

PKI

Part 1: Public-Key Certificates

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Outline

- Introduction to public-key certificates
 - certification paths
 - types of certificates
- Evolution of the X.509 certificate format
 - basic building blocks
 - mandatory contents
 - optional features

Definition of trust

- In general, trust refers to an aspect of a relationship between two entities A and B
- A can be said to “**trust**” B when A makes the assumption that it knows exactly how B will behave
- Note that there is risk associated with trust

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Sources of trust

- **Direct relationship:** kinship, mateship, contract, multiple prior transactions
- **Direct experience:** prior exposure, a prior transaction
- **Referred trust:** ‘word-of-mouth’, reputation, accreditation
- **Symbols of trust:** brands

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What is a certificate?

- A **Certificate** is a document generated by a **trusted** third party containing a certified statement
- everyday examples are driver's licenses, passports, and credit cards
- A **digital certificate** is a collection of electronic data 'digitally signed' by a trusted third party
- the signing ensures that tampering will be discovered

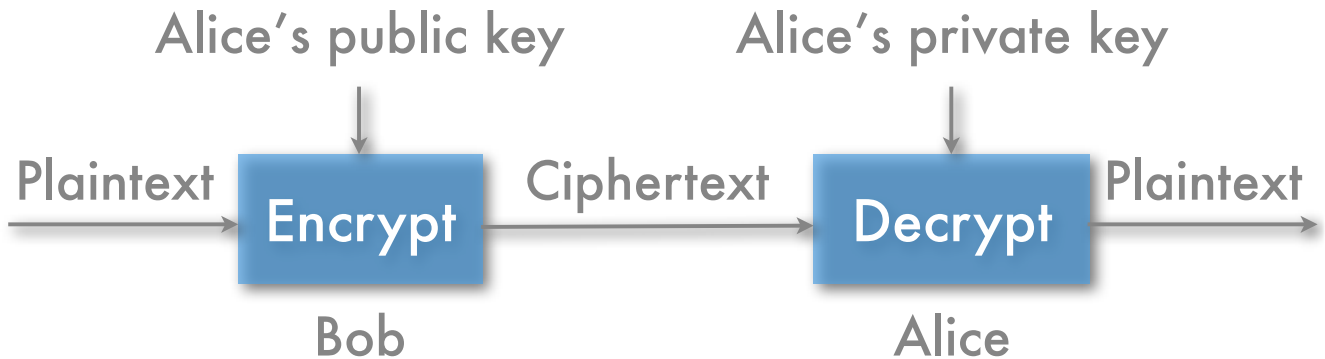
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Public-key cryptography

- **Public-key cryptography** enables us to realize digital certificates
- Public-key cryptography is based on two keys:
 - **private key**—must be kept secret
 - **public key**—is published
- The two keys are complementary, but the value of the private key cannot be determined from the public key in practice

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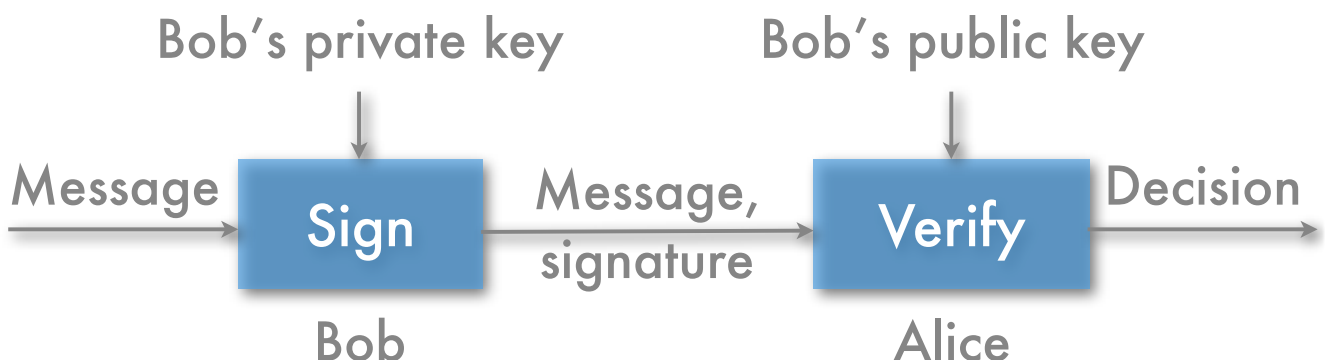
Encryption mode



- When Bob wants to send a **confidential** message to Alice, he uses Alice's public key

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Signing mode



- When Bob wants to send an **authenticated** message to Alice, he uses his private key to **sign** the message

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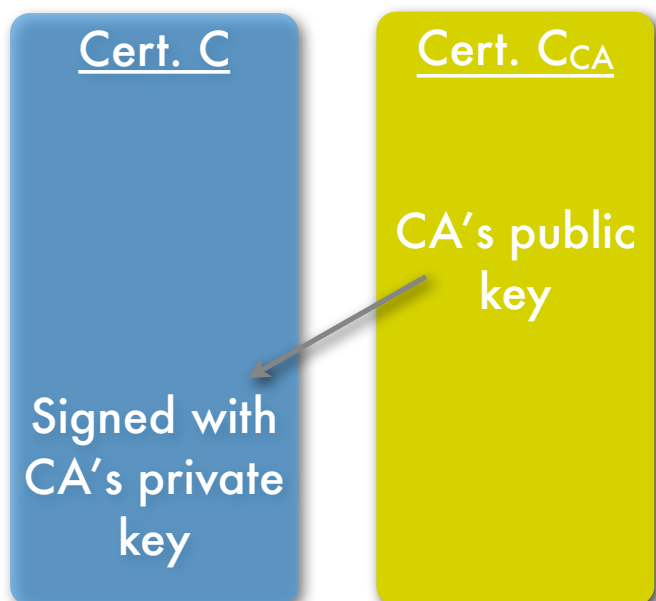
Public-key certificate

- A **public-key certificate** contains an entity's public key
- The certificate is generated by a trusted third party, called a **Certification Authority (CA)**
- The CA has verified the identity of the entity holding the private key corresponding to the public key in the certificate

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Certificate validation

- The public-key certificate, denoted C , is digitally signed with the CA's private key
- To validate C , the user must first get hold of the CA's certificate, C_{CA}
- The public key in C_{CA} is then used to verify the digital signature of C



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So far we have

A CA digitally signs a public-key certificate to guarantee its content and to enable detection of tampering

The certificate binds a public key to the name of the entity with the private key

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Lack of trust

- **Problem:**
 - Alice communicates with users whose certificates are issued by different CAs
 - Alice does not trust all these CAs
- **Solution:**
 1. CAs issue certificates to other CAs
 2. Alice extends a path of certificates until she reaches a CA she trusts

Certification path

- A CA is denoted a **trust point** (or trust anchor) if an end entity trusts the CA's public key
- A **certification path** is a chain of certificates:
 - the issuer of the first certificate is a trust point
 - the subject of the last certificate is the end entity
- A certification path is constructed to verify the certificate of the end entity

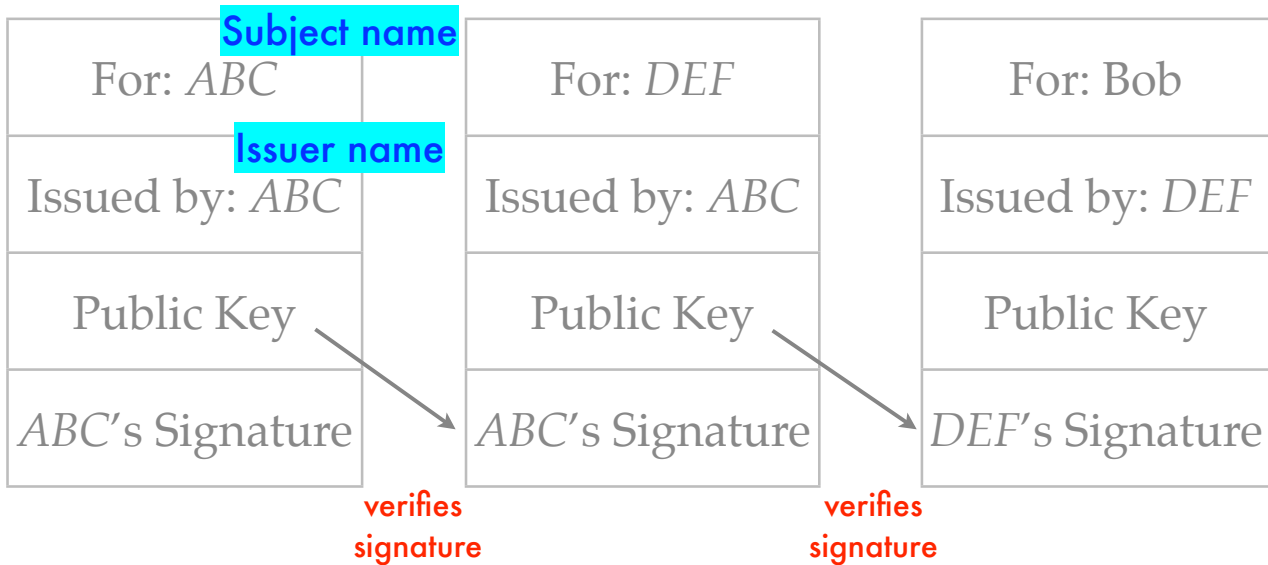
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Two-step path processing

1. **Path construction** involves collecting all certificates needed to form a complete path from an end entity to a trust point
2. **Path validation** involves examining each certificate in the path in turn, verifying the digital signature, examining validity period, checking revocation status, looking at policies, key usage restrictions, and so on

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Certification path



- Alice has *ABC's* public key
- *ABC's* certificate is the trust point

Example explanation

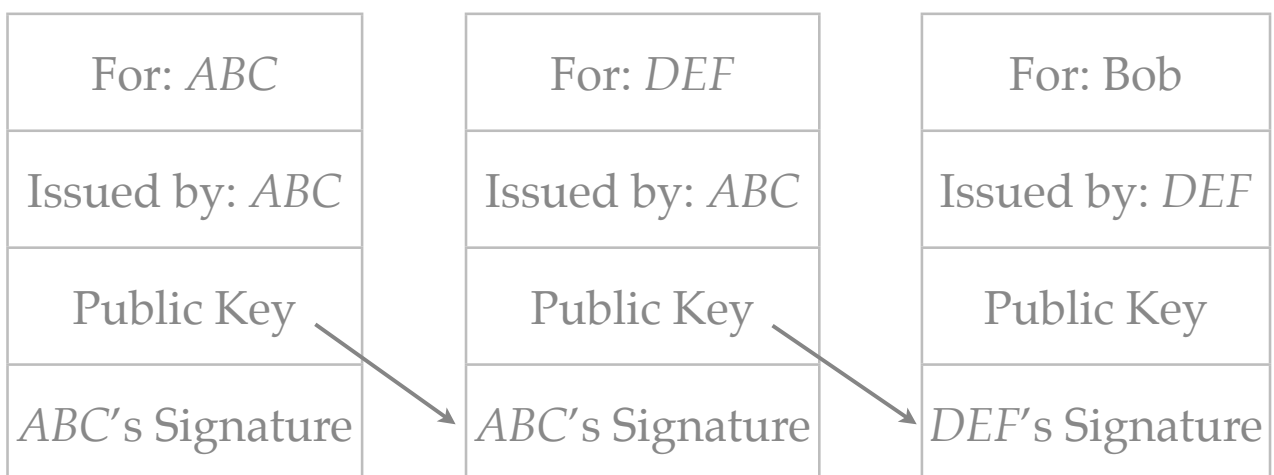
- Alice trusts the CA denoted *ABC*
 - she has *ABC's* public key
- *ABC* has issued a certificate to a CA denoted *DEF*
- Alice receives certificate from Bob signed by the private key of *DEF*
- To verify Bob's certificate Alice follows the certification path in the figure

Three types of certificates

1. **User certificates** for entities that are not CAs
2. **CA certificates** issued to CAs
 - part of certification paths
3. **Self-issued certificates**, or **root certificates**, are a special class of CA certificates where the issuer and the subject name are the same
 - used to distribute public-keys and to establish trust points

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Example revisited



**Self-issued
(or root)
certificate**

CA certificate

User certificate

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X.500 names

- **Distinguished Name (DN)**
 - X.500 hierarchical naming system
 - ordered list of naming attributes
 - the most common attributes are:
 - **c**=country, **o**=organization,
ou=organizational unit, **l**=locality,
cn=common name

`c=NO; o=UiB; ou=Department of Informatics; cn=Kjell Jørgen Hole`

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X.509 certificate evolution

- **Version 1:**
 - X.509 certificate specified in document CCITT Recommendation X.509
 - X.509 first published in 1988
- **Version 2:**
 - introduced in 1993
 - addressed the problem of reuse of X.500 names

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X.509 Version 3

- **Version 3** introduced certificate extensions
 - extension fields are used to include information not supported by basic certificate fields
- Only Version 3 certificates are considered during the remainder of the lecture series

certificate = X.509 Version 3 public-key certificate

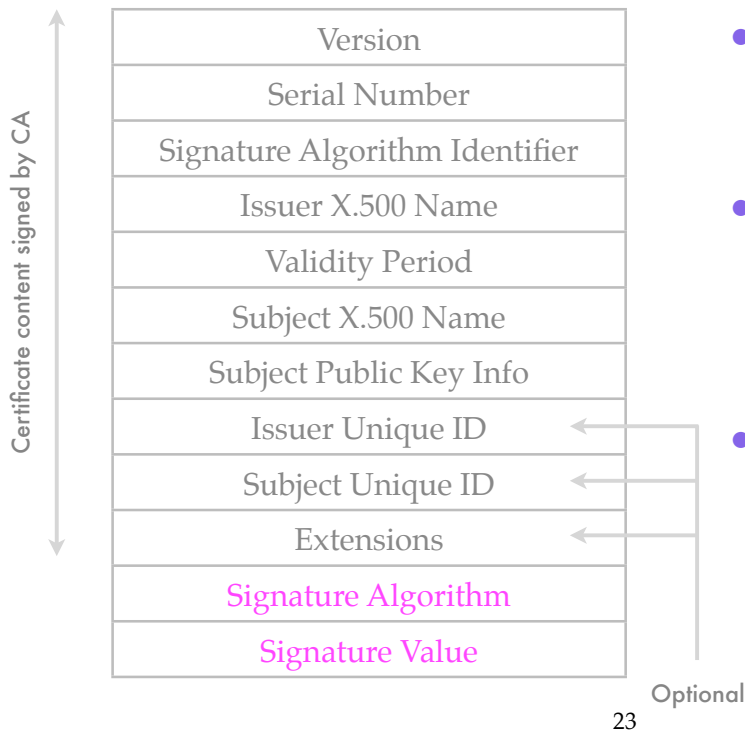
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Naming in X.509 Version 3

- Version 3 is not restricted to the X.500 naming system
- Any entity can be identified by one or more names of a variety of different forms:
 - Internet e-mail address
 - Internet domain name
 - Uniform Resource Locator (URI)
 - IP address

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X.509 certificate structure



- The table shows the certificate **fields**
- The content of the certificate is given by the 10 first fields
- The two last fields ensure that it is possible to detect tampering

Explanation of fields

- **Version:** indicator of Version 1, 2, or 3 format
- **Serial number:** unique identifying number for certificate, assigned by issuing CA
- **Signature Algorithm Identifier:** algorithm identifier of the digital signature algorithm used by the CA to sign certificate
- copy of the signature algorithm field protected by the digital signature

Explanations ...

- **Issuer:** X.500 name, i.e. DN, of the issuing CA
- **Validity Period:** Start and expiration dates
- **Subject Name:** X.500 name of the holder of the private key for which the corresponding public key is being certified
- **Subject-public-key information:** value of public key and an identifier for the algorithm to be used with the key

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Unique ID fields

- **Issuer Unique ID and Subject Unique ID:** optional bit strings used to make the names unambiguous in the event that the same names have been reassigned to different entities
 - difficult to manage, easy to overlook
 - fields should not be used

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Digital signature algorithms

Public key algorithm	Hash function	Algorithm identifier
RSA	MD5	md5WithRSAEncryption
RSA	SHA-1	sha1WithRSAEncryption
DSA	SHA-1	id-dsa-with-sha1
ECDSA	SHA-1	ecdsa-with-sha1

- Common digital signature algorithms

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Signature value

- **Signature value:** the field contains the value of the signature
- value is encoded as a bit string using conventions defined for the given signature algorithm
- Generated by the CA using the private key
- Anyone can verify the signature using the CA's public key

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Optional extensions

- **Extensions:** contains one or more certificate extensions. Each extension includes
 - an extension identifier
 - a **criticality flag** (critical / noncritical)
 - an extension value
- When the criticality flag is set the extension must be processed and understood, or the certificate is not to be used

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Criticality

- Noncritical extensions facilitate certificate sharing between different applications and graceful migration
- Critical extensions cause interoperability problems and should be avoided except to address security concerns

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Standard vs. private extensions

- Extensions allow a CA to include information not supported by the basic certificate content
- It is possible to define private extensions, however, they should be avoided to achieve interoperability
- Only standard extensions are discussed in the following

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Classification of extensions

- There are five different groups of extensions:
 1. **Subject ex:** is Bob a CA or an end entity?
 2. **Name ex:** Are `alice@fox.com` and `c=US; o=Fox Consulting; cn=Alice Adams` the same person?
 3. **Key ex:** Can this public key be used for key transport? verify digital signature?

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4. **Policy information ex:** Can I trust Alice's certificate? Is it appropriate for large value transactions?

5. **Additional info ex:** Where can I find

- certificates issued to a certain identity?
- certification revocation lists issued by some given CAs?

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Name extensions

- Initially, the only name form available was DN
- X.509 Version 3 has naming extensions called:
 - **subject alternative names**—mail addresses or DNS names for humans; URLs and DNS names for computers
 - **issuer alternative names**—list of general names, e.g. CA's mail address and IP address

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Policy extensions

- In early implementations, each CA issued certificates under only one (implicit) policy
 - it is clearly inefficient to deploy a separate CA for every policy
- Two standard policy extensions exist to solve this problem:
 - certificate policies extension
 - policy mapping extension

Certificate policies extension

- The certificate policies extension in a CA certificate indicates the policies under which the CA operates
- In an end entity certificate, the extension indicates the policy (policies) under which the certificate was issued
- A globally unique Object Identifier (OID) in the extension identifies a certain certificate policy

Certificate policies ...

- A OID may indicate that the certificate
 - is to be used with a particular application
 - has a certain relative quality (very good, good, or mediocre)
- Note that since the same certificate might be used for multiple applications, several policies might be identified in one certificate

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Policy mapping extension

- The policy mapping extension is used in CA certificates to translate policy information between two policy domains
- Policy mapping translates remote policy OIDs into local policy OIDs known to the certificate user
- The extension contains a list of one or more OID pairs

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Additional info extensions

- **CRL distribution points**—information on where and how to find one or more CRLs
- **Authority information access**—information on how to access CA information

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Summary

- A public-key certificate binds a public key to (the name of) an entity. This entity has the private key corresponding to the public key
- X.509 Version 3 certificates dominates on the Internet
- a certificate consists of many fields, some of which are optional
- the certificate content is signed with the CA's private key

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Summary

- There are three types of certificates:
 - user certificates
 - CA certificates
 - self-issued (or root) certificates

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Sources

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- R. Housley and T. Polk, [Planning for PKI](#), Wiley, 2001

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