Public Key Infrastructures

Gianluca Dini
Dept. of Ingegneria dell’Informazione
University of Pisa
Email: gianluca.dini@.unipi.it
Version: 15/04/2025

1

Public Key Infrastructures

CERTIFICATES: HOW TO DEFEAT THE MAN-IN-THE-MIDDLE

2

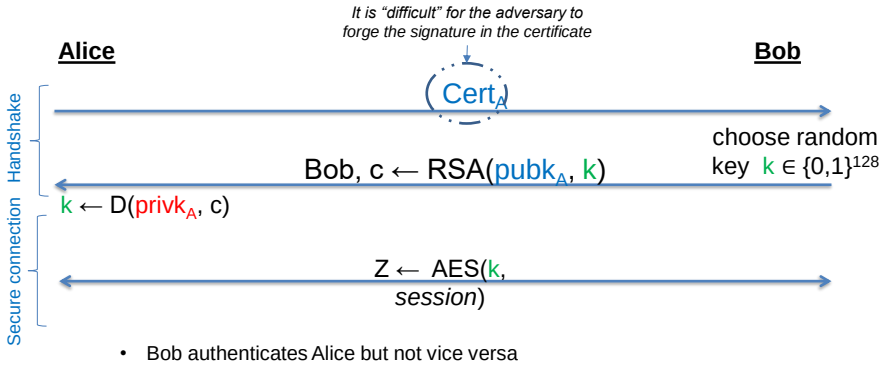
Certificates and Certification Authority

- Certificate format (basic):
  - **$Cert_A$ = Alice, $pubK_A$, L,…, S($priv_{CA}$, Alice || $pubK_A$ || L, …)**

    with **L** = validity period
- A certificate indissolubly binds the identity of a subject (Alice) to his/her public key ($pubK_A$); the binding is the digital signature of a Trusted Third Party called **Certification Autority** (CA)
  - In order to verify a certificate you need the CA's public key $pubK_{CA}$

6

Key Transport with Certificates



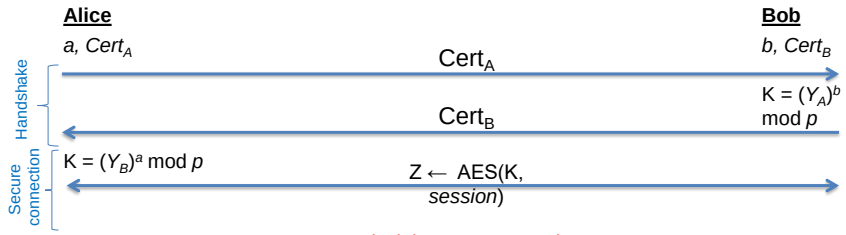
- Bob authenticates Alice but not vice versa

Disclaimer: oy protocol

7

Diffie-Hellman with certificates

- $Cert_A = Alice, Y_A, L_A, S_{CA}(Alice \,||\, Y_A \,||\, L_A)$ with
- $Y_A = g^a \bmod p$ Alice’s public key, and a Alice’s private key
- S_{CA} digital signature by certification authority CA



Disclaimer: oy protocol

8

PKIs

CERTIFICATION AUTHORITIES

9

CA’s obligations [→]

- CA must be reliable
  I. CA must verify that owner of ($privK_A$, $pubK_A$) pair is really entitled to use that name
     - CA establishes rules/policies to verify that a person has rights to the name
     - Identifying a subject is not easy; depends on country
  – CA must verify that the name (e.g., Alice) goes along with the key ($privK_A$)

10

CA’s obligations [↓]

- CA’s certificate must be (immediately) available
  – CA’s certificate is released at user registration time
  – CA’s certificate is published in newspapers
  – CA’s certificate is embedded in a browser installation package (is this secure?)
  – …

11

Trust delegation

- Certification is based on trust delegation/transfer

1. Bob trusts and delegates CA to verify Alice’s identity and attest the authenticity of $pubK_A$,
2. Bob trusts the authenticity of CA’s $pubK_{CA}$

consequently

- Through certificate $Cert_A$ signed by CA,
  Bob acquires trust (believes) in the authenticity of $pubK_A$

12

Important to remember

- What a certificate does
  - A certificate defines an indissoluble link between a subject’s identifier and public key
- A certificate does not
  - specify the meaning of that link
  - the possible uses of that key
  - make any statement on the trustworthiness of the subject

13

Assurance [→]

- How much can I trust that the identifier actually corresponds to the legitimate owner of the key?
- CA Policies
  - Authentication policy
  - Issuance policy
  - These policies are public
    - A child-CA cannot have less restrictive policies
- Assurance is not quantifiable
  - Estimate according to the policy and the application rigor

14

Assurance [→]

- Specification, design and implementation contribute to the assurance
- Example: medecine
  - The process
    - A medicine is produced by a known and honorable pharmaceutical manufacturer
    - The medicine is delivered to chemists in a in sealed container
    - When the medicine is sold, the seal is still intact

15

Assurance [↓]

- Trust foundations
  - Ministry allows sale if the medicine passes certain tests and complies with certain clinical standards
  - Auditing committees verify that the production process satisfies industrial standards
  - Presence of the safety seal

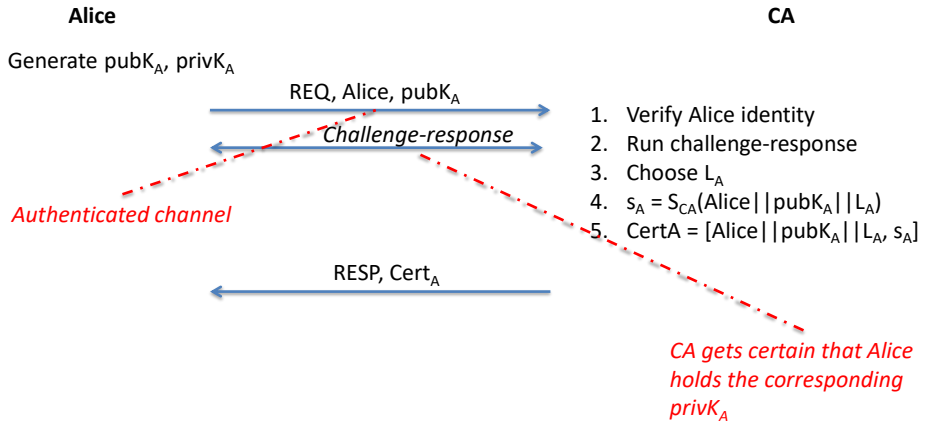
16

In-house or external CA?

- Implement your own CA or exploit a commercial one?
  - Cost-convenience ratio
    - High quality certification ➔ high costs
    - Low quality certification ➔ high risks
  - In-house
    - Pros – Complete control of the certification process
    - Cons – Cost of the infrastructure; limited scale
  - Commercial
    - Pros – Large scale
    - Cons – Trust delegation; no liability

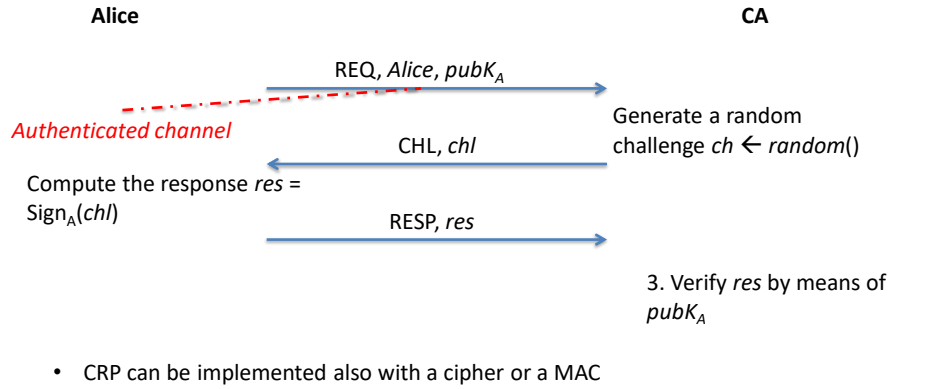
17

Certificate generation: user-provided keys [→]



18

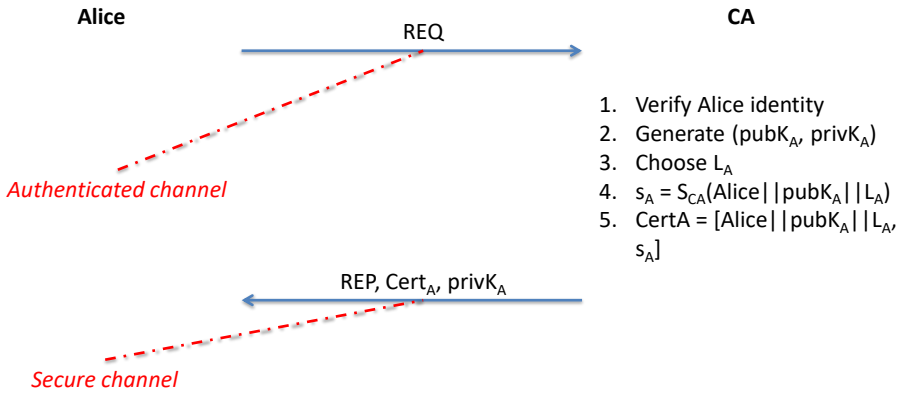
Challenge-response protocol



- CRP can be implemented also with a cipher or a MAC

19

Certificate generation: CA-generated keys



20

On key generation at CA-side

- Fatal crypto flaw in some Taiwan government-certified smartcards makes forgery a snap (www.arstechnica.com)
- Fatal flaw in the hw RNG
- Smartcards passed two international certifications (FIPS 140-2, Common Criteria)
- Research paper at AsiaCrypt 2013

21

Backup of private key [→]

Problems associated to private key:

- Public key encryption → backup of *decryption key*
  - Otherwise, encrypted data may become inaccessible
  - To be able to decrypt even after key lifetime expiration
  - Who makes backup matters
    - Government backs up of citizen's privKs → privacy issues
    - Company backs up of employee's privKs → Encrypted data belong to the company

22

Backup of private key [→]

still a private key but used for different purposes

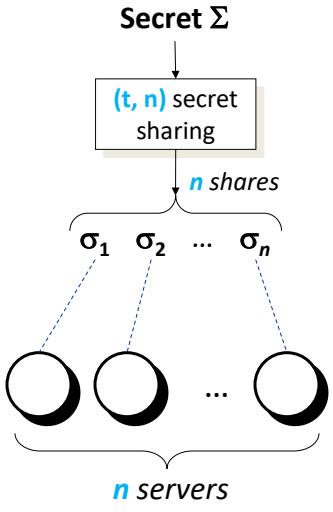
- Digital signature → backup of *signing key*
  - Delete the key after key expiration: cannot be used anymore after expiration
  - Why to backup a signing key?
    - Private key backup has adverse impact on non-repudiation
    - However, recovery from signing key loss is expensive in large scale apps as you must redistribute the pubK (e.g., Microsoft, Adobe, Visa)
  - How to backup
    - Technological solution: *Threshold crypto* (t out of n)

another cryptographic scheme: ①

- You want different key pairs for encryption and signing

23 ① Evolution of secret splitting: you have n shares but just need t/n shares to find your secret.

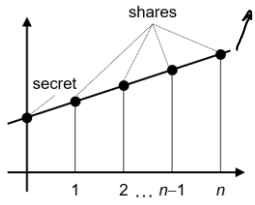
Threshold crypto (intuition)



SECRET SHARING

- The secret Σ (e.g., private key) is split into n shares
- At least t shares are necessary to reconstruct the secret
- The system tolerates the compromise of t–1 nodes

You need t pieces to show secret



I take a random line passing from this point, and I just need

Example: Polynomial (2, n) secret sharing

two shares to reconstruct secret. Generalizable to t shares

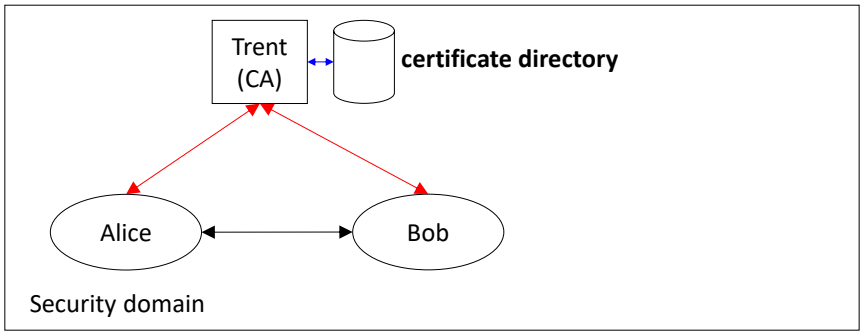
24

PKIs

EXPIRATION AND REVOCATION OF A CERTIFICATE

25

Single CA Model



- **Security domain** under control of the CA
- **Certificate directory** is a read-only database that stores certificates

26

Expired & revoked certificates

Verifying if a certificate is valid is easy. Doing so to check revocation is not easy.

- A certificate is expired if the validity period is expired
- If the private key gets compromised before expiration, then the certificate must be revoked
  - Examples: the private key has been revealed; the subject has changed role or left the organization
- Certificate revocation must be
  - Correct: revocation can be granted only to authorized parties, i.e., the owner or the issuer
  - Timely: revocation must be disseminated to all interested parties as soon as possible

} it is still valid, but privk has been compromised.

Nobody else can do it on your behalf, except your CA for you (issuer usually does so under push of authority)

27

How to verify a certificate

- Bob's verification of Alice's $Cert_A$
  1. Bob obtains CA's public key $pubK_{CA}$ [once at set-up]
  2. Bob verifies validity of CA's public key [once at set-up]
  3. Bob verifies the digital signature in $Cert_A$ by using $pubK_{CA}$
  4. Bob verifies that $Cert_A$ is valid
  5. Bob verifies that $Cert_A$ is not revoked
  6. If all these checks are successful, then Bob accepts $pubK_A$ as authentic Alice's key

Revocation methods

check for revocation

↳ Periodically browser downloads list of revoked certificates

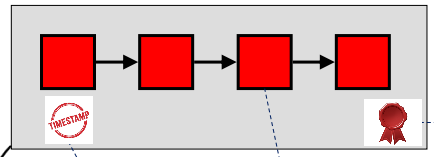
- Offline method: Certificate Revocation List (CRL)
- Online method: Online Certificate Status Protocol (OCSP)

↳ on demand asking

CRL

- A CRL is published periodically
- A revoked certificate lies in CRL until expiration
- Δ-CRL for efficiency

You can find one of this list usually in the certificate itself.



Digitally Signed by CA

serial number, revocation date, revocation reason

Timestamp states CRL freshness

You don't put names for privacy reasons: if bro had certificate revoked for being fined/convicted, that's invasion of privacy.

30

if you didn't have timestamp attacker could disseminate old lists and abuse newer revoked certificates.

OCSP

- Protocol sketch
  - Alice → OCSP: <OCSP RQST, Bob's cert serial nr.>
  - OCSP → Alice: $<\text{OCSP RESP, OK}|\text{KO}>_{\text{OCSP}}$
  - Protocol Pros
    - Lighter and simpler that CRL protocol
    - Effective if the adversary is not a MIM
  - Protocol Cons
    - In the clear ➔ confidentiality issues
    - Exposed to replay attack (nonces are an extension ☹)
    - Browsers silently ignore OCSP if the query times out (➔MIM)

31

PKIs

THE X.509 STANDARD

32

X.509 certificate format

Data structure containing 11 fields.

A data structure with several fields

1. Version (ver. 3 nowadays)
2. Serial number
3. Signature algorithm identifier ①
4. Issuer distinguished name (CA)
5. Validity interval
6. Subject distinguished name (Alice)
7. Subject public key information
8. Issuer unique identifier (v=2,3)
9. Subject unique identifier (v=2,3) ②
10. Extensions (v=3)
11. Signature

① Many digital sig. algorithms, you know which was used for alg. sig.

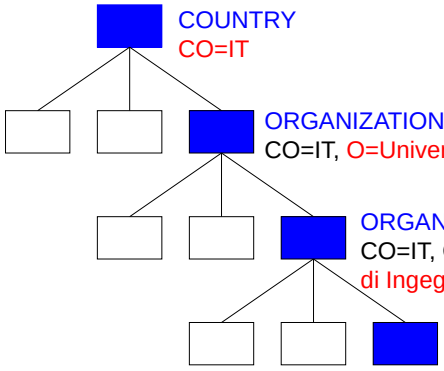
X.509 uses the Abstract Syntax Notation, ASN.1, (RFC 1422)
X.509 has been conceived for X.400 mail standard
X.509 uses Distinguished Names

33

② We won't look in details. Fields that help you manage problems that may arise with naming systems (3, 4): the an org. you might have same nicknames.

Distinguished names (X.500)

How names are constructed: hierarchical: Common name + Organizational Unit + Organization + Country



COUNTRY
CO=IT

ORGANIZATION
CO=IT, O=University of Pisa

There are other details beyond our interest

ORGANIZATIONAL UNIT
CO=IT, O=University of Pisa, OU=Dipartimento di Ingegneria della Informazione

COMMON NAME
CO=IT, O=University of Pisa, OU=Dipartimento di Ingegneria della Informazione, CN=Gianluca Dini

34

Example: https://www.mps.it

Certificate name
www.mps.it
Consorzio Operativo Gruppo MPS
Terms of use at www.verisign.com/rpa (c)00
Florence
Italy, IT

Issuer
VeriSign Trust Network
www.verisign.com/CPS Incorp.by Ref. LIABILITY LTD.(c)97 VeriSign

Details
Certificate version: 3
Serial number: 0x652D0F8ADAB4C7B168A27BBD1C3E9D9D
Not valid before: Mar 2 00:00:00 2004 GMT
Not valid after: Mar 2 23:59:59 2005 GMT
Fingerprint: (MD5) CA CA 88 08 EC D0 8E 49 A6 9A 66 C4 69 31 E0 AE
Fingerprint: (SHA-1) 82 64 CB 69 F0 43 86 43 FF B4 55 D4 25 EF 51 60 65 46 D3 87

contd

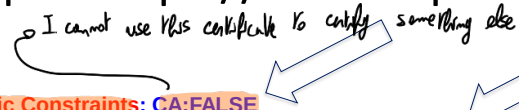
35

Example: https://www.mps.it

Public key algorithm: rsaEncryption
Public-Key (1024 bit):
Modulus:
00: E1 80 74 5E E7 E5 54 8B DF 6D 00 95 B5 96 27 AC
10: 66 93 E0 49 B9 6F 5B 73 53 1C BE 1C EB 47 64 B2
20: 12 95 70 E6 CD 50 67 02 88 E3 EE 9D B1 91 49 C8
30: 8D 58 19 4B 86 8F C0 2E 65 E8 F2 D4 82 CC 55 DB
40: 43 BC 66 DA 44 2F 53 B3 48 4B 37 15 F3 AB 67 C1
50: 69 B4 53 23 19 30 1A 19 23 7F 28 E0 E3 C0 6B 18
60: FF 84 C4 AC A9 74 28 DB FF E9 48 CA 75 D5 35 D6
70: 46 FB 7D D4 A7 3F A1 4B 00 60 14 DC D5 00 CF C7
Exponent:
01 00 01
Public key algorithm: sha1WithRSAEncryption
00: 23 A6 FE 90 E3 D9 BB 30 69 CF 43 2C FD 4B CF 67
10: D7 3C 46 22 9A 08 DB 05 1D 45 DC 07 F3 1E 4D 1F
20: 4B 11 23 5B 42 91 14 95 25 88 1F BD 60 E5 6F 84
30: 44 70 7A 95 EC 30 E4 46 4F 37 87 F1 B2 FA 45 04
40: 6F 7C BE 97 25 C7 20 E7 F3 90 55 51 99 3A 72 35
50: 40 F2 E8 E3 36 3A 7D 58 61 9C 91 D6 AC 34 E7 E8
60: 09 27 64 4F 2C 4C C2 D2 A3 32 DB 2B 7E F0 B6 F3
70: 69 96 E4 2B C3 2B 42 ED CA 2C 3C C8 F5 AA E6 71 *contd*

36

Example: https://www.mps.it



Extensions:
X509v3 Basic Constraints: CA:FALSE
X509v3 Key Usage: Digital Signature, Key Encipherment
X509v3 CRL Distribution Points:
URI:http://crl.verisign.com/Class3InternationalServer.crl
X509v3 Certificate Policies:
Policy: 2.16.840.1.113733.1.7.23.3
CPS: https://www.verisign.com/rpa
X509v3 Extended Key Usage: Netscape Server Gated Crypto, Microsoft Server Gated Crypto, TLS Web Server Authentication, TLS Web Client Authentication
Authority Information Access:
OCSP - URI:http://ocsp.verisign.com
Unknown extension object ID 1 3 6 1 5 5 7 1 12:
0_.].[0Y0W0U..image/gif0!0.0...+.....k...j.H.,{..0%.#http://logo.verisign.com/vslogo.gif

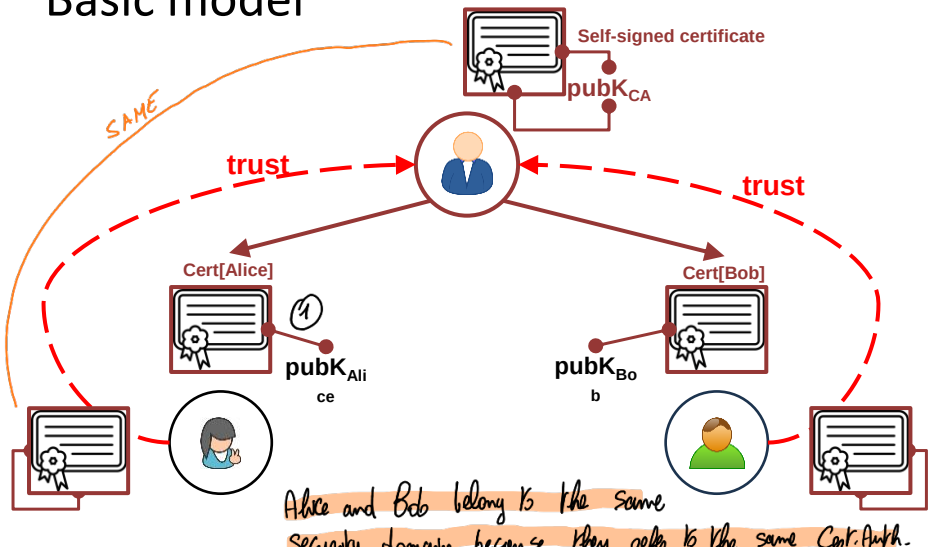
37

PKIs

TRUST MODELS

38

Basic model



40

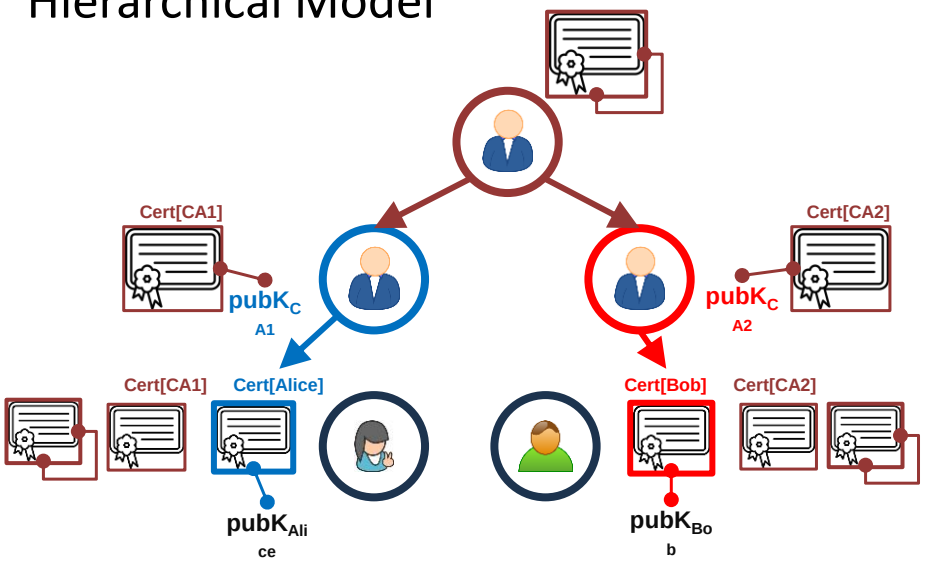
is same because she got it from CA. Same for Bob.
So if Alice sends Bob her own cert. Bob needs CA's pubK to verify certificate. Typically, when you get your own certificate, you also get the CA's pubK in the form of a self signed Cert. CA is the Root of trust.

Basic Model

- The Model
  - Every user trusts the root
  - The root releases certificates
- Inconvenient
  - Users have to go to the root in order to get the root self-signed certificate

41

Hierarchical Model



42 Variation of this: hierarchical model: Alice gets certified by the intermediate (sub)CA CA1, that signs Alice's Cert. It can do this because it is delegated by the root CA (root of trust). So Alice and Bob need to know root Cert. and delegates Cert.

So Alice needs to transfer her certificate and the certificate of CA1, that released her cert: Bob might not know it. Longer chains will give longer overhead

Hierarchical model: constrains on the certification path

- If CA_X certificates CA_Y (subordinate), the trust that CA_X has in CA_Y transitively propagates to all CAs reachable from CA_Y You could use multiple levels ①
- CA_X may limit this propagation by posing constraints

1. **on the chain length:** The chain after CA_Y has a limited length [length = 0 if you want to stop at previous examples]
2. **on the set of domains:** CAs in the chain after CA_Y must belong to a prefefined set of CAs

① By doing this certification, the trust propagates downwards

Esempio: https://www.mps.it

Certificate name
VeriSign Trust Network
www.verisign.com/CPS Incorp.by Ref. LIABILITY LTD.(c)97 VeriSign

Issuer
VeriSign, Inc.
Class 3 Public Primary Certification Authority
US

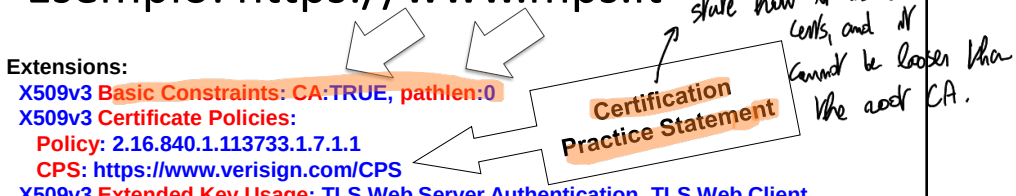
Details
Certificate version: 3
Serial number: 0x254B8A853842CCE358F8C5DDAE226EA4
Not valid before: Apr 17 00:00:00 1997 GMT
Not valid after: Oct 24 23:59:59 2011 GMT
Fingerprint: (MD5) BC 0A 51 FA C0 F4 7F DC 62 1C D8 E1 15 43 4E CC
Fingerprint: (SHA-1) C2 F0 08 7D 01 E6 86 05 3A 4D 63 3E 7E 70 D4 EF 65 C2 CC 4F

Esempio: https://www.mps.it

```
Public key algorithm: rsaEncryption
  Public-Key (1024 bit):
  Modulus:
    00: 6F 7B B2 04 AB E7 34 4F 9C 53 A7 02 B2 90 4F 22
    10: F9 3A 3C 5A 8B 51 2B FE CB 42 95 30 70 FE 8A B2
    20: D3 1D C1 B8 5A 49 5C F7 39 4E 4D B7 F3 3B 09 F1
    30: FA E5 28 93 3E 30 F5 63 AA 43 71 27 56 FE A3 BB
    40: CA C4 6C 75 B2 32 C1 07 D9 DD 25 40 F5 5C A9 D4
    50: 15 0A 34 9A ED 42 97 EA BD F1 B2 55 45 73 3C AA
    60: E7 B6 5B 6C 4C F0 AA 3B 36 E6 BC D3 05 D4 BF E1
    70: 2B 65 A2 25 39 18 85 1F 7D 02 19 D6 E8 80 82 D8
  Exponent:
    01 00 01
Public key algorithm: sha1WithRSAEncryption
    00: 08 01 EC E4 68 94 03 42 F1 73 F1 23 A2 3A DE E9
    10: F1 DA C6 54 C4 23 3E 86 EA CF 6A 3A 33 AB EA 9C
    20: 04 14 07 36 06 0B F9 88 6F D5 13 EE 29 2B C3 E4
    30: 72 8D 44 ED D1 AC 20 09 2D E1 F6 E1 19 05 38 B0
    40: 3D 0F 9F 7F F8 9E 02 DC 86 02 86 61 4E 26 5F 5E
    50: 9F 92 1E 0C 24 A4 F5 D0 70 13 CF 26 C3 43 3D 49
    60: 1D 9E 82 2E 52 5F BC 3E C6 66 29 01 8E 4E 92 2C
    70: BC 46 75 03 82 AC 73 E9 D9 7E 0B 67 EF 54 52 1A
```


45

Esempio: https://www.mps.it

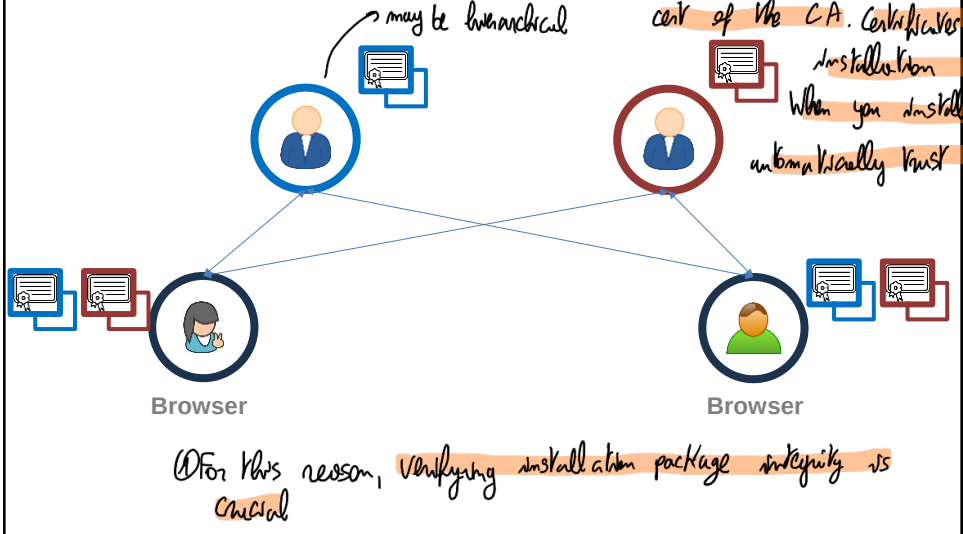


state how it issues certs, and it cannot be lower than the root CA.

```
Extensions:
  X509v3 Basic Constraints: CA:TRUE, pathlen:0
  X509v3 Certificate Policies:
    Policy: 2.16.840.1.113733.1.7.1.1
    CPS: https://www.verisign.com/CPS
  X509v3 Extended Key Usage: TLS Web Server Authentication, TLS Web Client
Authentication, Netscape Server Gated Crypto, 2.16.840.1.113733.1.8.1
  X509v3 Key Usage: Certificate Sign, CRL Sign
  Netscape Cert Type: SSL CA, S/MIME CA
  X509v3 CRL Distribution Points:
    URI:http://crl.verisign.com/pca3.crl
```


46

Web Model



47

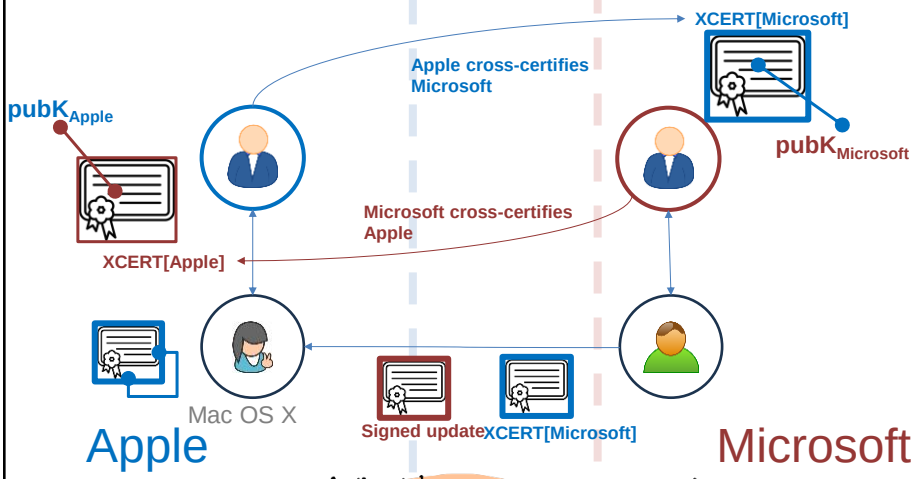
Examples

- Firefox
- Chrome
- Edge

- www.unipi.it ← GEANT Vereniging ← USERTrust (root)

48

Business Model



Ex: Microsoft releases a version of office that runs on apple machine. What happens when microsoft wants to update office? My mac os could not validate that update because it is signed by microsoft! Idea: when Apple and Microsoft make a contract to say that they support each other, they also cross certify each other. Apple certifies Microsoft, Microsoft certifies Apple. When you have update, you attach cross signed update

49

Incidents

- March 2011 – Comodo
  - 9 fraudulent certs
- Summer 2011 – DigiNotar
  - 500+ fraudulent certs
  - FOX-IT final report (long)
  - ENISA's resume (short)
- January 2013 – Turktrust
  - 100+ fraudulent certs
  - The TURKTRUST SSL certificate fiasco – what really happened, and what happens next?

62