Public Key Infrastructures

Gianluca Dini
Dept. of Ingegneria dell'Informazione
University of Pisa
Email: gianluca.dini@.unipi.it
Version: 2022-05-09

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Public Key Infrastructures

INTRODUCTION

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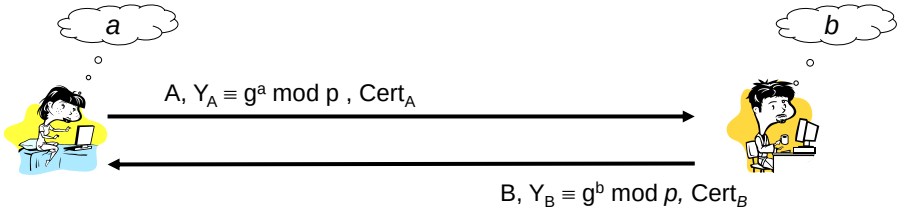
Man-in-the-middle Attack



$K_{AB} \equiv g^{a \cdot b} \bmod p$

$K_{AB} \equiv g^{a \cdot b} \bmod p$

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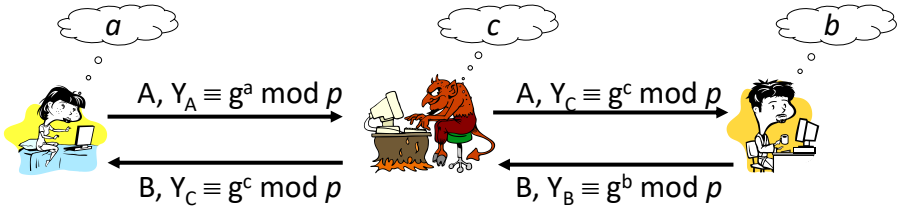
Man-in-the-middle Attack



$K_{AC} \equiv g^{a \cdot c} \bmod p$

$K_{AC} \equiv g^{a \cdot c} \bmod p$
$K_{BC} \equiv g^{b \cdot c} \bmod p$

$K_{BC} \equiv g^{a \cdot c} \bmod p$

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Certificate

- Certificate
  - Data structure that cryptographically links the identifier of a subject to the subject public key (and other stuff):

$$\mathbf{Cert_A = A, pubK_A, L_A, S_{CA}(A \,||\, pubK_A \,||\, L_A)}$$

    - A: identifier; $pubK_A$: public key; L_A: validity interval; || concatenation operator
  - Certification Authority (CA) is a TTP that attests the authenticity of a public key
  - CA's signature indissolubly links identifier and public key (and other parameters)

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CA's obligations

- CA must be reliable

I. CA must verify that the name (Alice) goes along with the key (privKA)

II. CA must verify that owner of (privK, pubK) 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

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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?)

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Trust delegation

- Certification is based on trust delegation (trust transfer)
  - Bob trusts and delegates CA to verify Alice's identity and attest the authenticity of $pubK_A$
  - Bob trusts the authenticity of CA's $pubK_{CA}$ *then*
  - Through a certificate $Cert_A$ signed by CA,
    Bob acquires trust (believes) in the authenticity of $pubK_A$

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Important to remember

- 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

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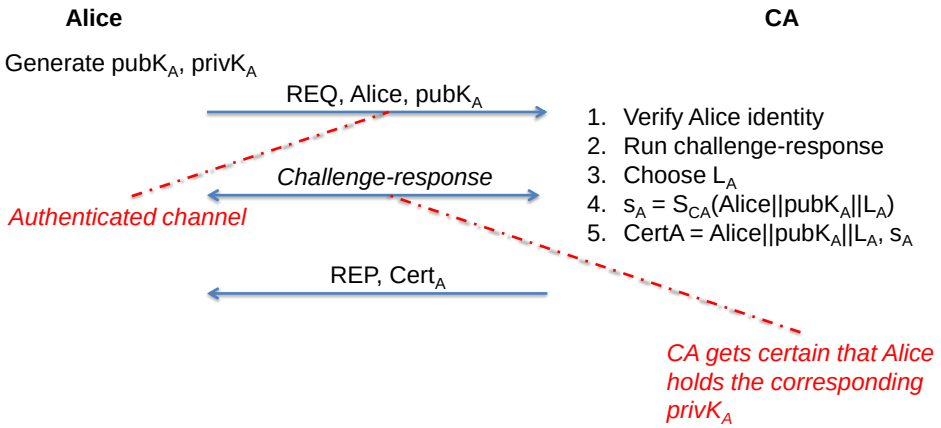
Certificate generation

User-provided Keys



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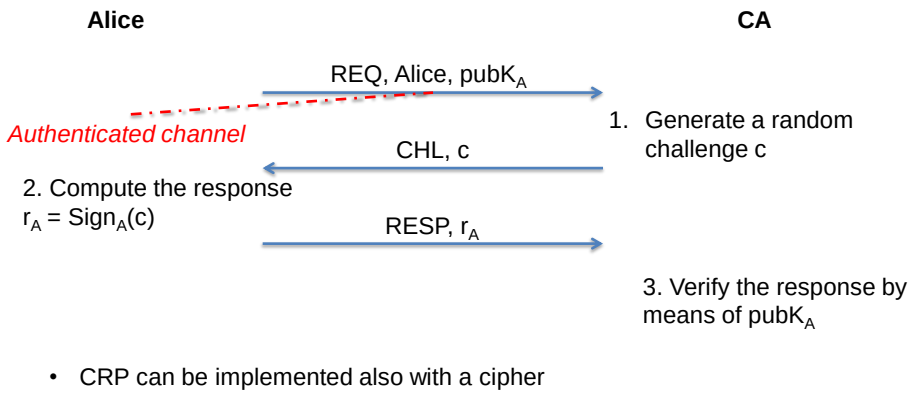
Challenge-response protocol

User-provided Keys



- CRP can be implemented also with a cipher

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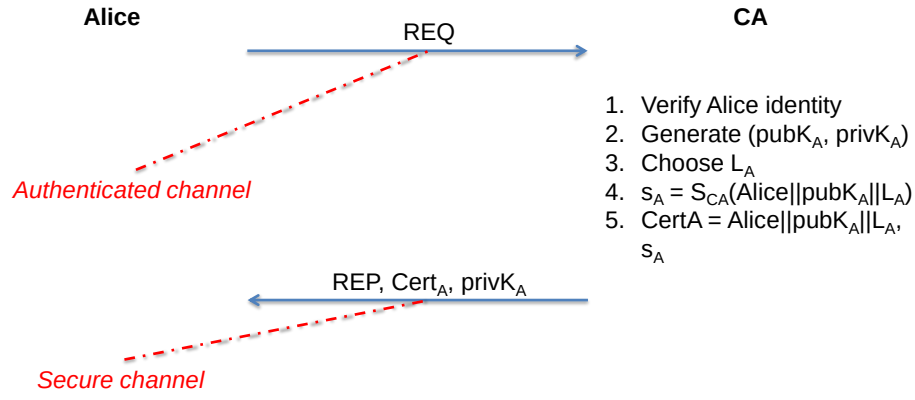
Certificate generation

CA-Generated Keys



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On key generation at CA-side

Fatal crypto flaw in some government-certified smartcards makes forgery a snap (*www.arstechnica.com*)

- Fatal flaw in the hw RNG
- Smartcards passed two international certifications
- Research paper at AsiaCrypt 2013

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Backup of private key

- Public key encryption
  - Backup privK, otherwise encrypted data may become inaccessible
  - Be able to decrypt even after key lifetime expiration
  - Government backs up of citizen's privK
    - This raises privacy issues
  - Company backs up of employee's privK
    - Encrypted data belong to the company
- Digital signature
  - Delete the key after key expiration, private key backup has adverse impact on non-repudiation
  - Expensive recovery in large scale apps as you have to redistribute the pubK
  - Threshold crypto (t out of n)

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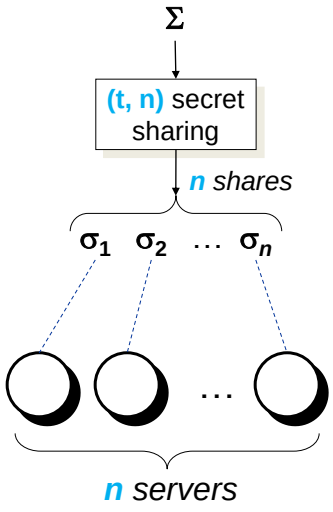
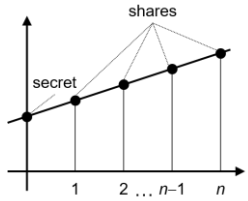
Threshold crypto (intuition)



SECRET SHARING

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



*Polynomial **(2, n)** secret sharing*

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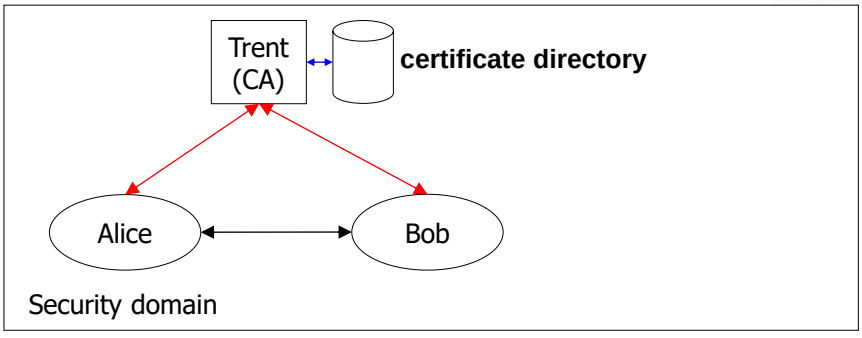
Single CA Model



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

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Expired & revoked certificates

- 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

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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
- If all these checks are successful, then Bob accepts $pubK_A$ as authentic Alice's key

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Revocation options

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

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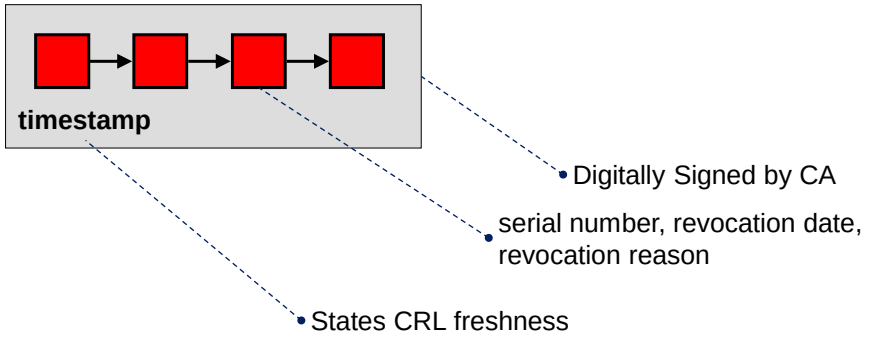
CRL

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



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OCSP

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- Protocol sketch
  - Alice → OCSP: <OCSP RQST, Bob's cert serial nr.>
  - OCSP → Alice: <OCSP RESP, OK|KO>$_{OCSP}$
  - 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)

PKIs

X.509 CERTIFICATES

X.509 certificate format

A data structure with several fields

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

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

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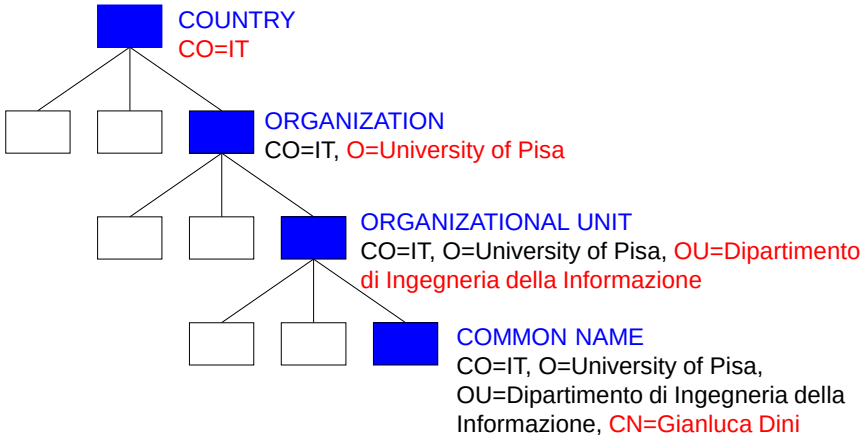
Distinguished names



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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

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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

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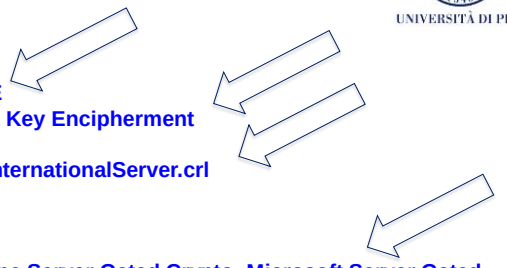
Example: https://www.mps.it



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

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PKIs

TRUST MODELS

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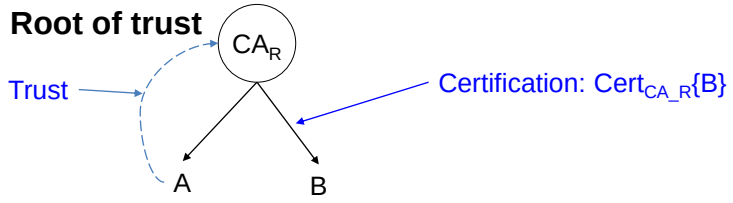
Centralized Trust Model



The Model

- Every user trusts the root
- The root releases certificates

Inconvenient

- Users have to go to the root in order to get a certificate

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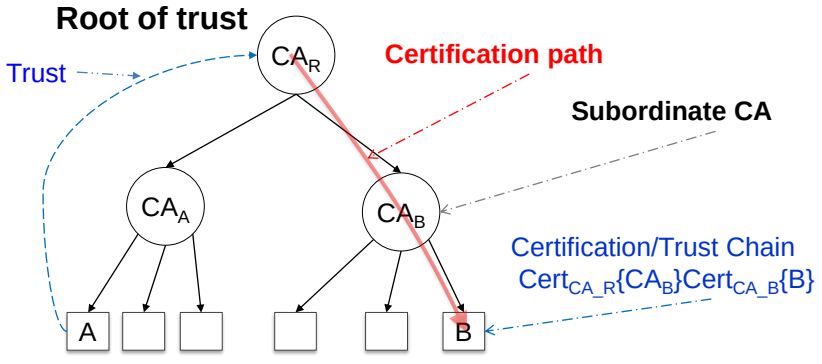
Centralized Trust Model



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Constrains on the certification path

- If CA_X certificates CA_Y, the trust that CA_X has in CA_Y transitively propagates to all CAs reachable from CA_Y
- CA_X may limit this propagation by posing constraints
  - **Constraint on the chain length –** The chain after CA_Y has a limited length
  - **Constraint on the set of domains –** CAs in the chain after CA_Y must belong to a prefefined set of CAs

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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

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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

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Esempio: https://www.mps.it

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

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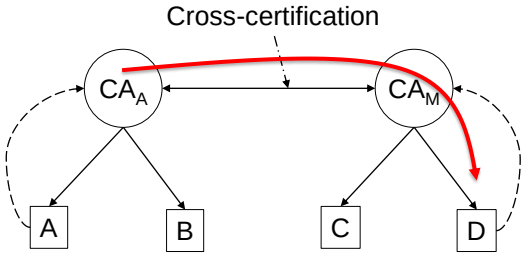
Cross-certification (enterprise model)



Certification/Trust Chain
$Cert_{CA\_A}\{CA_M\}Cert_{CA\_M}\{D\}$

- Technology-wise is «easy»
- What about Legal implications?

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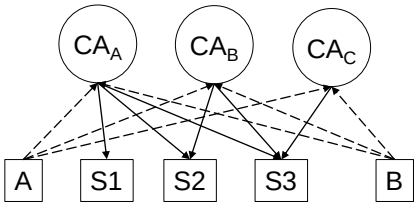
Browser model



Trusted CA list in browsers

- More levels are possible
  - Subordinate CAs
- A user trusts **all** CAs in his browser
  - There are 650 CAs but many of them are related => 75

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The CA Mess on the Web

- **Recommended reading**
  - An Observatory for the SSLiverse, Peter Eckersley, Jesse Burns, Defcon 18, Las Vegas, USA, July, 2010 (pdf, video)

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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?

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Countermeasures (→)

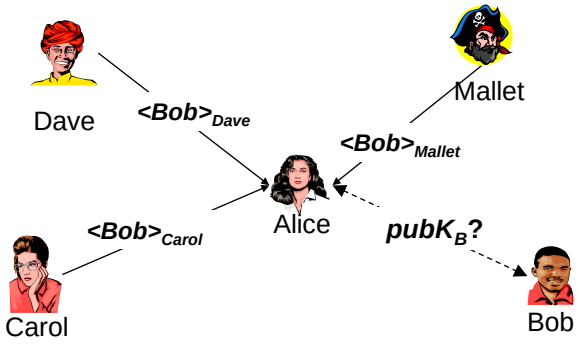
- Public key pinning
  - List of presumed-good Cas and list of known-good certs
  - Chrome
- Certificate transparency
  - To make public that a CA issued a cert
  - Resistance from business
- Convergence
  - Download a cert directly and from a set of trusted CAs and compare them

Countermeasures

- DANE (DNS-based Authentication of Name Entities)
  - Store a pubK in a DNS record; require DNSSEC
- Extended Validation certificates
  - «Prove the legal entity controlling the website or sw package… promise what we were promised a decade ago and we never got» [The inevitable collapse of the certification model]

Personal trust model (PGP model)

- The user decides how much trust to put in a certificate



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Personal trust model (PGP model)

- Alice determines the trust in $pubk_B$ according to the number of certificates she receives and the trust in the subjects issuing the certificates
- "PGP is for people who prefer to pack their own parachutes" [P. Zimmerman]

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PGP model - Validity and trust level

- Trust level in a key
  - Own key
    - Implicit trust
  - Others' keys
    - Complete trust
    - Marginal trust
    - No trust

The user defines the trust to put in a key

- A key may be
  - Valid, marginally valid, Invalid
  - A key is valid if it has been signed by a completely trusted key or by two marginally trusted keys

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PGP vs X.509

- Number of signatures
  - X.509 – A key is signed just once
  - PGP – A key may be signed multiple time
- Trust level
  - X.509 – A certificate is implicitly associated to a certain trust level
    - Depend on the CA policy
  - PGP – Every signature is associated to an explicit trust level
    - Signatures on the same key may have different trust levels
    - The meaning of a trust level depend on the context

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Personal Trust Model – PGP cons

- Hard to understand if you're not an expert
- Key revocation is a nightmare

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Browser behaviour

- Idealized model
- Reality
  - Revocation is blocking information (latency)
  - What if revocation infrastructure is unreachable?
  - Browsers have been forced to ignore revocation information when unavailable
  - Types of server certificates
    - DV, OV are not checked by default
    - EV is checked but, if unavailable, response is browser-dep

Defective By Design? - Certificate Revocation Behavior In Modern Browsers, SpiderLabs Blog, Apr. 4, 2011

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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

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