Asymmetric key management

Problems to solve (1/2)

- Ensure a proper generation of key pairs
  - Random generation of secret values
  - Increase efficiency without reducing security
- Ensure a correct use of asymmetric key pairs
  - Privacy of private keys
    - To prevent the repudiation of digital signatures
  - Correct distribution of public keys
    - To ensure confidentiality
    - To ensure the correct validation of digital signatures

Problems to solve (2/2)

- Evolution of **entity⇔key pair** bindings
  - We cannot have eternal key pairs!
  - To tackle catastrophic occurrences
    - e.g. loss of private keys
  - To tackle normal exploitation requirements
    - e.g. refresh of key pairs for reducing impersonation risks
  - To tackle the evolution of technology and know-how
    - e.g. new attack vectors, massive and faster hardware

Asymmetric Key Management : Goals

- Key pair generation
  - When and how should they be generated
- Exploitation of private keys
  - How can they be kept private
- Distribution of public keys
  - How can them be distributed correctly worldwide
- Lifetime of key pairs
  - Until when should they be used
  - How can one check the obsoleteness of a key pair

Generation of key pairs: Design principles

- Good random generators for producing secrets
  - Bernoulli ½ generator
    - Memoryless generator
    - P(b=1) = P(b=0) = 1/2
- Facilitate without compromising security
  - Efficient RSA public keys
    - Few bits, typically 2^k+1 values (3, 17, 65537 = 2^{16} + 1)
    - Accelerates operations with public keys
    - No security issues
- Self-generation of private keys
  - To maximize privacy
  - This principle can be relaxed when not involving signatures

Exploitation of private keys

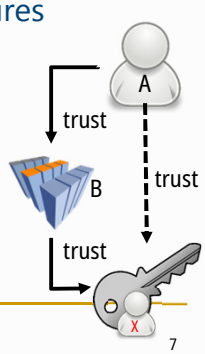
- Correctness
  - The private key represents a subject
    - Its compromise must be minimized
    - Physically secure backup copies can exist in some cases
  - The access path to the private key must be controlled
    - Access protection with password or PIN
    - Correctness of applications
- Confinement
  - Protection of the private key inside a (reduced) security domain (ex. cryptographic token)
    - The token generates key pairs
    - The token exports the public key but never the private key
    - The token internally encrypts/decrypts with the private key

Distribution of public keys

- Distribution to all **senders** of confidential data
  - Manual
  - Using a shared secret
  - Ad-hoc using digital certificates
- Distribution to all **receivers** of digital signatures
  - Ad-hoc using digital certificates
- Trustworthy dissemination of public keys
  - Trust paths / graphs

    If entity A trusts entity B and B trust in K_X^+,

    then A trusts in K_X^+
  - Certification hierarchies / graphs



Public key (digital) certificates

- Documents issued by a Certification Authority (CA)
  - Bind a public key to an entity
    - Person, server or service
  - Are public documents
    - Do not contain private information, only public one
  - Are cryptographically secure
    - Digitally signed by the issuer, cannot be changed
- Can be used to distribute public keys in a trustworthy way
  - A certificate receiver can validate it
    - With the CA's public key
  - If the signer (CA) public key is trusted, and the signature is correct, then the receiver can trust the (certified) public key
    - As the CA trust the public key, if the receiver trusts on the CA public key, the receiver can trust on the public key

Public key (digital) certificates

- X.509v3 standard
  - Mandatory fields
    - Version
    - Subject
    - Public key
    - Dates (issuing, deadline)
    - Issuer
    - Signature
    - etc.
  - Extensions
    - Critical or non-critical
- PKCS #6
  - Extended-Certificate Syntax Standard
- Binary formats
  - ASN.1 (Abstract Syntax Notation)
    - DER, CER, BER, etc.
  - PKCS #7
    - Cryptographic Message Syntax Standard
  - PKCS #12
    - Personal Information Exchange Syntax Standard
- Other formats
  - PEM (Privacy Enhanced Mail)
  - base64 encodings of X.509

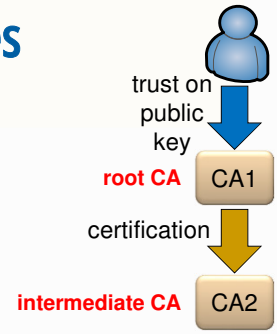
Key pair usage

- A key pair is bound to a usage profile by its public key certificate
  - Public keys are seldom multi-purpose
- Typical usages
  - Authentication / key distribution
    - Digital signature, Key encipherment, Data encipherment, Key agreement
  - Document signing
    - Digital signature, Non-repudiation
  - Certificate issuing
    - Certificate signing, CRL signing
- Public key certificates have an extension for this
  - Key usage (critical)

Certification Authorities (CA)

- Organizations that manage public key certificates
- Define policies and mechanisms for
  - Issuing certificates
  - Revoking certificates
  - Distributing certificates
  - Issuing and distributing the corresponding private keys
- Manage certificate revocation lists
  - Lists of revoked certificates

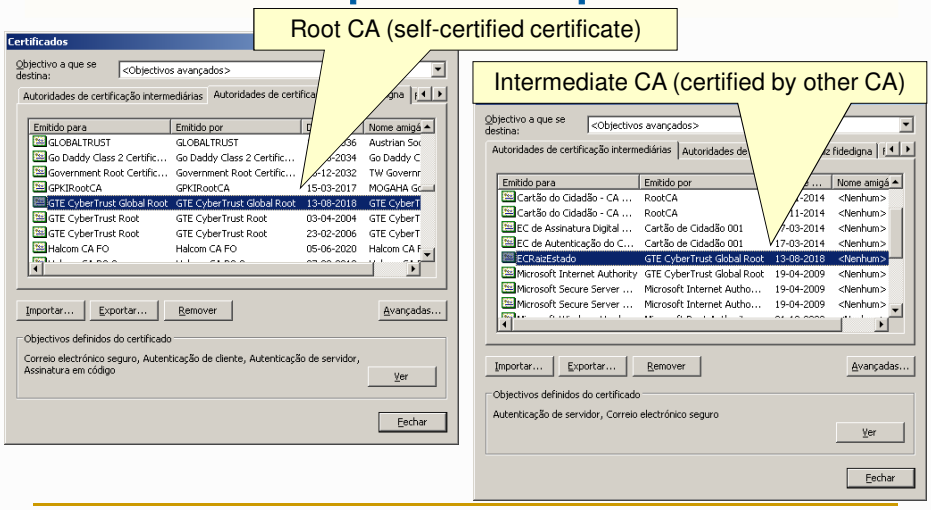
Trusted Certification Authorities



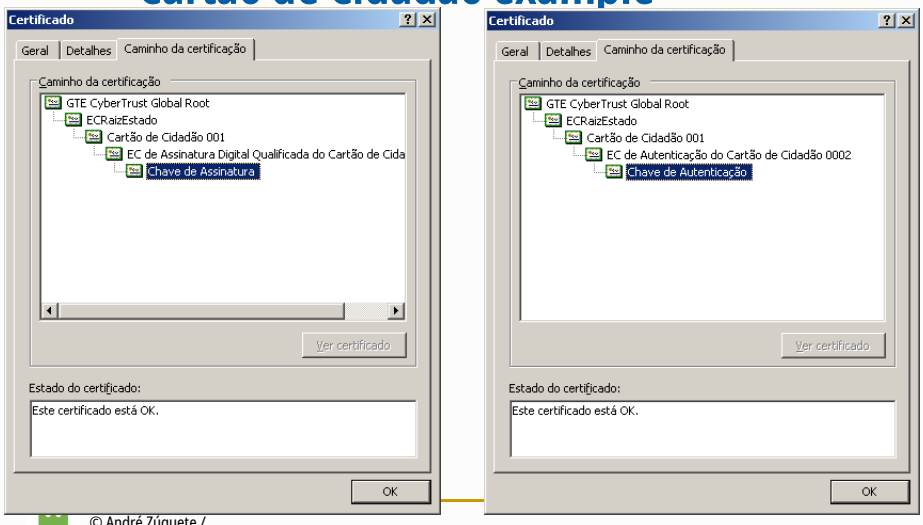
- CAs certified by other trusted CAs
  - Intermediate CAs
  - Using a certificate
  - Certification hierarchies
- CAs for which one has a trusted public key
  - Trusted anchor (or certification root)
  - Usually implemented by self-certified certificates
    - Issuer = Subject
  - Manual distribution
    - ex. within browsers code (Firefox, Chrome, etc.)

Manual distribution of trusted public keys (as root certificates):

Internet Explorer example



Certification hierarchies (or paths): Cartão de Cidadão example



Certification hierarchies: PEM (Privacy Enhanced Mail) model

- Distribution of certificates for PEM (secure e-mail)
  - Worldwide hierarchy (monopoly)
  - Single root (IPRA)
  - Several PCA (Policy Creation Authorities) bellow the root
  - Several CA below each PCA
    - Possibly belonging to organizations or companies
- Never implemented
  - Forest of hierarchies
    - Each with its independent root CA
    - Oligarchy
  - Each root CA negotiates the distribution of its public key along with some applications or operating systems
    - ex. Browsers, Windows

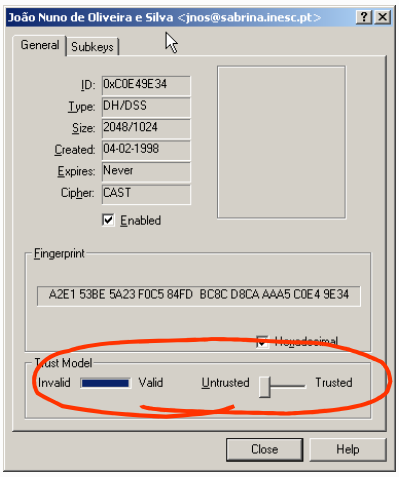
Certification hierarchies: PGP (Pretty Good Privacy) Model

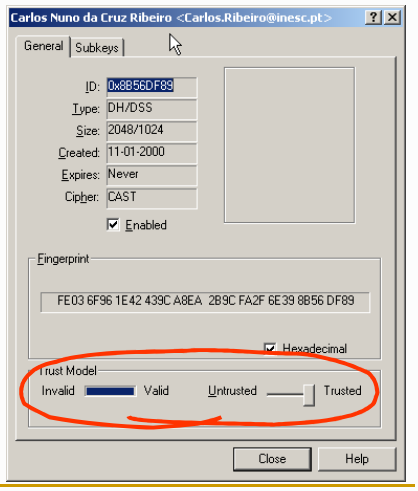
- Web of trust
  - No central trustworthy authorities
    - Each person is a potential certifier
    - Can certify a public key (issue a certificate) and publish it
  - People uses 2 kinds of trust
    - Trust in the keys they know
      - Validated using any means (FAX, telephone, etc.)
    - Trust in the behavior of certifiers
      - Assumption that they know what they are doing when issuing a certificate
- Transitive trust
  - If

    Alice trusts Bob is a correct certifier; and
    Bob certified the public key of Carl,
  - then

    Alice trusts the public key belongs to Carl

PGP public key certificates: Validity vs. trust





Refreshing of asymmetric key pairs

- Key pairs should have a limited lifetime
  - Because private keys can be lost or discovered
  - To implement a regular update policy
- Problem
  - Certificates can be freely copied and distributed
  - The universe of certificate holders is unknown!
    - Thus, cannot be told to eliminate specific certificates
- Solutions
  - Certificates with a validity period
  - Certificate revocation lists
    - To revoke certificates before expiring their validity

Certificate revocation lists (CRL)

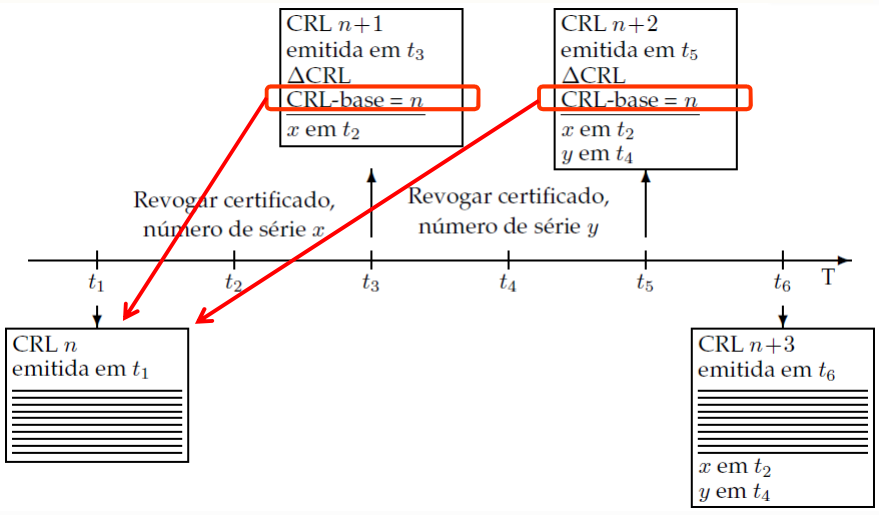
- Base or delta
  - Complete / differences
- Signed list of identifyers of prematurely invalidated certificates
  - Must be regurlarly fetched by verifiers
    - e.g. once a day
  - OCSP protocol for single certificate check
    - RFC 2560
  - Can tell the revocation reason
- Publication and distribution of CRLs
  - Each CA keeps its CRL and allows public access to it
  - CAs exchange CRLs to facilitate their widespreading

RFC 3280

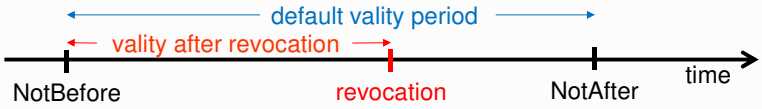
unspecified (0)
keyCompromise (1)
CACompromise (2)
affiliationChanged (3)
superseded (4)
cessationOfOperation (5)
certificateHold (6)

removeFromCRL (8)
privilegeWithdrawn (9)
AACompromise (10)

CRL and Delta CRL



Validity of signatures



- A signature is **valid** if it was generated during the **validity period** of the corresponding pub key certificate
  - The validity period starts on the certificate's **NotBefore** date field
  - By default, the validity ends on the **NotAfter** date field
    - Unless revoked
- A private key can be used out of that period
  - But the signature it produces is invalid
- A public key certificate can be used anytime
  - Namely, after the validity period to check past signatures

Distribution of public key certificates

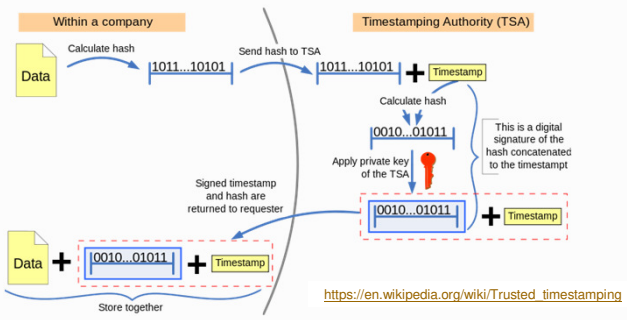
- Transparent (integrated with systems or applications)
- Directory systems
  - Large scale
    - ex. X.500 through LDAP
  - Organizational
    - ex. Windows 2000 Active Directory (AD)
- On-line
  - Within protocols using certificates for peer authentication
    - e.g. secure communication protocols (SSL, IPSec, etc.)
    - e.g. digital signatures within MIME mail messages
    - e.g. digital signatures within documents

Distribution of public key certificates

- Explicit (voluntarily triggered by users)
- User request to a service for getting a required certificate
  - e.g. request sent by e-mail
  - e.g. access to a personal HTTP page
- Useful for creating certification chains for frequently used terminal certificates
  - e.g. certificate chains for authenticating with the Cartão de Cidadão

Time Stamping Authority (TSA)

- A service that provides signatures over a timestamp
  - Linked with a data digest



- This is useful for adding trust to a data signature date
  - The date becomes linked to the signed data

PKI (*Public Key Infrastructure*)

- Infrastructure for enabling the use of keys pairs and certificates
  - Creation of asymmetric key pairs for each enrolled entity
    - Enrolment policies
    - Key pair generation policies
  - Creation and distribution of public key certificates
    - Enrolment policies
    - Definition of certificate attributes
  - Definition and use of certification chains (or paths)
    - Insertion in a certification hierarchy
    - Certification of other CAs
  - Update, publication and consultation of CRLs
    - Policies for revoking certificates
    - Online CRL distribution services
    - Online OCSP services
  - Use of data structures and protocols enabling inter-operation among components / services / people

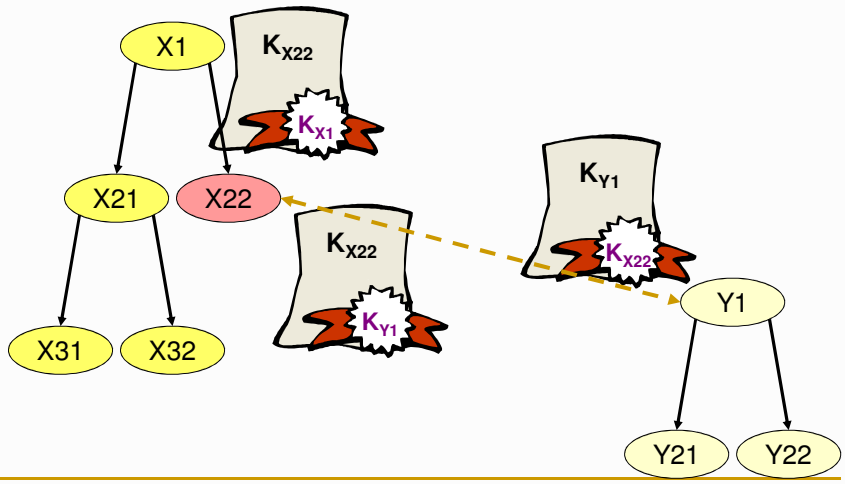
PKI:
Example: Cartão de Cidadão policies

- Enrollment
  - In loco, personal enrolment
- Multiple key pairs per person
  - One for authentication
  - One for signing data
  - Generated in smartcard, not exportable
  - Require a PIN in each operation
- Certificate usage (authorized)
  - Authentication
    - SSL Client Certificate, Email (Netscape cert. type)
    - Signing, Key Agreement (key usage)
  - Signature
    - Email (Netscape cert. type)
    - Non-repudiation (key usage)
- Certification path
  - Well-known, widely distributed root
    - GTE Cyber Trust Global Root
    - Baltimore CyberTrust Root
    - MULTICERT Root Certification Authority 01
  - PT root CA below GTE
  - CC root CA below PT root CA
  - CC Authentication CA and CC signature CA below CC root CA
- CRLs
  - Signature certif. revoked by default
    - Removed if owner explicitly requires the usage of signatures
  - Certificates revoked upon a owner request
    - Requires a revocation PIN
  - CRL distribution points explicitly mentioned in each certificate

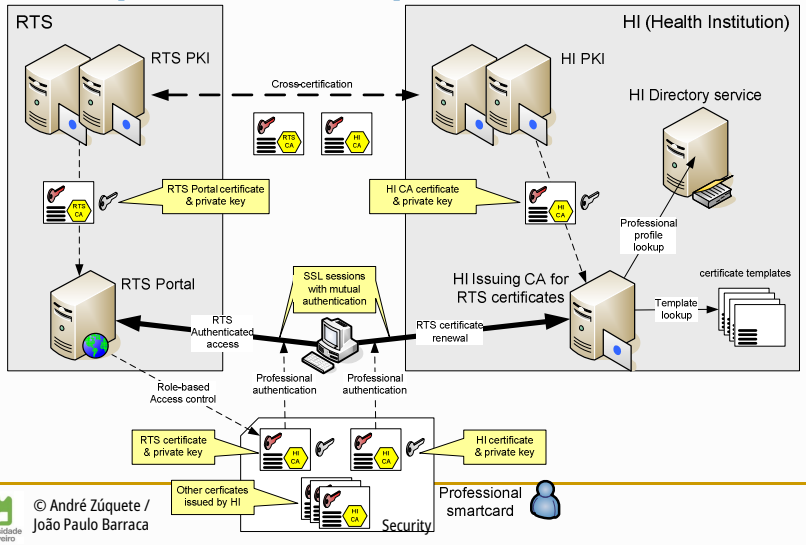
PKI:
Trust relationships

- A PKI defines trust relationships in two different ways
  - By issuing certificates for the public key of other CAs
    - Hierarchically below; or
    - Not hierarchically related
  - By requiring the certification of its public key by another CA
    - Above in the hierarchy; or
    - Not hierarchically related
- Usual trust relationships
  - Hierarchical
  - Crossed (A certifies B and vice-versa)
  - Ad-hoc (mesh)
    - More or less complex certification graphs

PKI:
Hierarchical and crossed certifications



Cross-certification of PKIs: A practical example



Additional documentation

- [RFC 3280] Internet X.509 Public Key Infrastructure: Certificate and CRL Profile
- Other RFCs

[RFC 4210] Internet X.509 Public Key Infrastructure Certificate Management Protocol (CMP)
[RFC 4211] Internet X.509 Public Key Infrastructure Certificate Request Message Format (CRMF)
[RFC 3494] Lightweight Directory Access Protocol version 2 (LDAPv2) to Historic Status
[RFC 6960] X.509 Internet Public Key Infrastructure Online Certificate Status Protocol - OCSP
[RFC 2585] Internet X.509 PKI Operational Protocols: FTP and HTTP
[RFC 2587] Internet X.509 PKI LDAPv2 Schema
[RFC 3029] Internet X.509 PKI Data Validation and Certification Server Protocols
[RFC 3161] Internet X.509 PKI Time-Stamp Protocol (TSP)
[RFC 3279] Algorithms and Identifiers for the Internet X.509 PKI Certificate and Certificate Revocation List (CRL) Profile
[RFC 3281] An Internet Attribute Certificate Profile for Authorization
[RFC 3647] Internet X.509 PKI Certificate Policy and Certification Practices Framework
[RFC 3709] Internet X.509 PKI: Logotypes in X.509 Certificates
[RFC 3739] Internet X.509 PKI: Qualified Certificates Profile
[RFC 3779] X.509 Extensions for IP Addresses and AS Identifiers
[RFC 3820] Internet X.509 PKI Proxy Certificate Profile