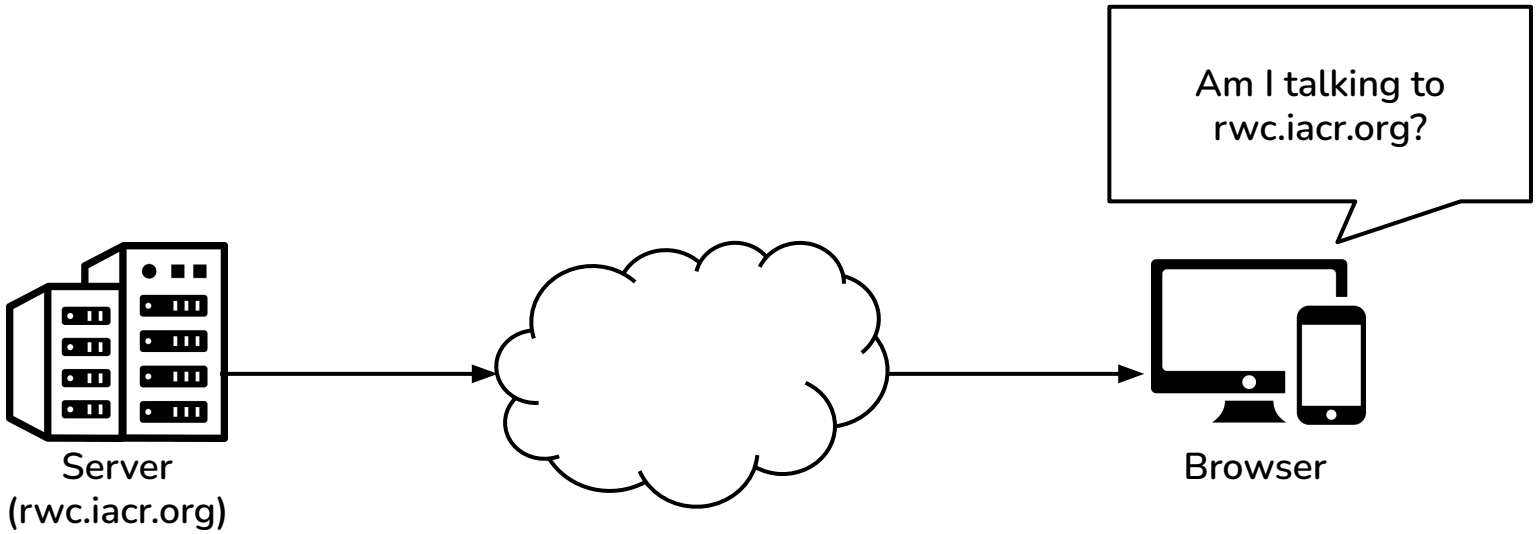
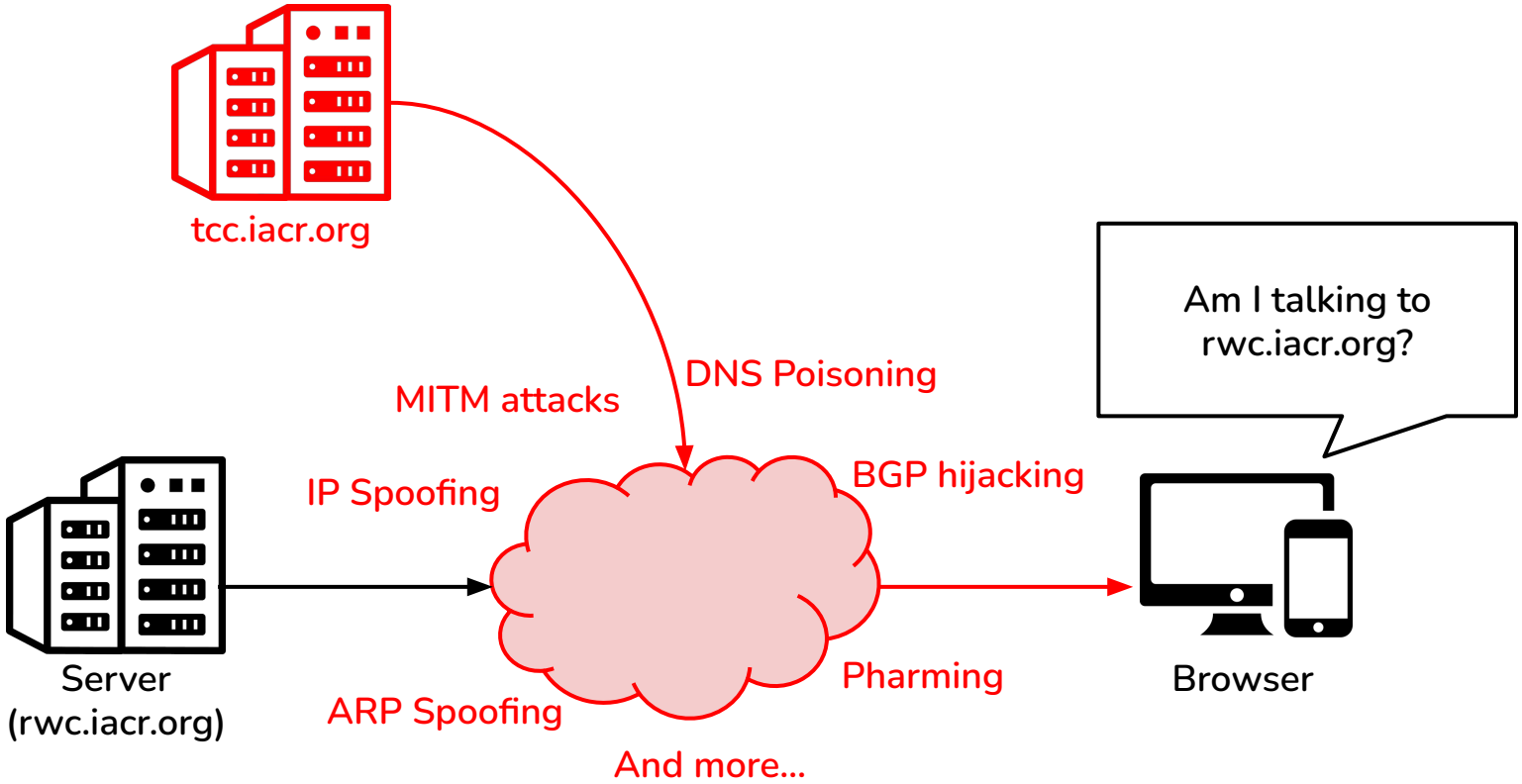
NOPE: Strengthening Domain Authentication with Succinct Proofs

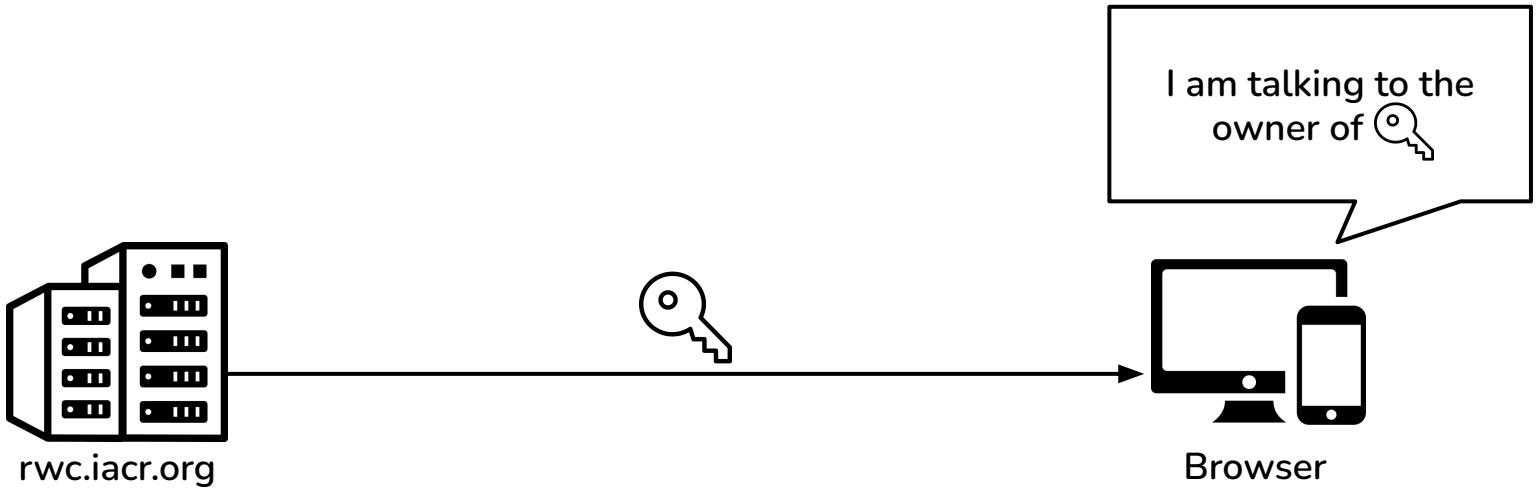
Zachary DeStefano, Jeff J. Ma,
Joseph Bonneau, and Michael Walfish

Appeared at SOSP 2024

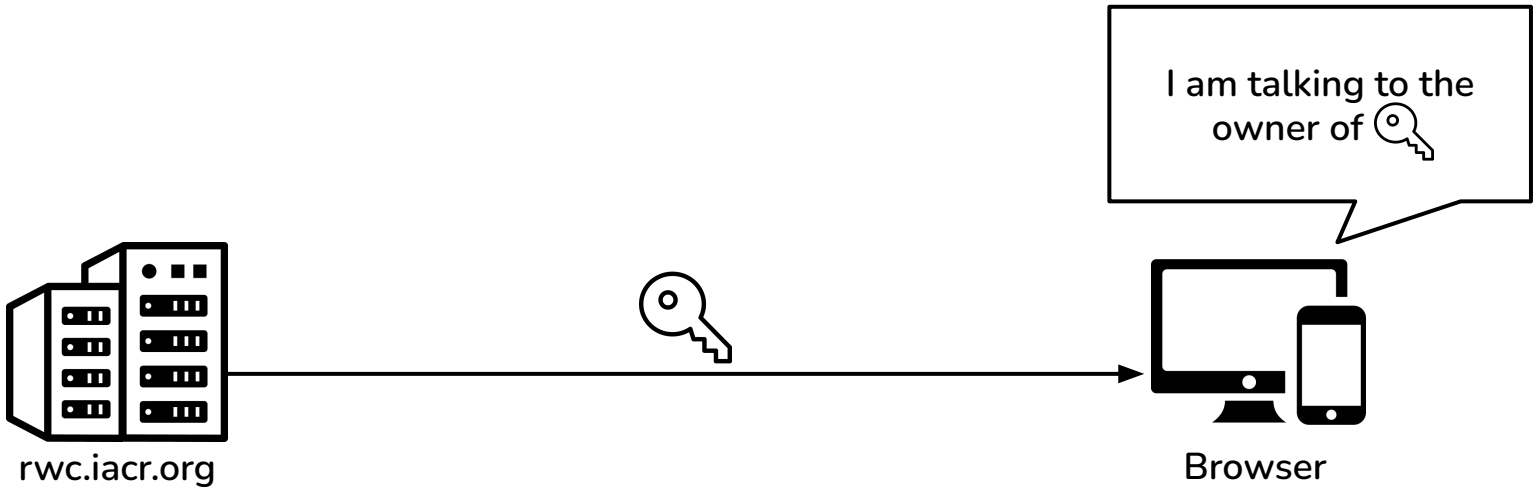

Am I talking to
rwc.iacr.org?
Server
(rwc.iacr.org)
Browser


tcc.iacr.org
DNS Poisoning
MITM attacks
IP Spoofing
BGP hijacking
Am I talking to rwc.iacr.org?
Server (rwc.iacr.org)
Pharming
ARP Spoofing
Browser
And more...

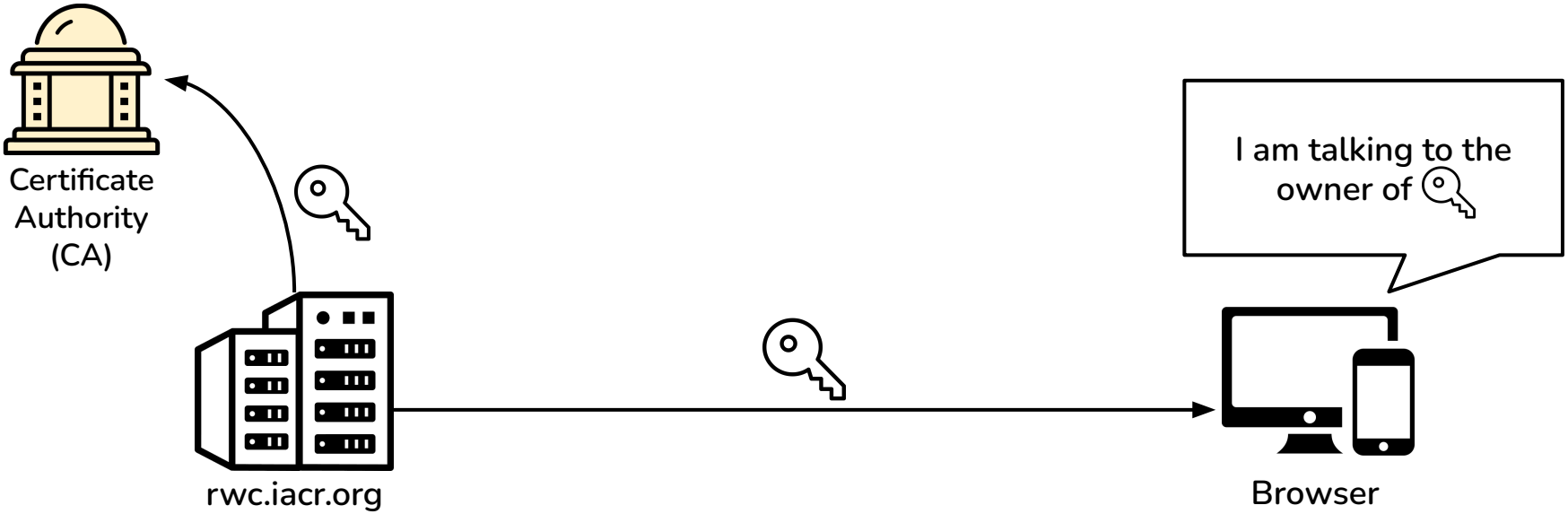
Authentication relies on TLS



Authentication relies on TLS – partially



Authentication also relies on CAs



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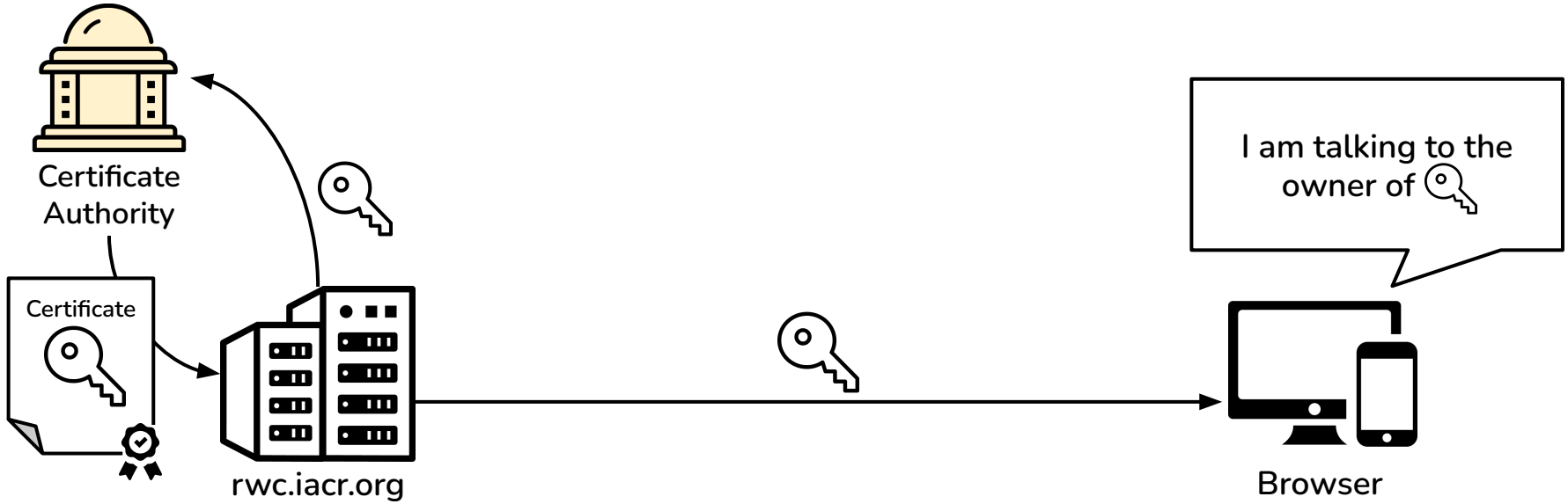

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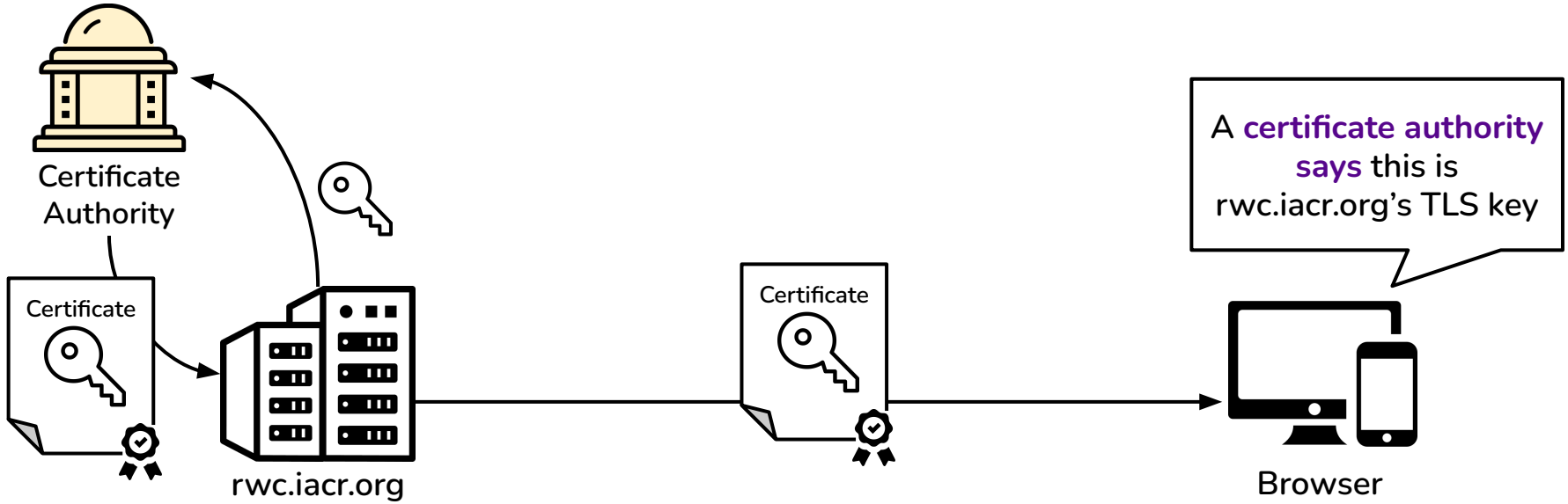

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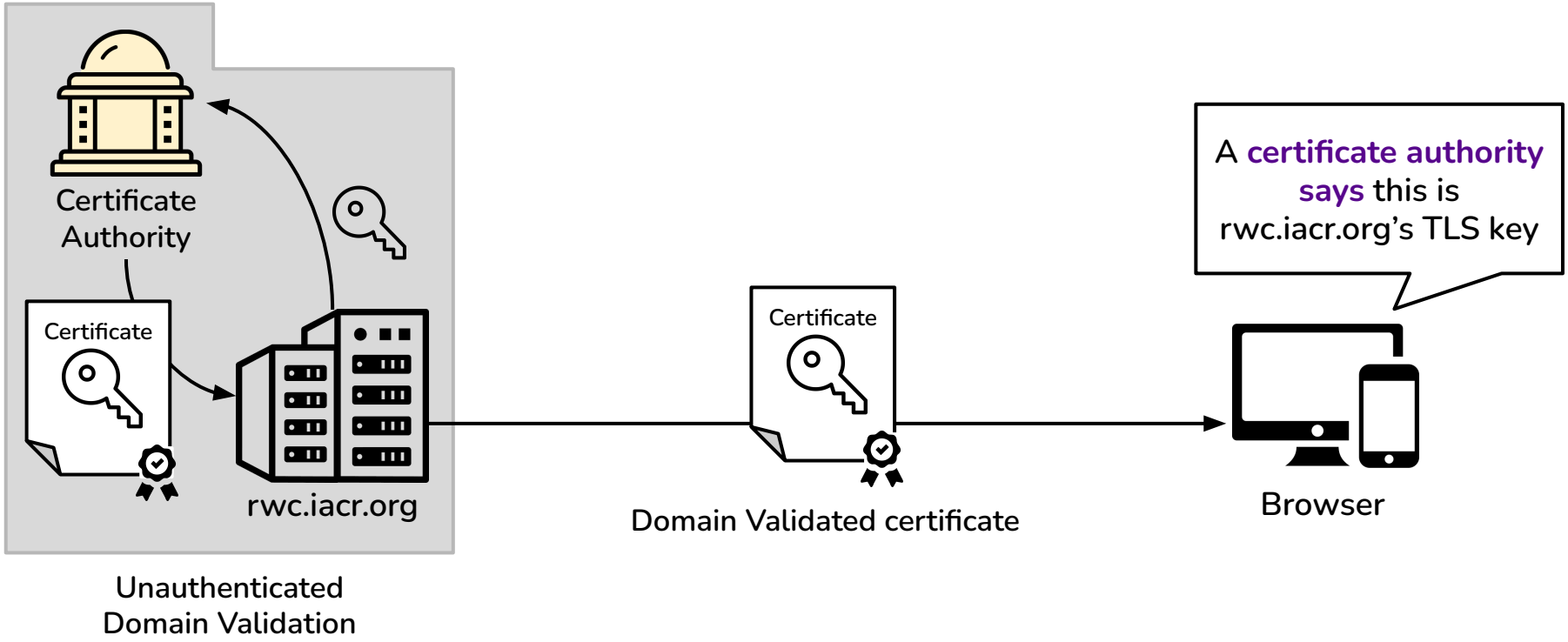
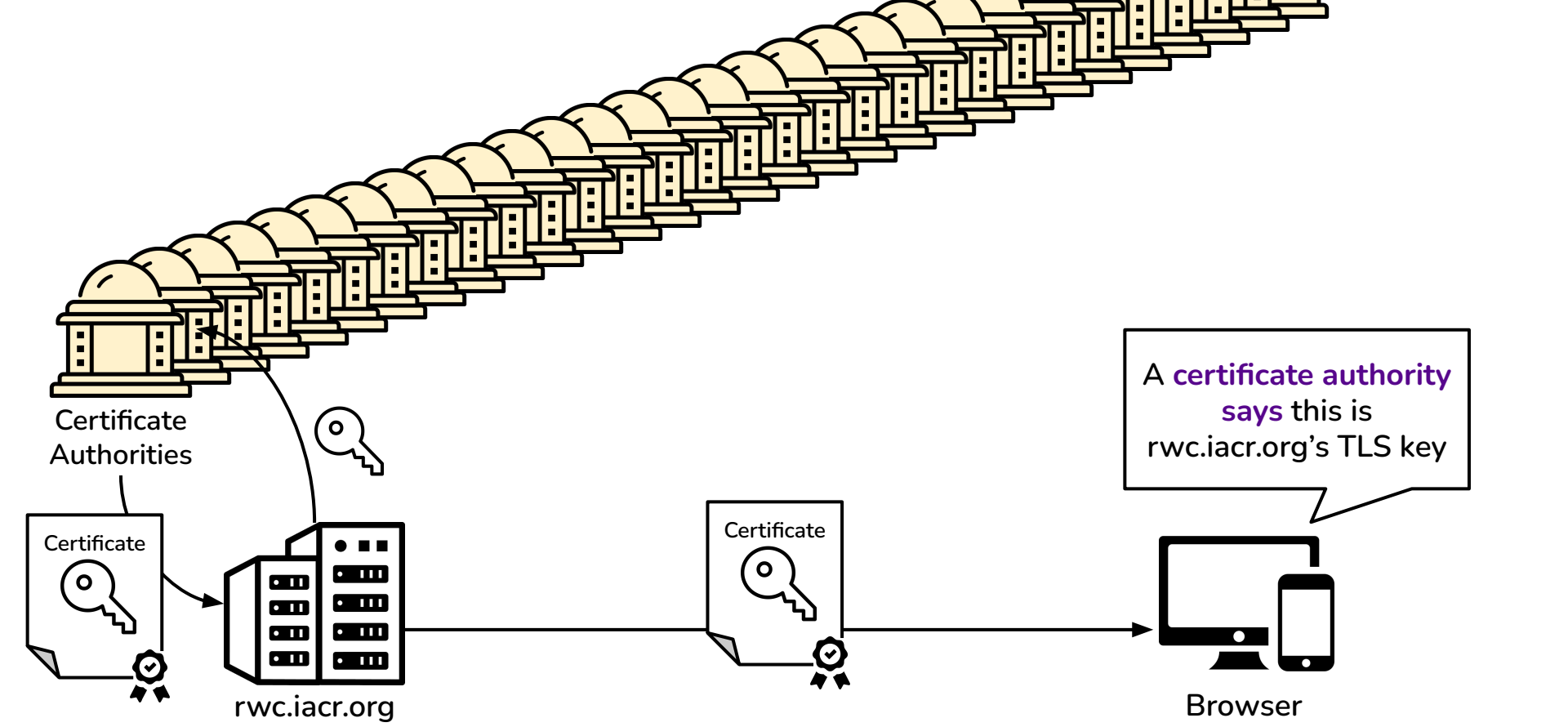
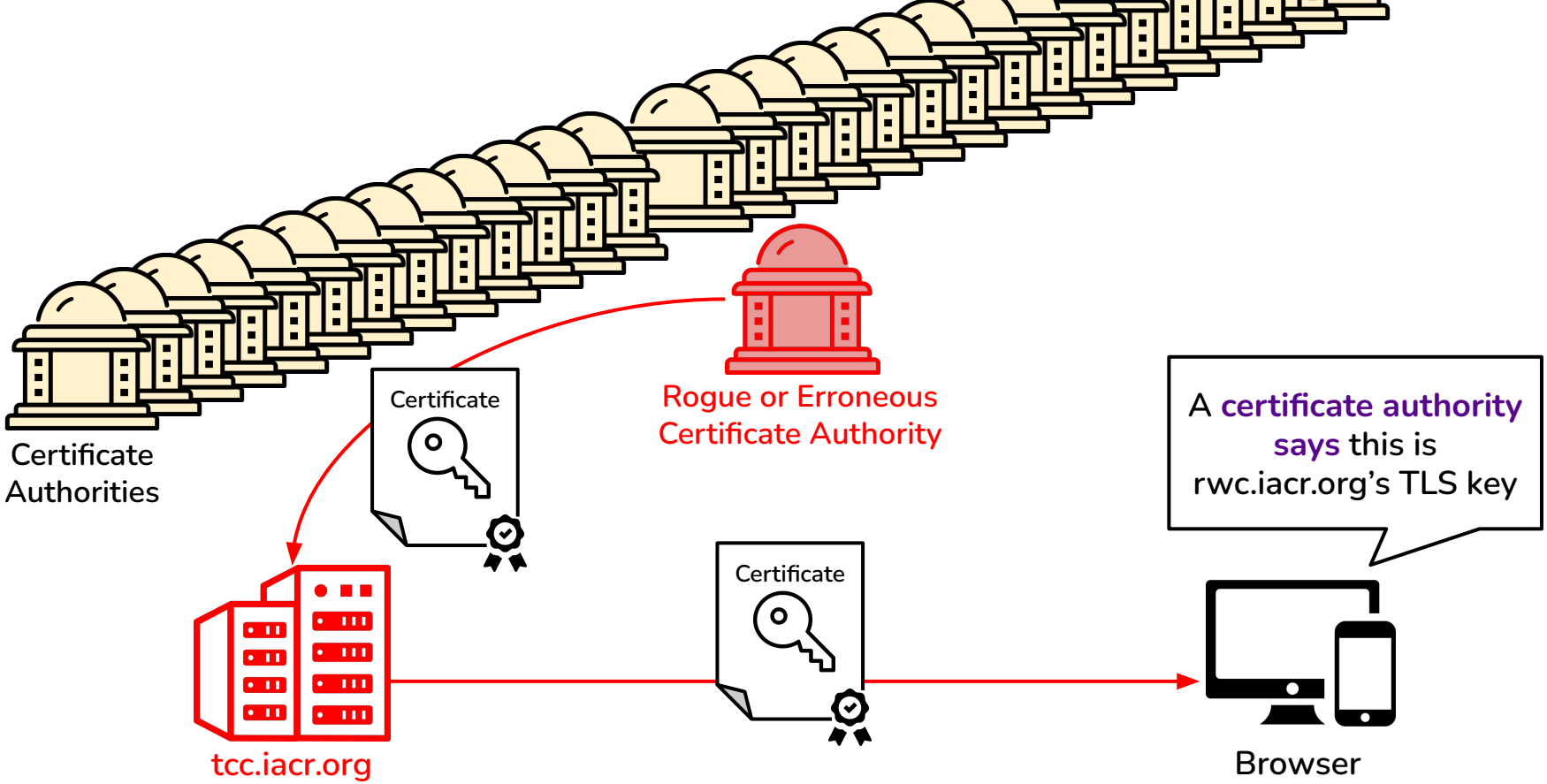



Certificate Authorities
Certificate
rwc.iacr.org
Certificate
A certificate authority says this is rwc.iacr.org's TLS key
Browser


Certificate Authorities
Rogue or Erroneous Certificate Authority
Certificate
Certificate
A certificate authority says this is rwc.iacr.org's TLS key
tcc.iacr.org
Browser

2008 - Thawte

Mike Zusman registers the email address sslcertificates@live.com and uses it to obtain a rogue SSL certificate from Thawte for Microsoft's live.com.

2009 - Null prefix attack

Moxie Marlinspike gets a certificate from ipsCA for a DNS name containing a null character. Although ipsCA correctly validates the DNS name as belonging to Moxie's domain, the null character tricks some clients into thinking the certificate belongs to www.paypal.com, enabling impersonation of PayPal.

2011 - TurkTrust

TurkTrust accidentally issues two intermediate CA certificates to subscribers. These intermediate certificates can be used to forge certificates for any domain on the Internet. Sixteen months later, one of them is used to forge a certificate for google.com.

Using BGP to Acquire Bogus TLS Certificates

Henry Birge-Lee[1], Yixin Sun[1], Annie Edmundson[1], Jennifer Rexford[1], and Prateek Mittal[1]
{birgelee, yixins, annee, jrex, pmittal}@princeton.edu

[1]Princeton University

2014 - NICCA

The National Informatics Centre (NIC) of India, a subordinate CA of the Indian Controller of Certifying Authorities (India CCA), issues rogue certificates for Google and Yahoo domains. NIC claims that their issuance process was compromised and that only four certificates were misissued. However, Google is aware of misissued certificates not reported by NIC, so it can only be assumed that the scope of the breach is unknown.

2016 - StartCom

Thijs Alkemade discovers that StartCom's brand new automated issuance API suffers from numerous flaws, including flaws that had previously been discovered and fixed by other CAs, that would allow attackers to obtain certificates for domains they don't control.

A Post Mortem on the Iranian DigiNotar Attack

SEPTEMBER 13, 2011

by Eva Galperin, Seth Schoen and Peter Eckersley

More facts have recently come to light about the compromise of the DigiNotar Certificate Authority, which appears to have enabled Iranian hackers to launch successful man-in-the-middle attacks against hundreds of thousands of Internet users inside and outside of Iran.

Mitigating the Hetzner/Linode XMPP.ru MitM interception incident

(If you just want some recommendations for what to do, skip down to the Recommendations section below.)

Today, the operator of jabber.ru and xmpp.ru reported that their service had been successfully subject to a man-in-the-middle attack via a combination of

- their hosting providers, Hetzner and Linode, intercepting traffic to their machines; and
- the unauthorized issuance of a Domain Validation certificate for their service by an attacker.

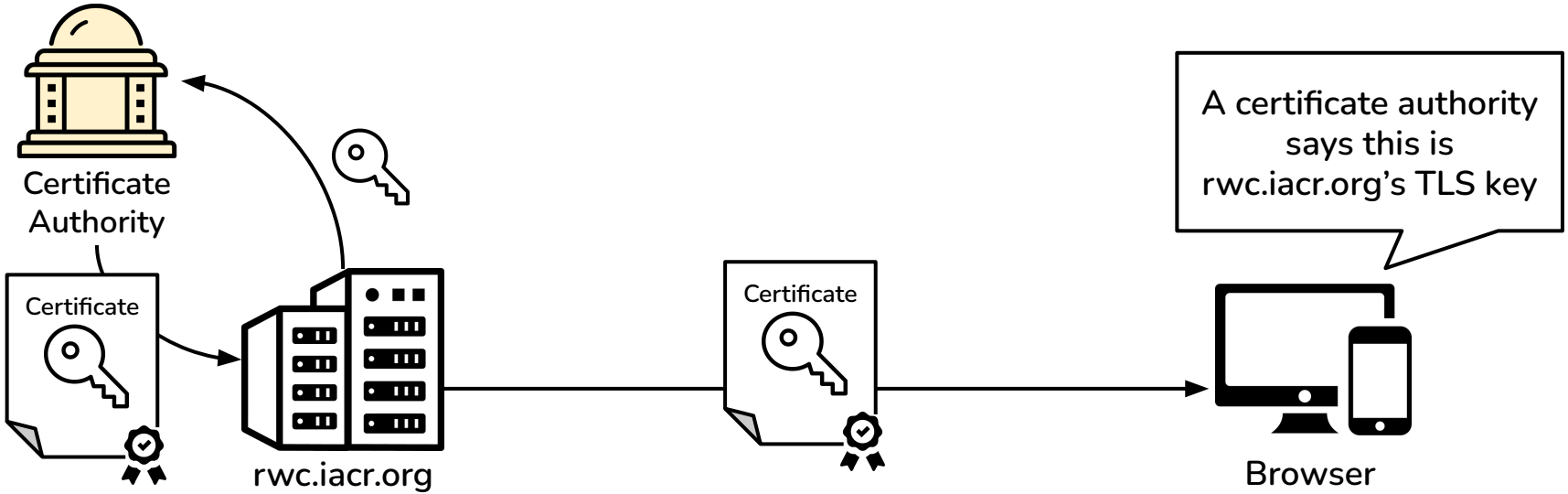
Keeping Positive – Obtaining Arbitrary Wildcard SSL Certificates from Comodo via Dangling Markup Injection

December 2, 2015

Duplicate Signature Key Selection Attack in Let's Encrypt

Existing proposals require modifying infrastructure

or are purely reactive.



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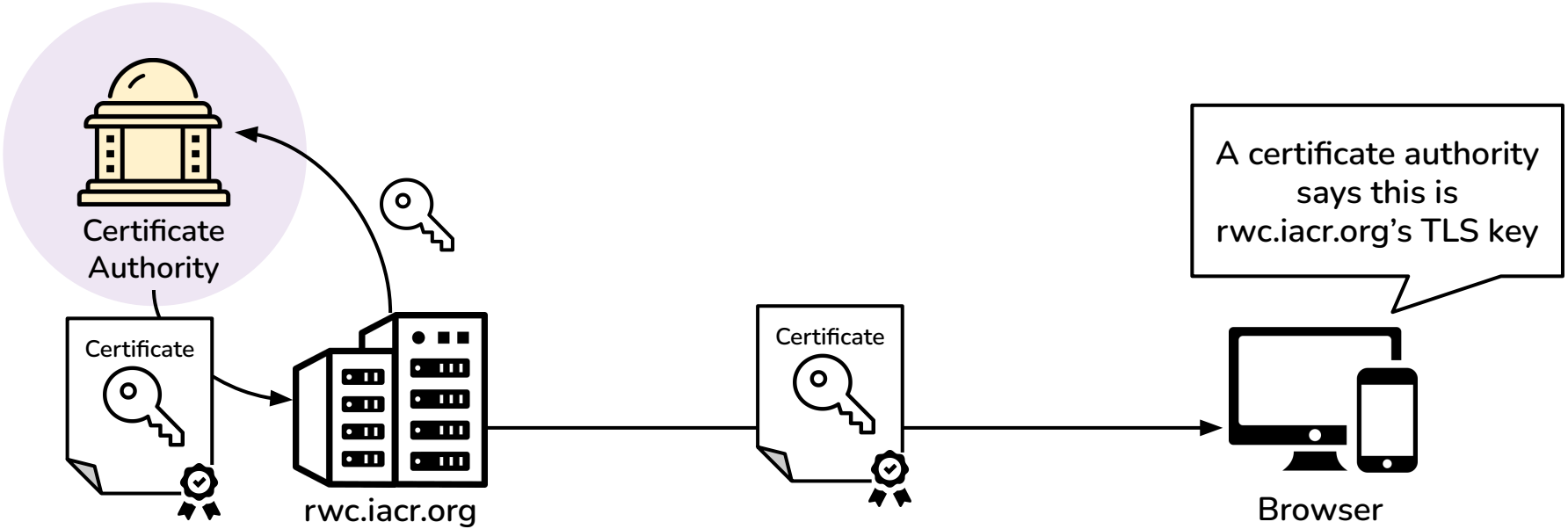

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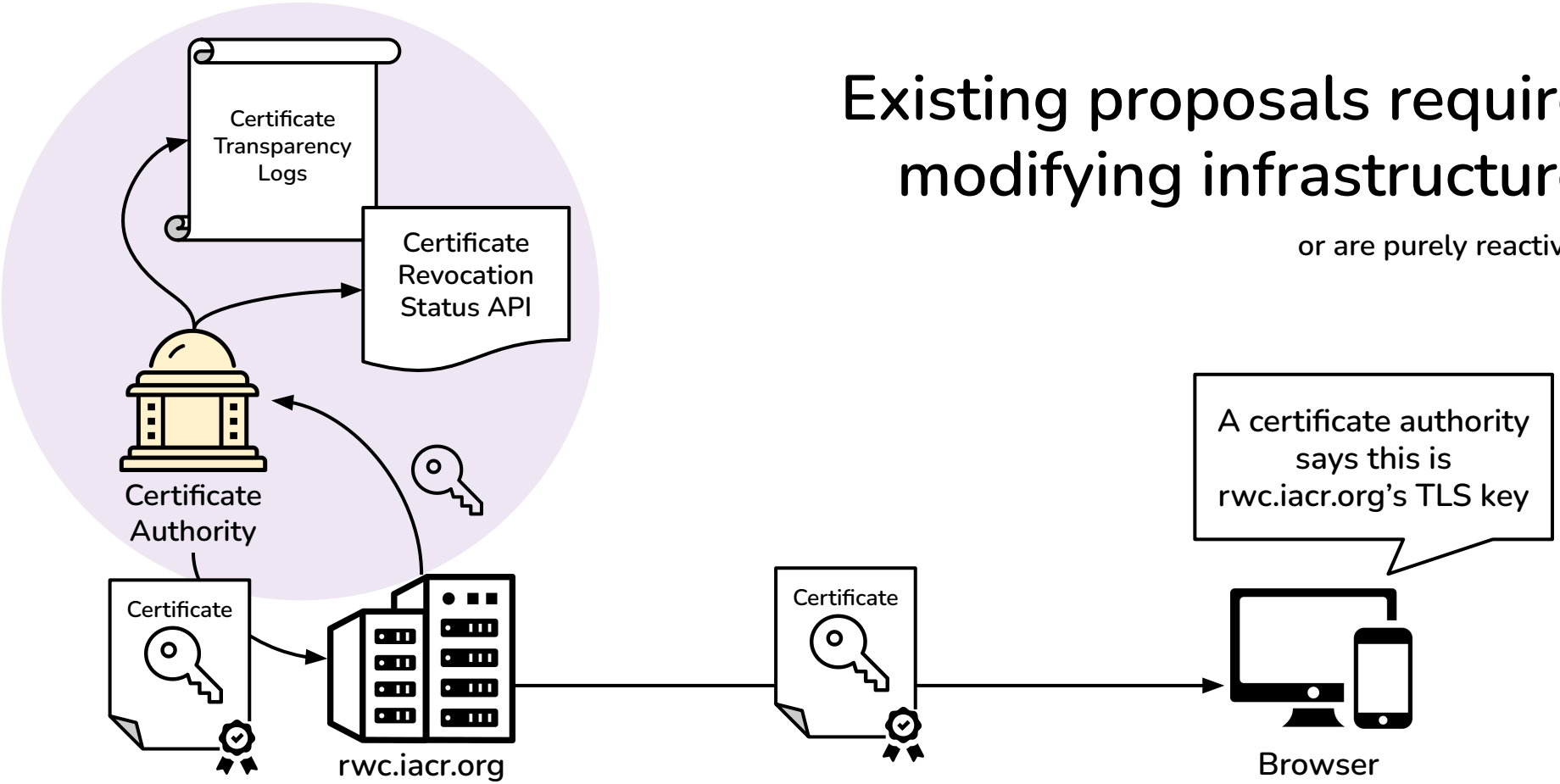
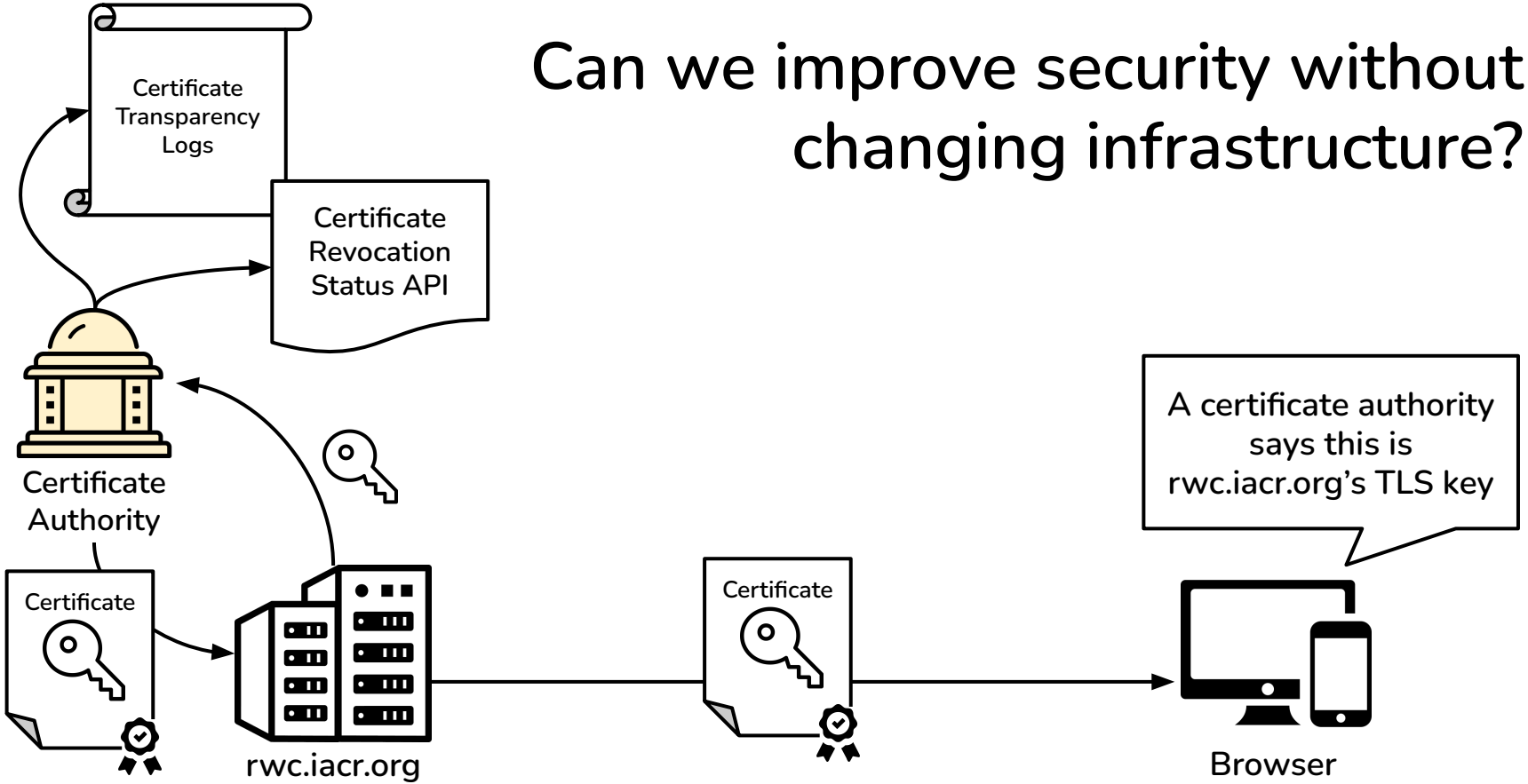


Can we improve security without changing infrastructure?



Key tool: succinct proofs

(probabilistic proofs, zero-knowledge proofs, SNARKs, SNARGs, PCPs)

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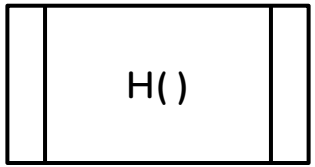
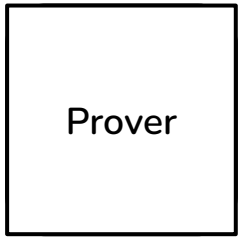


Computation



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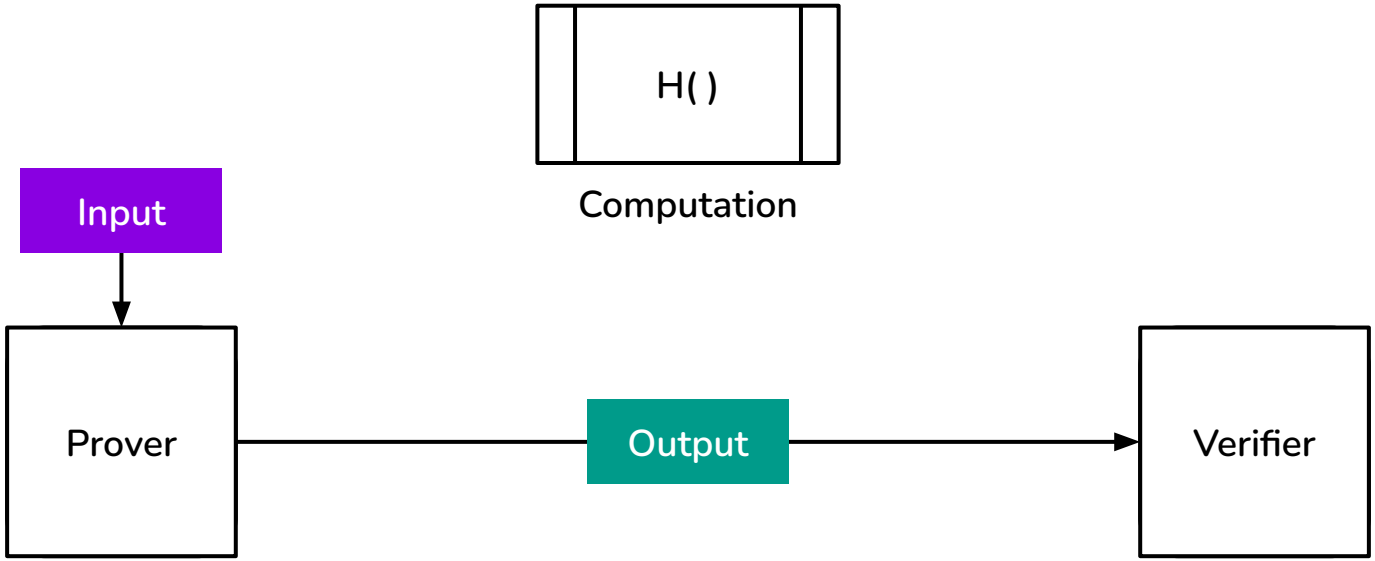

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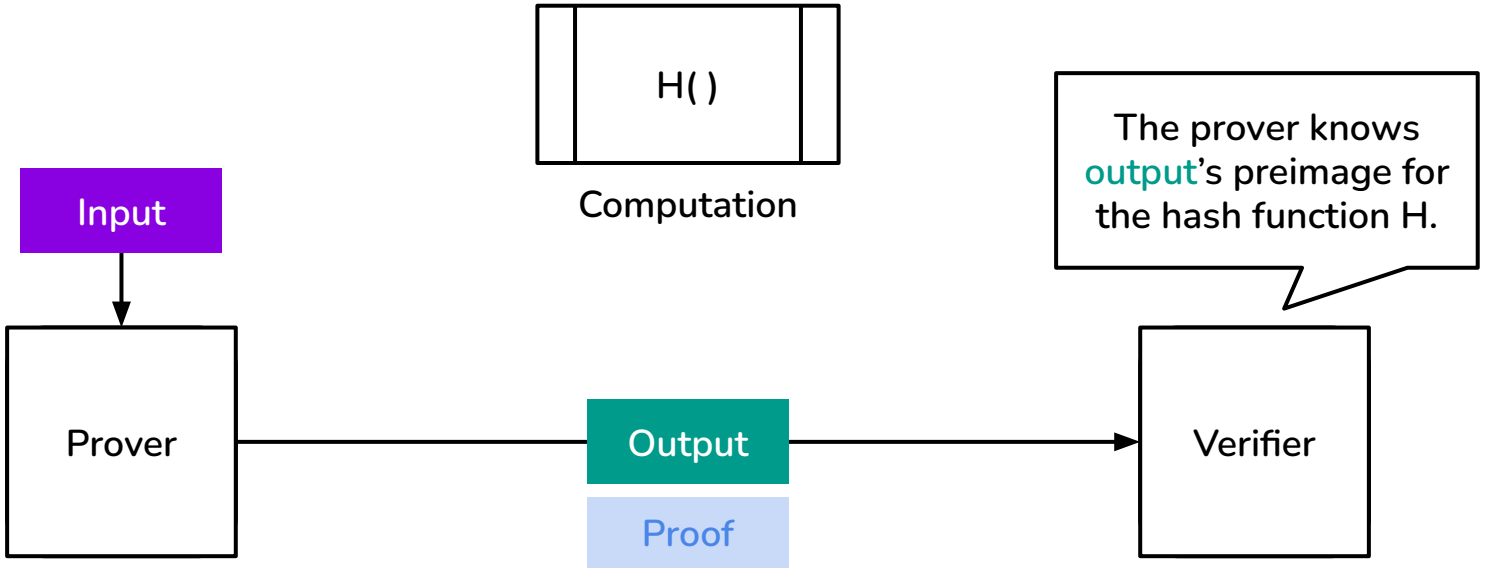

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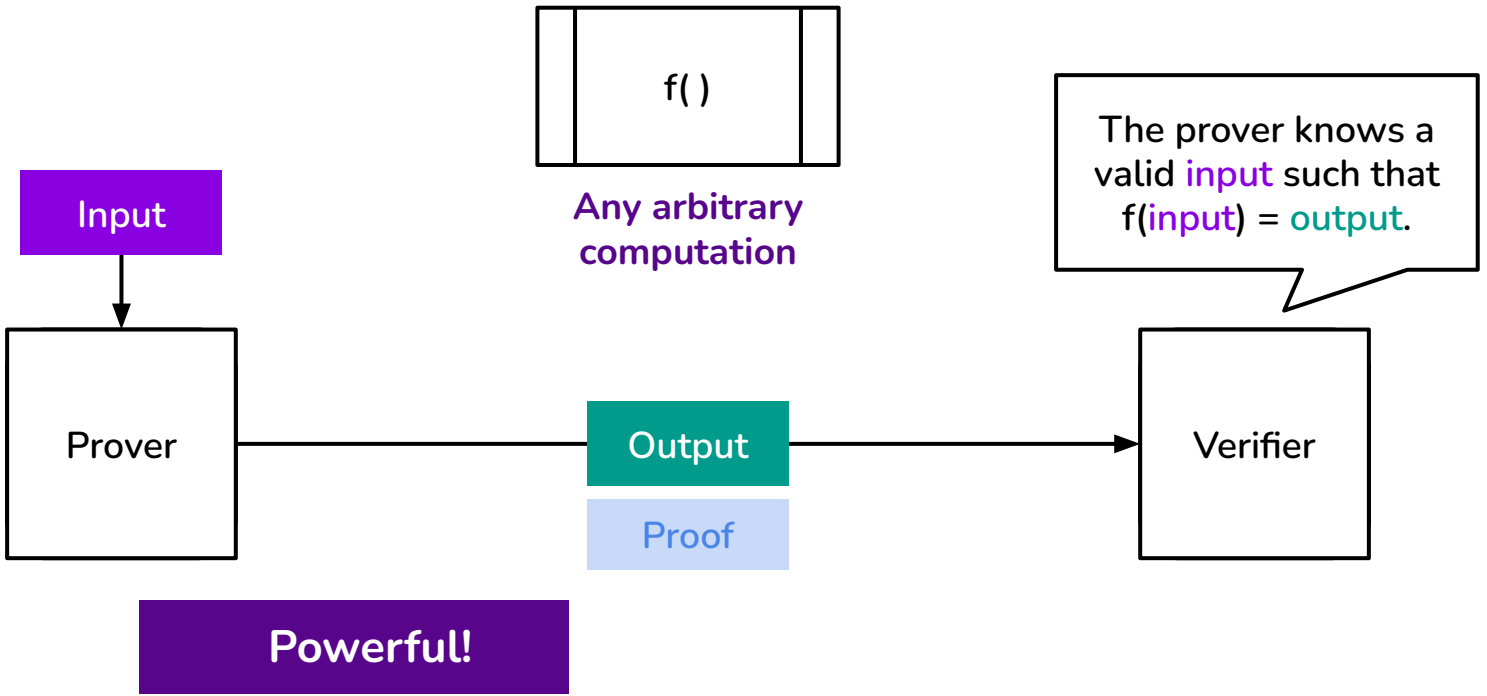

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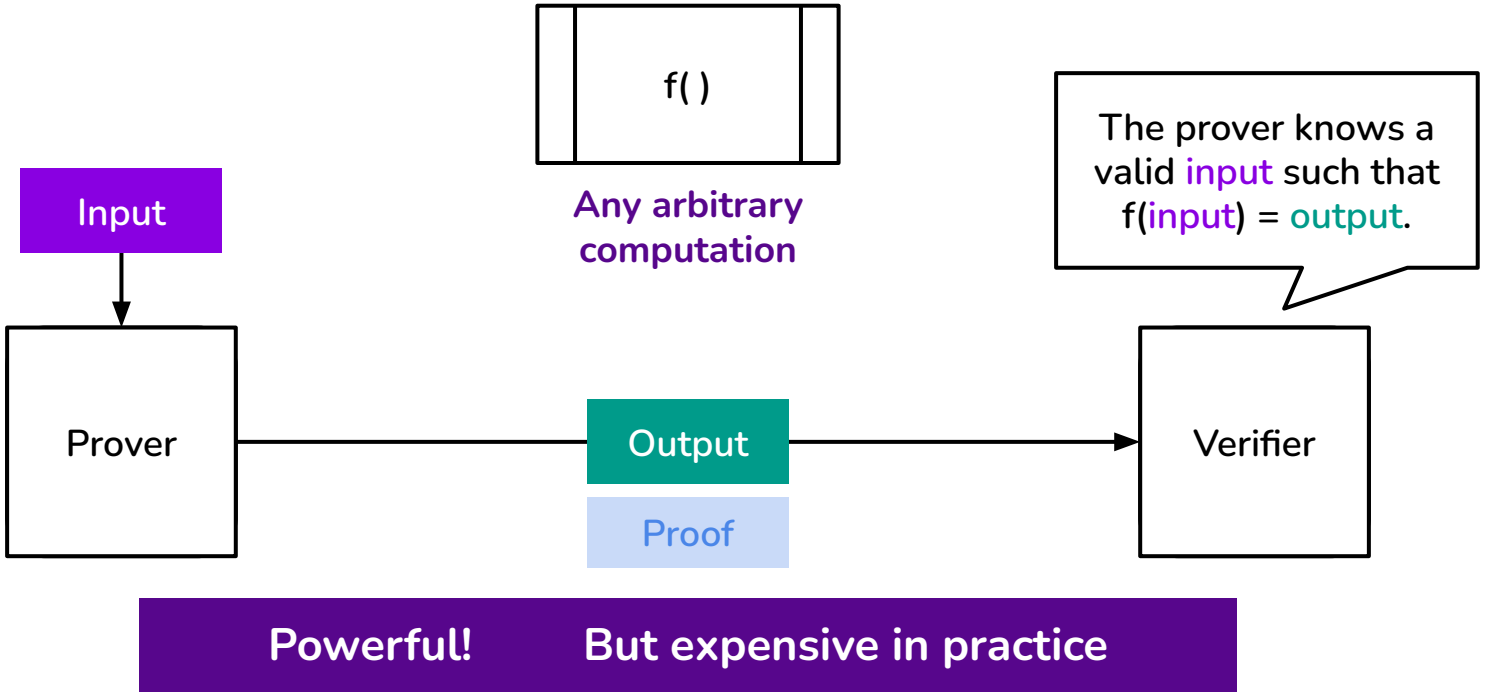
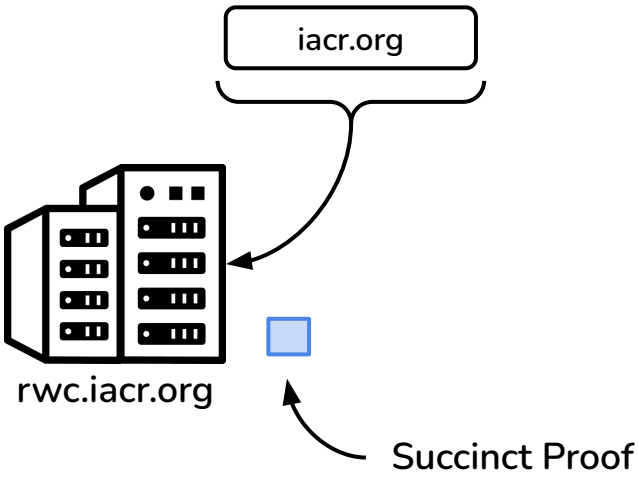


Our work, NOPE, in a nutshell



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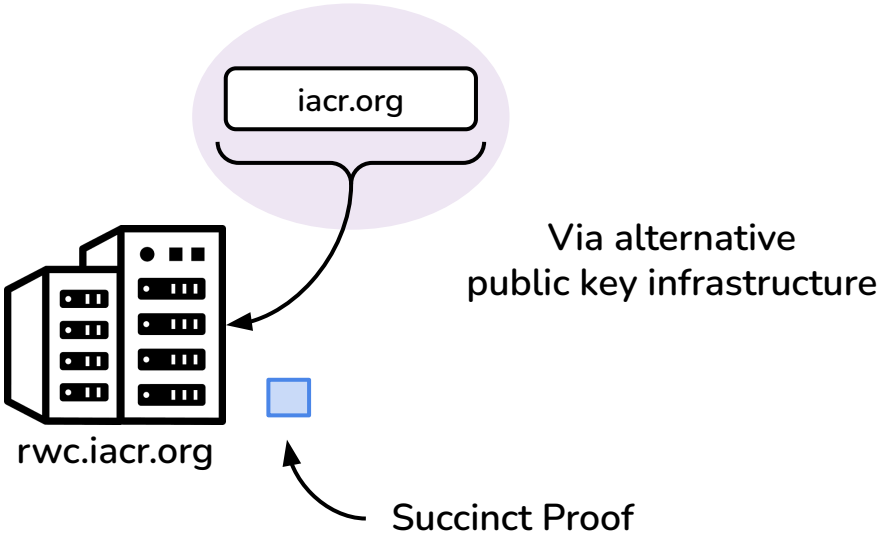

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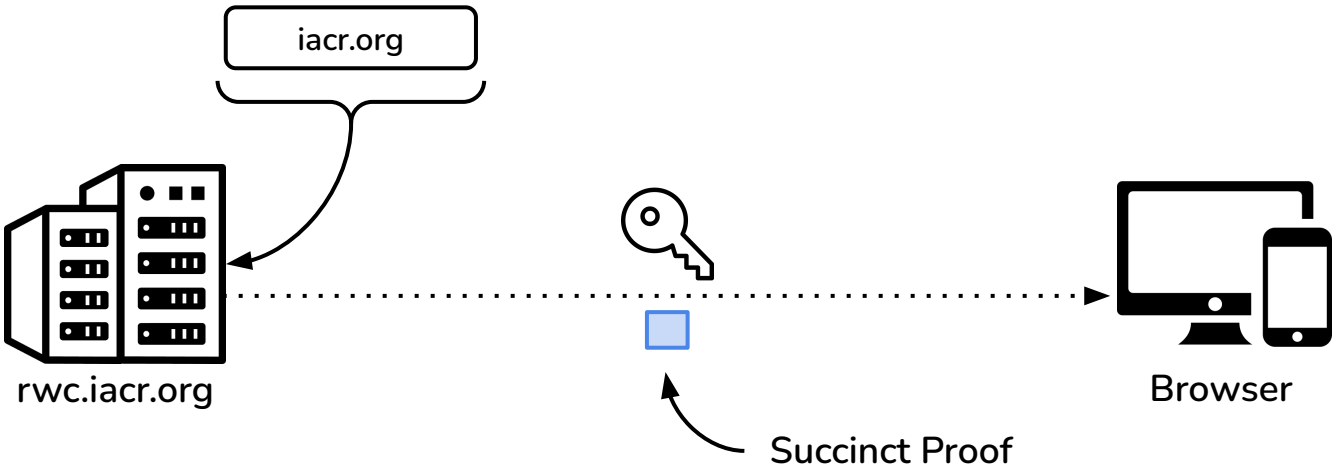

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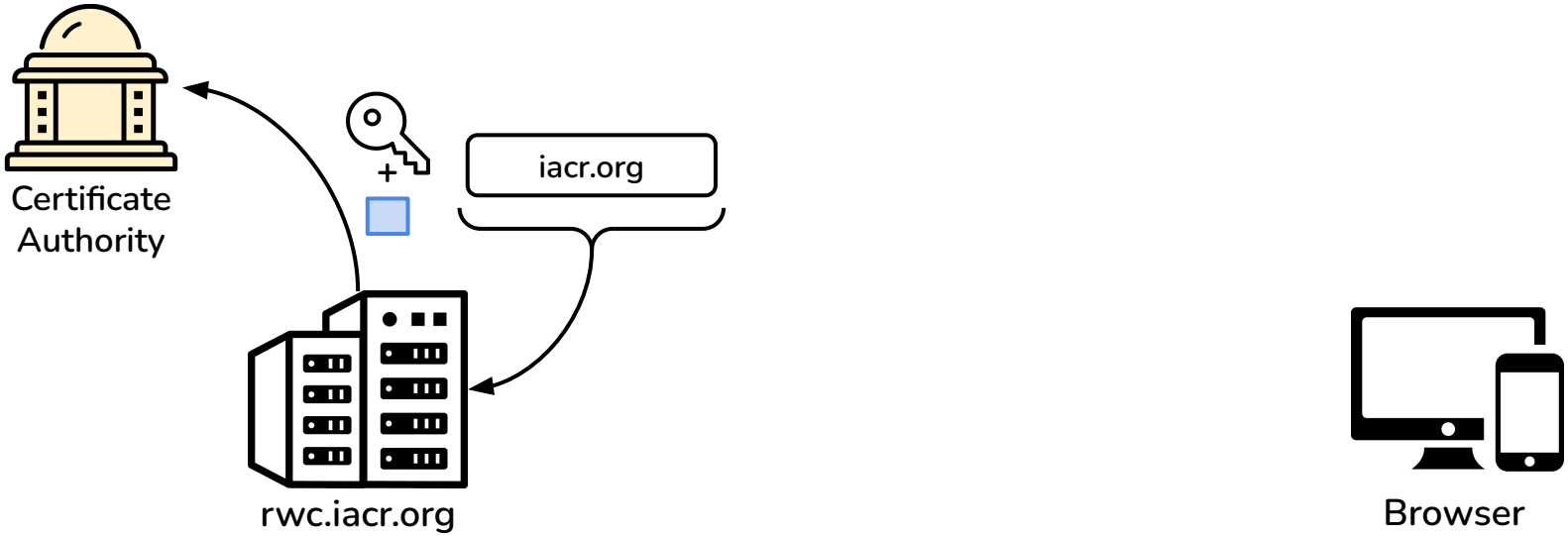

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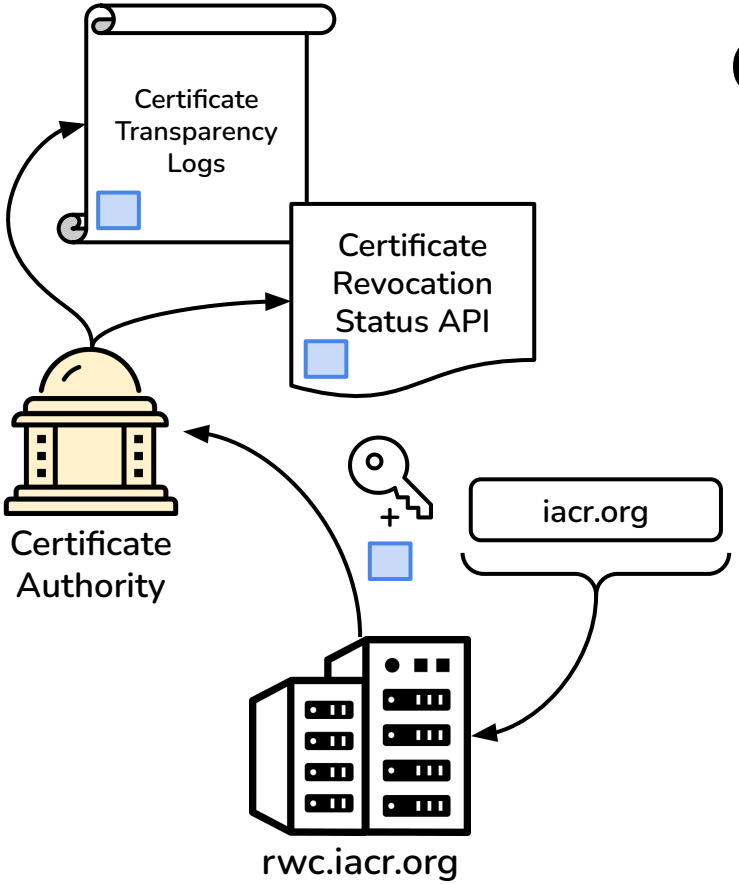

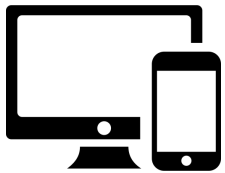

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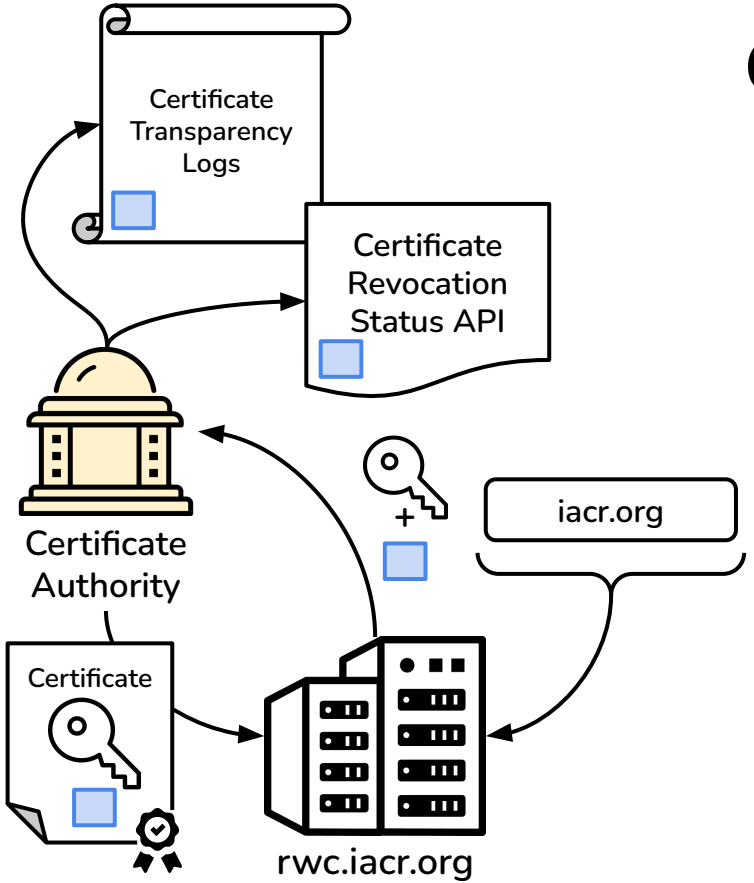

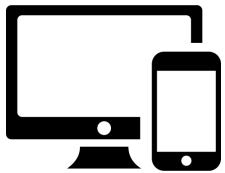

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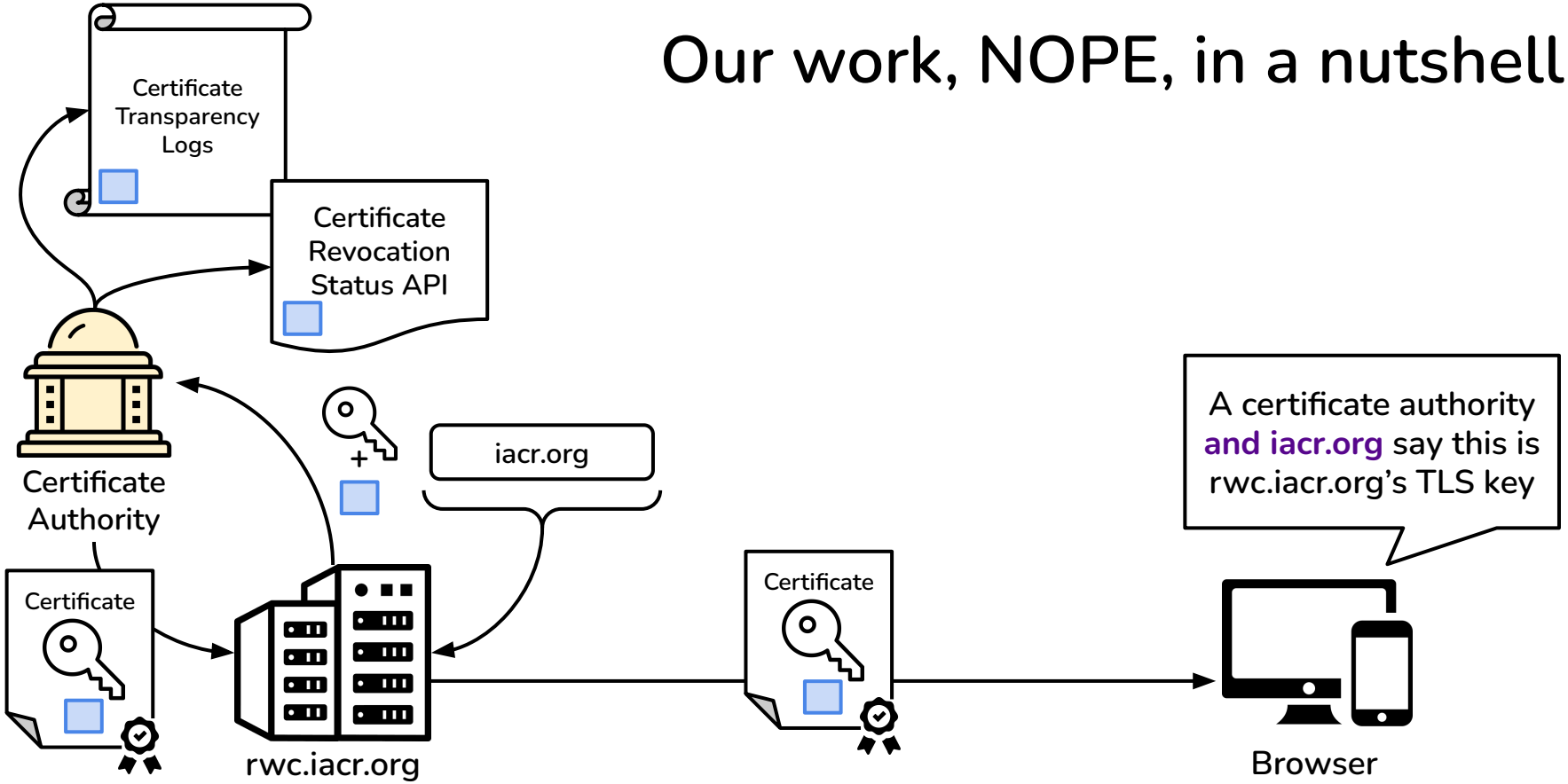


Welcome to NOPE

NOPE is a research project focused on improving server authentication by reducing dependence on certification authorities

Instead of solely relying on CAs, NOPE introduces a new method that uses succinct proofs, such as zero-knowledge proof
public key to a domain.

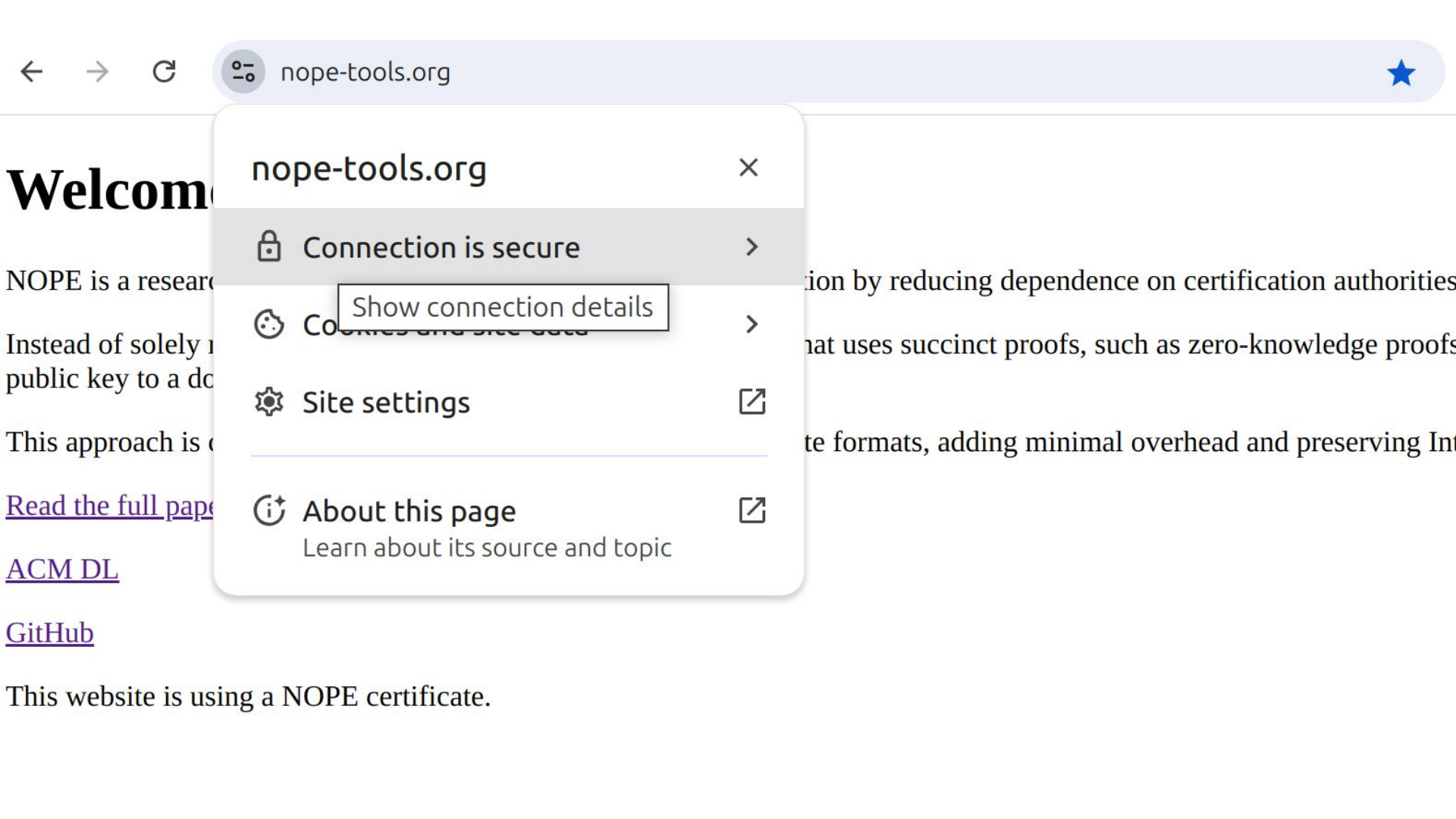
This approach is compatible with existing TLS servers and certificate formats, adding minimal overhead and preserving In

Read the full paper here.

ACM DL

GitHub

This website is using a NOPE certificate.



Welcom

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Read the full pape

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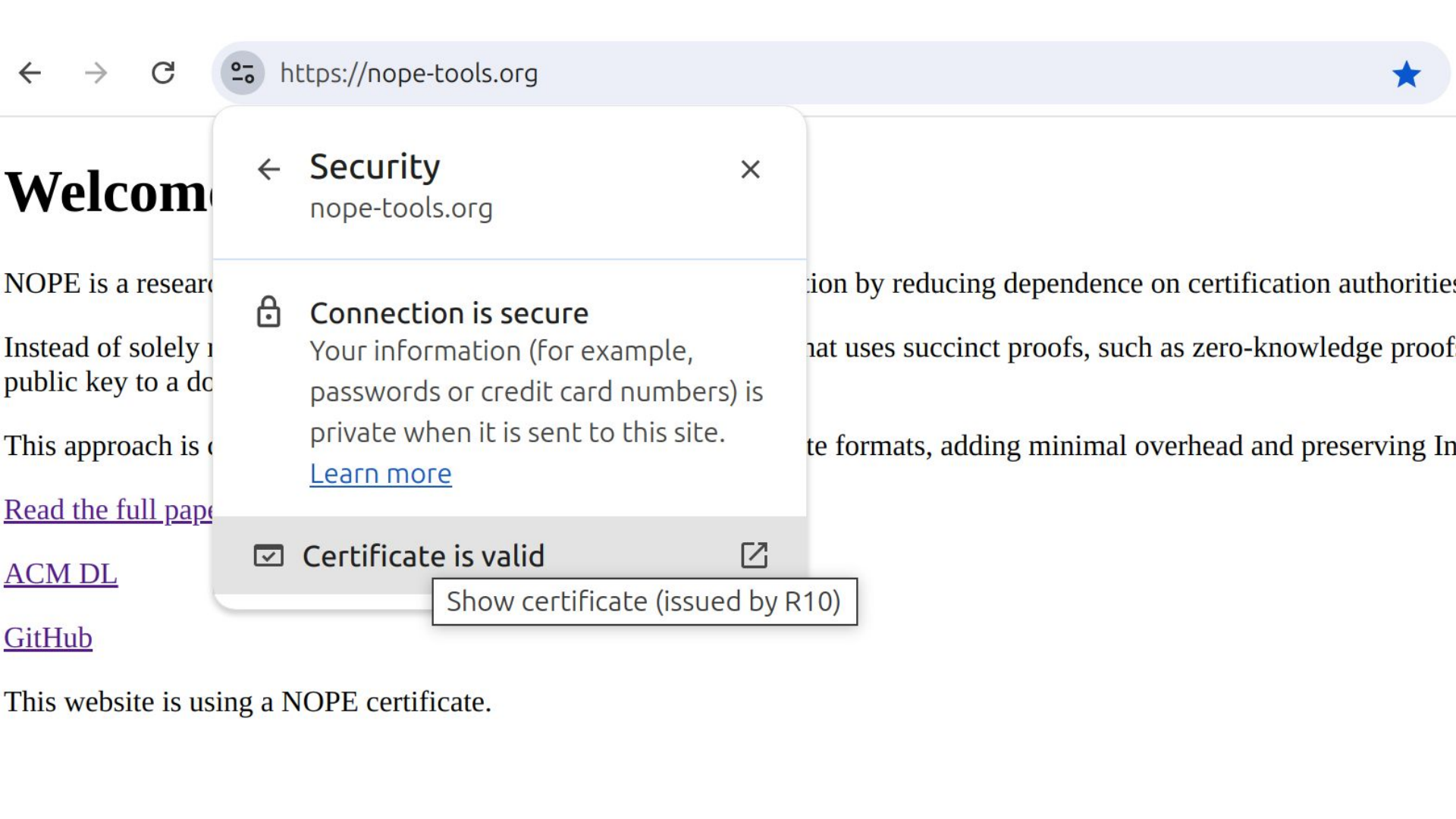

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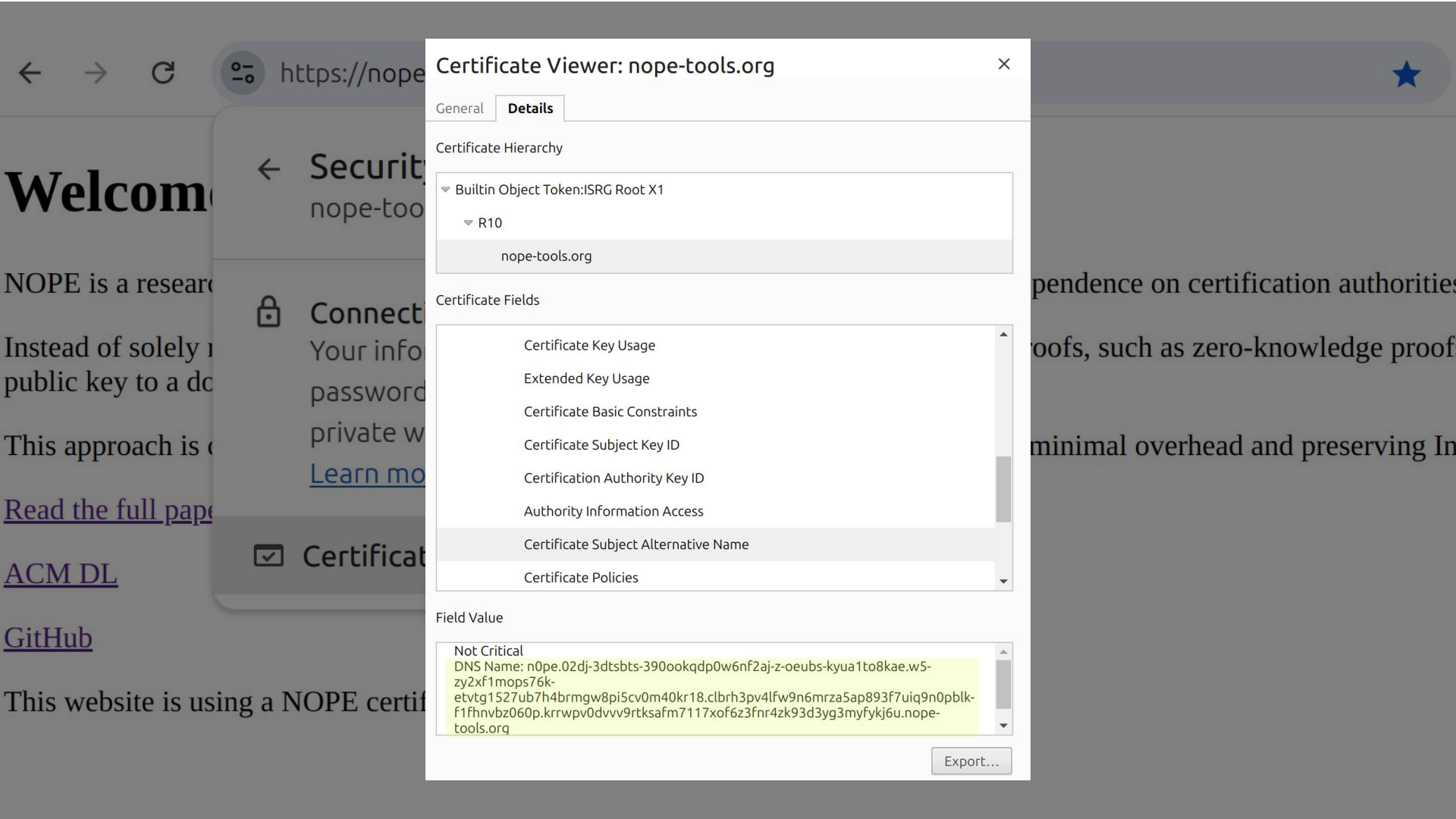
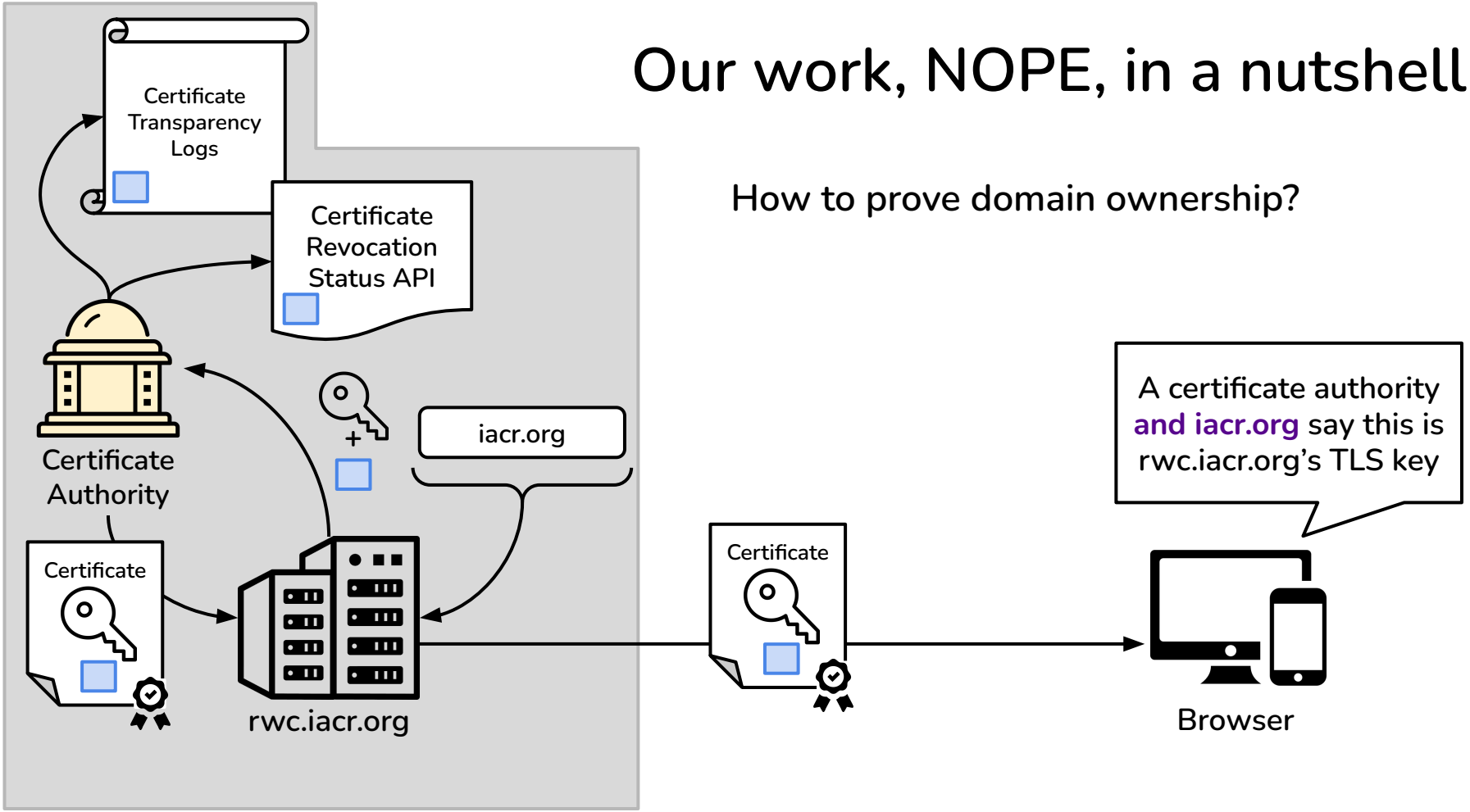

Certificate Viewer: nope-tools.org
General
Details
Certificate Hierarchy
Builtin Object Token:ISRG Root X1
R10
nope-tools.org
Certificate Fields
Certificate Key Usage
Extended Key Usage
Certificate Basic Constraints
Certificate Subject Key ID
Certification Authority Key ID
Authority Information Access
Certificate Subject Alternative Name
Certificate Policies
Field Value
Not Critical
DNS Name: n0pe.02dj-3dtsbts-390ookqdp0w6nf2aj-z-oeubs-kyua1to8kae.w5-zy2xf1mops76k-etvtg1527ub7h4brmgw8pi5cv0m40kr18.clbrh3pv4lfw9n6mrza5ap893f7uiq9n0pblk-f1fhnvbz060p.krrwpv0dvvv9rtksafm7117xof6z3fnr4zk93d3yg3myfykj6u.nope-tools.org
Export...

Our work, NOPE, in a nutshell

How to prove domain ownership?



There is a lesser used PKI, DNSSEC

There is a **lesser used** PKI, DNSSEC

Common objections

DNSSEC is used by fewer than 7% of all domains!

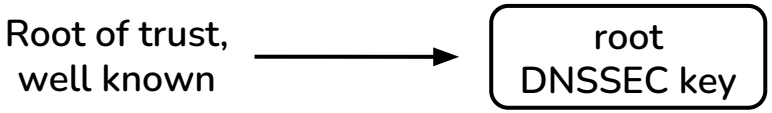
DNSSEC includes signatures with insecure schemes and parameters!

DNSSEC transport and validation is unreliable!

There is a **lesser used** PKI, DNSSEC

Common objections	Yes, however...
DNSSEC is used by fewer than 7% of all domains!	A domain owner can deploy DNSSEC for their own domain.
DNSSEC includes signatures with insecure schemes and parameters!	This was the case a decade ago, but not anymore.
DNSSEC transport and validation is unreliable!	NOPE does not require transporting DNSSEC records to clients.

DNSSEC from 30,000 feet



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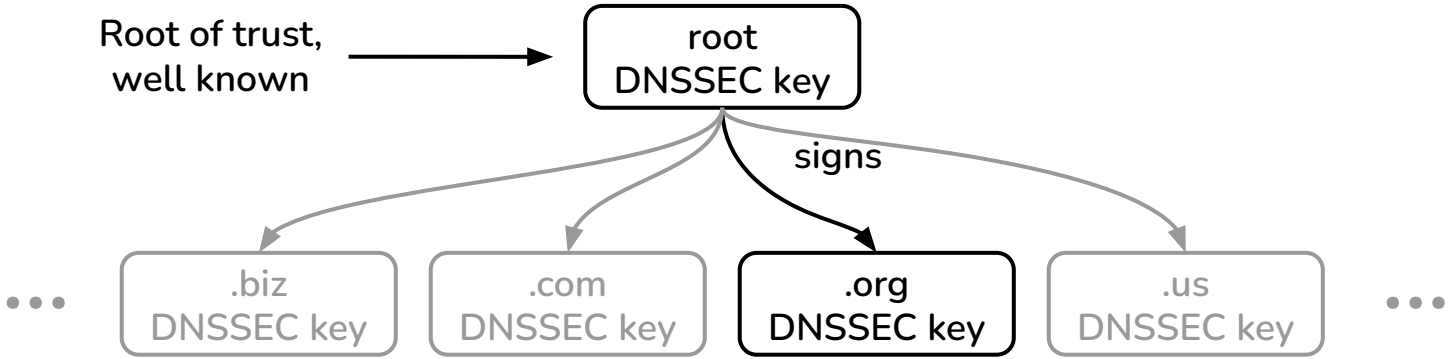

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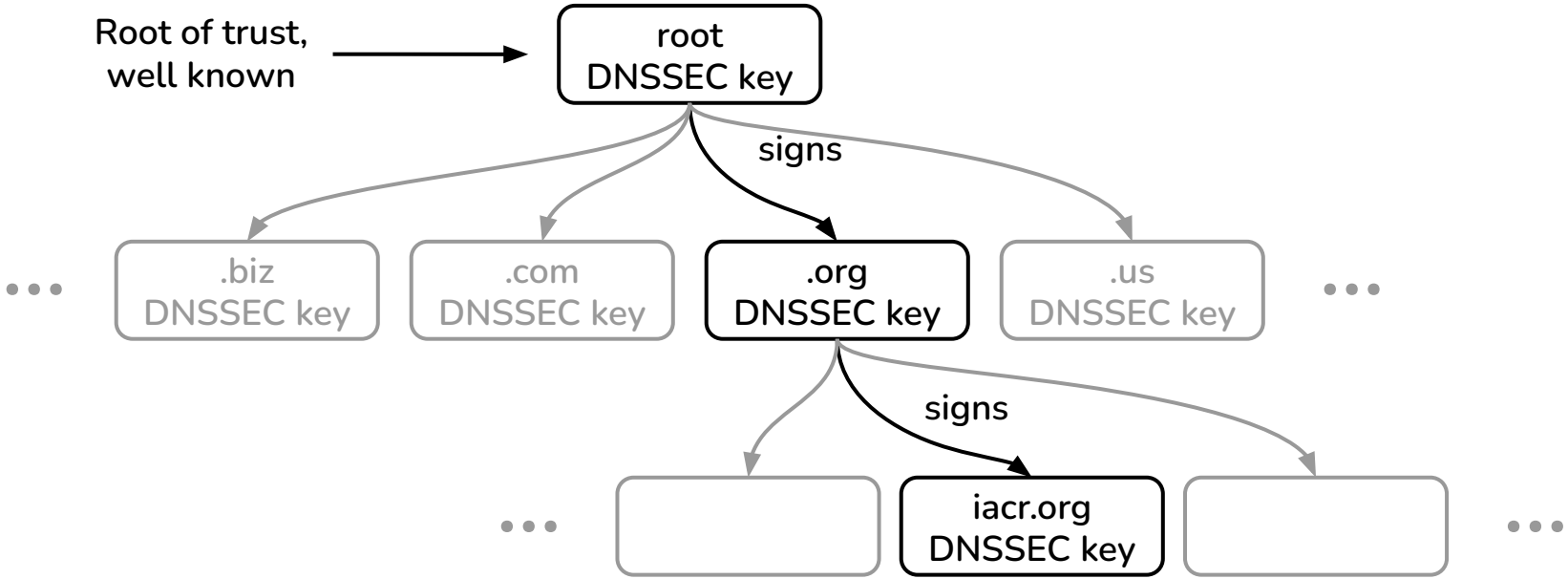

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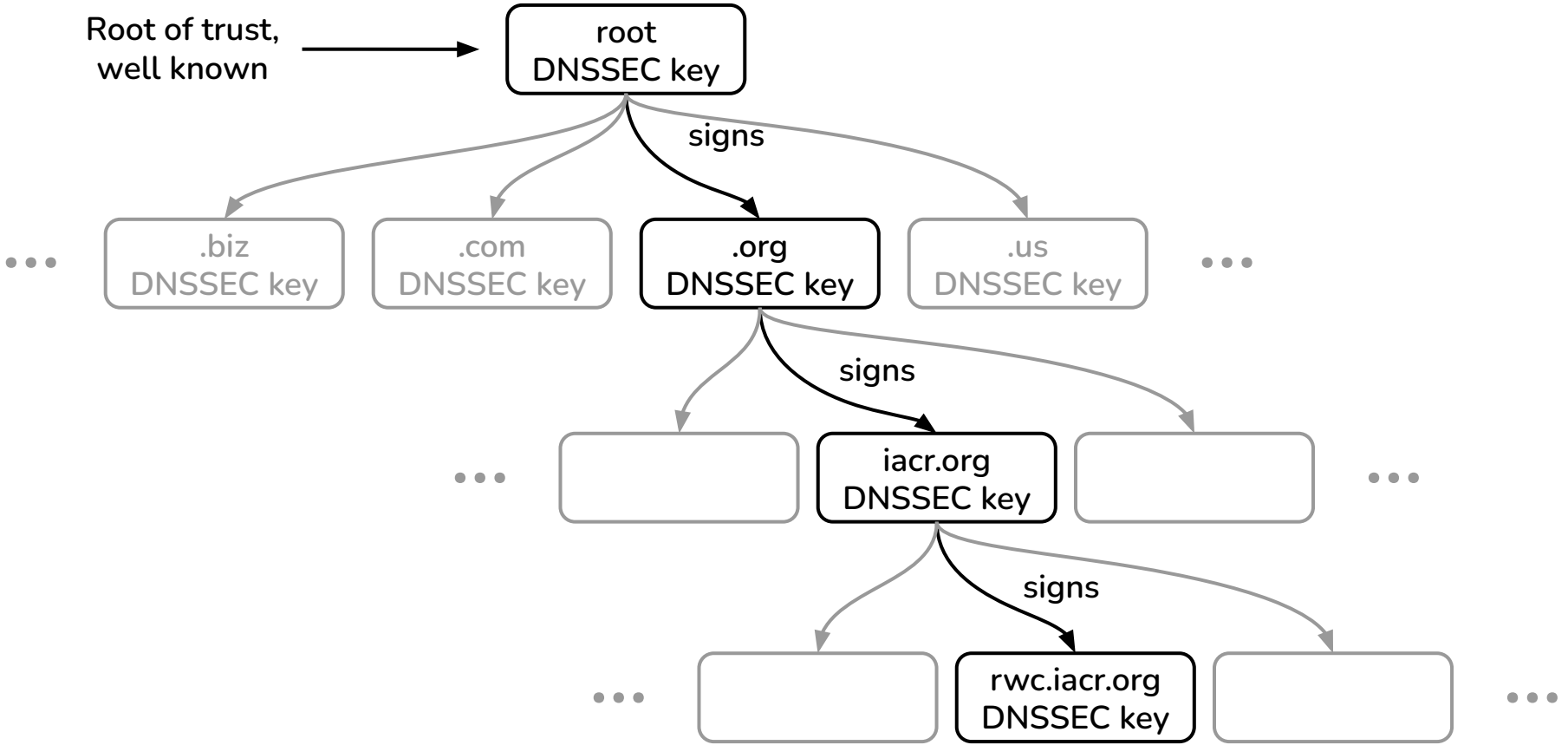
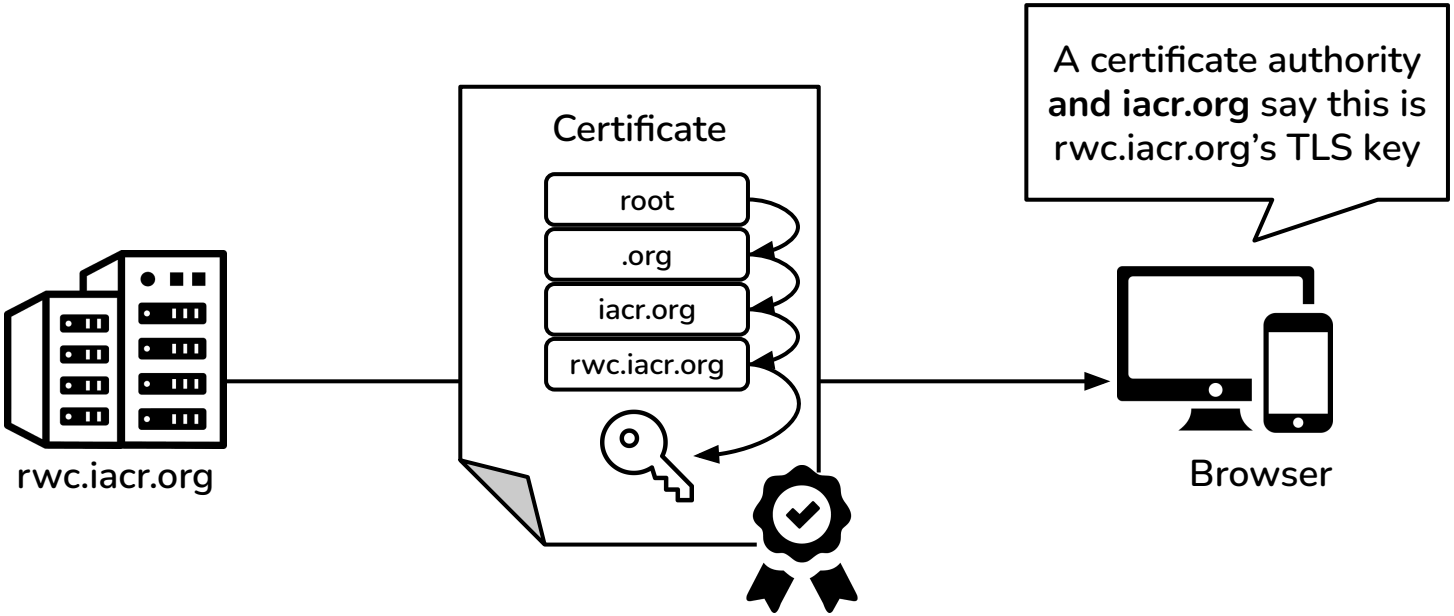


First attempt at building NOPE: use a DNSSEC chain as the proof



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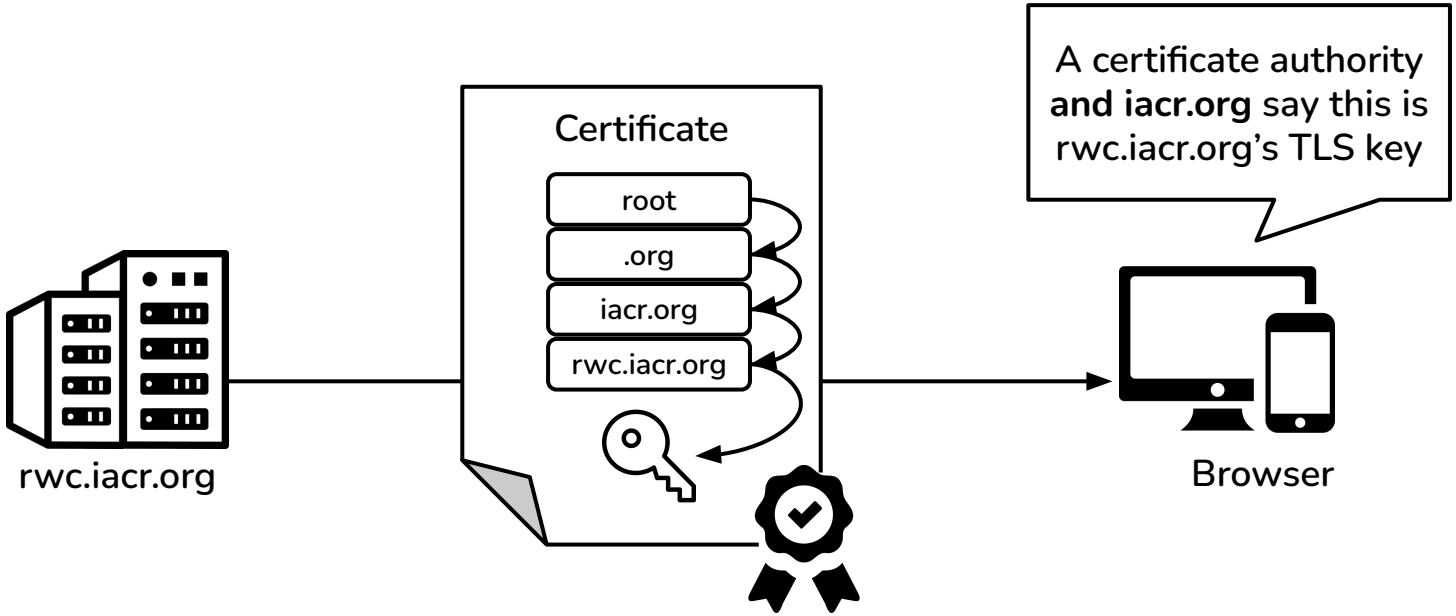
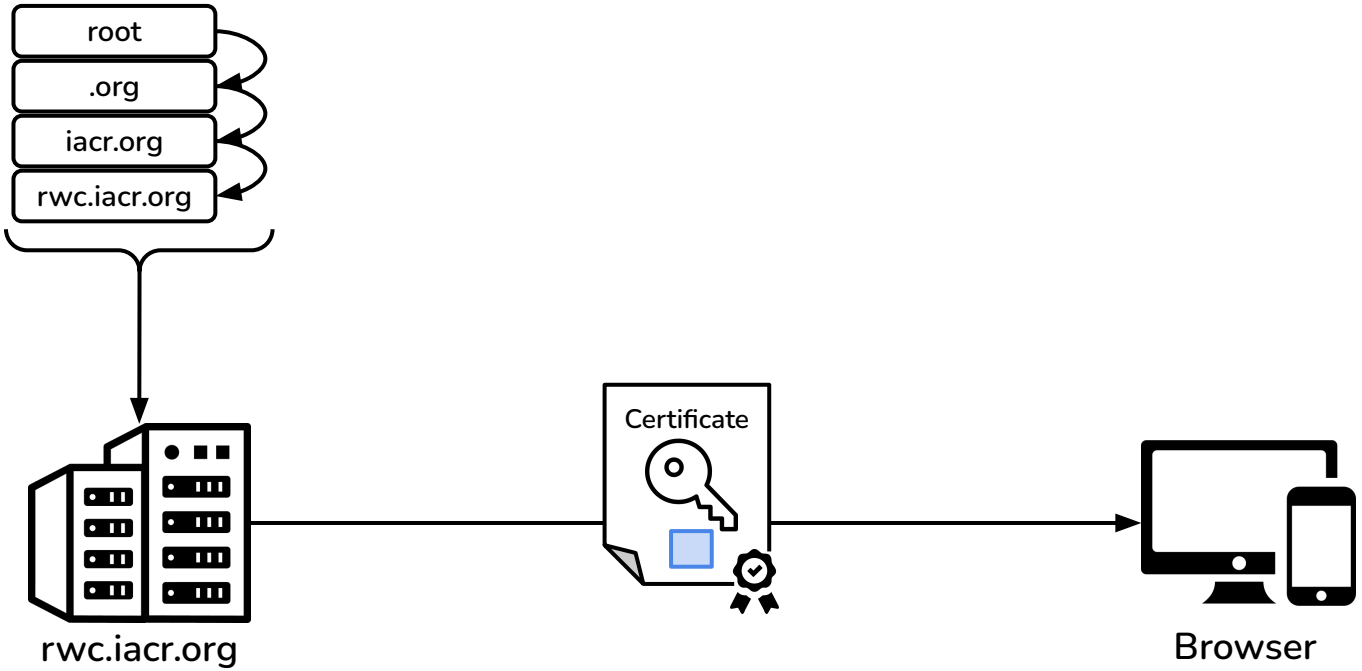


Including a DNSSEC chain in a certificate requires modifying infrastructure

Idea: prove the existence of the full DNSSEC chain



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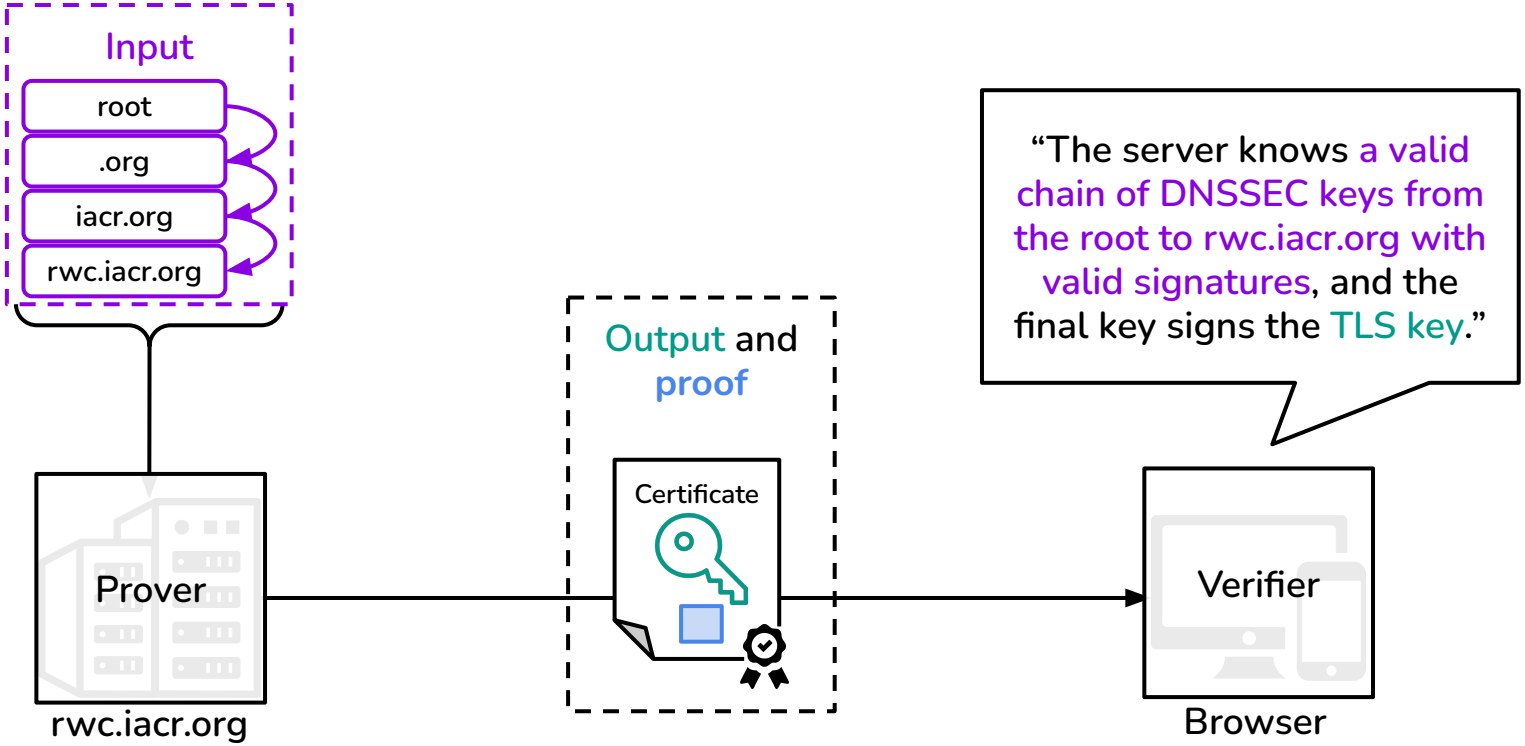

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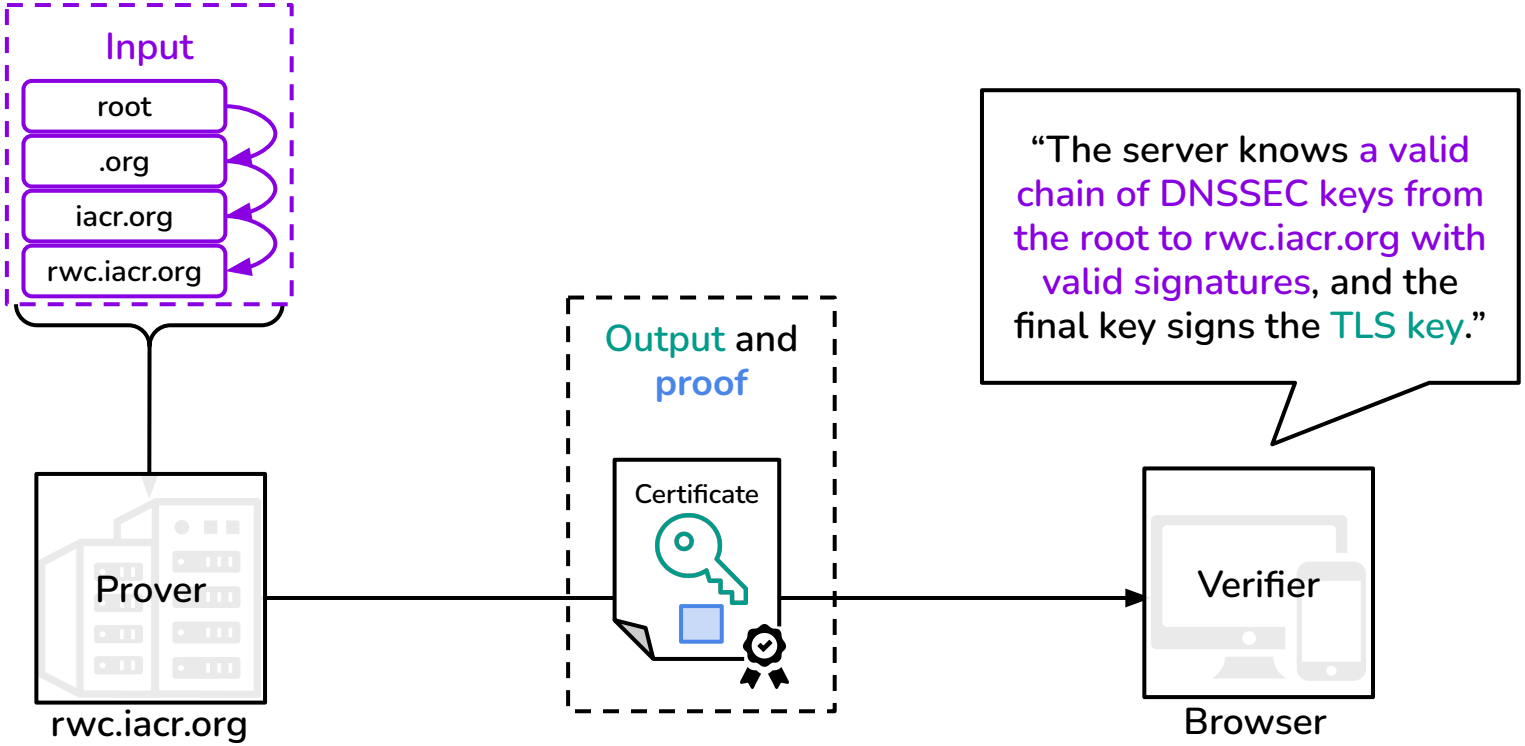
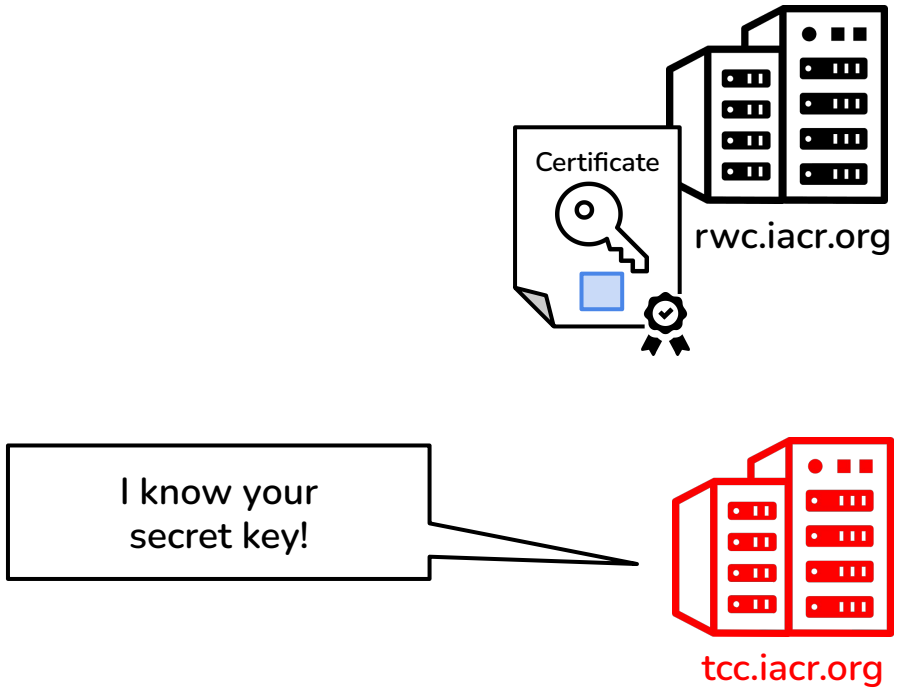
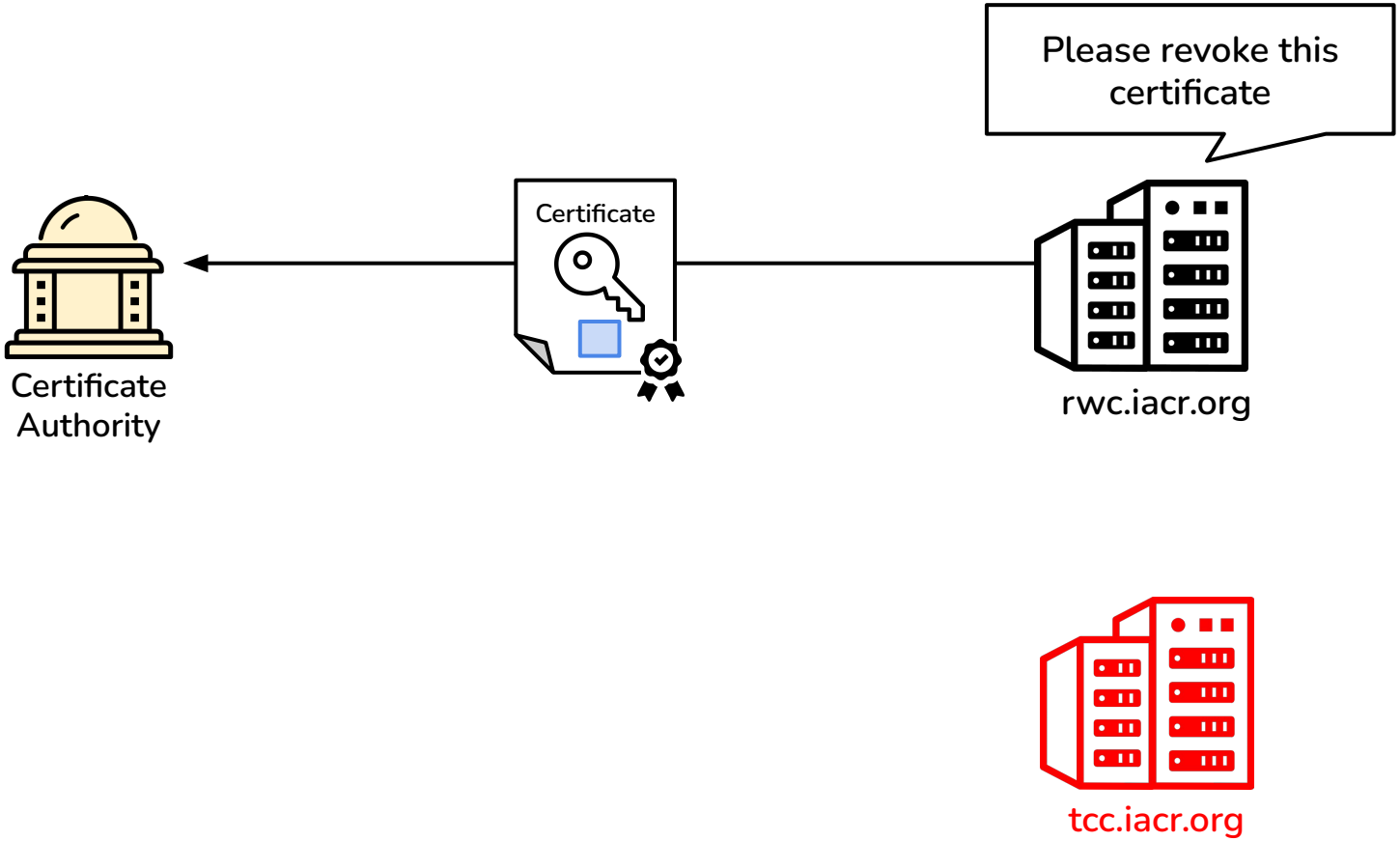
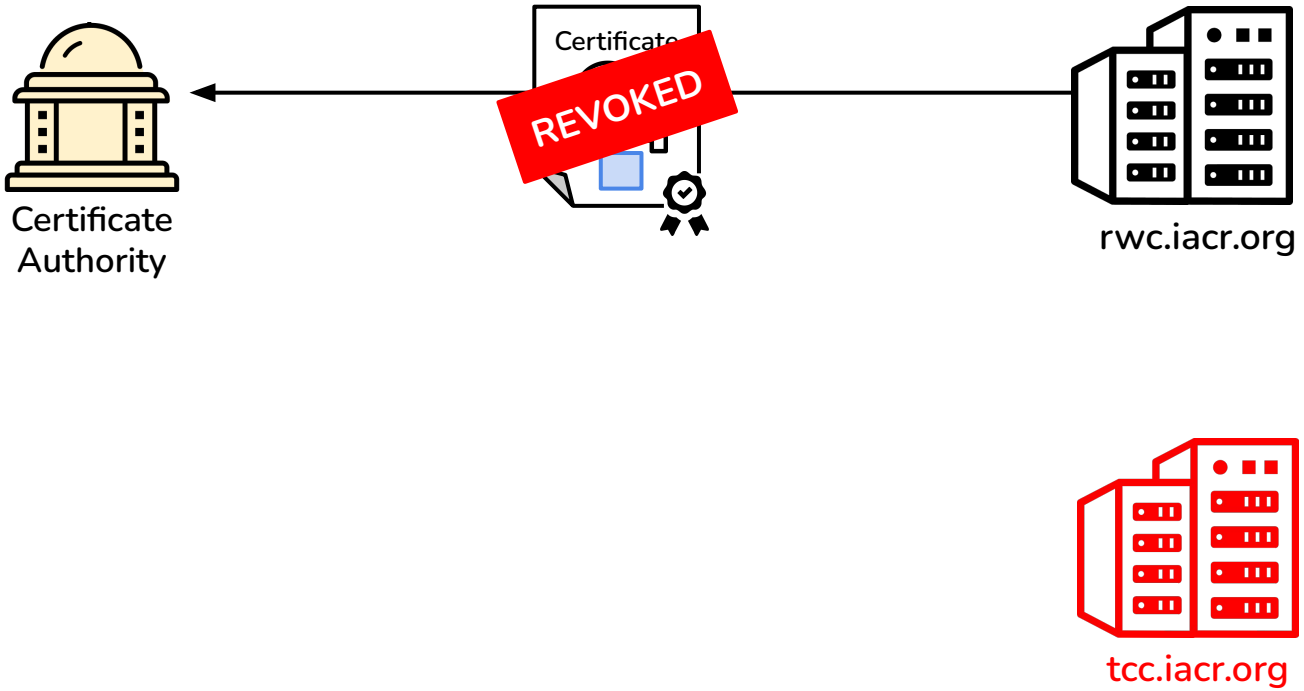


One challenge: how to revoke these proofs?


Certificate
rwc.iacr.org
I know your
secret key!
tcc.iacr.org


Please revoke this certificate
Certificate
Certificate Authority
rwc.iacr.org
tcc.iacr.org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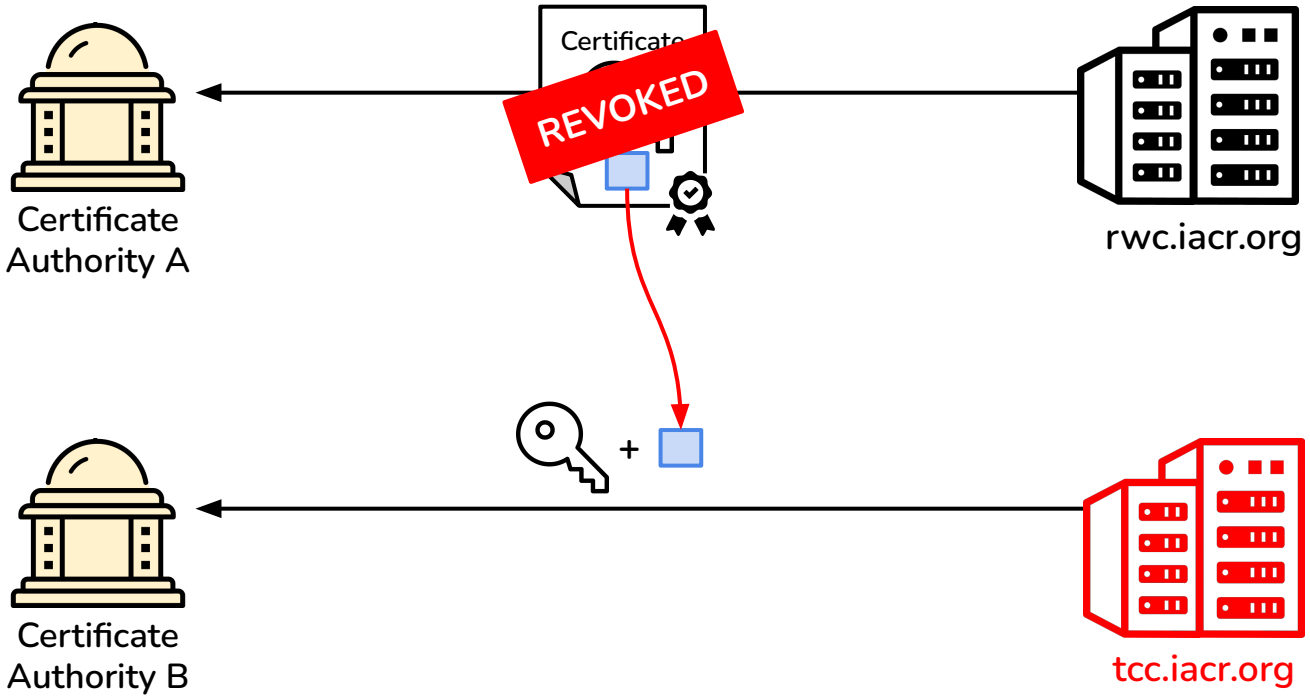
Certificate Authority
rwc.iacr.org
tcc.iacr.org


Certificate
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Certificate Authority A
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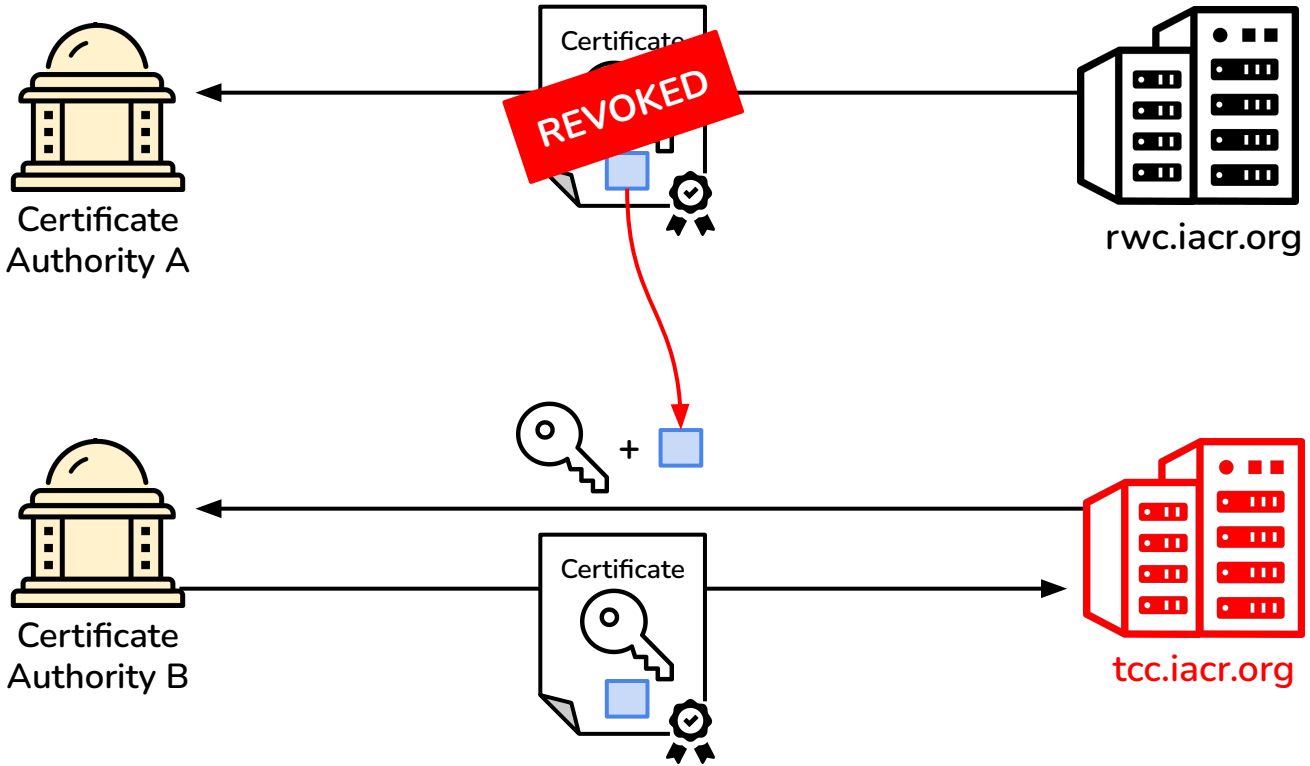
+
Certificate Authority B
tcc.iacr.org


Certificate
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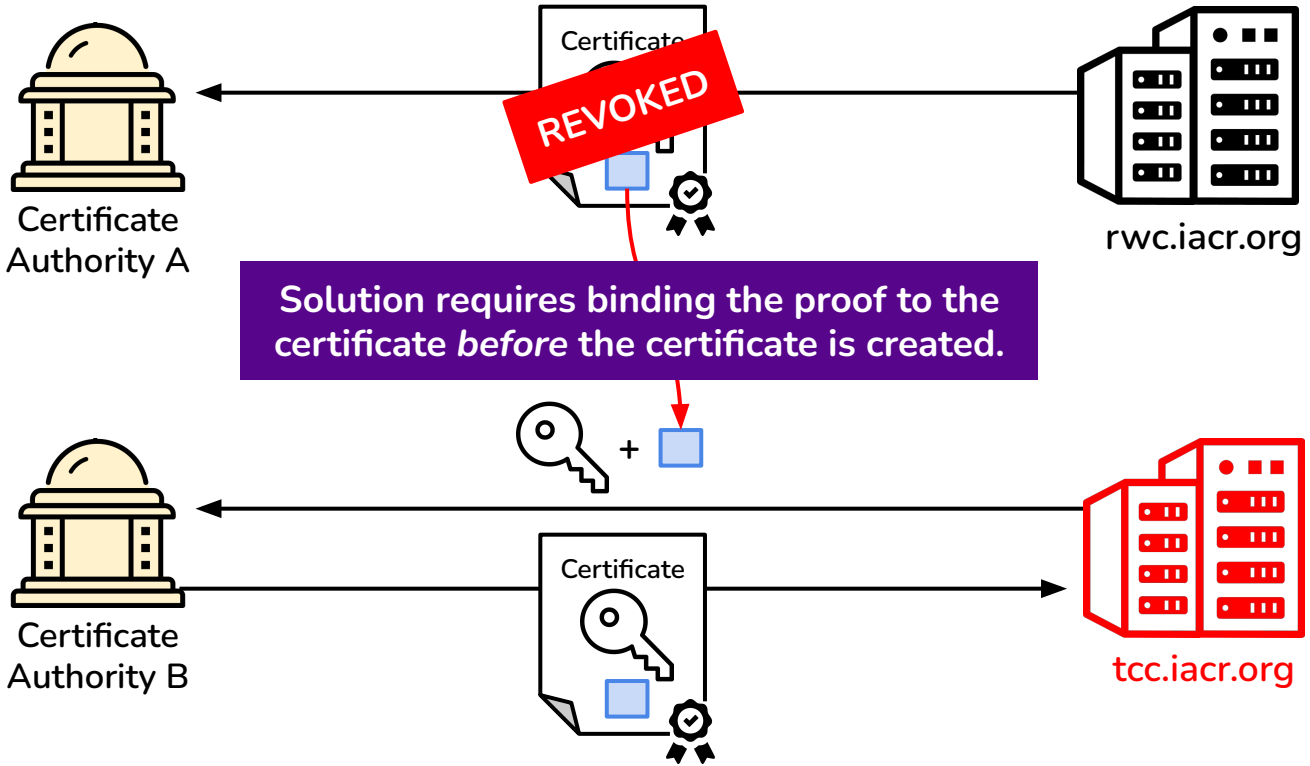
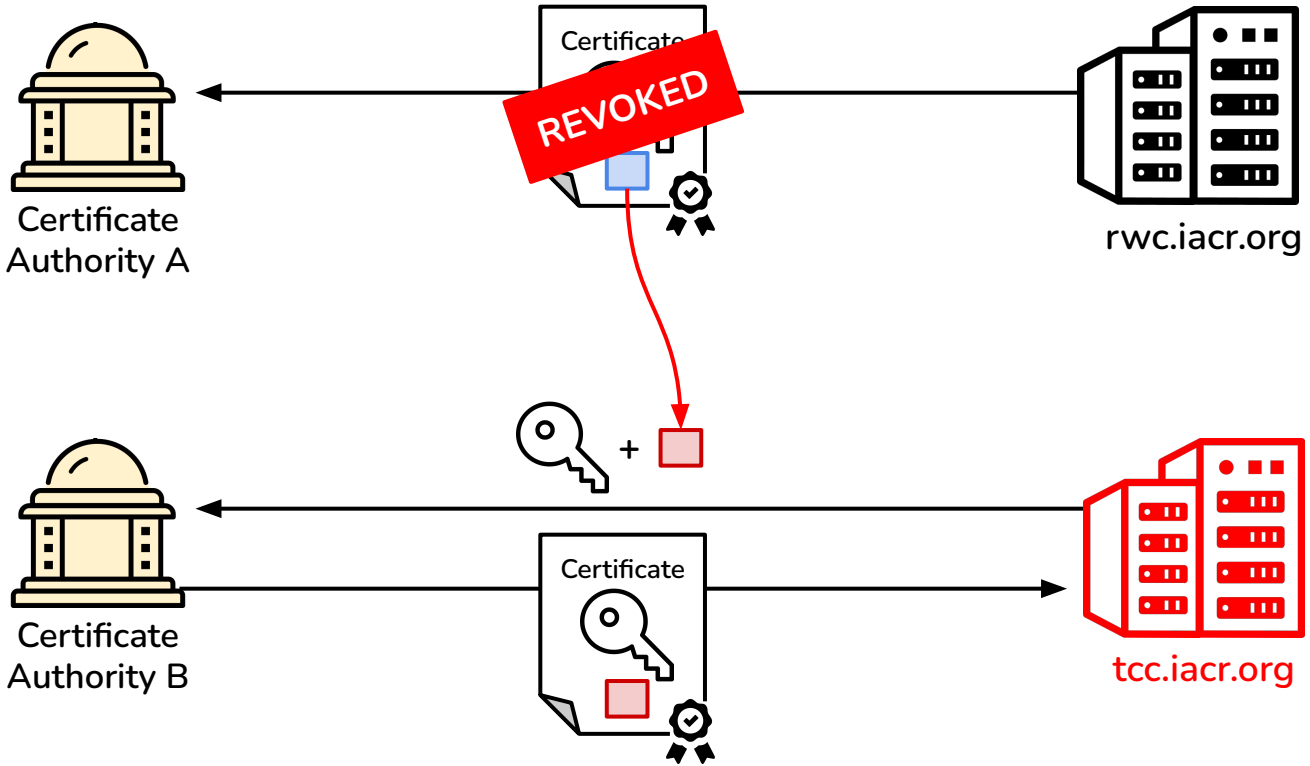

Certificate
REVOKED
Certificate Authority A
rwc.iacr.org
Solution requires binding the proof to the certificate *before* the certificate is created.
+
Certificate Authority B
Certificate
tcc.iacr.org


Certificate
REVOKED
Certificate Authority A
rwc.iacr.org
+
Certificate Authority B
Certificate
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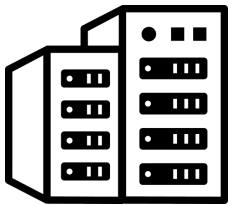
Implementation and evaluation of NOPE

(a) Can NOPE be concretely instantiated?

(b) What are the costs of NOPE?



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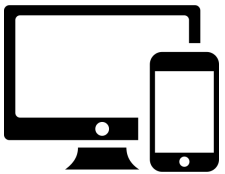
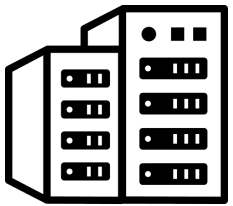


Browser

Implementation and evaluation of NOPE

➡ **(a) Can NOPE be concretely instantiated?**

(b) What are the costs of NOPE?



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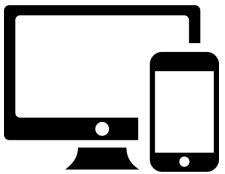
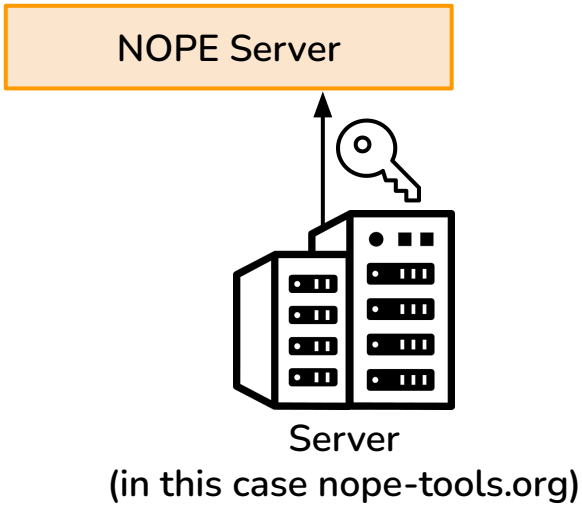
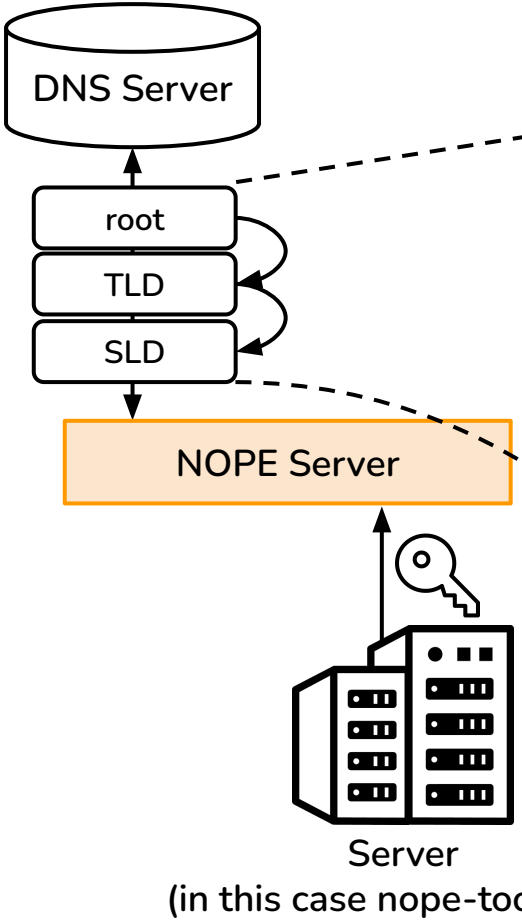


Browser

Implementation of NOPE



Implementation of NOPE

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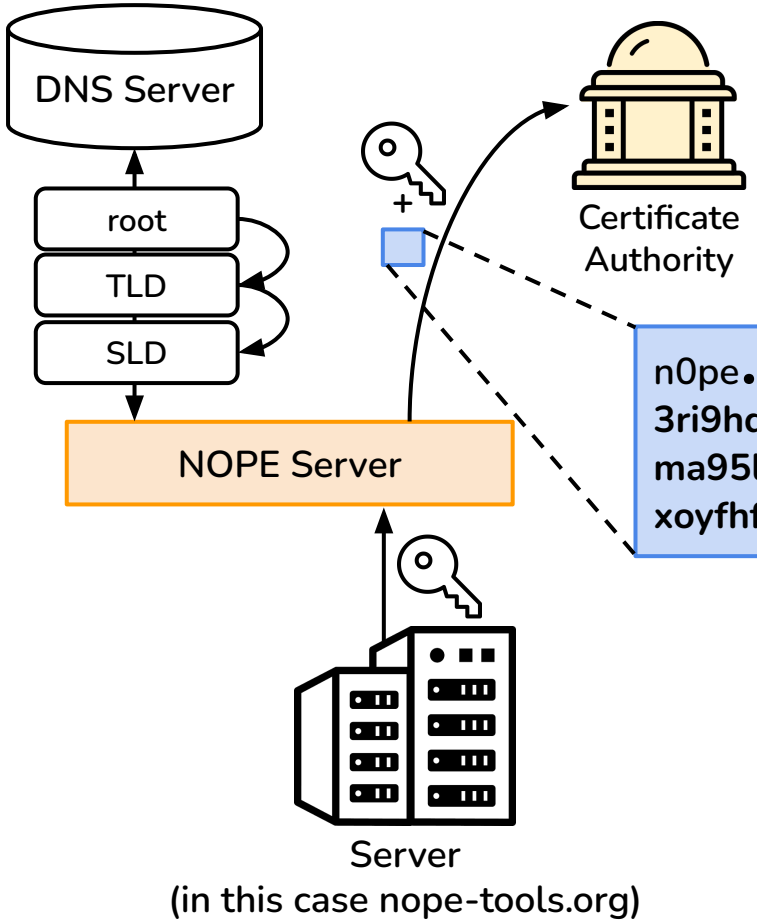
Implementation of NOPE



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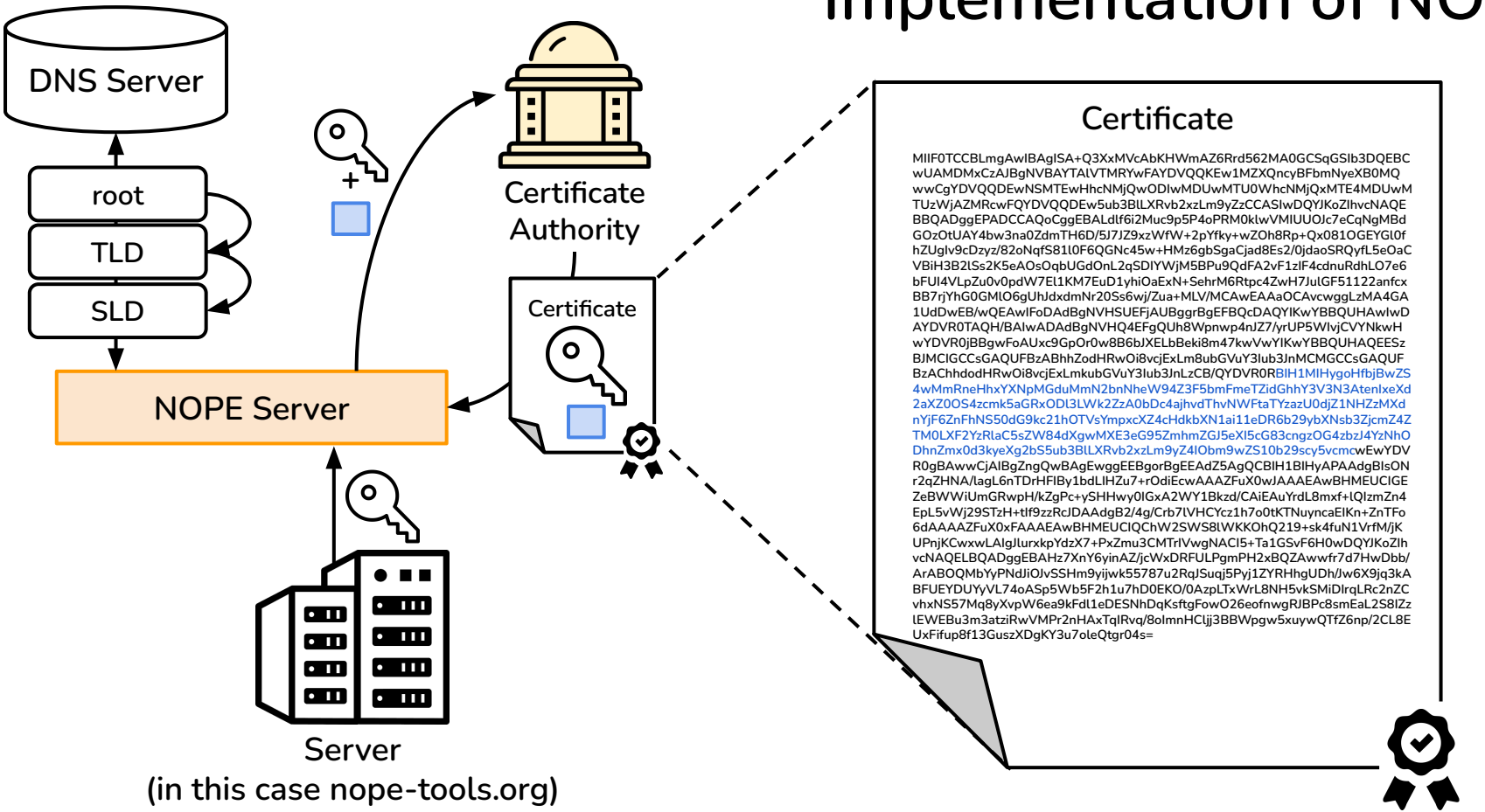
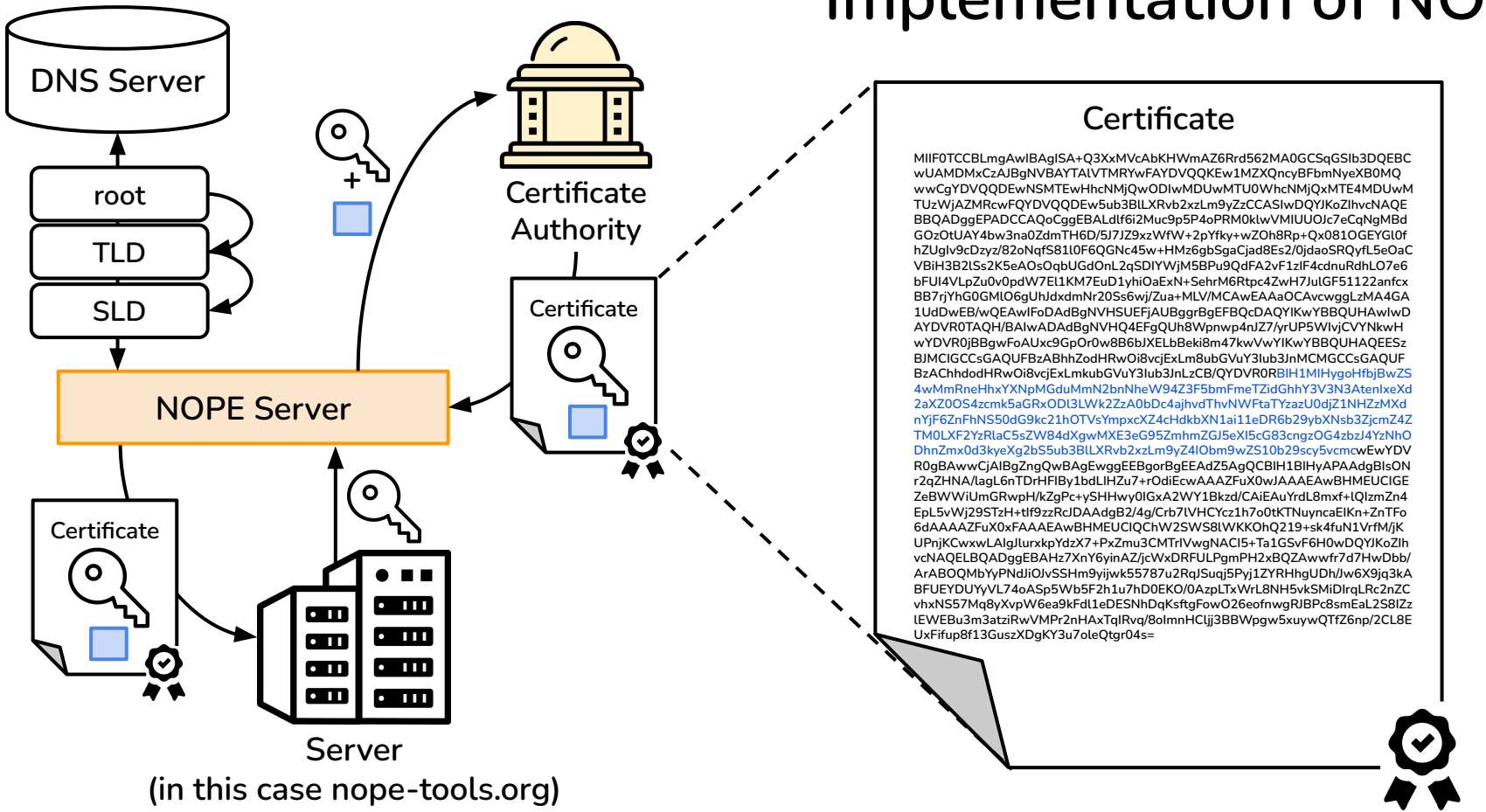
The proof is encoded in a domain owner's **subdomain**

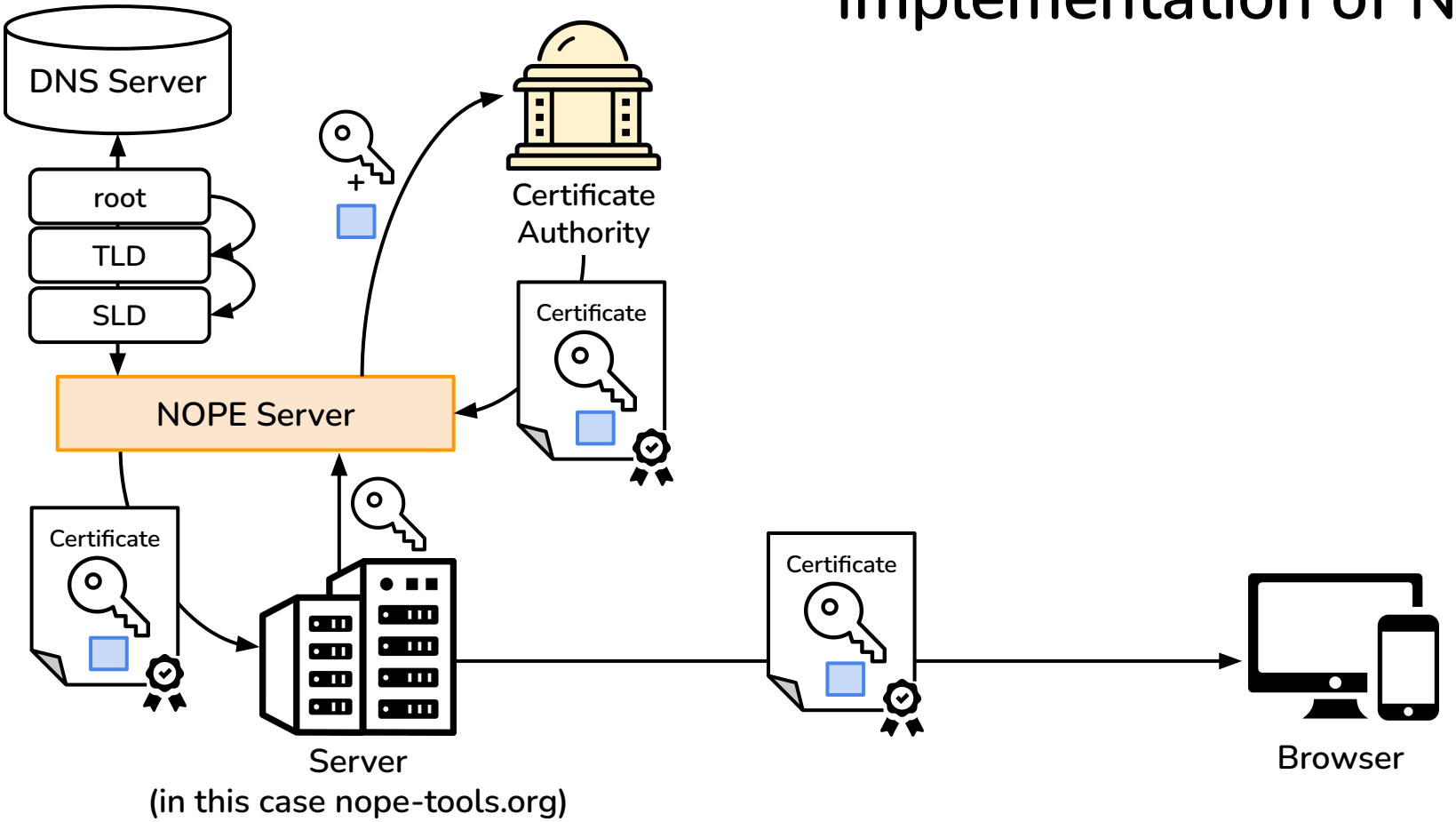
Implementation of NOPE



Implementation of NOPE



Implementation of NOPE



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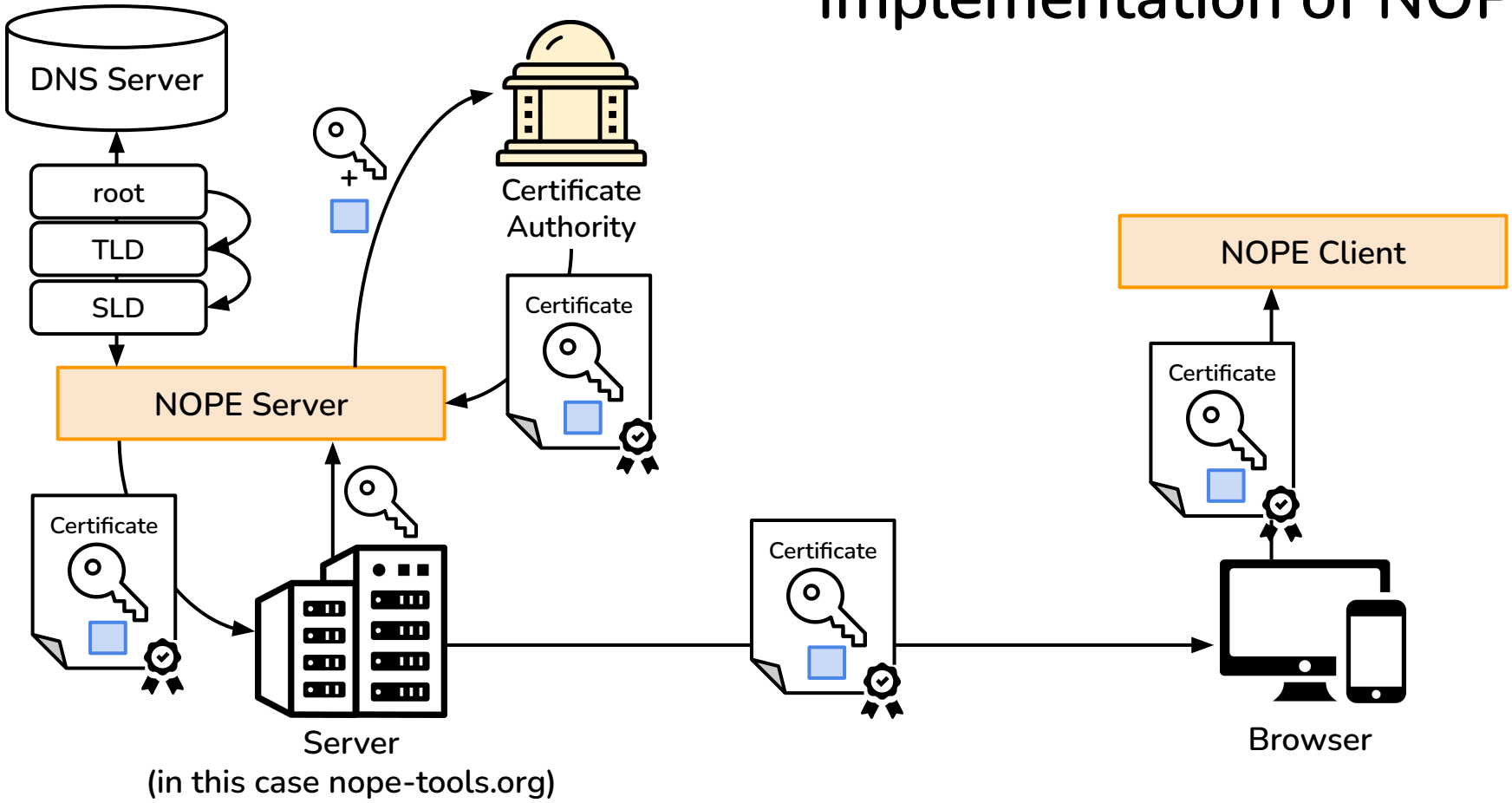
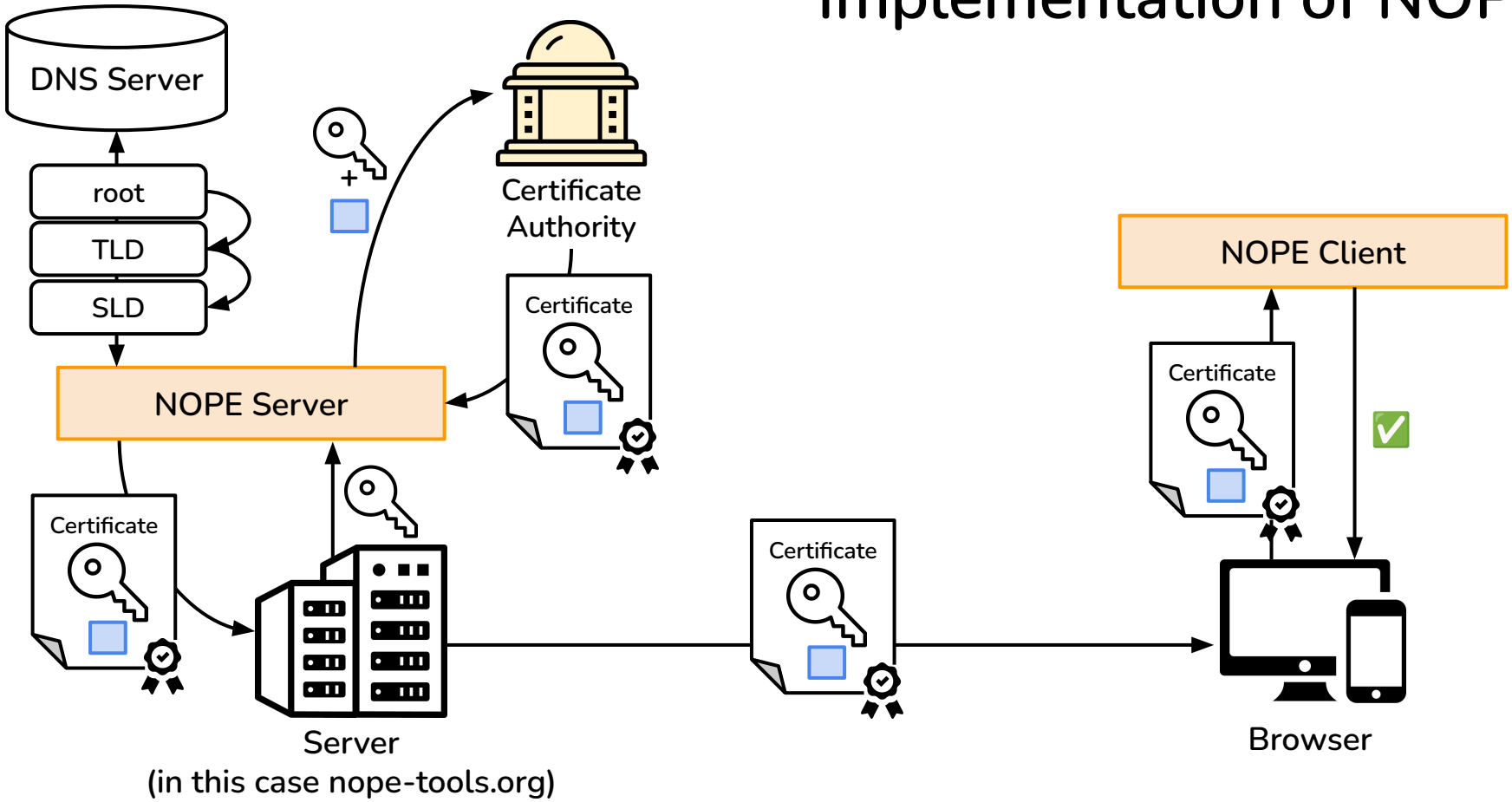


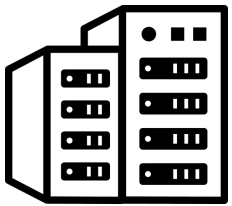
Implementation of NOPE



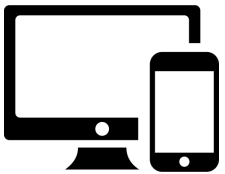
Implementation and evaluation of NOPE

(a) NOPE **can** be concretely instantiated

➡ **(b) What are the costs of NOPE?**



iacr.org



Browser

Overheads of NOPE are manageable

	Status quo	NOPE
Certificate chain size	2.5 KB	2.7 KB

All benchmarks run on a Google Cloud [59] e2-highmem-2 machine on a single thread

Overheads of NOPE are manageable

	Status quo	NOPE
Certificate chain size	2.5 KB	2.7 KB
Certificate issuance time	30 s	84 s

All benchmarks run on a Google Cloud [59] e2-highmem-2 machine on a single thread

Overheads of NOPE are manageable

	Status quo	NOPE
Certificate chain size	2.5 KB	2.7 KB
Certificate issuance time	30 s	84 s
Verification time (in browser)	0.3 ms	34.9 ms

All benchmarks run on a Google Cloud [59] e2-highmem-2 machine on a single thread

Overheads of NOPE are manageable

	Status quo	NOPE
Certificate chain size	2.5 KB	2.7 KB
Certificate issuance time	30 s	84 s
Verification time (in browser)	0.3 ms	34.9 ms
Verification time (native)	0.3 ms	1.5 ms

All benchmarks run on a Google Cloud [59] e2-highmem-2 machine on a single thread

Related Work

Domain Authentication

Efficient Constraint Representations

Succinct Proofs for Networking

Related Work

Domain Authentication

Efficient Constraint Representations

Succinct Proofs for Networking

Domain Authentication

Alternative designs: AKI, ARPKI, CertLedger, ENS, MonkeySphere, RHINE, Sovereign Keys
CA Strengthening: CAge, CAA, CertLock, Convergence, HPKP, Multi-Perspective Validation, TACK
Reactive approaches: CIRT, CRL, Forced perspectives, Gossip, Short-Lived Certificates, OCSP, YPIR

Related Work

Domain Authentication

Efficient Constraint Representations

Succinct Proofs for Networking

Efficient constraint representations

Control Flow: Buffet, Fairplay, Ginger, Libsnark, Pantry, Pinocchio, vRAM, vSQL, xJsnark, Zaatar
Cryptographic operations: circom-ecdsa, Cinderella, vSQL, WARPfold, xJsnark, Zombie
Parsing and string manipulation: Cinderella, zkLogin, ZK-JSON

Related Work

Domain Authentication

Efficient Constraint Representations

Succinct Proofs for Networking

Succinct proofs for networking

Digital Identity: Aptos Keyless, Cinderella, IDEA-DAC, zk-creds, zkPassport, ZK Email, ZK-JSON
Network protocols: DiStefano, DECO, DIDO, Janus, TLSNotary, zkTLS, ZKMB, Zombie

Takeaways of NOPE

It is practical to enhance Internet security right now, without any changes to existing Internet infrastructure.

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Succinct proofs provide an efficient interface between legacy protocols and systems.

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Succinct proofs provide an efficient interface between legacy protocols and systems.

Future work:

- Deploying NOPE natively in browsers
- Applying succinct proofs of DNSSEC, beyond server authentication