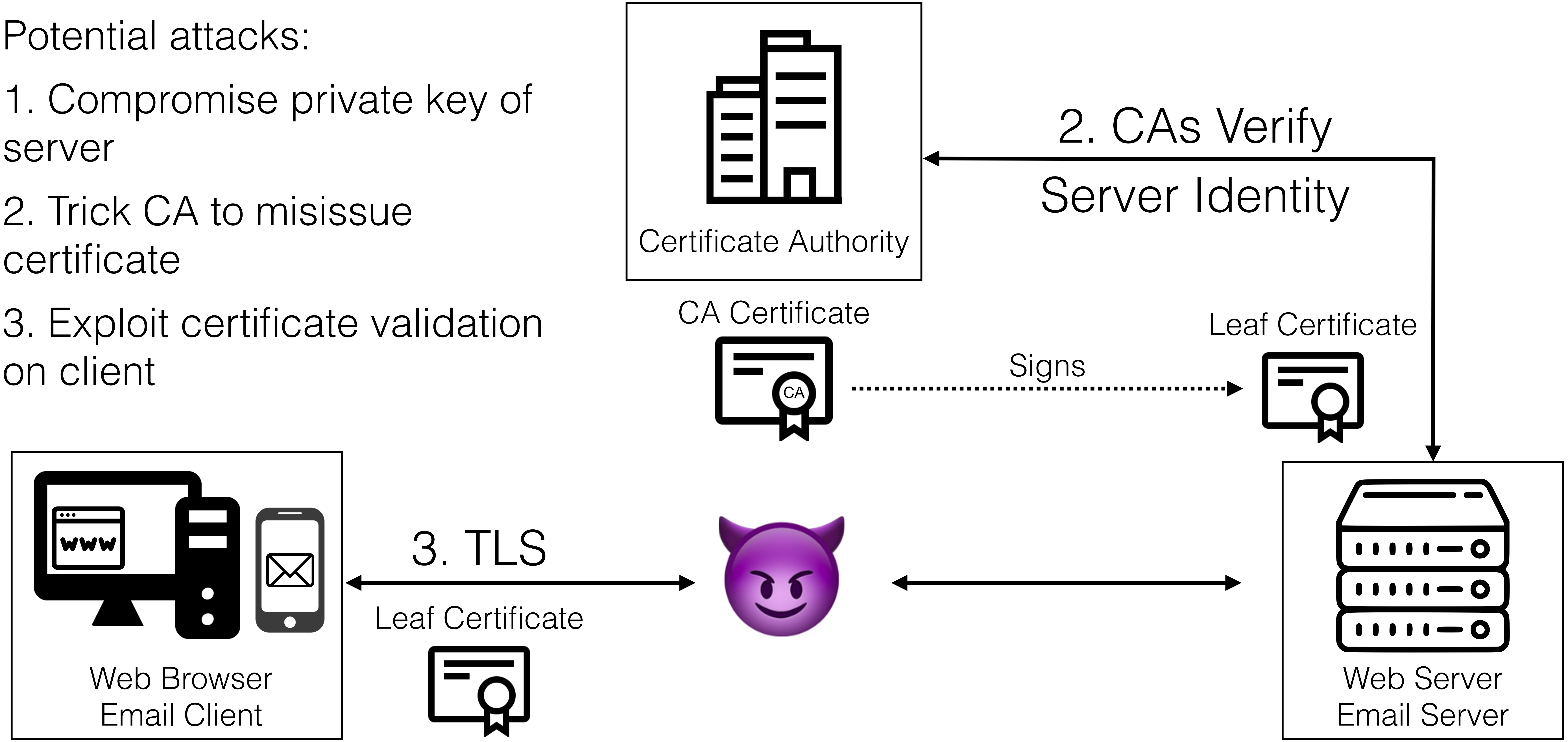
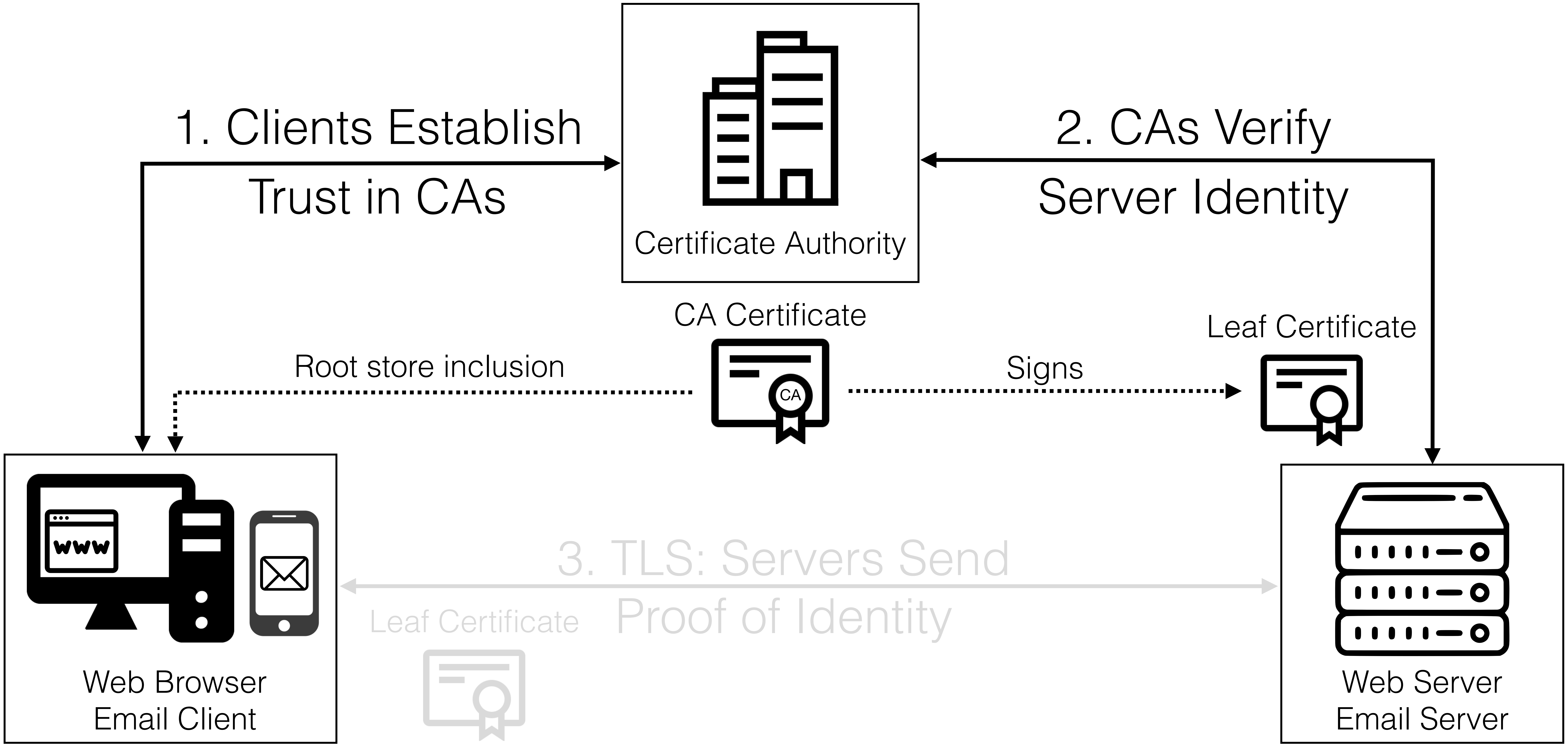
Threat Model

Potential attacks:

1. Compromise private key of server
2. Trick CA to misissue certificate
3. Exploit certificate validation on client



Web PKI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Certificate Issuance

Goals:

1) verify that a network identifier (i.e., IP address or DNS Name) controls some cryptographic public key

2) generate a certificate that attests to this linkage

How to verify? What does “control” mean?

But first, what’s a certificate?

Certificates

Signed document that attests to the connection between an identity and an authorized public key

TLS uses:

- X.509 certificate schema (what fields in what order)
- ASN.1 data format (field types, expression syntax)
- DER encoding (converting everything to bytes)

More info: https://letsencrypt.org/docs/a-warm-welcome-to-asn1-and-der/

Certificates

```
Certificate root
   TBS certificate
      Validity
         datetime:start “Apr 30 08:42:02 2018 GMT”
         datetime:end “Dec 21 22:24:54 2019 GMT”
      Issuer
         Field
            oid:commonName “Let’s Encrypt”
            string:name
      Subject
         Field
            oid:commonName
            string:name “gatech.edu"
      Subject Public Key Info
         oid:rsaEncryption
         Subject Public Key
            int:modulus
            int:exponent
      Extensions
   Signature
      oid:sha256WithRSAEnc.
      bytes:signatureValue
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Subject identity and public key

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Validity Period

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Validity Period

Extensions: Permitted key usages, policies, additional identities (Subject Alternate Identity)

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Subject identity and public key

Issuer (Certificate Authority)

Validity Period

Extensions: Permitted key usages, policies, additional identities (Subject Alternate Identity)

Signature: TBS signed by Issuer public key

Certificate Chains

CA Certificate A

Issuer: Foo CA

Subject: Foo CA

Public key: 0xabc123…

…

Signature: 0x823cdf…

Self-signed

Certificate Chains

CA Certificate A

Issuer: Foo CA
Subject: Foo CA
Public key: 0xabc123…
…
Signature: 0x823cdf…

Self-signed

Leaf Certificate

Issuer: Foo CA
Subject: domain.com
Public key: 0xb21f35…
…
Signature: 0xa392b…

Certificate Chains

CA Certificate A

Issuer: Foo CA
Subject: Foo CA
Public key: 0xabc123…
…
Signature: 0x823cdf…

Self-signed

Same Subject + pubkey
Different Issuer

CA Certificate B

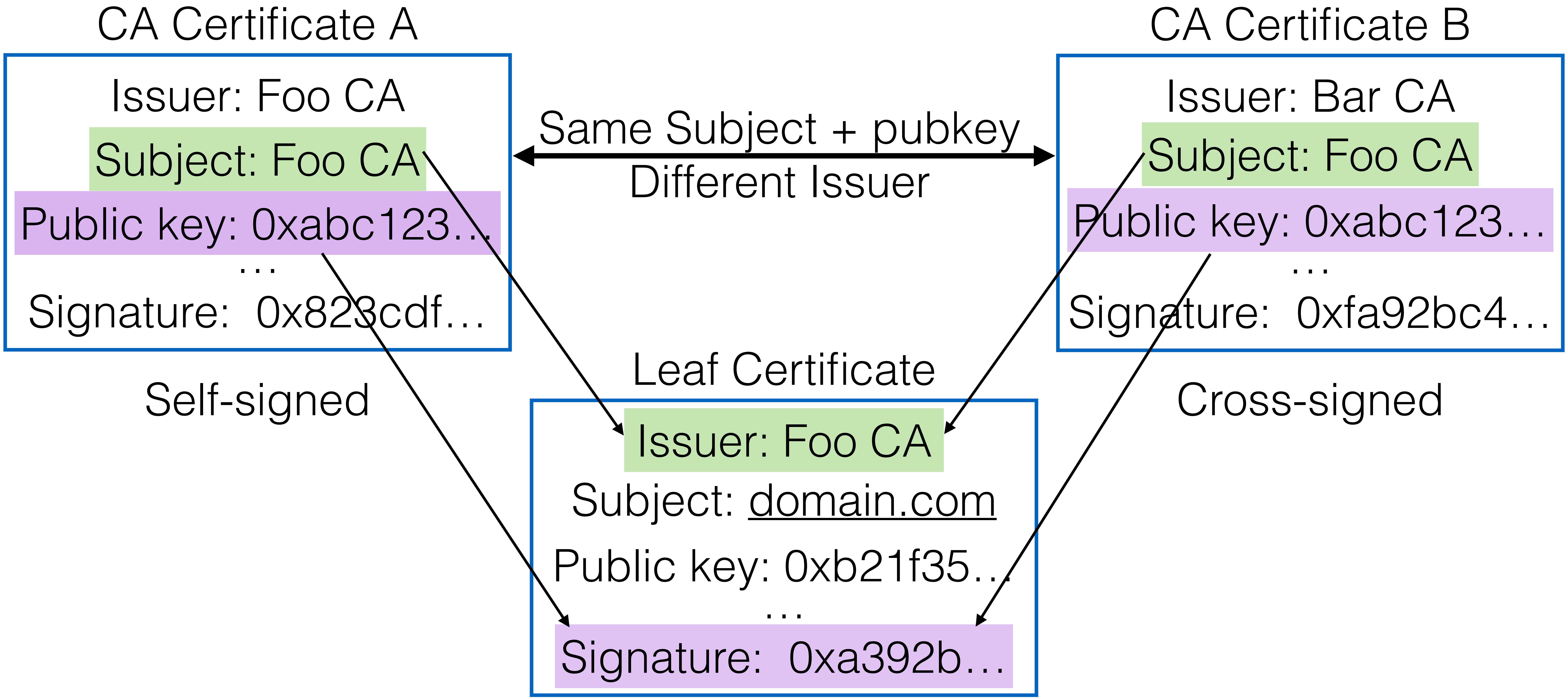
Issuer: Bar CA
Subject: Foo CA
Public key: 0xabc123…
…
Signature: 0xfa92bc4…

Cross-signed

Leaf Certificate

Issuer: Foo CA
Subject: domain.com
Public key: 0xb21f35…
…
Signature: 0xa392b…

Cross-Signing



Cross-Signing

Broke: one certificate chain

Woke: many possible certificate chains

Broke: certificates as nodes, signatures as edges

Woke: certificates as edges, entities as nodes

Entity chains

Entity A

Name: Foo CA
Public key: 0xabc123…

Issuer: Foo CA
Subject: Foo CA
Public key: 0xabc123…
…
Signature: 0x823cdf…

CA Certificate A

Entity B

Name: domain.com
Public key: 0xb21f35…

Issuer: Foo CA
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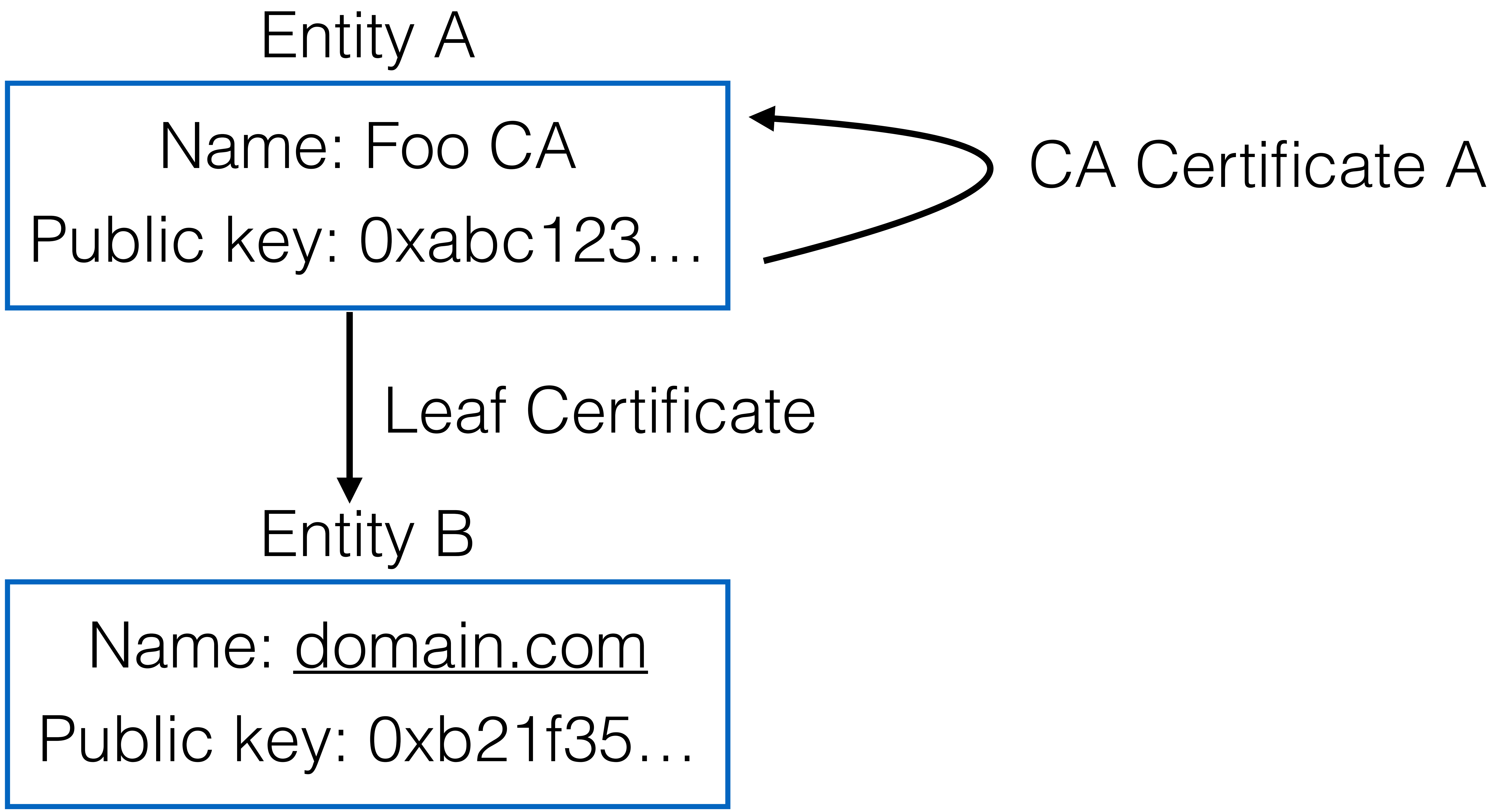
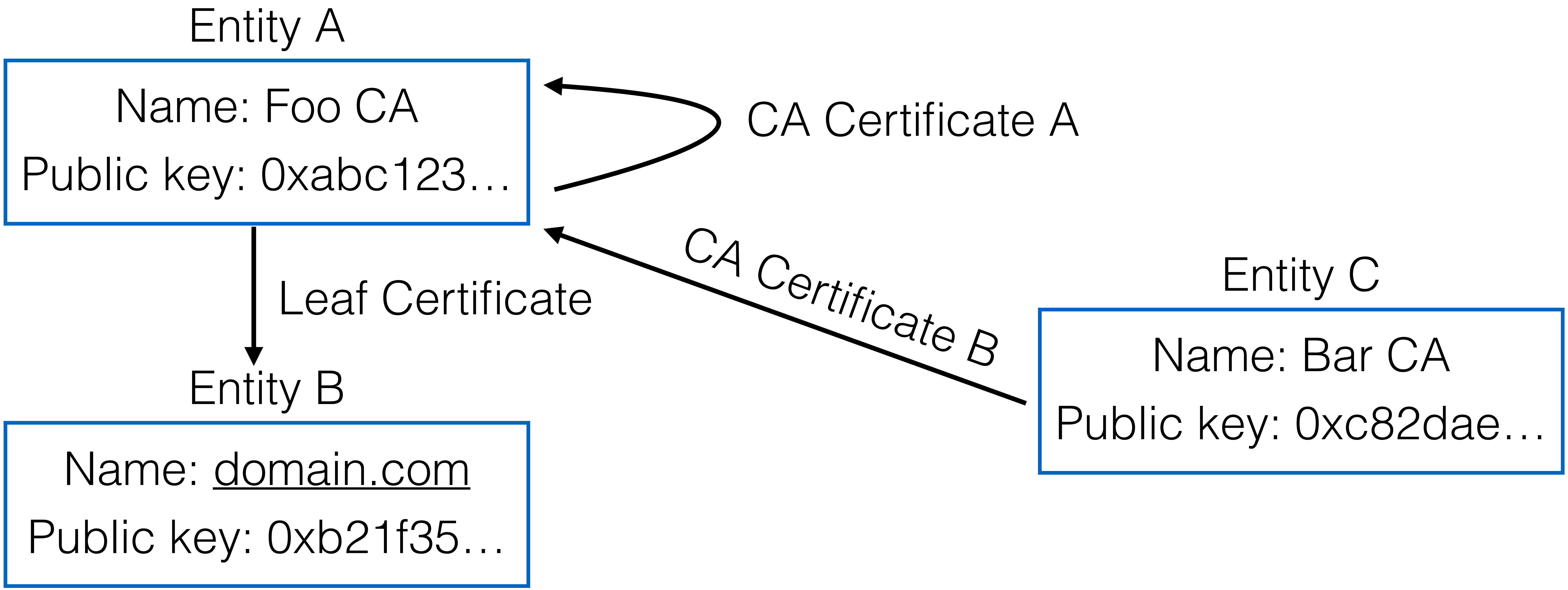
Leaf Certificate

Entity chains



Entity chains



Certificate Issuance

Goals:

1) verify that a network identifier (i.e., IP address or DNS Name) controls some cryptographic public key

2) generate a certificate that attests to this linkage

How to verify? What does “control” mean?

Historical Issuance (ca. 2012)

Confirming the Applicant as the Domain Name Registrant directly with the Domain Name Registrar;

Communicating directly with Registrant via address, email, or telephone number provided by the Registrar;

Communicating directly with the Registrant using the contact information listed in the WHOIS record's "registrant", "technical", or "administrative" field;

Communicating with the Domain's administrator using an email address created by pre-pending 'admin', 'administrator', 'webmaster', 'hostmaster', or 'postmaster' followed by the Domain Name;

Relying upon a Domain Authorization Document;

Having the Applicant demonstrate practical control over the FQDN by making an agreed-upon change to information found on an online Web page identified by a uniform resource identifier containing the FQDN;

Using any other method of confirmation, provided that the CA maintains documented evidence that it establishes that the Applicant is the Registrant or has control over the FQDN to at least the same level of assurance as those methods previously described.

Historical Issuance (ca. 2012)

If CA == DNS Registrar
Confirming the Applicant as the Domain Name Registrant directly with the Domain Name Registrar;

Communicating directly with Registrant via address, email, or telephone number provided by the Registrar;
WHOIS info directly from registrar
Communicating directly with the Registrant using the contact information listed in the WHOIS record's "registrant", "technical", or "administrative" field;

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Modern Issuance (ca. 2021)

	Contact Method	Contact Info Source
A. Manual Contact	Phone Fax Postal Mail SMS Email	WHOIS DNS (TXT, CAA) 'admin'-like email

Automatable

	Step 1.	Step 2.
B. Random Token	CA sends token to client	CA retrieves token from: DNS server HTTP / TLS server

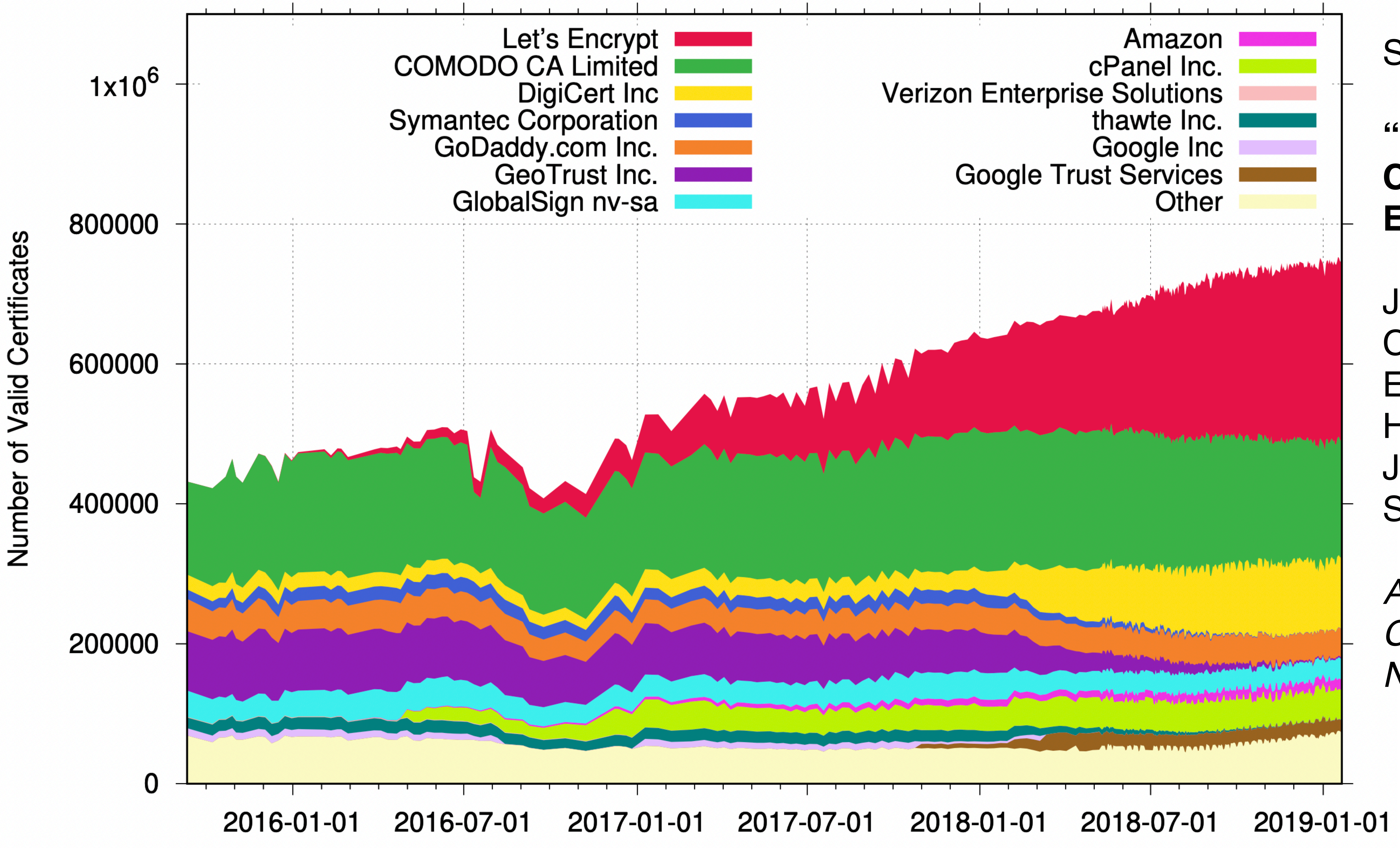
ACME

- RFC 8555: Automatic Certificate Management Environment (2019)
- Automates certificate issuance + revocation (to be discussed)

Open Source Software (OSS):

ACME client	*ACME client + web server*	*ACME CA*
certbot	Caddy®	Let’s Encrypt/Boulder
Star 28.4k	Star 35.1k	Unstar 4k

Let’s Encrypt



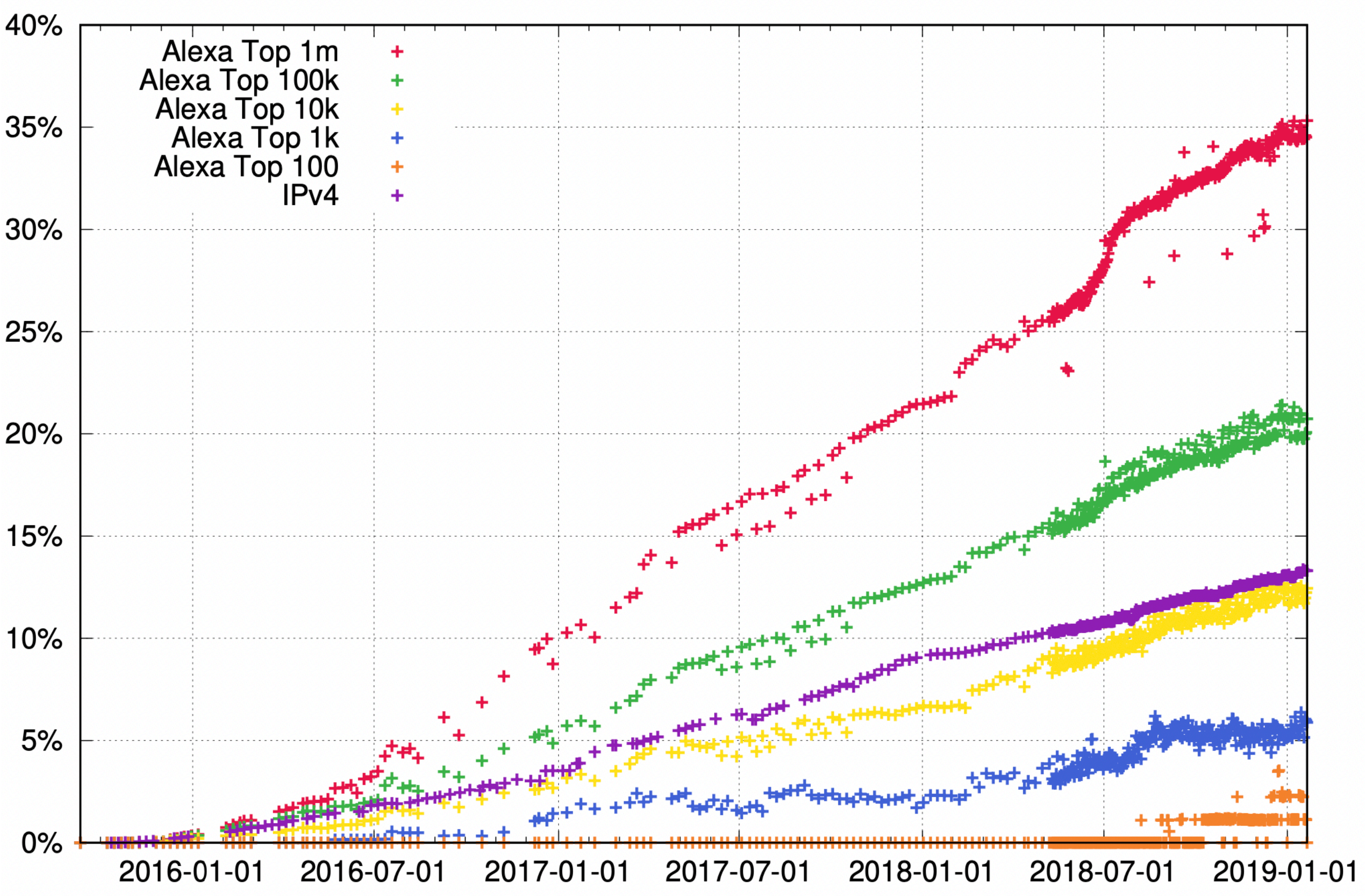
Source:

“Let's Encrypt: An Automated Certificate Authority to Encrypt the Entire Web”

Josh Aas, Richard Barnes, Benton Case, Zakir Durumeric, Peter Eckersley, Alan Flores-Lopez, J. Alex Halderman, Jacob Hoffman-Andrews, James Kasten, Eric Rescorla, Seth Schoen, Brad Warren.

ACM Conference on Computer and Communications Security (CCS), November 2019

Let's Encrypt



% of top sites that use Let's Encrypt

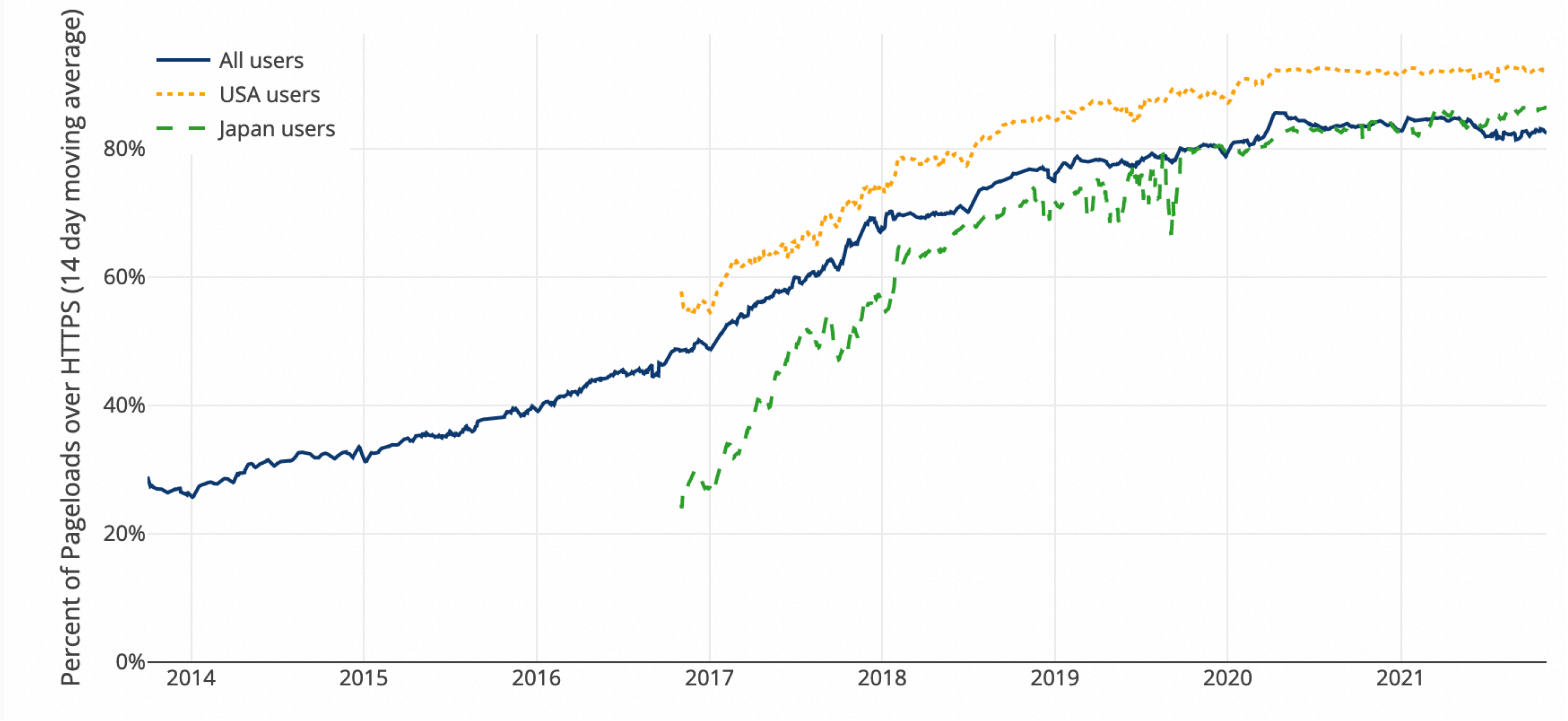
Automation + open standards —> free + easy-to-use

Combined with browser carrots/ sticks, LE has enabled massive HTTPS adoption

Georgia Tech

HTTPS Adoption

(14-day moving average, source: Firefox Telemetry)



Certificate Revocation

Why do we need to revoke certificates?

RFC 5280 Revocation Reasons

- unspecified (0)
- keyCompromise (1)
- cACompromise (2)
- affiliationChanged (3)
- superseded (4)
- cessationOfOperation (5)
- certificateHold (6)
- removeFromCRL (8)
- privilegeWithdrawn (9)
- aACompromise (10)

Only need to revoke unexpired certificates

Shorter certificate validity periods (enabled by ACME) leads to fewer revocations

How can we revoke certificates? Engineering problem

Online Revocation Checks

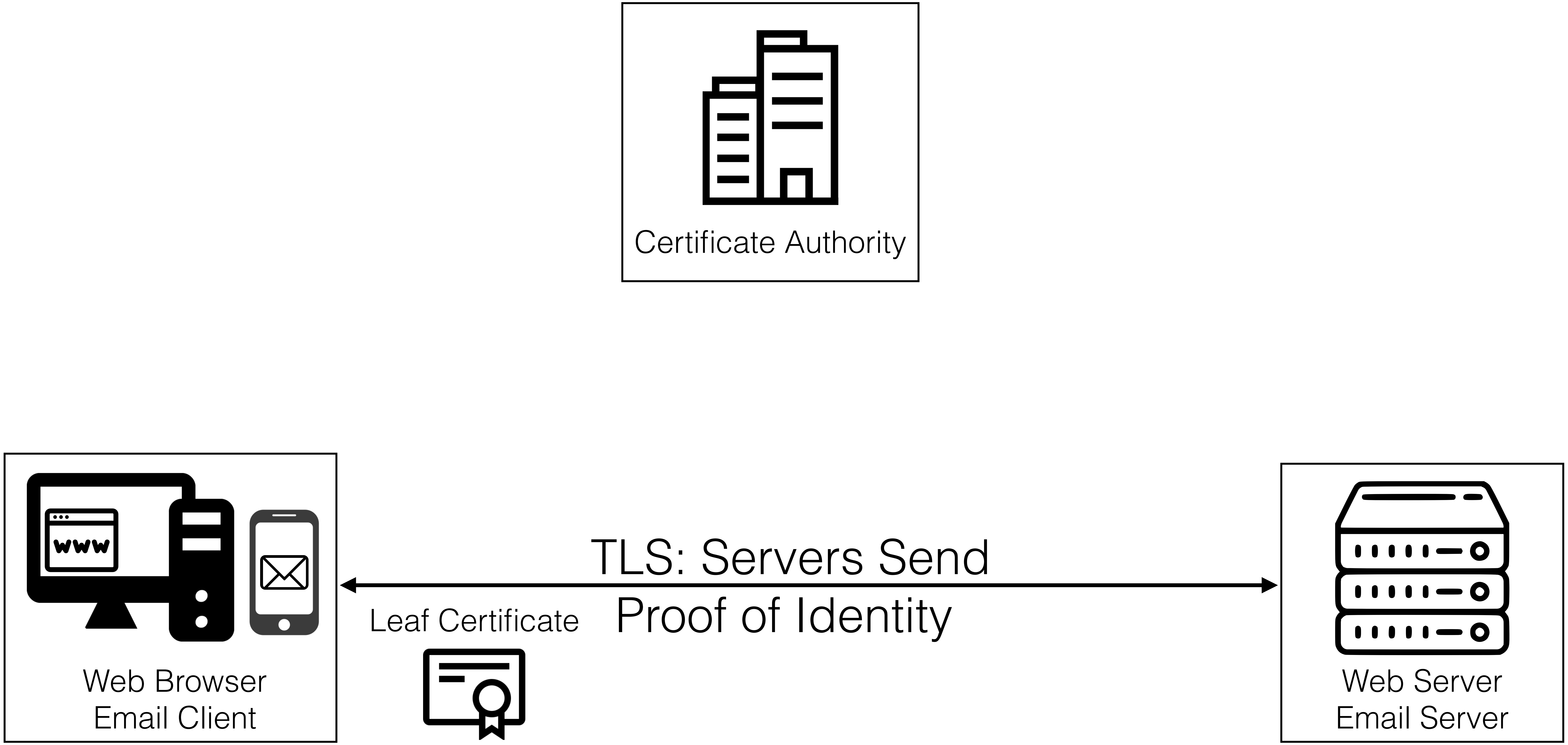
Before validating TLS cert, contact CA and retrieve a Certificate Revocation List (**CRL**) or use Online Certificate Status Protocol (**OCSP**) to check revocation for a single certificate

CRLs: require additional retrieval of large (~MBs) file that blocks TLS validation.

OCSP: generates lots of traffic to CA. Privacy-concerns.

What if CA is unavailable/inaccessible? Fail-open!

Online Revocation Checks



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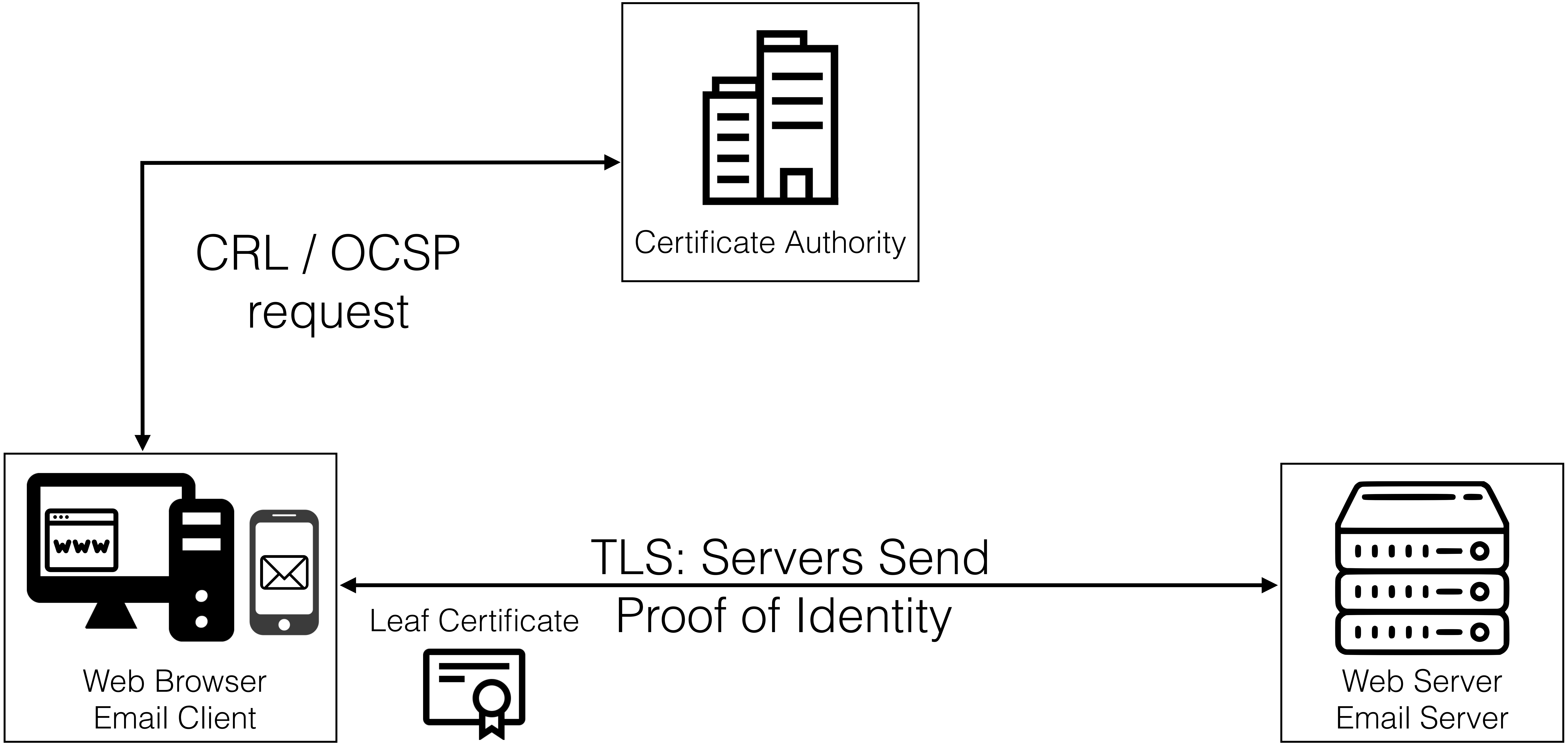
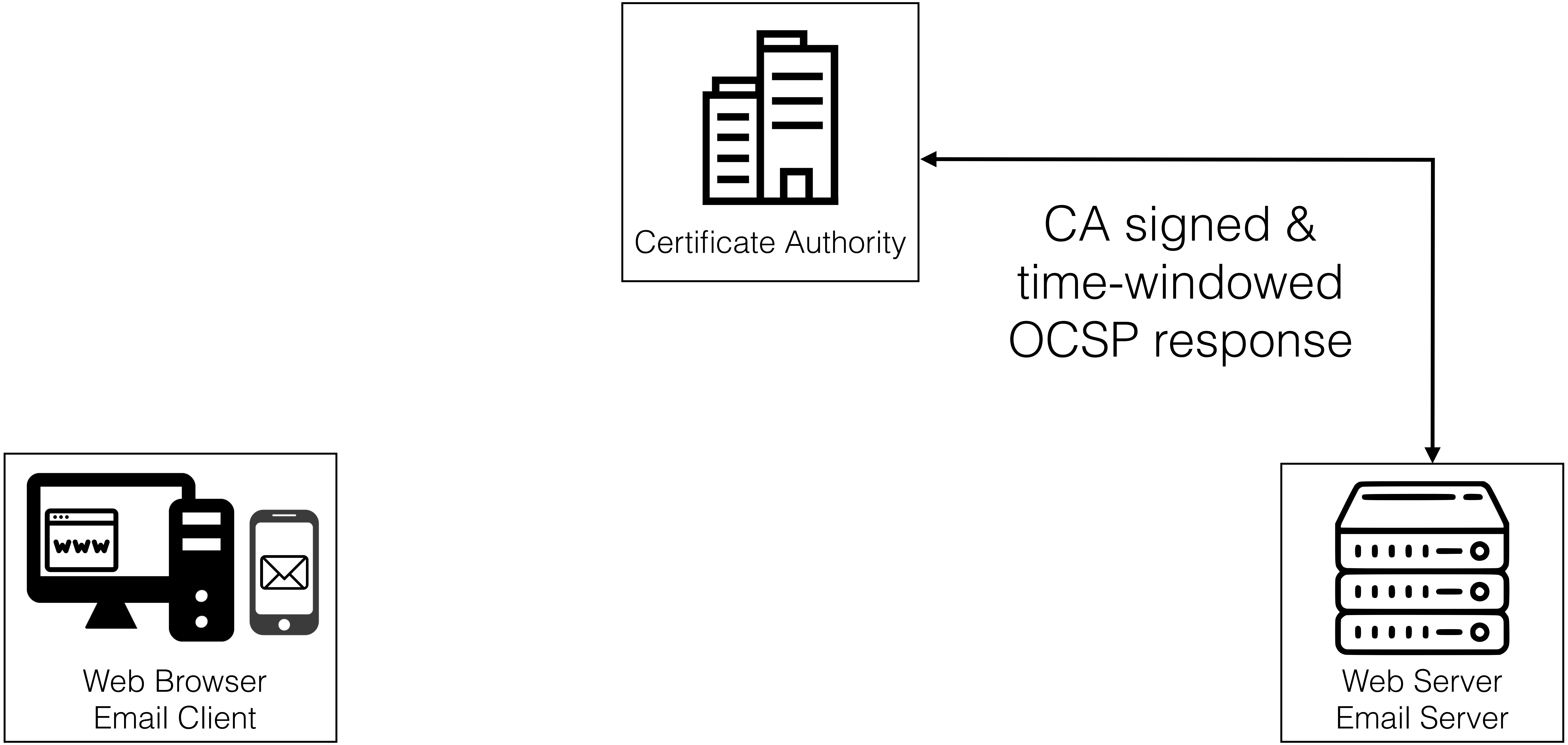


OCSP Stapling



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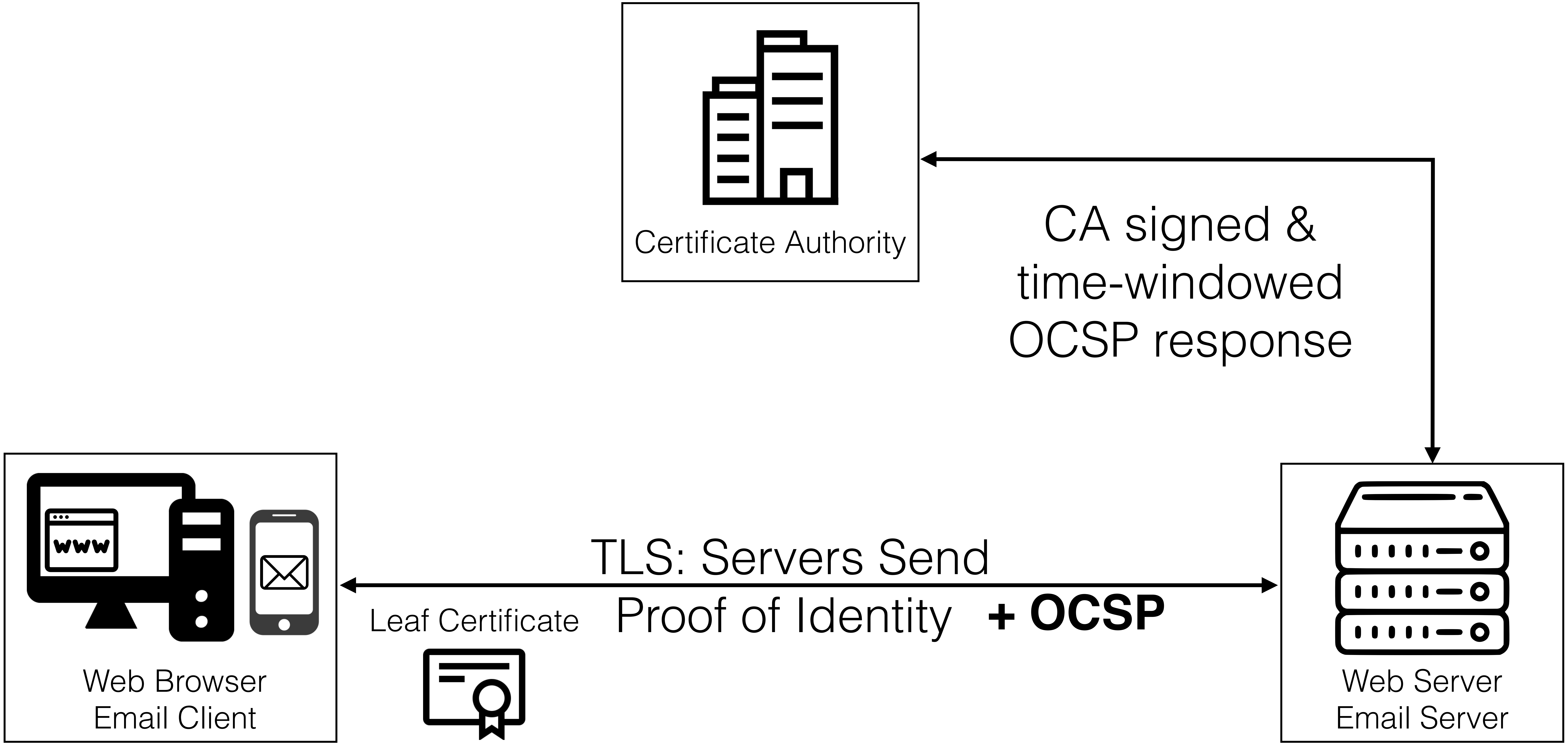

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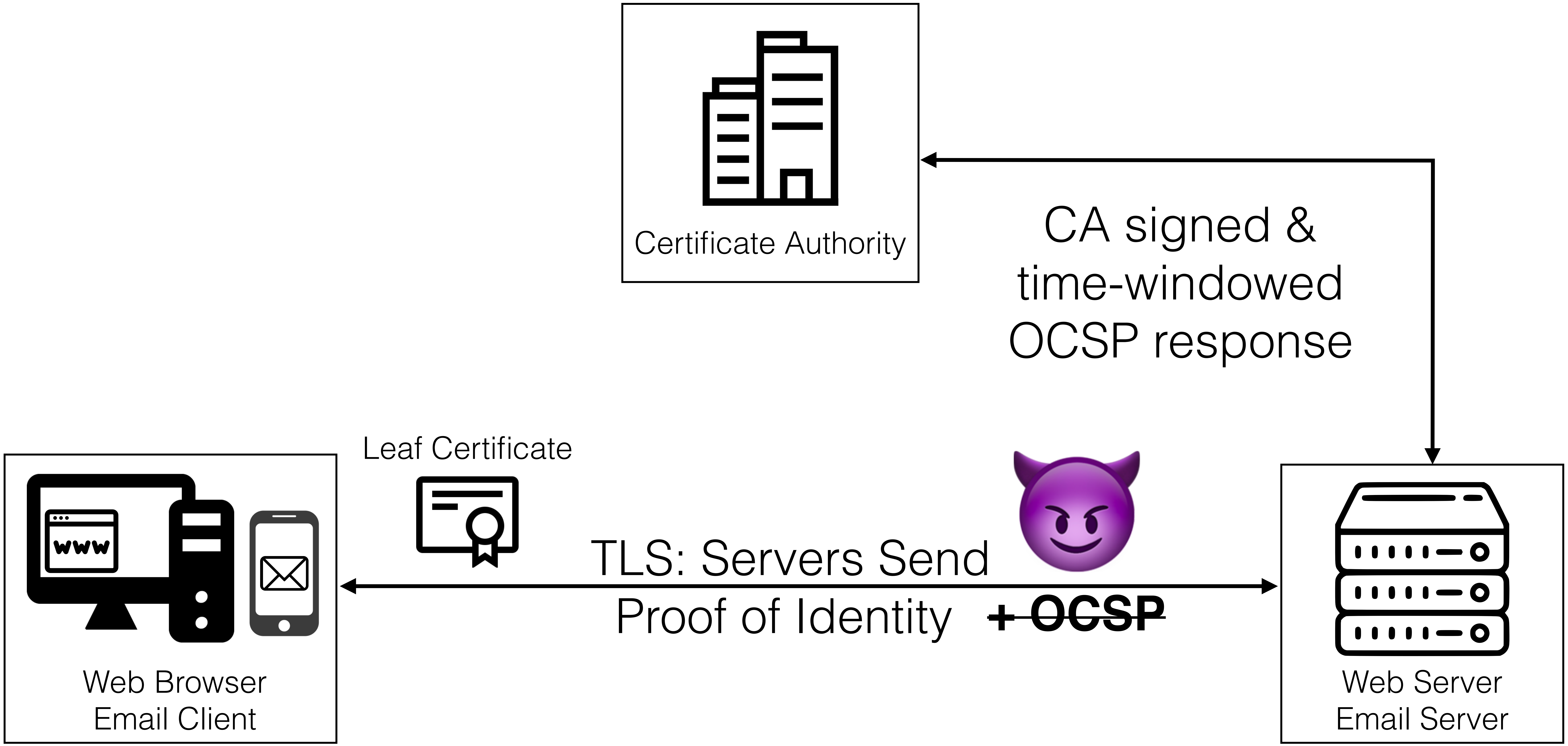
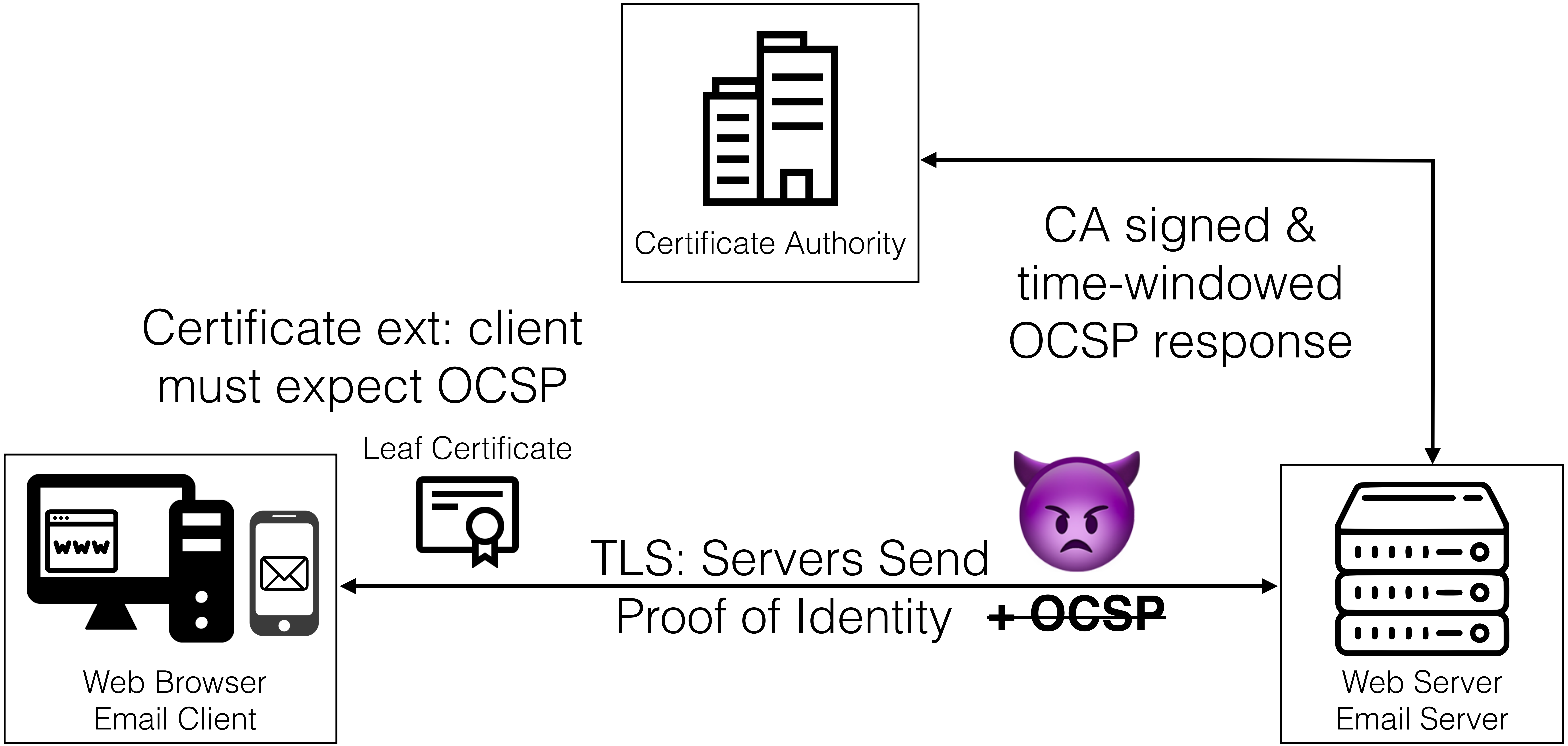
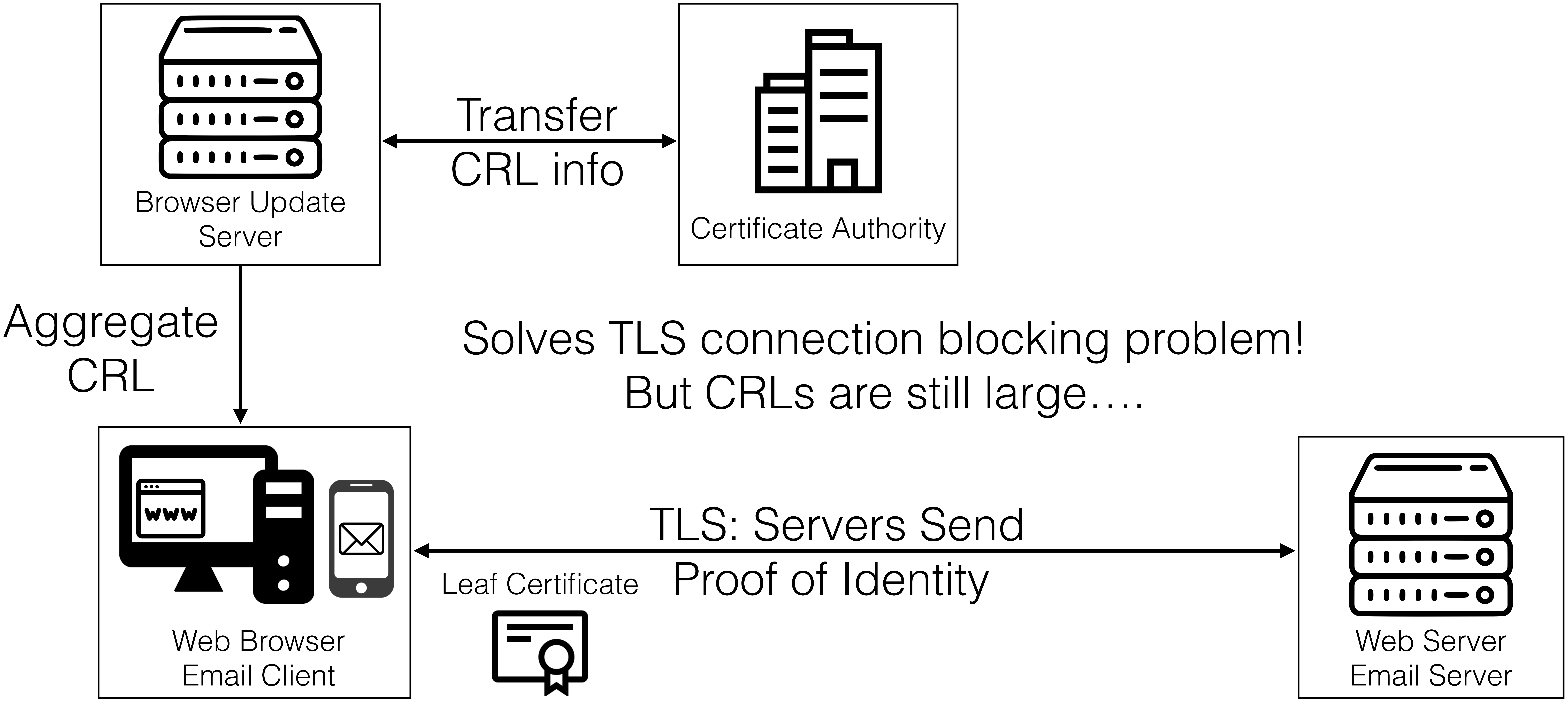


OCSP Must Staple

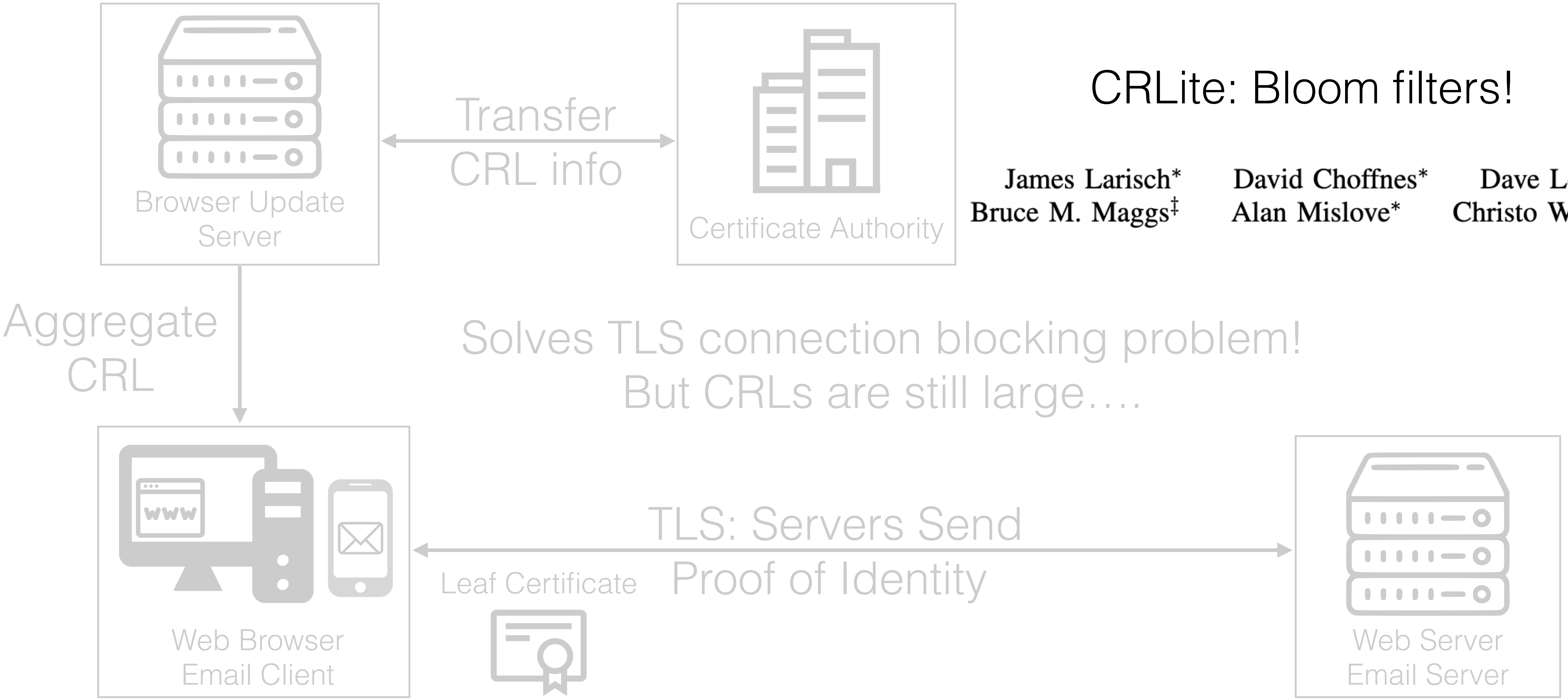


CRL Aggregation + Pushing



Solves TLS connection blocking problem!
But CRLs are still large….

CRL Aggregation + Pushing



CRLite: Bloom filters!

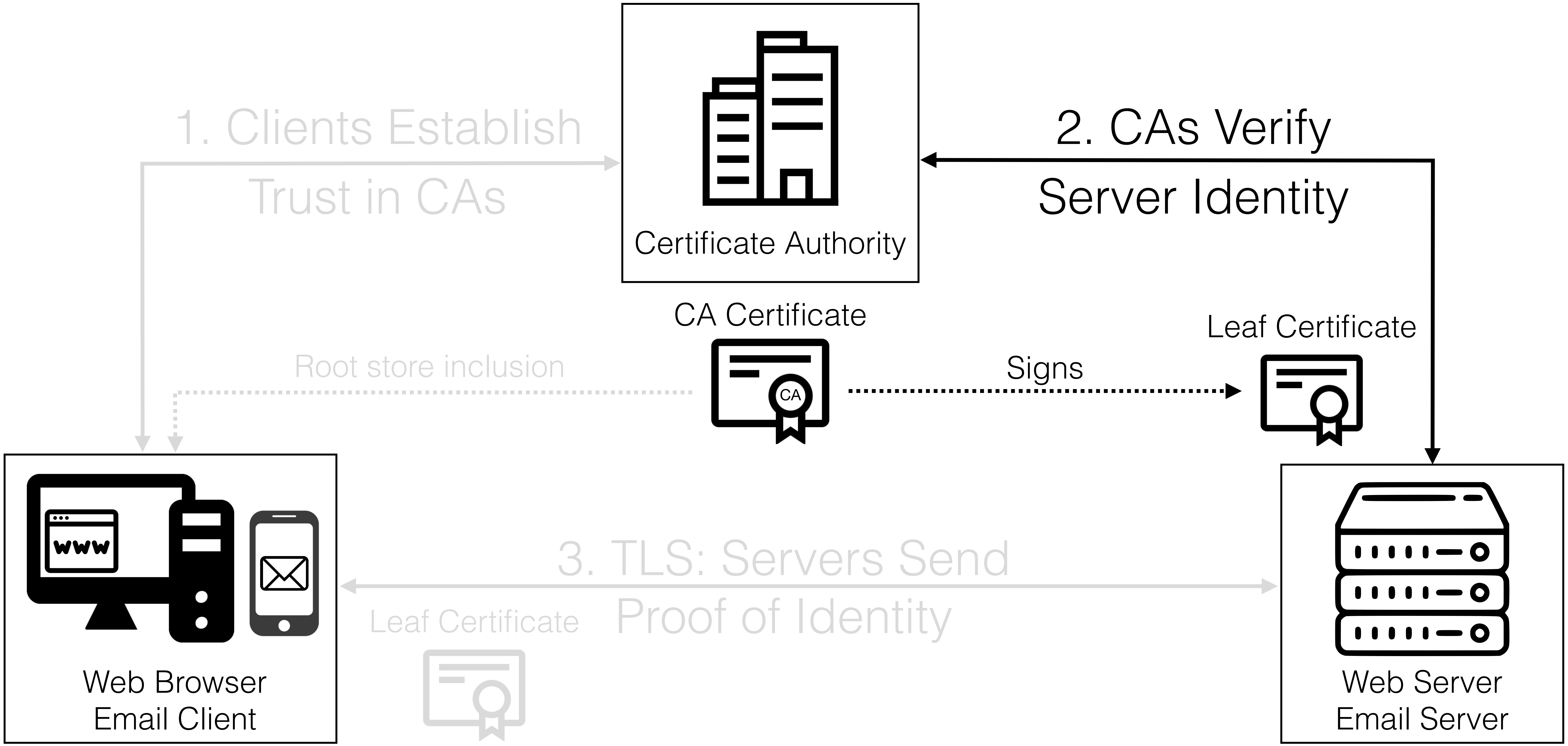
James Larisch* David Choffnes* Dave Levin†
Bruce M. Maggs‡ Alan Mislove* Christo Wilson*

Solves TLS connection blocking problem!
But CRLs are still large….

Certificate Revocation

- Browsers currently implement a hodgepodge of CRL / OCSP / OCSP+stapling, with Firefox having experimental support for CRLite
- Outstanding question: is it worth streamlining revocation versus reducing certificate lifetimes (i.e., certificates become a caching mechanism)
- CA certificate revocation is a separate process that uses bespoke CRL push methods (separate Apple, Chrome, Firefox, Microsoft mechanisms)

Web PKI



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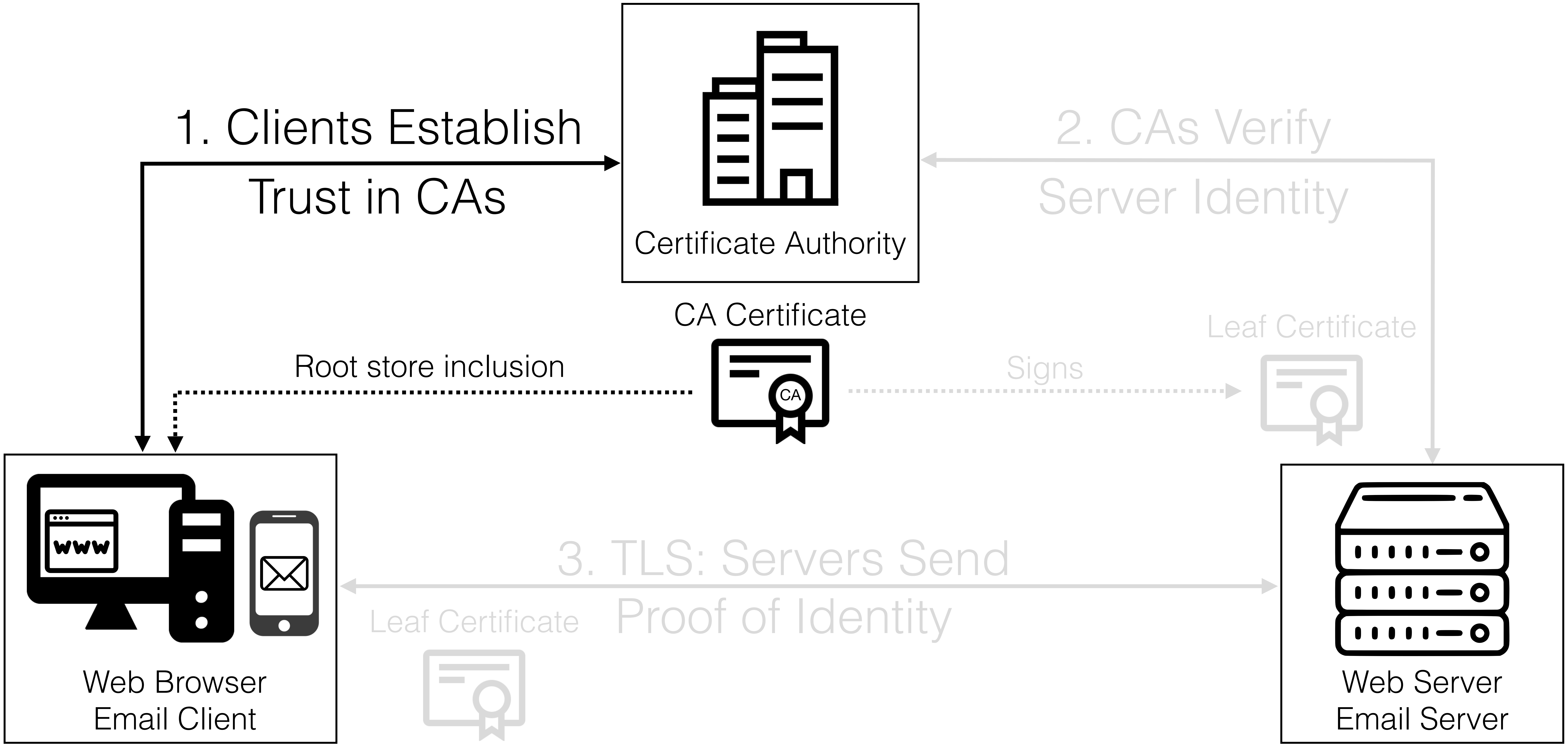
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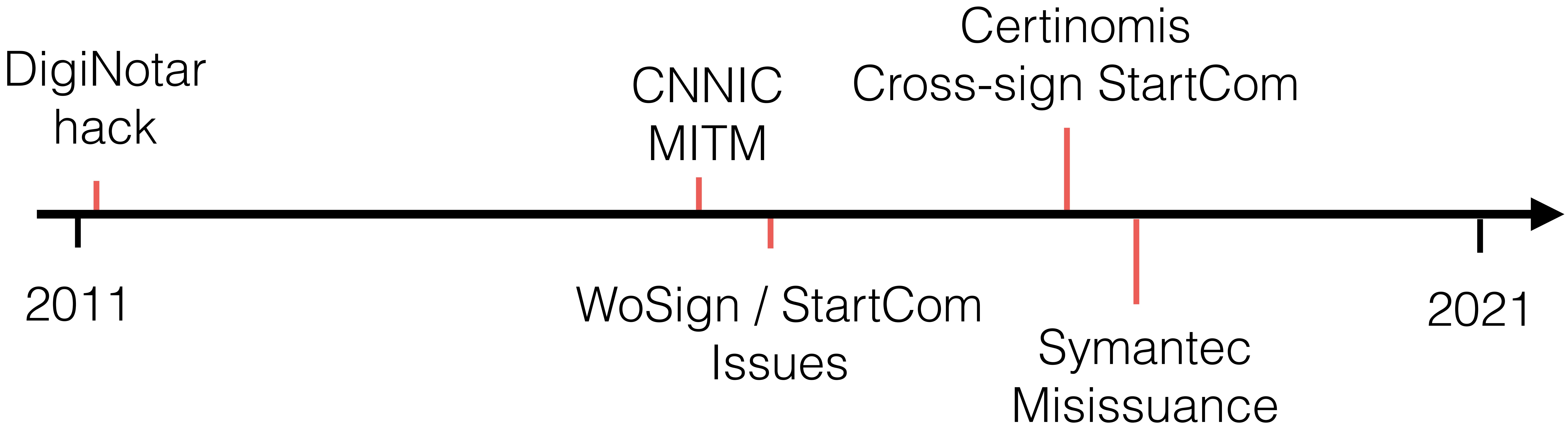
Trust Issues

Current web PKI design: every trust anchor is a single point of failure



Question: How to evaluate CA trustworthiness? Look at their issuance practices…

Certificate Transparency

Certs are public! But annoying to collect —> CAs can hide in shadows

Idea: require provable, explicit disclosure of certs before trusting; community will find bad things

Mechanism:

1. CAs submits “precertificates” to CT logs, which anyone can run.
2. CT logs return signed certificate timestamp (SCT) that are embedded into final certificate
3. During TLS, browsers verify SCT against a set of trusted logs

More info: https://certificate.transparency.dev/howctworks/

Trusting CAs

Question: How to evaluate CA trustworthiness?

0. Business / government relationships

1. Independent audits from traditional accounting firms

    Compliance with WebTrust/ETSI standards, CA/Browser Forum Baseline Requirements, root store + CA policy

2. Mozilla also performs public discussion

Current practices

Zlint: See how well CAs follow technical standards / pass unit tests!

CA transparency: disclosure and measurement of CA behavior

Trusted CAs

User Agents

Web Browsers

Chrome | Chrome Mobile | Opera | Firefox

Safari | Mobile Safari | Edge | IE | Chromium

Other TLS Clients / Libraries

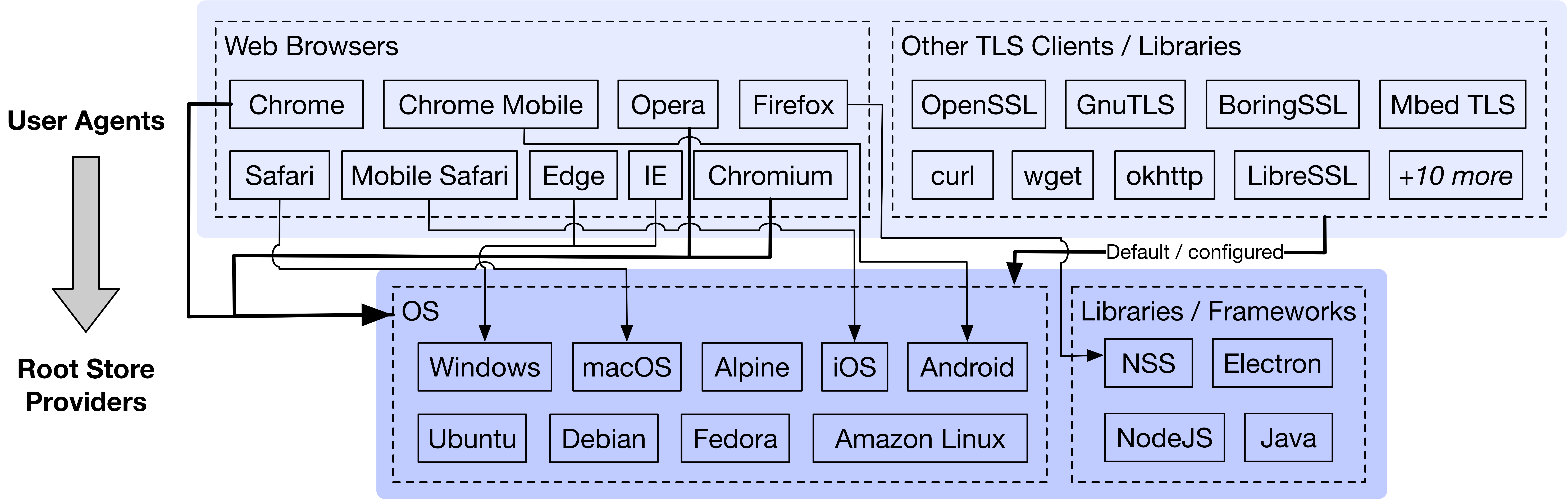
OpenSSL | GnuTLS | BoringSSL | Mbed TLS

curl | wget | okhttp | LibreSSL | *+10 more*

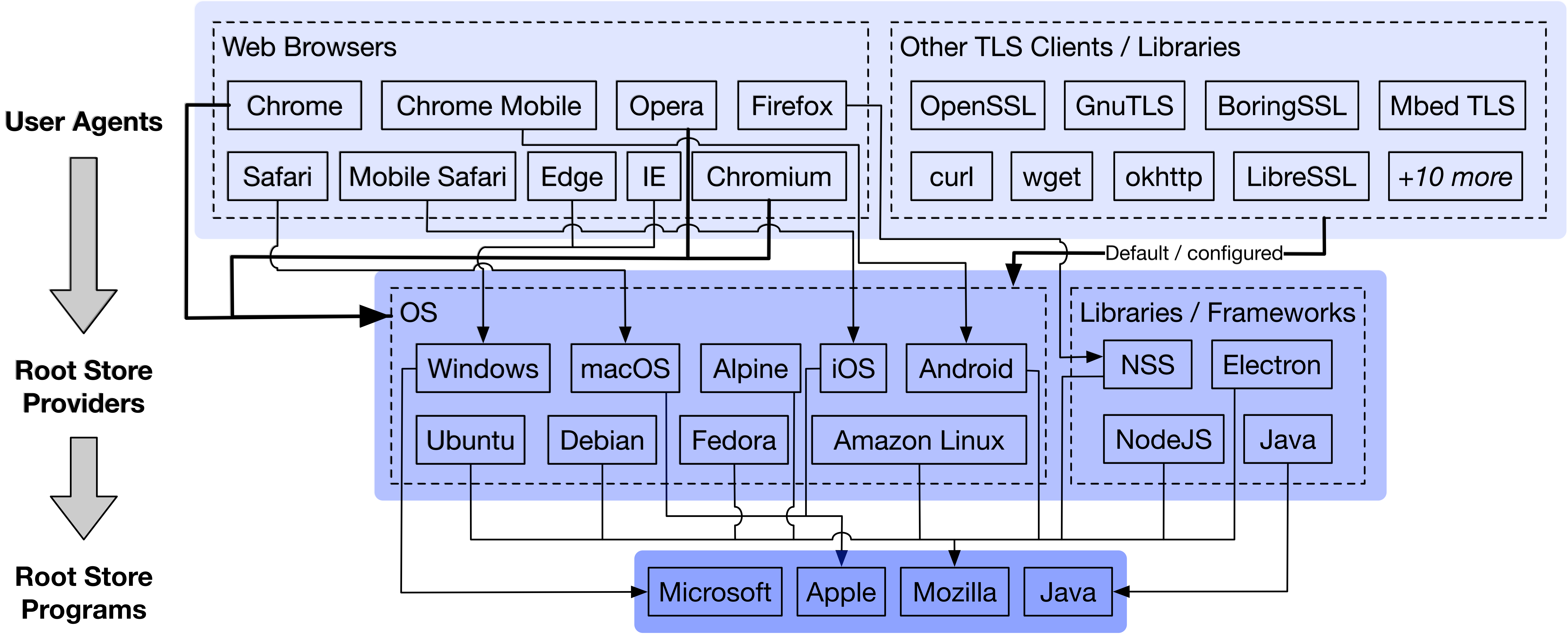
Root stores for 77% of global CDN top 200 user agents

Additional default root store for dozens of libraries / TLS clients

Root store providers



Root store programs



Recap

Authentication/identity is the foundation for confidentiality / integrity

Web PKI exists as a scalability/interception-avoidance mechanism for global web server auth

Certificates are not trustable themselves; they are attestation links between entities (name + pub key)

Trusting the right CAs is imperative - brittle current PKI design

Transparency can lead to better security, and opens the door for new research!

Closing Remarks

- Major network security challenges: malware, Distributed Denial of Service (DDoS), social engineering
- What is the core issue? Distinguishing good data from bad data? Cat-and-mouse game, sometimes indistinguishable (DDoS)
- Distinguishing good originators/creators of data: web server auth is a good start, but what we really want is authenticating web content
- Interesting challenges: identifier selection, verification protocols, policies built on top of authentication

Research Opportunities

Improving web server auth

Empirical evaluation of CA behavior + policy

Program analysis/testing of web PKI software

Breaking the fuzzy grey-areas of certificate issuance

New web content auth

Take a holistic look at how current web content is identified and authenticated

Exploring new protocol design, implementation, deployment

WebPKI and Trust

CS249i: The Modern Internet

Zane Ma
Georgia Institute of Technology
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https://zanema.com