# Digital signatures



## Digital signatures: goals

- Authenticate the contents of a document
  - Ensure its integrity
- Authenticate its author
  - Ensure the identity of the creator/originator
- Non-repudiation
  - Prevent signing repudiation

# Digital signatures: fundamental approach

- Signature generation
  - Production of a value using a private key
  - Signer (or signatory) is the private key owner
- Signature verification
  - Validation of an expression using the signature and a public key
  - Anyone can verify
    - Since public keys can be universally known
  - Signature can be linked to the public key owner



# Signature schemes

- With message (or document) recovery
  - The message is fully recovered upon a signature validation
  - Signature validation is mandatory prior to message observation
- With appendix
  - The signature is detached from the message
  - The message can be observed anytime

## Key elements of a digital signature

- The message (or document)
  - It only makes sense with the signed object
- The signature date
  - Because is usually required
  - Because key pairs have validity periods
- The identity of the signatory
  - Otherwise it would not mean anything



## The document to sign

- It may accommodate digital signatures as appendixes
  - PDF, XML
  - DOCX (archive of XML components)
- Other formats may group document and signature
  - S/MIME (mail)
  - JOSE (JSON Object Signing and Encryption)

## The signature date

- It may be given by the signatory machine
  - Does not protect against time forgery attacks by the signatory
- It may be given by a Time Stamping Authority (TSA)
  - Does not protect against the future discovery of the private keys used



## The identity of the signatory

- Usually provided by a X.509 public key certificate
  - It provides several attributes of the identity
  - It provides the public key for signature validation
  - It provides the acceptable signing time frame
    - Together with the respective CRL

# Optional elements of a digital signature

- Attributes that can help to interpret it
  - Location
    - Where it was signed
  - Reason
    - Why it was signed
  - Appearance
    - Handwritten signature (usually without legal value)
    - Name of the signatory
    - Date of signature
    - Some kind of logo



# Digital signatures' algorithms

- Message recovery scheme
  - Asymmetric encryption and decryption
  - Only for RSA
- Message appendix scheme
  - Digest functions
  - Asymmetric signature and validation
  - RSA, ElGamal (DSA), EC

- Signing
  $A_x(doc) = info + E(K_x^{-1}, doc)$
- Verification
  info→$K_x$
  $D(K_x, A_x(doc))$
  Check integrity of doc

- Signing
  $A_x(doc) = info + E(K_x^{-1}, h(doc+info))$
  $A_x(doc) = info + S(K_x^{-1}, h(doc+info))$
- Verification
  info→$K_x$
  $D(K_x, A_x(doc)) \equiv h(doc + info)$
  $V(K_x, A_x(doc), h(doc + info)) = True$

# RSA signatures

- Creation with private key
  - Validation with the corresponding public key
- Special padding for Signature Scheme w/ Appendix
  - RSASSA-PKCS#1 (v1.5)
    - Deterministic
  - RSASSA-PSS (Probabilistic Signature Scheme)
    - Randomized (EMSA-PSS)
- Hash function prefixing
  - ASN.1 algorithm OID

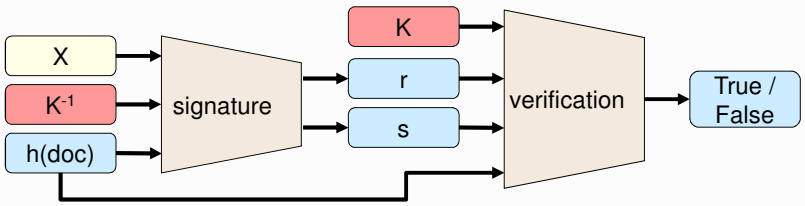


# ASN.1 digest algorithm prefixes

| Digest | ASN.1 OID | Perfix (bytes) |
|---|---|---|
| MD5 | 1.2.840.113549.2.5 | 30 20 30 0C 06 08 **2A 86 48 86 F7 0D 02 05** 05 00 04 10 |
| RIPEMD-160 | 1.3.36.3.2.1 | 30 21 30 09 06 05 **2B 24 03 02 01** 05 00 04 14 |
| SHA-1 | 1.3.14.3.2.26 | 30 21 30 09 06 05 **2B 0E 03 02 1A** 05 00 04 14 |
| SHA-224 | 2.16.840.1.101.3.4.2.4 | 30 2D 30 0D 06 09 **60 86 48 01 65 03 04 02 04** 05 00 04 1C |
| SHA-256 | 2.16.840.1.101.3.4.2.1 | 30 31 30 0D 06 09 **60 86 48 01 65 03 04 02 01** 05 00 04 20 |
| SHA-384 | 2.16.840.1.101.3.4.2.2 | 30 41 30 0D 06 09 **60 86 48 01 65 03 04 02 02** 05 00 04 30 |
| SHA-512 | 2.16.840.1.101.3.4.2.3 | 30 51 30 0D 06 09 **60 86 48 01 65 03 04 02 03** 05 00 04 40 |

# Digital Signature Standard (DSS)

- With a variant of ElGamal
  - Digital Signature Algorithm (DSA)
  - Uses a random value **X**, and its multiplicative inverse, $\mathbf{X^{-1}}$
  - **r** depends on **X**, **s** depends on $\mathbf{X^{-1}}$
- With elliptic curves (ECDSA)
  - Similar to DSA with EC






# Blind signatures

- Signatures made by a "blinded" signer
  - Signer cannot observe the contents it signs
  - Similar to a handwritten signature on an envelope containing a document and a carbon-copy sheet
- Useful for ensuring anonymity of the signed information holder, while the signed information provides some extra functionality
  - Signer X knows who requires a signature (Y)
  - X signs $T_1$, but Y afterwards transforms it into a signature over $T_2$
    - Not any $T_2$, a specific one linked to $T_1$
  - Requester Y can present $T_2$ signed by X
    - But it cannot change $T_2$
    - X cannot link $T_2$ to the $T_1$ that it observed when signing

# Chaum Blind Signatures

- Implementation using RSA
  - Blinding
    - Random blinding factor $k$
    - $k \times k^{-1} \equiv 1 \pmod{N}$
    - $m' = k^e \times m \bmod N$
  - Ordinary signature (encryption w/ private key)
    - $A_x(m') = (m')^d \bmod N$
  - Unblinding
    - $A_x(m) = k^{-1} \times A_x(m') \bmod$



# Qualified electronic signature

- An electronic signature compliant with the EU eIDAS Regulation
  - Regulation No 910/2014
- Enables to verify the authorship of a declaration in electronic data exchange
  - Over long periods of time
- Can be considered as a digital equivalent to handwritten signatures

## Qualified electronic signature

- Three main requirements:
  - The signatory must be linked and uniquely identified to the signature
  - The data used to create the signature must be under the sole control of the signatory
  - Must have the ability to identify if the data that accompanies the signature has been tampered with since the signing of the message



## Qualified electronic signature

- Must be created using a qualified signature creation device
  - This device uses specific hardware and software that ensures that the signatory only has control of their private key
- A qualified trust service provider manages the signature creation data that is produced
  - But the signature creation data must remain unique, confidential and protected from forgery

## Signature devices

- Crypto tokens
  - Smartcards
  - Cartão de Cidadão
- Cloud HSM (Hardware Secure Modules)
  - Mainly for mobile devices
  - Chave Móvel Digital



## PKCS #11

- Crypto tokens' standard interface
  - Cryptoki
- Enables applications to use arbitrary PKCS #11 libraries
  - Developed for a specific set of crypto tokens
- Specification in C
  - There are interfaces for other languages

# Microsoft Cryptographic API (CAPI)

- Unique OS security middleware hub
  - Applications use the abstractions it provides
- Cryptographic Services Providers (CSP)
  - Target-specific software module under the CAPI
    - It enables a particular functionality
  - Signature capabilities can be added with CSPs
    - For local crypto tokens
    - For remote, cloud-based HSMs



# Long-Term Validation (LTV)

- A document signature may become invalid upon an initial verification
  - Due to a late certification revocation
- Signature algorithms may become vulnerable
  - Allowing signatures with old credentials to be forged
- LTV attempts to handle both issues
  - With successive signature layers
  - Performed by signed documents' holders

# LTV Advanced Electronic Signatures (AdES)

- PAdES
  - PDF Advanced Electronic Signature
- CAdES
  - Cryptographic Message Syntax Advanced Electronic Signatures
- XAdES
  - XML Advanced Electronic Signatures