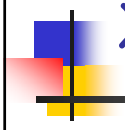


Digital Certificates and X.509 Authentication Service

Digital Certificates

- A digital certificate is:
  - An assertion
  - Digitally signed by a "certificate authority"
- An assertion
  - Can be anything
  - Usually an identity assertion
  - Can also be a list of authorizations

Public-Key Certificates

reliable distribution of public-keys

- public-key encryption
  - sender needs public key of receiver
- public-key digital signatures
  - receiver needs public key of sender
- public-key key agreement
  - both need each other's public keys

Digital Certificates

- A certificate authority (CA) is
  - Someone who signs certificates
  - Has a "known" public key
  - Is "famous" enough for this to be useful
- Thus, a certificate is
  - A cryptographic proof that the CA believes the assertions

X.509 Certificate Authority Scope

A CA can vary dramatically in scope.

- At the large end are commercial CAs like Thawte, Verisign, Belsign, GTE Cybertrust or others.
  - These commercial CAs issue certificates to millions of users.
- At the smaller end are CAs operated by departments within a company:
  - These CAs issue certificates to a small number of users.
  - These smaller CAs may be intermediate CAs whose certificates are signed by higher-level CAs inside the organization.

X.509 Authentication Service Introduction

- ITU-T X.509:
  - Part of X.500 Directory Services
  - Issued in 1988; revised in 1993 and 1995
  - Defines a framework for authentication service using the X.500 directory
    - Repository of public-key certificates
  - Based on use of public-key cryptography and digital signatures
  - Recommends use of RSA

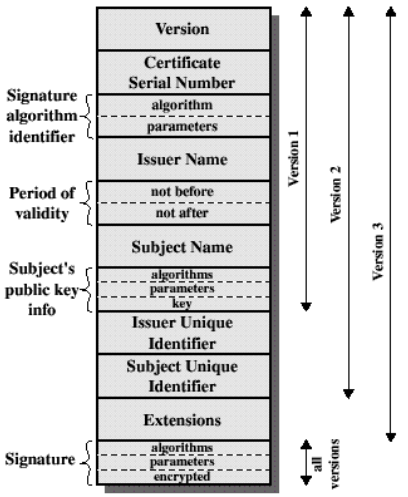
X.500 Directory

- X.500 Directory
  - Repository of public-key certificates
    - Public key of user
    - Signed with private key of trusted third party
  - Server (or set of servers) that maintain a user information database
    - Mapping from user name to network address
    - Other user attributes and information

Public-key Certificates

- Associated with user
- Created by trusted third party
  - Certificate authority (CA)
  - Placed in directory by CA or by the user
- Directory server
  - location for certificate access
  - does not create the certificates

X.509 Public-key Certificate Formats



Example of X.509 Certificate

```
Certificate:
  Data:
    Version: 1 (0x0)
    Serial Number: 7829 (0x1e95)
    Signature Algorithm: md5WithRSAEncryption
    Issuer: C=ZA, ST=Western Cape, L=Cape Town, O=Thawte Consulting cc, OU=Certification Services Division,
         CN=Thawte Server CA/emailAddress=server-certs@thawte.com
    Validity
      Not Before: Jul  9 16:04:02 1998 GMT
      Not After : Jul  9 16:04:02 1999 GMT
    Subject: C=US, ST=Maryland, L=Pasadena, O=Brent Baccala,
         OU=FreeSoft, CN=www.freesoft.org/emailAddress=baccala@freesoft.org
    Subject Public Key Info:
      Public Key Algorithm: rsaEncryption
      RSA Public Key: (1024 bit)
        Modulus (1024 bit):
          00:b4:31:98:0a:c4:bc:62:c1:88:aa:dc:b0:c8:bb: 33:35:19:d5:0c:64:b9:3d:41:b2:96:fc:f3:31:e1:
          66:36:d0:8e:56:12:44:ba:75:eb:e8:1c:9c:5b:66: 70:33:52:14:c9:ec:4f:91:51:70:39:de:53:85:17:
          16:94:6e:ee:f4:d5:6f:d5:ca:b3:47:5e:1b:0c:7b: c5:cc:2b:6b:c1:90:c3:16:31:0d:bf:7a:c7:47:77:
          8f:a0:21:c7:4c:d0:16:65:00:c1:0f:d7:b8:80:e3: d2:75:6b:c1:ea:9e:5c:5c:ea:7d:c1:a1:10:bc:b8:
          e8:35:1c:9e:27:52:7e:41:8f
        Exponent: 65537 (0x10001)
  Signature Algorithm: md5WithRSAEncryption
    93:5f:8f:5f:c5:af:bf:0a:ab:a5:6d:fb:24:5f:b6:59:5d:9d:92:2e:4a:1b:8b:ac:7d:99:17:5d:cd:19:f6:ad:ef:63:2f:92:
    ab:2f:4b:cf:0a:13:90:ee:2c:0e:43:03:be:f6:ea:8e:9c:67: d0:a2:40:03:f7:ef:6a:15:09:79:a9:46:ed:b7:16:1b:41:72:
    0d:19:aa:ad:dd:9a:df:ab:97:50:65:f5:5e:85:a6:ef:19:d1: 5a:de:9d:ea:63:cd:cb:cc:6d:5d:01:85:b5:6d:c8:f3:d9:f7:
    8f:0e:fc:ba:1f:34:e9:96:6e:6c:cf:f2:ef:9b:bf:de:b5:22:68:9f
```

X.509 Certificate Format

- The general format for a certificate is:
  - Version V
  - Serial number SN
  - Signature algorithm identifier AI
  - Issuer Name CA
  - Period of Validity T_A
  - Subject Name A
  - Subject's Public-key Information A_p
  - Issuer Unique Identifier (added in Version 2)
  - Subject Unique Identifier (added in Version 2)
  - Extensions (added in Version 3)
  - Signature

X.509 Standard Notation

- User certificates generated by a CA use the following standard notation:

  $CA\langle\langle A\rangle\rangle = CA\{V, SN, AI, CA, T_A, A, A_p\}$

  where

  $Y\langle\langle X\rangle\rangle$ = the certificate of user X issued by the certification authority Y

  $Y\{I\}$ = the signing of I by Y consisting of I with an encrypted hash code appended.

X.509: Obtaining A User Certificate

- User certificates generated by a CA have the following characteristics:
  - Any user with access to the public key of the CA can recover the user public key that was certified.
  - No party other than the CA can modify the certificate without being detected.
- Since they are unforgeable, they can be placed in a directory without the need for the directory to make special efforts to protect them.

X.509: CA Trust Issues

- If all users subscribe to the same CA, then there is a common trust of that CA.
  - All user certificates can be placed in the directory for access by all users.
  - Any user can transmit his/her certificate directly to other users.
- Once B is in possession of A's certificate, B has confidence that:
  - Messages it encrypts will be secure.
  - Messages signed with A's private key are unforgeable.

X.509: Multiple CAs

- Large User Community
  - Not Practical to Support All Users
  - More Practical to Have Multiple CAs
  - Each CA Provides Its Public Key to A Smaller User Group

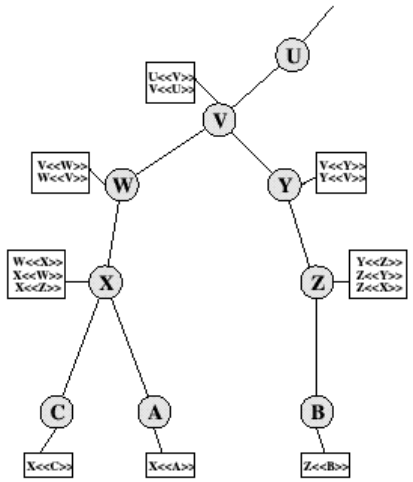
X.509 Multiple CAs: Problem

- Consider this Scenario …
  - User A obtained A's certificate from CA X1.
  - User B obtained B's certificate from CA X2.
  - If A does not know X2's public key, B's certificate is useless.
    - A can read B's certificate
    - A cannot verify the signature

X.509 Multiple CAs: Solution

- Solution: CAs X1 and X2 exchange public keys
- Now…
  - A gets X2's certificate signed by X1
  - A gets B's certificate signed by X2
  - Now, A has trusted copy of X2's public key
    - Verifies the signature
    - Obtains B's public key

X.509: CA Hierarchy Example



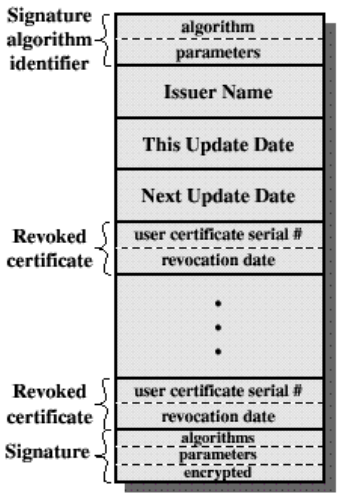
X.509: Certificate Revocation

- Certificates have a period of validity, a *lifetime*.
  - Normally, a new one is issued just prior to the expiration of the old one.
- In some cases, a certificate may need to be revoked prior to its expiration:
  - User's secret key is assumed to be compromised.
  - User is no longer certified by this CA.
  - CA certificate is assumed to be compromised.

X.509: Certificate Revocation List (CRL)

- Each CA maintains a list of all revoked not-expired certificates.
  - issued by that CA to users
  - issued to other CAs
- Certificate Revocation List (CRL) posted to the directory is signed by the issues and includes:
  - issuer's name
  - list creation date
  - next CRL creation date
  - revoked certificate entries (serial number and revocation date)

X.509: Certificate Revocation List (CRL)



X.509: CRL delivery

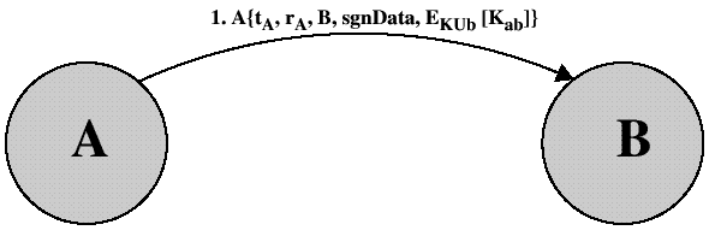
Two basic Certificate Revocation List delivery models:

- **Polling**: the current CRL is requested by the certificate user when he/she needs key on a digital certificate
  - Problem: time delay between revocation and publication
- **Pushing**: the new CRL is delivered by the CA to the user as soon as new revocation occurs
  - Problems: storage of new pushed CRLs even if irrelevant and danger of interception and deletion

X.509: Authentication Procedures

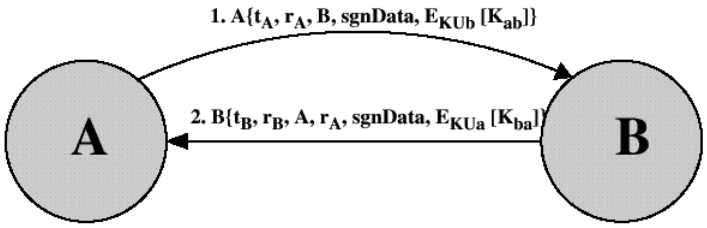
- Three alternative authentication procedures
  - Each use public-key signatures
  - Each assumes that two parties know each other's public key.
    - either obtained from Directory
    - or obtained in an initial message

X.509: One-way Authentication



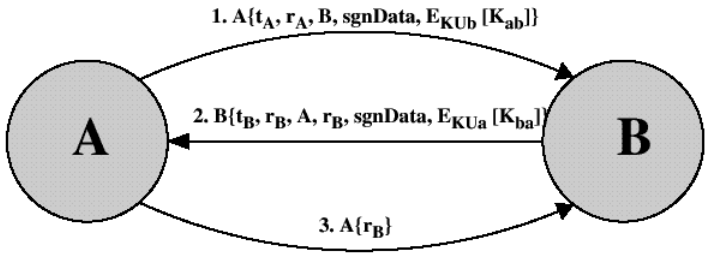
- A single transfer of information from one user (A) to another (B) and establishes the following:
  - Identity of A and message generated by A
  - Message is intended for B
  - Integrity and originality of the message.

X.509: Two-way Authentication



- In addition, two-way authentication establishes the following:
  - identity of B and that the reply message is generated by B (the target of the first message)
  - message is intended for A
  - integrity and originality of the reply

X.509: Three-way Authentication



- Final message from A to B contains a signed copy of the nonce (r_B) received from B.
  - eliminates the need to check timestamps.
  - used when synchronized clocks are not available.

X.509 Version2 Inadequacies and Version3 Solution

Insufficient information conveyed in the certificate

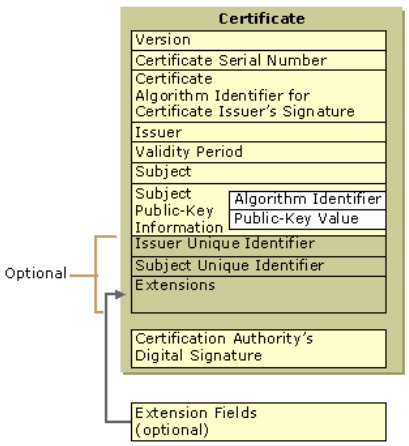
- Subject field issues
  - inadequate to identify key owner
  - inadequate for many applications (that require, for example, e-mail or URL)
- No security policy information
- No method to limit damage (in case of faulty or malicious CA)
- No key differentiation
- Solution: two approaches
  - either add fields to version 2 format
  - or add optional extension fields (!)

X.509 Version 3 Certificate

Note: public key infrastructure in Windows 2000 supports X.509 version 3 certificates.

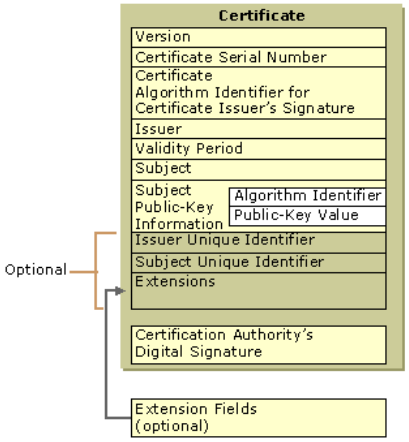
The definitions for the Version 3 fields are:

- Version: Version of the certificate format; for example, version 3 (code is 2).



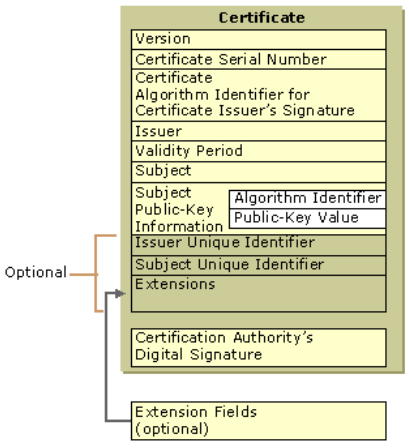
X.509 Version 3 Certificate

- Certificate Serial Number: The unique integer that is assigned by the issuing CA.
  - The CA maintains an audit history for each certificate so that certificates can be traced by their serial numbers.
  - Revoked certificates also can be traced by their serial numbers (and the issuing CA's name).



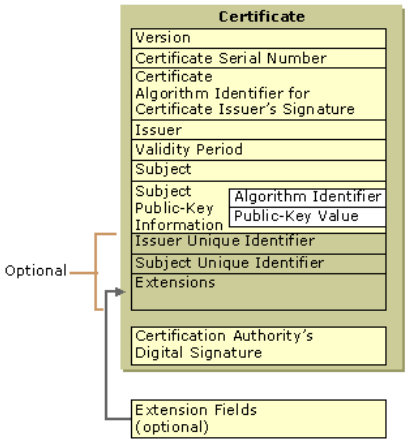
X.509 Version 3 Certificate

- Certificate (Signature) Algorithm Identifier: The public key cryptography and message digest algorithms that are used by the issuing CA to digitally sign the certificate.
- Issuer Name: The name of the issuing CA such as:
  - X.500 directory name
  - Internet e-mail address
  - X.400 e-mail address
  - URL



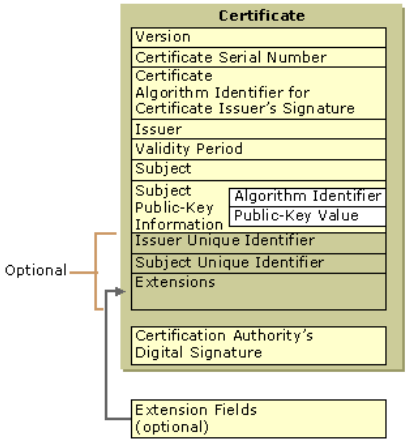
X.509 Version 3 Certificate

- Validity Period: The certificate's start and expiration dates.
  - define the interval during which the certificate is valid, although the certificate can be revoked before the designated expiration date.



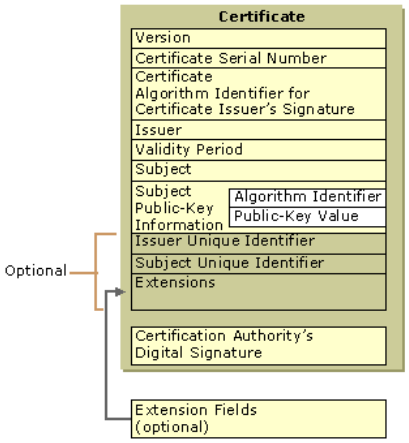
X.509 Version 3 Certificate

- Subject: The name of the subject (owner) of the certificate such as:
  - X.500 directory name
  - Internet e-mail address
  - URL
- Subject Public-Key Information: The public key and the public key cryptography algorithm.
  - The algorithms for which the public key set can be used, such as digital signing, secret key encryption, and authentication.



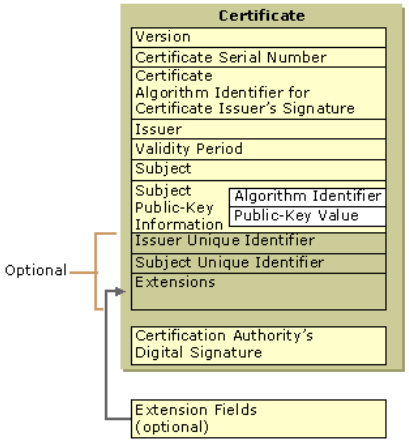
X.509 Version 3 Certificate

- Issuer Unique Identifier: Optional information (bit string) for uniquely identifying the issuer, when necessary.
- Subject Unique Identifier: Optional information (bit string) for uniquely identifying the subject, when necessary.



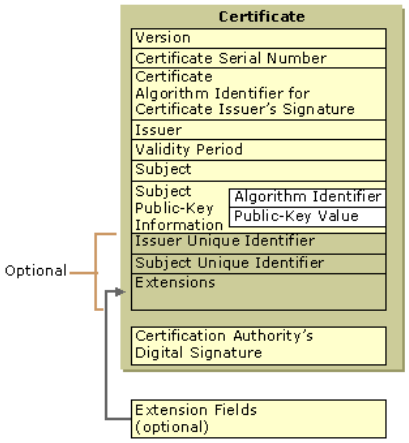
X.509 Version 3 Certificate

- Extensions: Additional information that can be specified for optional use by public key infrastructures. Common extensions include a list of specific uses for certificates (for example, S/MIME secure mail or IPSec authentication), CA trust relationship and hierarchy information, a list of publication points for revocation lists, and a list of additional attributes for the issuer and subject.



X.509 Version 3 Certificate

- Certification Authority's Digital Signature: The CA's digital signature of all the previous fields, which is created as the last step in generating the certificate. (Called *Encrypted*)



X.509 Version 3 Certificate

- 3 extension categories
  - Key and policy information
  - Subject and issuer attributes
  - Certification path constraints

X.509 Extensions: Key and Policy

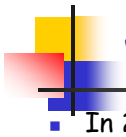
- Subject and issuer keys information
- Indicators of certificate policy
- Extension fields
  - Authority key identifier (to differentiate keys of the same CA)
  - Subject key identifier (to differentiate keys of the same subject)
  - Key usage (bit string for 9 possibilities, such as key and/or data encryption, signature verification on certificates/CRLs, …)
  - Private-key usage period (for signatures)
  - Certificate policies (used for issuing and for certificate usage)
  - Policy mappings (from CA to CA, for matching policies of different CAs)

X.509 Extensions: Certificate Subject Attributes

- Alternate names for either the certificate subject or the certificate issuer
- Extension fields
  - Subject alternative name (additional identities to be bound to the subject)
  - Issuer alternative name (to associate, e.g., internet style identities to issuer)
  - Subject directory attributes (such as DoB or clearance, to be used by X.500 directory)

X.509 Extensions: Certification Path Constraints

- Provide constraints for certificates issued by CAs for other CAs.
- Extension fields
  - Basic constraints (can subject be CA and length of allowed certification path from this CA)
  - Name constraints (name space for allowed subjects in subsequent certificates)
  - Policy constraints (for path validation, either prohibiting or requiring policy)



Vulnerability and Exploits

- In 2005, shown "how to use hash collisions to construct two X.509 certificates with identical signatures and differerent public keys", using a collision attack on the MD5 hash function.
- In 2008, presented a practical attack to create a rogue Certificate Authority, accepted by all common browsers, by exploiting the issuing X.509 certificates based on MD5.
- X.509 certificates based on SHA-1 appeared to be secure until April 2009 when researchers produced a method to increases the likelihood of a collision
- There are implementation errors with X.509 that allow e.g. falsified subject names using null-terminated strings or code injections attacks in certificates
- Implementations suffer from design flaws, bugs, different interpretations of standards and lack of interoperability.
  - Many implementations turn off revocation check and policies are not enforced