6 Cryptographic Techniques – A Brief Introduction

Literature:

Bruce Schneier: Applied Cryptography, 2nd ed., John Wiley 1996

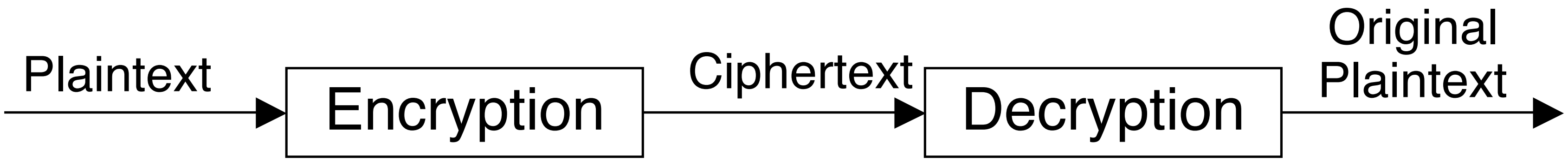
Donal O'Mahony, Michael Peirce, Hitesh Tewari: Electronic Payment Systems for E-Commerce, 2nd ed., Artech House 2001 (Chapter 3)

Purpose of Cryptographic Techniques

- To protect the content of communication between two parties
  - Protection against various kinds of attacks
  - Preserving confidentiality and integrity of a message
  - Computer-equivalent to packaging and sealing
- To establish the identity of communication partners (*authentication*)
  - Computer-equivalent to hand-written signature
  - *Nonrepudiation (Zurechenbarkeit):*
    Avoiding false denial of the fact that someone has sent a message

- Applications for networked multimedia:
  - Encrypted content in DRM, decryption only for authorized users
  - Packaging keys and right specifications in DRM
  - Identifying business partners for payment procedures
  - Protecting electronic forms of money
  - Protecting important personal data

Encryption and Decryption



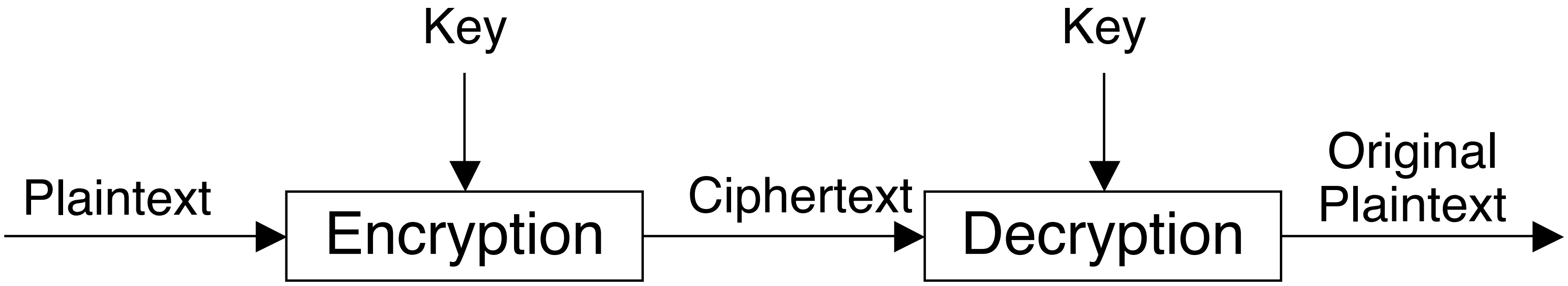
- A *sender* (often called Alice) wants to send a *message* to a *receiver* (often called *Bob*), in a way that an eavesdropper (often called *Eve*) cannot read the message.
  – Plaintext message (binary data) M
  – Ciphertext C
- Encryption E:

  $E(M) = C$
- Decryption D:

  $D(C) = M$

  such that $D(E(M)) = M$
- Encryption/Decryption should not rely on keeping the algorithms secret.
  – Kerckhoffs principle

Encryption and Decryption Keys



- Encryption *E:*

  $E(K_1, M) = C$
- Decryption *D:*

  $D(K_2, C) = M$

  such that $D(K_2, E(K_1, M)) = M$
- Special case:
  Identical keys for encryption and decryption

Attack Terminology

- Ciphertext-only attack
  – Recover the plaintext or the keys based only on the ciphertext
- Known-plaintext attack:
  – Deduce the keys from given plaintext and corresponding ciphertext
- Chosen-plaintext attack:
  – Attacker (cryptanalyst) can obtain the encoding result on an arbitrary plaintext
- Chosen-ciphertext attack:
  – Attacker (cryptanalyst) can obtain the decoding result on an arbitrary ciphertext

- Brute-force attack
  – Trying out all possible keys
  – Breakability depends on available computing power

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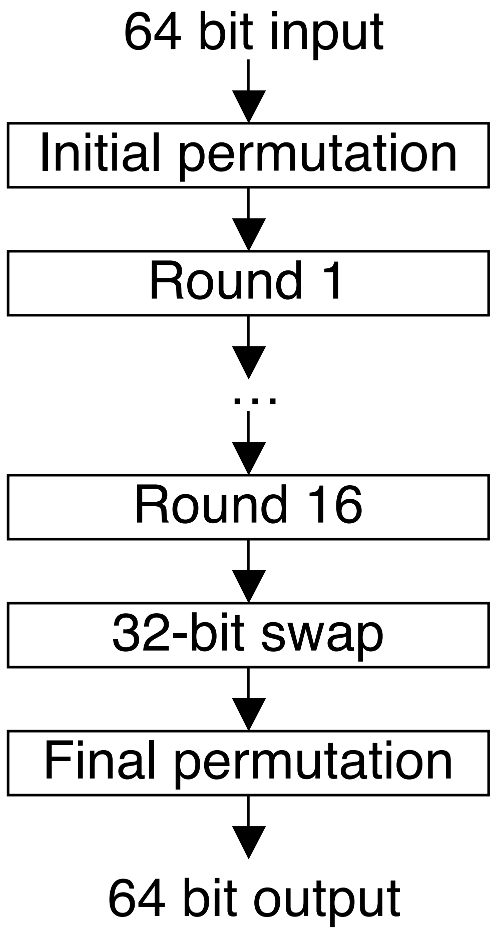
Symmetric Cryptographic Algorithms

- Encryption and decryption using the same key
  – Alternatively: One key can be computed from the other

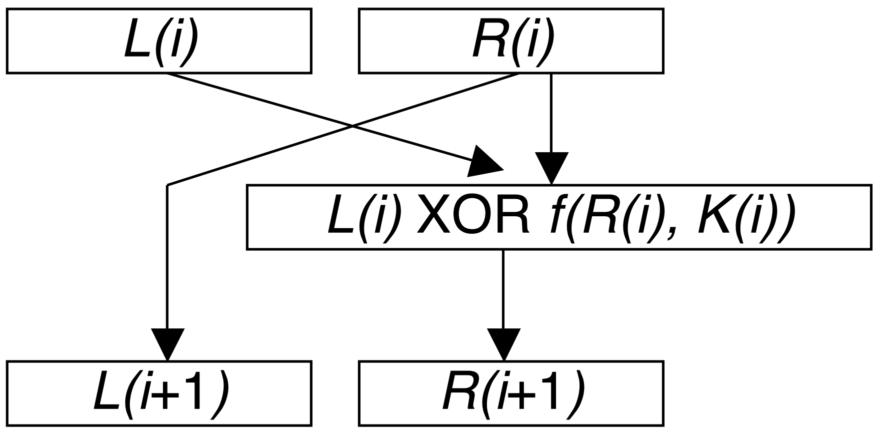
- Stream algorithms or *stream ciphers:*
  – Operate bit-by-bit (or byte-by-byte)

- Block algorithms or *block ciphers:*
  – Operate on larger groups of bits (blocks)
  – Block size should not be too large - typical 64 bits

Data Encryption Standard DES



- Symmetric block cipher (64 bit blocks)
- Adopted by U.S. government in 1977, based on IBMs *Lucifer* algorithm
  - Designed for hardware realization
- Key length: 56 bits
- Each of the 16 “rounds”:



Encoding and decoding algorithms identical

- *f* does a number of permutations and substitutions

DES – Example for an Aging Standard

- Brute force attack to DES: 2^{56} permutations to be tried
  - 56 bit keys considered unbreakable in 1977
- Specialized hardware can test DES keys very fast
  - Rumours persist that the NSA (US National Security Agency) can break 56-bit DES in a few minutes time
  - 1997: DES Challenge
    - » After 4 months, a DES-encrypted message could be decrypted
  - 2000: DES Challenge III won by “distributed.net” in 22 hours
    - » Specialized supercomputer + CPU time from 100.000 PCs in the Internet
    - » Key test rate 240 billion keys/second
- Practical workaround: “Triple DES”
- Obstacle for unbreakable codes:
  - U.S. government apparently wants to be able to break the standard encryptions
- Strong cryptographic products are considered weapon technology by the U.S. government!
  - Export restrictions

IDEA

- Xuejia Lai/James Massey (ETH Zürich) 1990
  - Strengthened against “differential cryptoanalysis” in 1992
  - Partially patented by Ascom (Switzerland) until 2011
- Block cipher, working on 64 bit blocks
- Key length 128 bit
- Twice as fast as DES (in particular fast in software)
- Idea: “Mixing operations from different algebraic groups”
  - XOR
  - Addition modulo 2^{16}
  - Multiplication modulo $2^{16}+1$

- Can be considered as quite safe according to current knowledge

Advanced Encryption Standard AES

- U.S. National Institute of Standards and Technology (NIST)
  - 1997: Call for proposals for an unclassified, publicly disclosed symmetric encryption algorithm, key sizes 128, 192, and 256 bits
  - 15 submissions, 5 candidates selected (MARS, RC6, Rijndael, Serpent, Twofish)
  - 2000: Rijndael declared to be official AES
- Rijndael (Joan Daelen, Vincent Rijmen, Belgium):
  - Between 10 and 14 rounds, depending on key and block length
  - Operations in each round:
    - » XOR
    - » Byte substitution
    - » Row shift (in a grid representation)
    - » Mixing of columns based on polynomial (in a grid representation)
- Other common alternative symmetric algorithms: RC4, RC6

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Asymmetric or Public Key Encryption

- Main problem of symmetric cryptography:
  How to obtain the shared, secret key?
  - Off-line transportation
  - Key distribution architectures, e.g. Kerberos
- Public-key cryptography: Whitfield Diffie, Martin Hellman 1976
  - Each person gets a *private* (secret) key and a *public* key

- Public-Key Cryptosystem:

  Encryption with public key: $PK(M) = C$

  Decryption with secret key: $SK(C) = M$

  such that $SK(PK(M)) = M$
  - By publicly revealing PK, user does not reveal an easy way to compute SK.
- Mathematical background: "Trapdoor one-way function"
  - e.g. prime factorization of large numbers

RSA: Mathematics

- Ronald Rivest, Adi Shamir, Leonard Adleman 1978 (MIT)
- Creating a public/secret key pair:
  - Choose two large primes p and q and compute the “modulus” $n = pq$
  - Randomly choose a number $e < n$, relatively prime to $\phi = (p-1)(q-1)$ (Eulers totient function)
    - » (n, e) is the public encryption key
  - Compute d as inverse of e (modulo ϕ): i.e. such that $(ed \equiv 1) \bmod \phi$
    - » (n, d) is the secret decryption key
- Encryption:

  $C = M^{e} \bmod n$
- Decryption:

  $M = C^{d} \bmod n$

For an example, see e.g. http://www.di-mgt.com.au/rsa_alg.html

RSA: Mathematics – Example

- Creating a public/secret key pair:
  - Choose two (large) primes p and q and compute the “modulus” $n = pq$
    - » *p = 11, q = 13, n = 143 (in practice much larger!)*
  - Randomly choose a number $e < n$, relatively prime to $\phi = (p-1)(q-1) = 120$
    - » E.g. *e = 23 (in practice, Fermat primes are used, e.g. 3, 17 and 65537)*
    - » (*143*, *23*) is the public encryption key
  - Compute d such that $(ed \equiv 1) \bmod \phi$, i.e. $(ed-1) = k\,\phi$, i.e. $(23\,d-1) = k\,120$
    - » Apply extended Euclidian algorithm: *d = 47, k = 9*
    - » (*143*, *47*) is the secret decryption key
- Encryption:

  $C = M^{e} \bmod n$, *e.g.* $C = 7^{23} \bmod 143 = 2$ *(Modular arithmetic)*
- Decryption:

  $M = C^{d} \bmod n$, *e.g.* $M = 2^{47} \bmod 143 = 7$

RSA: Pragmatics

- Key size is variable, typical 1024 bits
- RSA relies on exponentiation which is computing-intensive
  - DES is at least 100 times as fast as RSA in software and 1000 to 10000 times as fast in hardware
- Security of RSA is conjectured to rely on factorization of large numbers into primes
- Hybrid usage of symmetric and asymmetric cryptosystems *(enveloping)*
  - Choose a symmetric key (e.g. for AES)
  - Encode the symmetric key with an asymmetric cryptosystem (e.g. RSA) to transmit the shared (symmetric) key to the communication partner
  - Combination of advantages:
    - » Use asymmetric system for keeping the secrets locally
    - » Use symmetric system for mass-data encoding
- RSA is part of many Internet protocols for secure interaction, e.g. S/MIME, SSL, TLS, IPsec, ...

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Digital Signature with Asymmetric Cryptosystems

- Message authentication (digital signature):
  - To establish trust that a message actually originates from a certain sender
  - Must involve full message body, i.e. similar to message encryption
- Some asymmetric cryptosystems allow to use "inverse encryption" for a digital signature, e.g. RSA
  - For such cryptosystems, the inverse equation holds: $PK(SK(M)) = M$
  - Encryption with own secret key
  - Verification possible by anybody knowing the public key
- Example: Suppose Alice wants to send a message M to Bob ensuring the message's integrity and that it is from her

  $S = M^d \bmod n$ — (n, d) is Alice's secret key
  Equivalent to decryption algorithm

  - Alice sends M and S to Bob
- Bob verifies:

  $M = S^e \bmod n$ — (n, e) is Alice's public key
  Equivalent to encryption algorithm

- Other digital signature standards exist, e.g. DSS/DSA (Digital Signature Standard/Algorithm by NIST)

Message Digesting or Hashing

- Sometimes not encryption, but integrity of message is the goal
  - Simpler algorithms similar to symmetric encryption
- Hash (or *digesting*) function for messages
  - Computes short code from long message
  - Difficult to invert (i.e. to obtain message from code)
  - Collision-resistant (i.e. unlikely to find two messages with same hash code)

- Examples of message digesting algorithms:
  - MD5 (Ron Rivest) (128 bit code)
  - Secure Hash Algorithm SHA (NIST) (160 bit code)

- Combination of message digest and signing the digest:
  - Faster way of authenticating a message

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Public Key Infrastructure

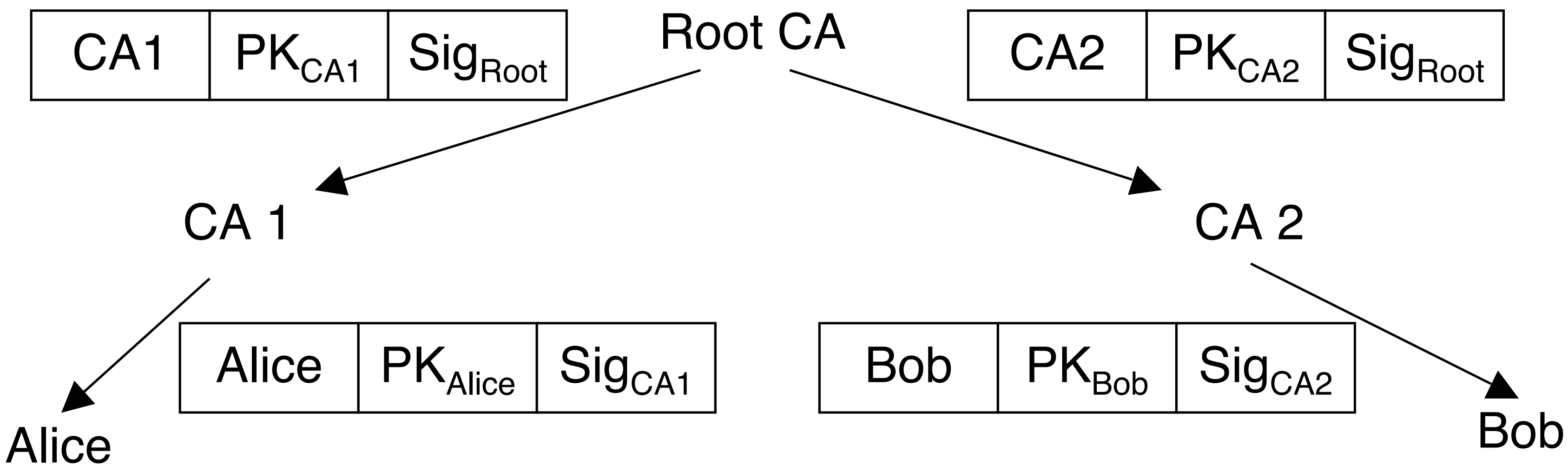
- Weak point in public-key cryptosystems
  - Bogus public key associated with a valid identity
  - Attacker can masquerade as another person
- Establishing trust in public keys:
  - Trusted Third Party (TTP)
    - e.g. governmental organisation, financial institution
  - TTP issues a message *(certificate)* that contains
    - User identity
    - Public key
    - Validity period
    - Issuer (TTP identity)
  - TTP "signs" certificate
    - This can be achieved by using the own public key
    - All participants know the signatures (public keys) of TTP, i.e. can trust that the certificates actually come from the issuing TTP

Certificate

Identity	PK	Signa-ture

Certification Authorities

- A TTP issuing certificates is a *Certification Authority* (CA)
- CAs are organized in a hierarchy, signature of root CA universally known



The certificates for the public key can be transferred with the message (or put on a website etc.)
E.g. message from Alice to Bob:

Digital Signatures and PKI

- The “chain of trust” in a PKI can be reduced to the single fact
  - Everybody knows the public key PK_{Root} of the Root CA
- Root CA signs CAx certificates using its secret key SK_{Root}
  - Everybody can verify the certificates using PK_{Root}
- CAx signs certificates using its secret key SK_{CAx}
  - Everybody can verify the certificate as soon as he has PK_{CAx}
  - ... which he can obtain from a Root-signed certificate

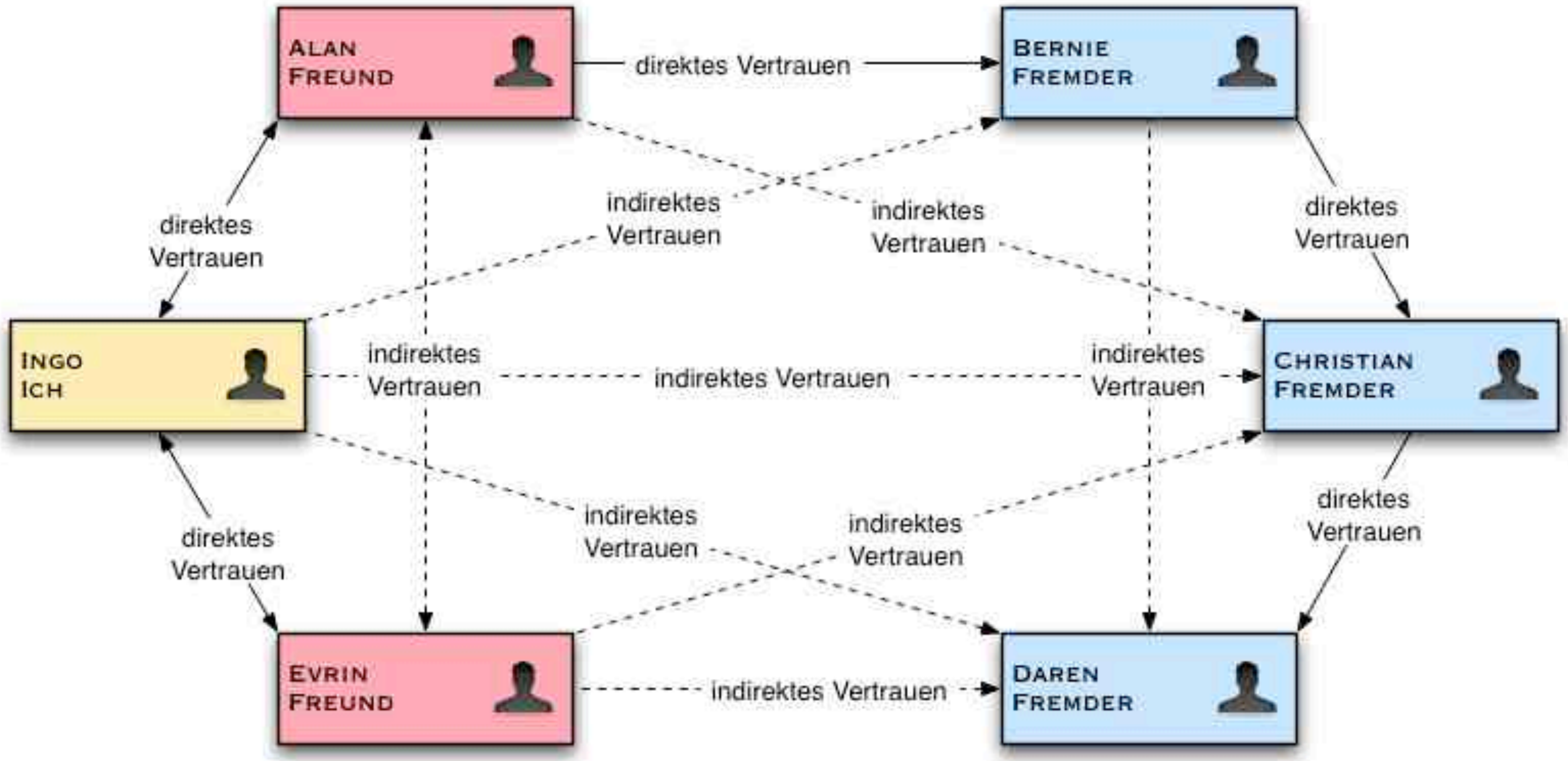
CA1	$\mathrm{PK}_{\mathrm{CA1}}$	$\mathrm{Sig}_{\mathrm{Root}}$	Alice	$\mathrm{PK}_{\mathrm{Alice}}$	$\mathrm{Sig}_{\mathrm{CA1}}$	Message...

X.509

- ITU-T X.500 recommendations series
  - Global database representing objects (people and processes)
  - Tree structured
    - Top level = countries
  - Identity of an object is a pathname in the tree: *Distinguished Name (DN)*
    - E.g. “c=GB, o=Universal Exports, cn=James Bond”
      (o: organization, cn: common name)
- ITU-T recommendation X.509
  - Public key certificate data format
  - Linking a public key with an X.500 Distinguished Name (= Identity)
  - Further fields for validity etc.

Web of Trust

- No central certification authority; mutual certification
- Users can define individual level of trust in the owner of a key
- Well-known implementations: PGP and GPG



Picture: Wikipedia