Computer Security and Cryptography

CS381

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2016-05

Organization

- Week 1 to week 16 (2016-02-24 to 2016-06-08)
- 东上院502
- Monday 3-4节; week 9-16
- Wednesday 3-4节; week 1-16
- lecture 10 + exercise 40 + random tests 40 + other 10
- Ask questions **in** class – counted as points
- Turn ON your mobile phone (after lecture)
- Slides and papers:
  - http://202.120.38.185/CS381
    - **computer-security**
  - http://202.120.38.185/references
- TA: '薛伟佳' xue_wei_jia@163.com, '黄格仕' <huang.ge.shi@foxmail.com>
- Send homework to: laix@sjtu.edu.cn and to TAs

Rule: do not disturb others!

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Contents

- Introduction -- What is security?
- Cryptography
  - Classical ciphers
  - Today's ciphers
  - Public-key cryptography
  - Hash functions/MAC
  - Authentication protocols
- Applications
  - Digital certificates
  - Secure email
  - Internet security, e-banking

Network security
- SSL
- IPSEC
- Firewall
- VPN

Computer security
- Access control
- Malware
- DDos
- Intrusion

Examples
- Bitcoin
- Hardware
- Wireless

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References

- W. Stallings, *Cryptography and network security - principles and practice*，Prentice Hall.
- W. Stallings, 密码学与网络安全：原理与实践（第4版），刘玉珍等译，电子工业出版社，2006
- Doug Stinson , *Cryptography Theory and Practice*, Third Edition, CRC Press, 2005
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- A.J. Menezes, P.C. van Oorschot and S.A. Vanstone, *Handbook of Applied Cryptography*. CRC Press, 1997, ISBN: 0-8493-8523-7, http://www.cacr.math.uwaterloo.ca/hac/index.html
- B. Schneier, *Applied cryptography*. John Wiley & Sons, 1995, 2nd edition.
- Protocols Lounge, http://sky.fit.qut.edu.au/~choo/lounge.html
- Berrry Schoenmakers, Cryptographic Protocols, www.win.tue.nl/~berry/2WC01
- 裴定一,徐祥, 信息安全数学基础, ISBN 978-7-115-15662-4, 人民邮电出版社,2007.

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overview

IT-security
•Definition
•5 services
•1-way function

Classical Shannon | Security Un/condition | Integer factor Discrete log

Block cipher Stream cipher | **Hash MAC** | **PKC signature**

Key-manage → **Kerberos** | **Certificate PKI**

Intrusion Malware | **Firewall** | **IPSEC VPN** | **SSL TLS** | **PGP S/MIME**

applications

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Kerberos

- centralised secrete-key third-party authentication in a distributed network
- 1983-1991 MIT Project Athena, for authentication in campus networks
- 1988，Kerberos v4 used by :
  – MS windows / MAC OS X / RedHat Linux 4

(Greek) Kerberos- 3-headed hound which guards the gates of the Underworld.

3: authentication, clearing, auditing

Kerberos

- allows users access to services distributed through network
- without needing to trust all workstations
- rather all trust a central authentication server

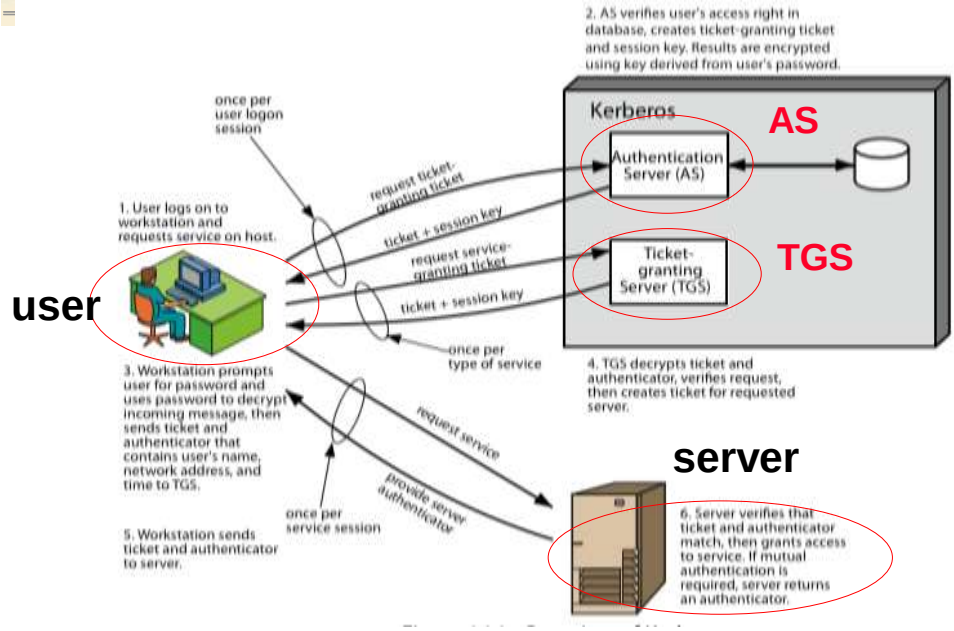
- two versions in use: 4 & 5

Kerberos v4 Dialogue

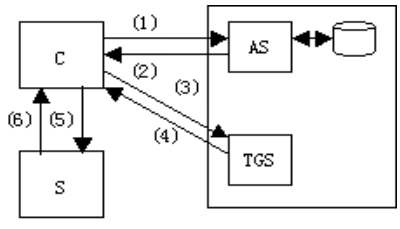
users authenticate to Authentication Server (AS)

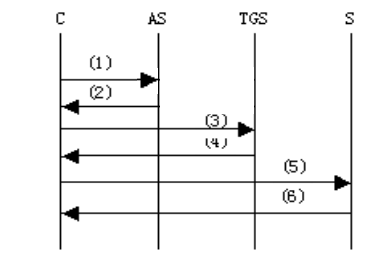
1. obtain ticket granting ticket from AS
   - once per session
2. obtain service granting ticket from TGT
   - for each distinct service required
3. client/server exchange to obtain service
   - on every service request

Kerberos v4



Kerberos v4





Kerberos v4 Dialogue

（1）C -->AS: $ID_C||ID_{tgs}||TS_1$

（2）AS --> C: $E_{K_c}[K_{c,tgs}||ID_{tgs}||TS_2||Lifetime_2||Ticket_{tgs}]$

$Ticket_{tgs}= E_{K_{tgs}}[K_{c,tgs}||ID_C||AD_C||ID_{tgs}||TS_2||Lifetime_2]$

（3）C --> TGS: $ID_V||Ticket_{tgs}||Authenticator_C$

$Authenticator_C= E_{K_{c,tgs}}[ID_C||AD_C||TS_3]$

（4）TGS --> C: $E_{K_{c,tgs}}[K_{c,v}||ID_V||TS_4||Ticket_V]$

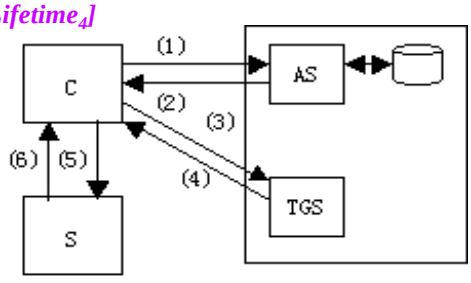
$Ticket_V= E_{K_v}[K_{c,v}||ID_C||AD_C||ID_V||TS_4||Lifetime_4]$

（5）C --> V: $Ticket_V||Authenticator_C$

$Authenticator_C= E_{K_{c,v}}[ID_C||AD_C||TS_5]$

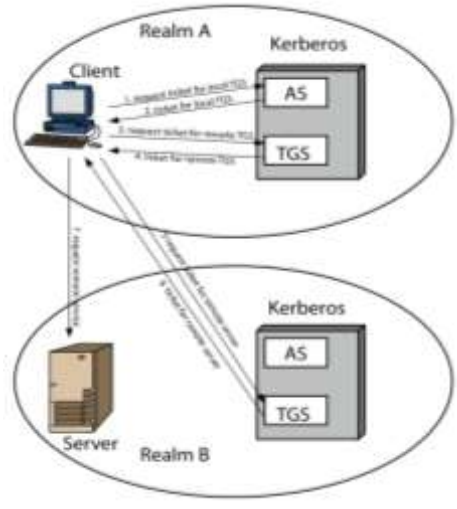
（6）V --> C: $E_{K_{c,v}}[TS_5+1]$

Ticket$_{tgs}$ can be reused within lifetime



Kerberos realms

- a Kerberos realm:
  - a Kerberos server
  - users registered with Kerberos server
  - application servers, sharing keys with server
- typically a single administrative domain
- if have multiple realms, their Kerberos servers must share keys and trust



Kerberos Version 5

- developed in mid 1990's
- specified as Internet standard RFC 1510
- provides improvements over v4
  - addresses environmental shortcomings
    - encryption alg, network protocol, byte order, ticket lifetime, authentication forwarding, interrealm auth
  - and technical deficiencies
    - double encryption, non-std mode of use, session keys, password attacks

Kerberos v5

- Kerberos v5 improves v4

(1) C → AS: $Options||ID_C||Realm_C||ID_{tgs}||Times||Nonce_1$

(2) AS → C: $Realm_C||ID_C||Ticket_{tgs}||E_{K_c}[K_{c,tgs}||Times||Nonce_1||Realm_{tgs}||ID_{tgs}]$

$Ticket_{tgs}=E_{K_{tgs}}[Flags||K_{c,tgs}||Realm_C||ID_C||AD_C||Times]$

(3) C → TGS: $Options||ID_V||Times||Nonce_2||Ticket_{tgs}||Authenticator_C$

$Authenticator_C=E_{K_{c,tgs}}[ID_C||Realm_C||TS_1]$

(4) TGS → C: $Realm_C||ID_C||Ticket_V||E_{K_{c,tgs}}[K_{c,v}||Times||Nonce_2||Realm_V||ID_V]$

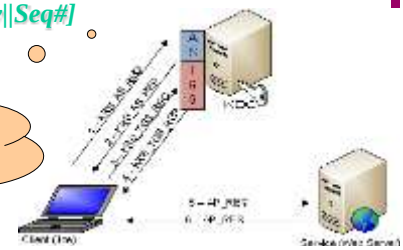
$Ticket_V=E_{K_V}[Flags||K_{c,v}||Realm_C||ID_C||AD_C||Times]$

(5) C → V: $Options||Ticket_V||Authenticator_C$

$Authenticator_C=E_{K_{c,v}}[ID_C||Realm_C||TS_2||Subkey||Seq\#]$

(6) V → C: $E_{K_{c,v}}[TS_2||Subkey||Seq\#)$

Subkey and Seq are optional;
Subkey: session-key, default is $K_{c,v}$;
Seq#: the session id, to prevent replay。



PKI

- asymmetric cipher, public-key cryptosystem: user share some trusted information
- Certificates establish such trust on public-keys
- PKI (public-keys infrastructure) is the managing system of certificates

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RSA public-key encryption

- Is PK_B belong to Bob? ----trust

Alice $PK_A = (n_A, e_A)$
$SK_A = (p_A, q_A, d_A)$

Bob $PK_B = (n_B, e_B)$
$SK_B = (p_B, q_B, d_B)$

Get PK_B, Compute C

$C = E_{PKB}[M] = (M)^{eB} \bmod n_B$ →

$C^d = (M^e)^d = M^{k\phi(n)+1} = M^{k\phi(n)} M = M$

$M = E_{SKB}[C] = (C)^{dB} \bmod n_B$

Trust on public-key

- Trust: binding between identity and public-key
- Ways to establish trust
  - Direct: by person, post, phone.
  - Indirect: by introduction (PGP)
  - Use TTP: TTP signed public-key, i.e., certificate.
  - PKI is a framework for managing the certificates
  - Other: Identity-based: use the identity (name, address,..) as public-key.

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Public-key Certificates

- Certificates establish trust in public keys
  - through a binding of user-ID and Public-key,
  - by TTP's signature
- Certificates for:
  - encryption public keys
  - verification public keys
- Certification Authority (CA)
  - trusted third-party

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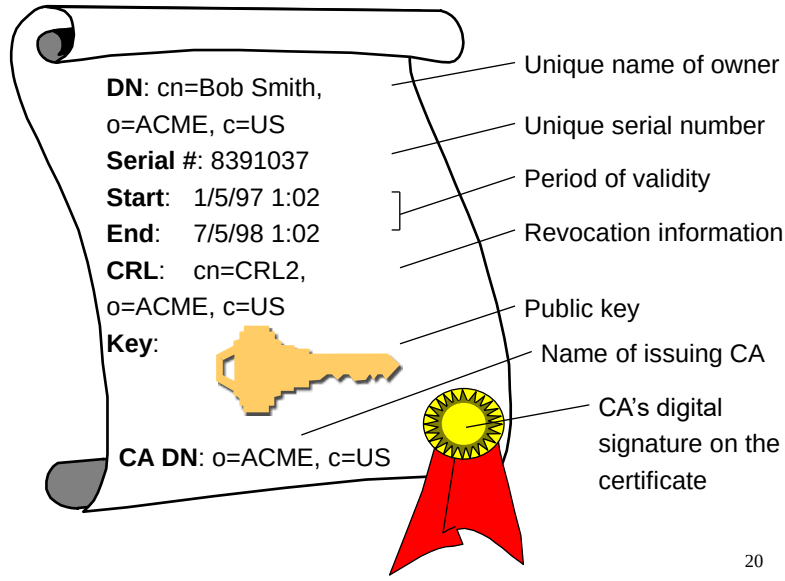
What is in a certificate?



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Basic PKI components

- Registration Authority (RA): binding the user credential with his public keys – trust establishment
- Certification Authority (CA): Issue certificates – (user's public-key, CA's signature)
- Certificate Repository / Directory: storing certificates – for public accessing

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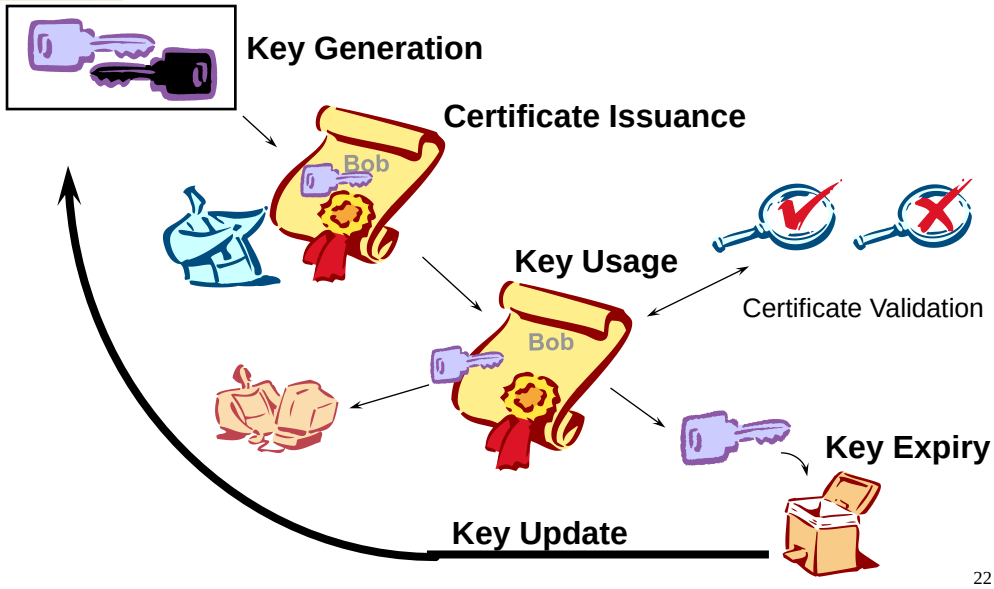
Key Lifecycle



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Different lifecycle of 2 key pairs

	public	private
encryption	Encryption key **destroy old keys**	Decryption key keep after expiration
signature	Verification key kept after expiration	Signing key **destroy old keys**

Principle of key separation

Use different key pairs for encryption and signing

- Although the same key pair can be used for both encryption and signing, it is better to use 2 pairs.
  - Different life cycle (private decryption key and public verification key should be kept after expiration; public encryption key and private signing key should be destroyed after expiration)
  - To prevent oracle attacks (use sign to decrypt, use decrypt to sign)
  - Good practice for forward-security (compromise of key for one application does not effect the security of other applications)
  - Required when both non-repudiation and key recovery are needed.

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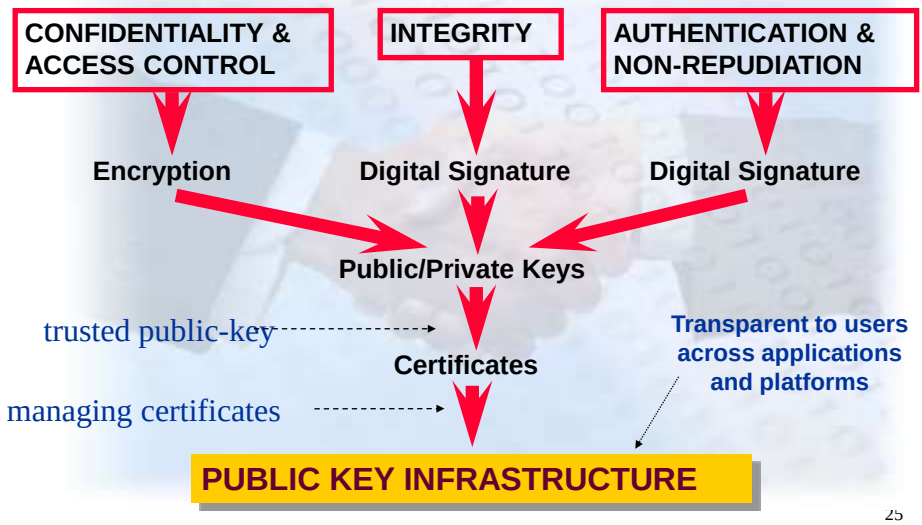
PKI (Public Key Infrastructure)



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ITU-T X.509 (V4)

- ITU-T Recommendation X.509 (2000) / ISO/IEC 9594-8 (2001):
- Information Technology
  - Open Systems Interconnection
  - The Directory:
  - Public-Key and Attribute Certificate Frameworks

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Standard organizations

- ISO: http://www.iso.ch
- IETF: http://www.ietf.org/
- ITU-T: http://www.ituaj.or.jp/book/itut-rec.html
- NIST FIPS: http://www.itl.nist.gov/fipspubs/by-num.htm
- 3GPP: http://www.3gpp.org/
- ANSI: http://www.ansi.org/
- CEN: http://www.cenorm.be/
- Common criteria: http://csrc.nist.gov/cc/
- ETSI: http://www.etsi.org/main.htm
- 全国信息安全标准技术委员会:http://www.tc260.org.cn/
- OID: http://oid.elibel.tm.fr

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Frameworks overview

- a framework for obtaining and trusting a public key of an entity in order to
  - encrypt information to be decrypted by that entity,
  - or in order to verify the digital signature of that entity.
- The framework includes
  - the issuance of a public-key certificate by a Certification Authority (CA) and
  - the validation of that certificate by the certificate user:
    - establishing a trusted path of certificates between the certificate user and the certificate subject;
    - verifying the digital signatures on each certificate in the path;
    - validating all the certificates along that path (i.e. that they were not expired or not revoked at a given time).

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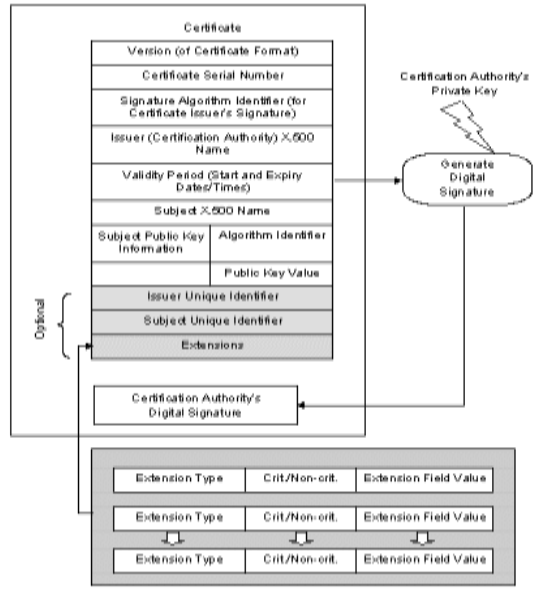
X.509 Version 3 Digital Certificate



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Fields in specification

- **Version**: Indicator of version 1,2 or 3.
- **Serial number**: Unique identifying number for this certificate.
- **Signature Algorithm identifier** of the digital signature algorithm of CA.
- **Issuer**: X.500 name of the issuing CA.
- **Validity**: Start and expiration dates and times of the certificate.
- **Subject**: X.500 name of the holder of the private key (subscriber).
- **Subject public-key information**: The value of the public-key for the subject together with an identifier of the algorithm with which this public-key to be used.
- **Issuer unique identifier**: An optional bit string used to make the issuing certification authority name unambiguous.
- **Subject unique identifier**: An optional bit string used to make the subject name unambiguous.

- signature (of hash of all fields in certificate)

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Certificate specification of ASN.1 data type

- Certificate ::= SIGNED { SEQUENCE {
  - version [0] Version DEFAULT v1,
  - serialNumber CertificateSerialNumber,
  - signature AlgorithmIdentifier,
  - issuer Name,
  - validity Validity,
  - subject Name,
  - subjectPublicKeyInfo SubjectPublicKeyInfo,
  - issuerUniqueIdentifier [1] IMPLICIT UniqueIdentifier OPTIONAL,
    -- if present, version must be v2 or v3
  - subjectUniqueIdentifier [2] IMPLICIT UniqueIdentifier OPTIONAL,
    -- if present, version must be v2 or v3
  - extensions [3] Extensions OPTIONAL
    -- If present, version must be v3 -- } }

- ASN.1--Abstract Syntax Notation number One

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certification path

- *certification path*: A list of certificates needed to allow a particular user to trust the public key of another
  - certification path logically forms an unbroken chain of trusted points in the Directory Information Tree between two users wishing to authenticate

```
Certificates                ::=   SEQUENCE {
        userCertificate             Certificate,
        certificationPath           ForwardCertificationPath OPTIONAL }
CertificationPath           ::=   SEQUENCE {
        userCertificate             Certificate,
        theCACertificates           SEQUENCE OF CertificatePair OPTIONAL }
```

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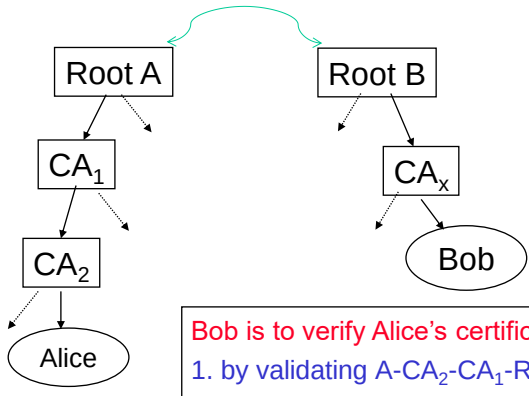
Certification path – 4 methods



Bob is to verify Alice's certificate

1. by validating A-CA_2-CA_1-RootA; Trust (certificate) of RootA should be in B's browser
2. By cross certification – between RootA and RootB
3. Bob can install RootA.
4. Direct trust (highest)

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Certificate Revocation

- certificates have a period of validity
- may need to revoke before expiry, eg:
  1. user's private key is compromised
  2. user is no longer certified by this CA
  3. CA's certificate is compromised
- CA's maintain list of revoked certificates
  - the Certificate Revocation List (CRL)
- users should check certificates with CA's CRL

Certificate Revocation

- Revocation: Canceling a certificate before its originally scheduled validity period
  - Compromised key, change name, …
- Certificate Revocation Lists (CRL)
  - A CRL is a time-stamped list of revoked certificates that has been digitally signed by a CA and made available to certificate users.
  - Each revoked certificate is identified in a CRL by its certificate serial number – generated by the issuing CA.
- Types of revocation lists:
  - Certificate revocation list (CRL)
  - Authority revocation list (ARL)
  - Delta revocation list
- CRL checking:
  - CRL Distribution Point: Identifies the point or points that distribute CRL's on which a revocation 0f this certificate would appear if this certificate were to be revoked.
  - Delta-CRL's: It is a digitally signed list of the changes that occurred since the issuance of the prior base CRL.
  - Online Status Checking: uses OCSP (Online Certificate Status Protocol)

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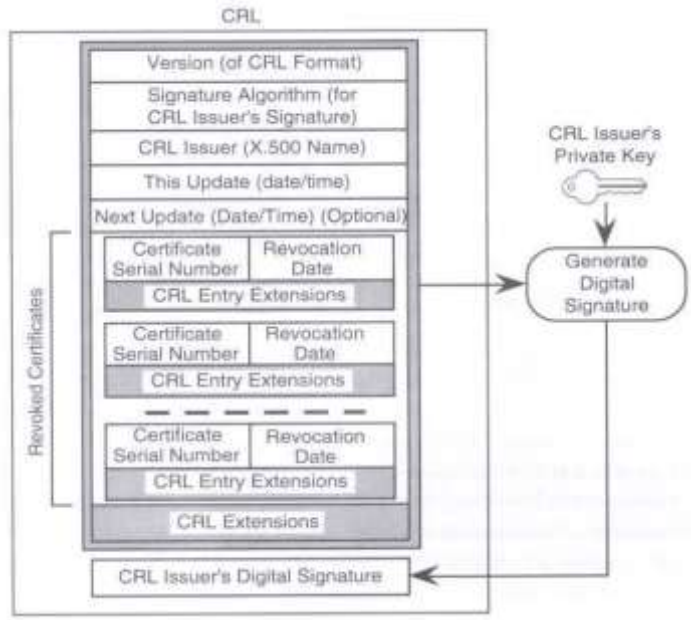
X.509 Certificate Revocation List



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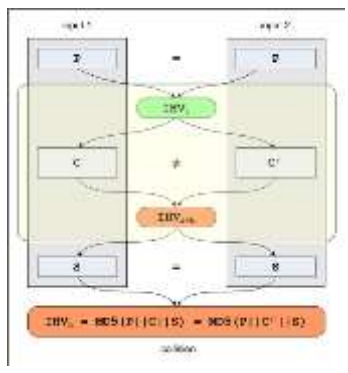
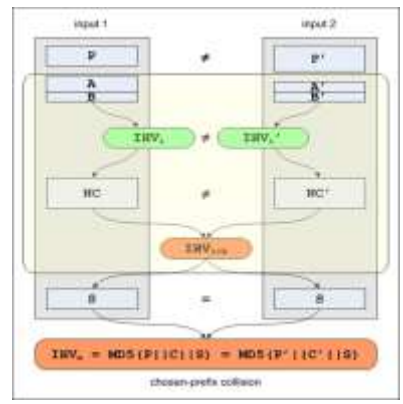
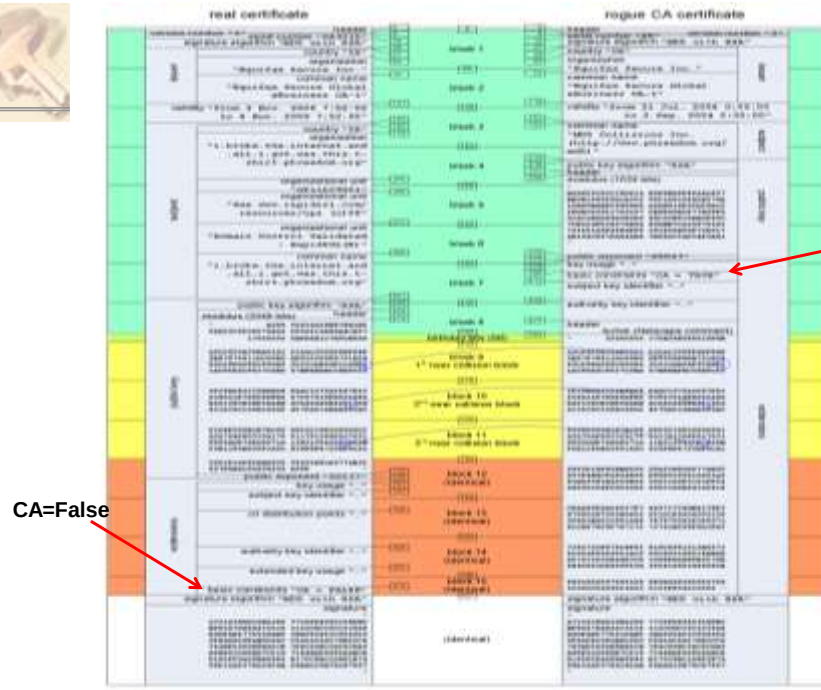
MD5 collision – chosen-prefix collision

- "rogue certificates" [M. Stevens,,09] http://eprint.iacr.org/2009/111
  - 2 certificates with different data fields (especially CA=TRUE/FALSE) and public-keys, but with same MD5 hash code.
  - free-start collision: comp.=2^{16}







From http://www.win.tue.nl/hashclash/rogue-ca/

counterfeit certificate

- Flame was signed with a fraudulent certificate purportedly from the Microsoft Enforced Licensing Intermediate PCA certificate authority.[14]
- The malware authors identified a Microsoft Terminal Server Licensing Service certificate that still used the weak MD5 hashing algorithm,
- produced a counterfeit certificate that was used to sign malware to make them appear to have originated from Microsoft.
- A successful collision attack against a certificate was previously demonstrated in 2008,[15] but Flame implemented a new variation of the chosen-prefix collision attack

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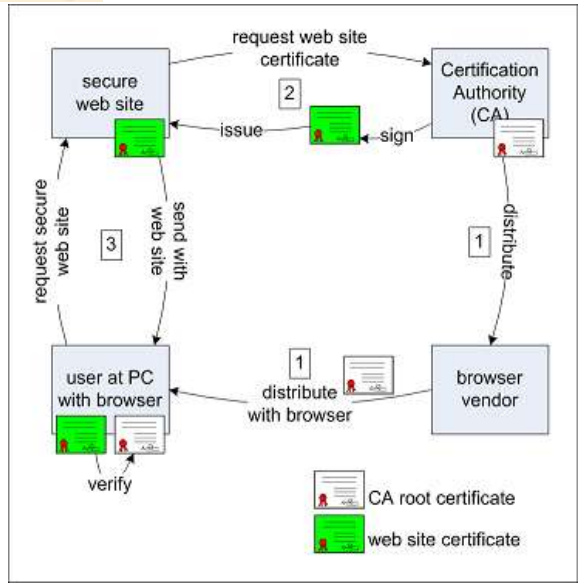
Normal use of certificates



证书验证

- **CA根证书置于浏览器中**
- **CA签发网站证书**
- **用户验证网站证书的根CA签名**
- **普通网站证书不能用于签发下级证书**

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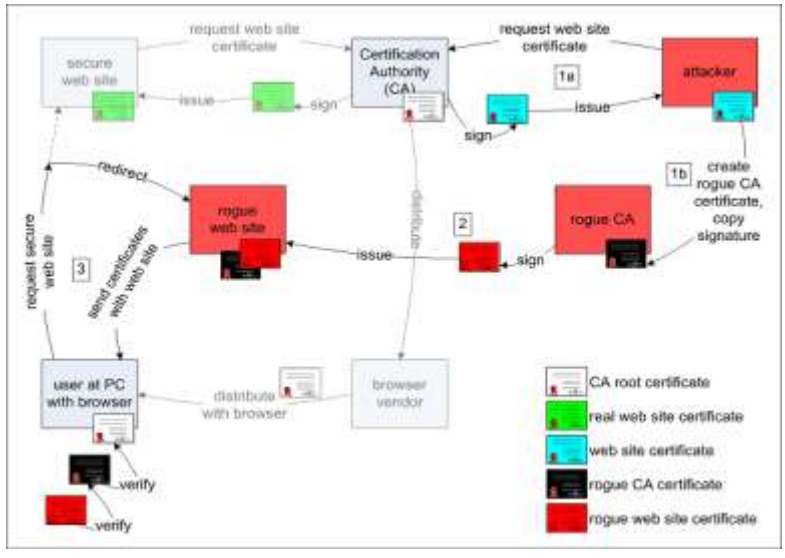
rouge certificates



伪CA证书与普通网站证书有相同的签名（hash 碰撞）

伪CA证书可签发新的伪证书（网站，软件）

伪证书可通过MS浏览器验证

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问题出在哪里？

- Microsoft Terminal Server Licensing Service still used the MD5 hashing
- **MD5碰撞--〉深入研究 --〉构造伪证书**
- **用伪证书签发的软件（Flame）可通过IE验证**
- **Fix：stop using MD5 (06-12)**
- "Microsoft releases Security Advisory 2718704". Microsoft. 3 June 2012.

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Summary

- Kerberos
- PKI
  - Certificates
  - X.509

- Next – secure email
  - PGP
  - S/MIME

Exercise 12

1. Alice and you work together in SJTU. Both of you have public-key certificates issued by CA of SJTU, CA_{SJTU} 's certificate is issued by a root-CA imbedded in browser. Therefore Alice and you trust each other's key.
   a) After 1 year, the root-CA says that CA_{SJTU} 's certificate has expired (so that your browser says Alice's key is not valid), but CA_{SJTU} tells you directly that Alice's key is still secure. Question: can you trust Alice's key or not, and why?
   b) If CA_{SJTU} says Alice's certificate has expired, but Alice tells you on the phone that her key is still secure. Can you trust Alice's key or not, and why?

Deadline: before next lecture

Format: Subject: CS381-某某某-EX.#

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