

6 Cryptographic Techniques – A Brief Introduction

6.1 Introduction to Cryptography

6.2 Symmetric Encryption

6.3 Asymmetric (Public-Key) Encryption

6.4 Digital Signatures

6.5 Public Key Infrastructures

Literature:

Bruce Schneier: Applied Cryptography, 2nd ed., John Wiley 1995

Wolfgang Ertel: Angewandte Kryptographie, Hanser 2007

Purpose of Cryptographic Techniques

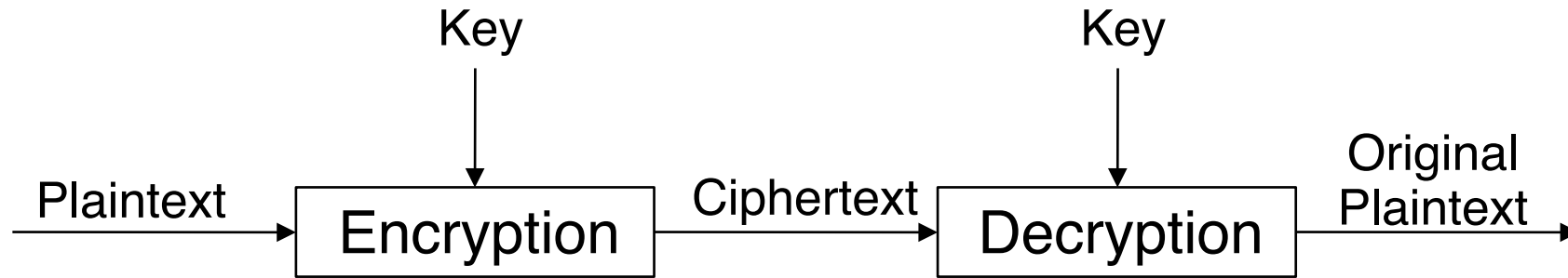
- To protect the content of communication between two parties
 - Protection against various kinds of attacks
 - Preserving confidentiality and integrity of a message
 - Computer-equivalent to packaging and sealing
- To establish the identity of communication partners (*authentication*)
 - Computer-equivalent 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 (*symmetry*)

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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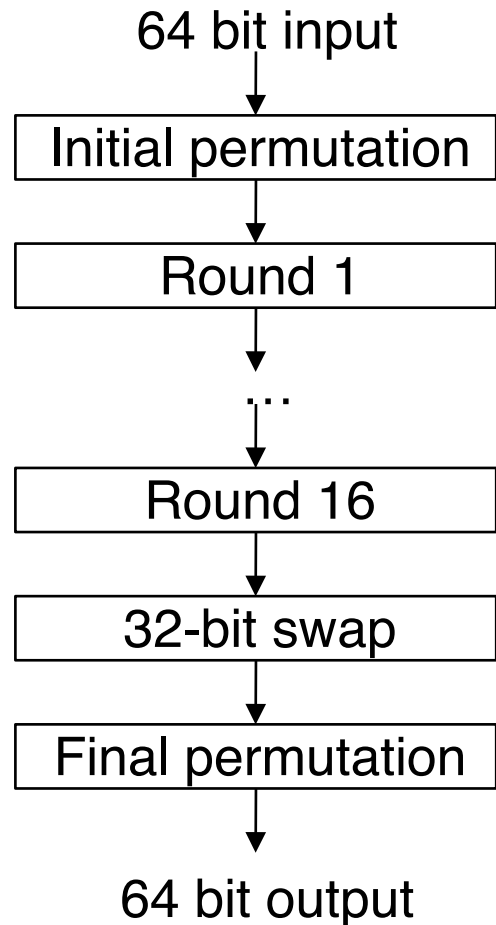
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Symmetric Cryptographic Algorithms

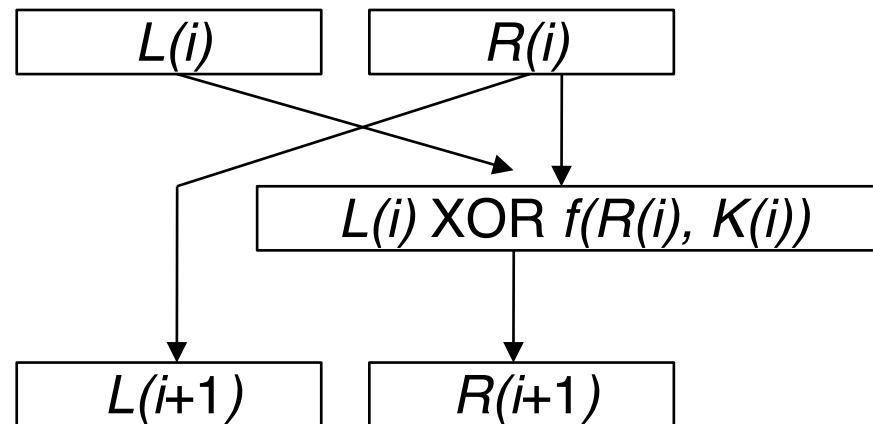
- Encryption and decryption using the same key
 - Alternatively: One key can be computed from the other
- Stream algorithms or *stream ciphers*:
 - Operate bit-by-bit (or byte-by-byte)
- Block algorithms or *block ciphers*:
 - Operate on larger groups of bits (blocks)
 - Block size should not be too large - typical 64 bits

Data Encryption Standard DES



Encoding and decoding algorithms identical

- 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”:



- 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 cryptanalysis” 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 Daemen, 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 (Rivest Cipher)

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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 $(ed \equiv 1) \pmod{\phi}$
 - » (n, d) is the secret decryption key

- Encryption:

$$C = M^e \pmod{n}$$

- Decryption:

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

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 $(ed \equiv 1) \pmod{\phi}$, i.e. $(ed-1) = k\phi$, i.e. $(23d-1) = k120$
 - » Apply extended Euclidian algorithm: $d = 47, k = 9$
 - » $(143, 47)$ is the secret decryption key

- Encryption:

$$C = M^e \pmod{n}, \text{ e.g. } C = 7^{23} \pmod{143} = 2 \text{ (Modular arithmetic)}$$

- Decryption:

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

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: Alice wants to send a message M to Bob ensuring the message’s integrity and that it is from her
 - $S = M^d \text{ mod } n$ (n, d) is Alice’s secret key – Equivalent to decryption algorithm
 - Alice sends M and S to Bob
- Bob verifies:
 - $M = S^e \text{ mod } n$ (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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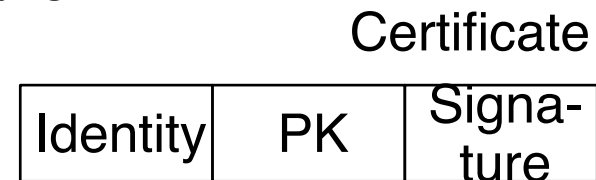
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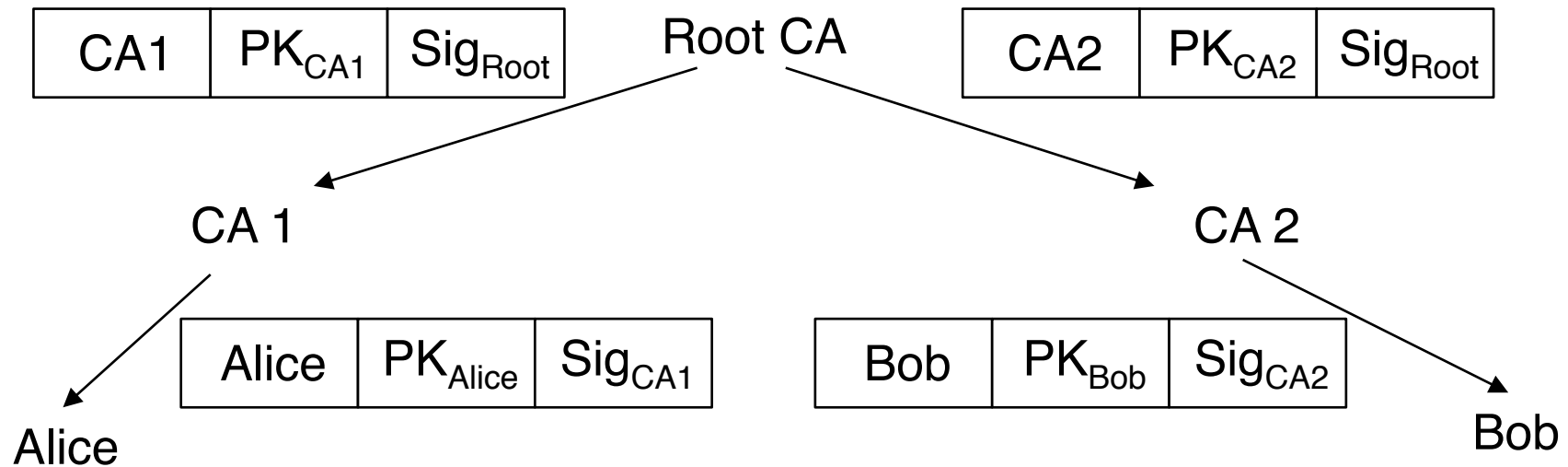
Public Key Infrastructure

- 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



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

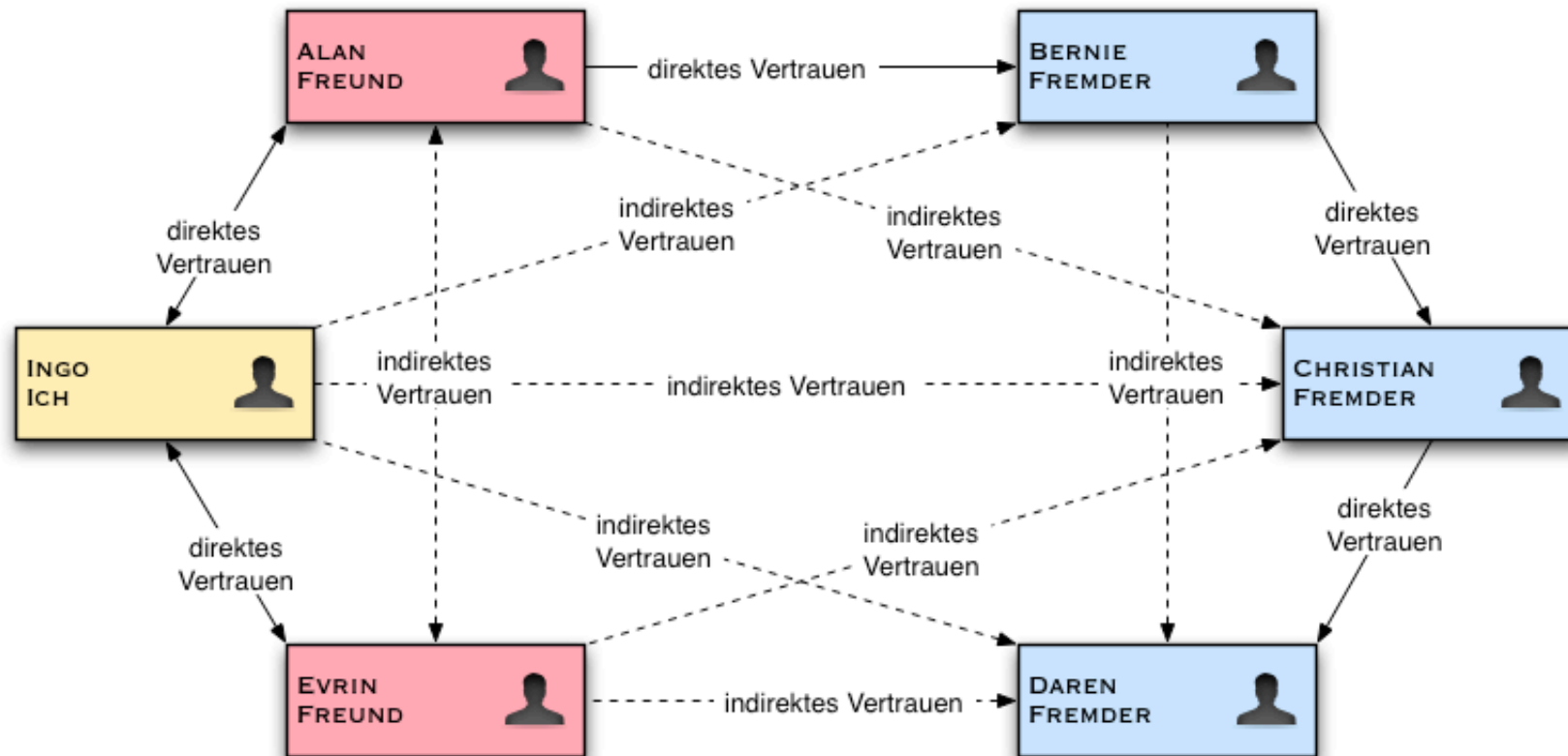


X.509

- 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