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Certificates and PKI

Simple in Principle - Complicated in Praxis

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Overview

- We use complex math to build a cryptographic system
- Enables TLS (and HTTPS)
- Universally applicable in networks
- Identify devices and code
- Build on top of public-private-key cryptography
- Simple concept, complicated standards

https://www.math.auckland.ac.nz/~sgal018/crypto-book/crypto-book.html

Public-Private-Key Cryptography

- Also called *Asymmetric Cryptography*
- Use math to generate key pairs
- Encrypt with one
  - Decrypt with the other
- Encrypted messages give no hint on the key itself
- Public key can be shared
- Private key must stay private
- Use someone's public on a message
  - It can only be read with the private key

Notes on Asymmetric Cryptography

- It is slow compared to symmetric crypto
  - It makes sense if you see the math
- Commonly used to establish a shared secret between client and server
  - Shared secret enables symmetric cryptograhpy
- Verifying the receiver across a network is taken for granted nowadays
- Thanks number theory

Who makes the Terminology - The IETF

- IETF (Internet Engineering Task Force)
- Founded in 1986
- Develop **voluntary** standards
- Publishes technical documents RFCs
- RFC (Request For Comments)
  - Historical acronym now RFC means RFC

https://www.ietf.org/about/introduction/

RFC 4949 - 1/3

- **Entity**
  - "*An active part of a system – a person, a set of persons (e.g., some kind of organization), an automated process, or a set of processes – that has a specific set of capabilities.*"
  - Anything that exists logically or conceptually
    - Your computer, your code, you yourself
  - Can be a server, software package, email contact
- **Identity**
  - "*The collective aspect of a set of attribute values (i.e., a set of characteristics) by which a system user or other system entity is recognizable or known.*"
  - Do not confuse with *Identifier*
  - Identifier is a unique key representing an identity

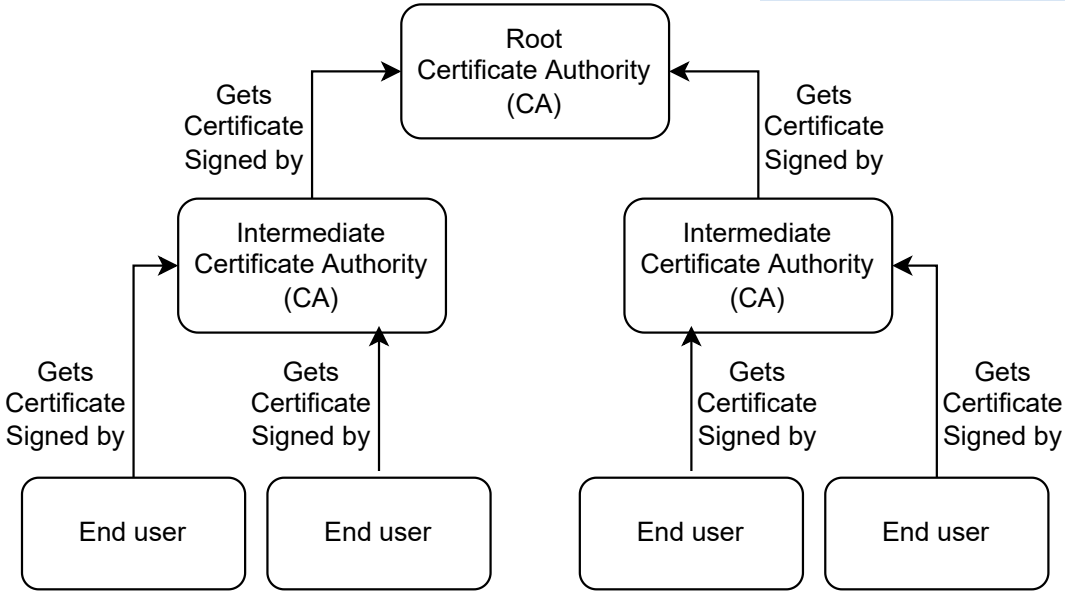
https://www.rfc-editor.org/rfc/rfc4949

RFC 4949 - 2/3

- **Claim**
  - An entity may declare an attribute
  - “My name is Max Mustermann”
  - Another entity may **Authenticate** a claim
- **Authentication**
  - Process of confirming the truth of a claim
  - When you login, you claim to be a user
    - And verify the claim by giving your password
- **End Entity** or End User
  - “*A system entity that is the subject of a public-key certificate and that is using, or is permitted and able to use, the matching private key only for purposes other than signing a digital certificate; i.e., an entity that is not a CA.*”

RFC 4949 - 3/3

- **Certificate Authority (CA)**
  - An entity that issues certificates to subscribers
- **Subscriber**
  - "*A user that is registered in a PKI and, therefore, can be named in the "subject" field of a certificate issued by a CA in that PKI.*"
- **Public-Key Certificate**
  - "*A digital certificate that binds a system entity's identifier to a public key value, and possibly to additional, secondary data items.*"
  - A public and metadata (hostname, expiry date, etc.)
- **Root Certificate**
  - "*A certificate for which the subject is a root.*"
  - "*The self-signed public-key certificate at the top of a certification hierarchy.*"


Root
Certificate Authority
(CA)
Gets
Certificate
Signed by
Gets
Certificate
Signed by
Intermediate
Certificate Authority
(CA)
Intermediate
Certificate Authority
(CA)
Gets
Certificate
Signed by
Gets
Certificate
Signed by
Gets
Certificate
Signed by
Gets
Certificate
Signed by
End user
End user
End user
End user

The gwdg.de Certificate

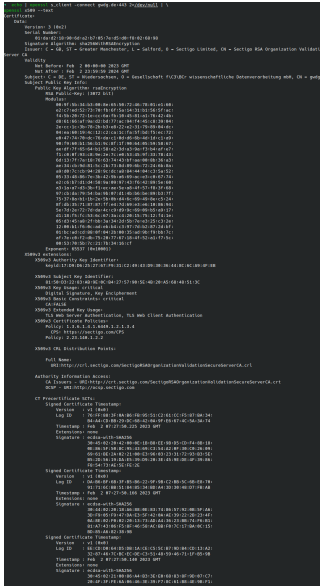
shell

```
echo | openssl s_client -connect gwdg.de:443 2>/dev/null | \
  openssl x509 --text
```

The gwdg.de Certificate

Find from top to bottom:

- Unique Serial Number
- Issuer metadata
- Validity range
- Subject metadata
  - Including encoded public key
- X509v3 extensions
  - Extended Key Usage
  - Basic Constraints
  - CRL Distribution Points
  - Authority Information Access
  - CT Precertificate SCTs
  - Subject Alternative Name
- Signature Algorithm



The hps.vi4io.org Certificate

shell

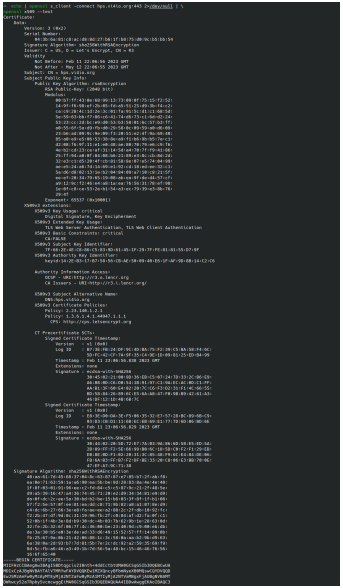
```
echo | openssl s_client -connect hps.vi4io.org:443 2>/dev/null|\
  openssl x509 --text
```

The hps.vi4io.org Certificate

Find differences top to bottom:

- Issuer metadata
- Validity range
- Subject metadata
- X509v3 extensions
  - CRL Distribution Points
  - Authority Information Access
  - CT Precertificate SCTs
  - Subject Alternative Name

At the end, you will understand most fields



Certificate Standard: X.509

- Most common format
  - Separate from SSH and PGP
- From the “PKIX standards”
- Works out-of-the-box for TLS and HTTPS clients and servers
  - Good ecosystem support
- Arose from X.500 project in 1988
  - ITU-T (International Telecommunication Union Standards Body) tried to build a phone book

https://www.rfc-editor.org/rfc/rfc5280
https://cabforum.org/baseline-requirements-documents/

Certificate Encoding

- X.509 builds on ASN.1, another ITU-T standard
- ASN.1 (Abstract Syntax Notation One) is an encoding standard
  - Similar to JSON and Protobuf
- ASN.1 does not define binary representation
  - Its encoding rules can lead to incompatible binaries
- DER (Distinguished Encoding Rules) is an ASN.1 encoding format
  - Most commonly used for X.509
  - Sometimes also BER (Basic Encoding Rules) another ASN.1 encoding format
  - DER encoding/decoding handled by libraries

https://www.rfc-editor.org/rfc/rfc5280
https://cabforum.org/baseline-requirements-documents/

Problematic Standards

- Certificates may be DER format or something “fancier”
  - Raw DER is binary data
- PEM (Privacy Enhanced EMail) encapsulates certificates
  - Adds header and footer
  - May hold any DER certificate, private key, public key
  - Similar to PGP and S/MIME
  - Don’t ask why it’s called “EMail” that’s another 4 RFC document
- PEM headers hold labels to describe payload
  - Attempt at standardization via RFC 7468
  - Labels can be inconsistent
- PEM file “typically” stored as `.pem`, `.crt` or `.cer`
  - Raw DER is commonly stored as `.der`

https://www.rfc-editor.org/rfc/rfc7468

Another Layer

- PEM might be included in an “envelope” with additional data
  - A “Certificate” might be a PEM file or an envelope with a PEM
- Envelopes are part of PKCS (Public Key Cryptography Standards)
  - Published by RSA (the company, not the algorithm)
- Most relevant are PKCS#7 and PKCS#12
  - Both can contain certificate chains
  - May hold PEM and raw DER, BER
  - May be stored as raw DER or as PEM
- PKCS#7 was rebranded as CMS (Cryptographic Message Syntax) by the IETF
  - Commonly stored as `.p7b` or `.p7c` and used in Java
- PKCS#12 commonly used with Microsoft products
  - Commonly stored as `.pfx` or `.p12`

https://www.rfc-editor.org/rfc/rfc3447
https://www.rfc-editor.org/rfc/rfc2315
https://www.rfc-editor.org/rfc/rfc7292

Key Encoding

- General pattern:
  - ASN.1 data structure
  - DER binary encoding
  - PEM headers
- Private keys commonly use PKCS#8
  - Can be encrypted using a passphrase
  - Uses another encoding standard within a PEM

A PEM in the Wild

- `hpcsa-course-vm-key.pem` was created for your cloud setup by OpenStack
- Try reading it with

shell

```
openssl x509 --text -noout -in hpcsa-course-vm-key.pem
```

- This fails, its a PEM but not a certificate

shell

```
openssl rsa -check -in hpcsa-course-vm-key.pem
```

- This prints your RSA private key

Summary

- X.509 is the standard for certificates
- DER is a common encoding used with it
- PEM encapsulates binary DER certificates for better usability on the web
- PKCS#7 and PKCS#12 encapsulate certs with additional certs and data
- Private keys are commonly PEM encoded

Overview

- By definition: Needs no certificates!
- Only goal: Bind names to public keys
  - `~/.ssh/authorized_keys` is a PKI
- Web PKI builds on top of certificates
  - Enables secure communication via the internet
- Anyone can create a public key and publish it
  - PGP (Pretty Good Privacy) concept
- On the web, what public keys and certificates to trust?

Trust Stores

- Trust Store contains preconfigured trusted root certificates
  - Usually preinstalled in your OS
  - Root certificates are self-signed
  - Who to trust to pick these?
- Microsoft, Apple, Mozilla (and partially Google) have trust store programs
- Over 100 CAs in most trust stores
  - Not all of them are morally "trustworthy"
  - Some governments operate CAs to spy on their citizens or impersonate websites
  - Some CAs were compromised in the past
- Trust stores are only as secure as the least secure CA

Attack Vector: Headset

- 2018 Sennheiser headset software installed a root certificate
  - Into the trust store of users
  - With the belonging private key hidden in the application
- Attackers would extract the private key
  - Use it to sign new web certificates
  - Systems with the Sennheiser software installed would accept them
- This is one example, there are more cases

https://medium.com/asecuritysite-when-bob-met-alice/your-headphones-might-break-the-security-of-your-computer-4f304ed86611

Improvements to Security

- Baseline for issuing CAs was made more strict
- RFC 6962 introduced CT (Certificate Transparency)
  - Impartial observers check for fraudulent certificates
  - Checks are recorded in the certificates
- Root CA certificates are not used for automatically singing certificates
  - Only kept on special air-gaped machines
  - Intermediate certs used for automatic signing (certificate chain)
- Do not disable certificate path validation
  - e.g., `curl -k`
  - Unless you know you can trust the server

https://www.rfc-editor.org/rfc/rfc6962

Inspecting Your Trust Store

- On Linux installed via `ca-certificates` package
- In `/etc/ssl/certs`
- Extract and inspect certs

shell

```
trust extract --format=x509-directory x509-certs && cd $…
openssl x509 -noout -text -inform=der -in NAME.pem
```

- Look for
  - Issuer
  - Subject
  - Validity
  - x509 extensions

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6 Practical Problems

7 Let's Encrypt

Getting a Certificate from a CA - In Theory

1. You create a key pair
2. You submit your key with your data to a CA
3. CA validates your data
4. CA signs and returns a certificate

- After some time your certificate expires
  - Replace it using above process

Getting a Certificate from a CA - In Practice

Solve two **hard** problems in computer science

- Cache invalidation
- Naming things

DNs (Distinguished Names)

- Certificate issuer/subject metadata field
  - `Subject: YOUR_NAME`
  - `YOUR_NAME` could be `my.domain.de`
- Historical artifact
- Instead only use CN (Common Name)
- List domains under SANs (Subject Alternative Names)
  - `DNS:my.domain.de`
  - Wildcards are possible `DNS:*.pages.gwdguser.de`
  - Be careful with wildcards

Generating a Key Pair

- Optimally, generate the key pair yourself
- Ensure security of the private key
- From key pair generate a CSR (Certificate Signing Request)
  - CSR is signed, can be freely shared
- Send CSR to a CA

Certificate Signing Request Validation

CSR Validation has 3 Options:

- DV (Domain Validation)
  - Check DNS name in WHOIS record
  - Either send an email
  - Or use ACME (Automatic Certificate Management Environment)
    - For a HTTP challenge
    - For a DNS TXT record check
- OV (Organization Validation) and EV (Extended Validation)
  - Builds on top of DV
  - Associate legal entity with certificate
  - Takes days or weeks to process
- DV is good enough usually

https://ietf-wg-acme.github.io/acme/draft-ietf-acme-acme.html

Domain Validation Security

- What does successful DV mean?
  - Some entity was at one point in time able to either
    - Read email
    - Configure DNS
    - Serve an HTTP challenge
  - Relies on the security of these layers
  - Fraudulent certificates were issued
    - e.g., on an Amazon domain in 2018

https://doublepulsar.com/hijack-of-amazons-internet-domain-service-used-to-reroute-web-traffic-for-two-hours-unnoticed-3a6f0dda6a6f

Certificate Expiration

- Validity range on certs is very common
- Not a hard requirement
- Incorrect system clocks are a problem
  - Out of sync system clock might reject a valid cert
  - Systems without internal time reset to UNIX epoch 0 or 01.01.1970
- Private keys should have proper life cycle
  - Separate keys for certificate singing and encryption

Certificate Renewal

- No standard process
- Just replace the old cert with a new one
- Short lived certs are better for security
- Let's Encrypt defaults to 90 days

Certificate Revocation

- Certs might be unneeded
- Private keys can be compromised
- ⇒ Revoke the certificate
- Revoking X.509 certs is a mess
- Revocation status cannot be encoded in a certificate
- 2 systems in use
  - CRLs (Certificate Revocation Lists)
  - OCSP (Online Certificate Singing Protocol)

https://scotthelme.co.uk/revocation-is-broken/

CRLs (Certificate Revocation Lists)

- Defined in RFC 5280
- Long list of serial numbers of revoked certs
- Can be linked in a certificate
  - "Look for my serial number here, if I am on this list, I am revoked"
- What if the CRL endpoint is unreachable?
  - The certificate is accepted
- Lists are often cached
  - Propagating new revocations takes time

https://www.ietf.org/rfc/rfc5280

OCSP (Online Certificate Signing Protocol)

- Defined in RFC 2560
- Similar to CRL, endpoints can be queried for status of a cert
- Queries are for a specific certificate
- Privacy issue: The OCSP responder knows the websites you are visiting
- Solved by OCSP stapling
  - Owner of cert gets short-lived token from OCSP to validate cert
  - Might as well use short-lived certificates

https://www.ietf.org/rfc/rfc2560

Using a Certificate

1. Set up a HTTPs server
2. Point it to certificate file and public key
3. Done

Overview

- Non-profit company
- https://letsencrypt.org/
- Founded in 2012
- Provides a free service for acquiring certificates
  - Only supports automatic domain-validation
  - Over 300 mil (unexpired) certificates - November 2022

https://letsencrypt.org/stats/

Certbot

- Open-source tool
- Allows obtaining certificates from Let's Encrypt
- Can also install them via plugins
  - Support Apache, NGINX, etc.
- Automatically renew certificates
- Uses ACME for DV

https://github.com/certbot/certbot

Exercise

- Please work on the exercise now.