Chapter 2
Basics of Cryptography

- Overview Cryptographic Algorithms
- Attacking Cryptography
- Properties of Encryption Algorithms
- Classification of Encryption Algorithms

Cryptographic Algorithms: Overview

- During this course two main applications of cryptographic algorithms are of principal interest:
  - ***Encryption*** of data: transforms plaintext data into ciphertext in order to conceal its' meaning
  - ***Signing*** of data: computes a *check value* or *digital signature* to a given plain- or ciphertext, that can be verified by some or all entities being able to access the signed data
- Some cryptographic algorithms can be used for both purposes, some are only secure and / or efficient for one of them.
- Principal categories of cryptographic algorithms:
  - ***Symmetric cryptography*** using 1 key for en-/decryption or signing/checking
  - ***Asymmetric cryptography*** using 2 different keys for en-/decryption or signing/checking
  - ***Cryptographic hash functions*** using 0 keys (the "key" is not a separate input but "appended" to or "mixed" with the data).

Attacking Cryptography (1): Cryptanalysis

- *Cryptanalysis* is the process of attempting to discover the plaintext and / or the key
- Types of cryptanalysis:
  - *Ciphertext only:* specific patterns of the plaintext may remain in the ciphertext (frequencies of letters, digraphs, etc.)
  - *Known ciphertext / plaintext pairs*
  - *Chosen plaintext or chosen ciphertext*
  - Newer developments: *differential cryptanalysis, linear cryptanalysis*
- Cryptanalysis of public key cryptography:
  - The fact that one key is publicly exposed may be exploited
  - Public key cryptanalysis is more aimed at breaking the cryptosystem itself and is closer to pure mathematical research than to classical cryptanalysis
  - Important directions:
    - Computation of discrete logarithms
    - Factorization of large integers

Attacking Cryptography (2): Brute Force Attack

- The *brute force attack* tries every possible key until it finds an intelligible plaintext:
  - Every cryptographic algorithm can in theory be attacked by brute force
  - On average, half of all possible keys will have to be tried

Average Time Required for Exhaustive Key Search

Key Size [bit]	Number of keys	Time required at 1 encryption / μs	Time required at 10^6 encryption / μs
32	$2^{32} = 4.3 * 10^9$	$2^{31}\ \mu s = 35.8$ minutes	2.15 milliseconds
56	$2^{56} = 7.2 * 10^{16}$	$2^{55}\ \mu s = 1142$ years	10.01 hours
128	$2^{128} = 3.4 * 10^{38}$	$2^{127}\ \mu s = 5.4 * 10^{24}$ years	$5.4 * 10^{18}$ years

Attacking Cryptography (3): How large is large?

Reference Numbers Comparing Relative Magnitudes

Reference	Magnitude
Seconds in a year	$\approx 3 * 10^{7}$
Seconds since creation of solar system	$\approx 2 * 10^{17}$
Clock cycles per year (1 GHz computer)	$\approx 3.2 * 10^{16}$
Binary strings of length 64	$2^{64} \approx 1.8 * 10^{19}$
Binary strings of length 128	$2^{128} \approx 3.4 * 10^{38}$
Binary strings of length 256	$2^{256} \approx 1.2 * 10^{77}$
Number of 75-digit prime numbers	$\approx 5.2 * 10^{72}$
Electrons in the universe	$\approx 8.37 * 10^{77}$

Important Properties of Encryption Algorithms

- Consider, a sender is encrypting plaintext messages P1, P2, ... to ciphertext messages C1, C2, ...
  Then the following properties of the encryption algorithm are of special interest:
- *Error propagation* characterizes the effects of bit-errors during transmission of ciphertext to reconstructed plaintext P_1', P_2', ...
  - Depending on the encryption algorithm there may be one or more erroneous bits in the reconstructed plaintext per erroneous ciphertext bit
- *Synchronization* characterizes the effects of lost ciphertext data units to the reconstructed plaintext
  - Some encryption algorithms can not recover from lost ciphertext and need therefore explicit re-synchronization in case of lost messages
  - Other algorithms do automatically re-synchronize after 0 to n (n depending on the algorithm) ciphertext bits

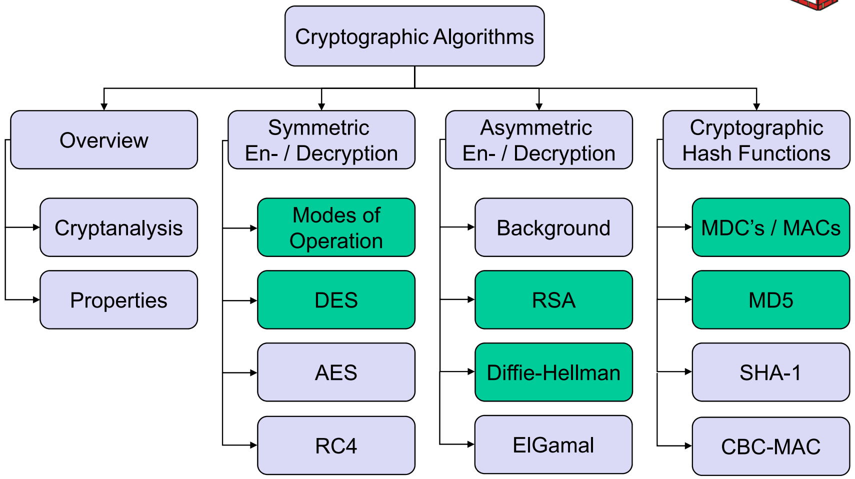
Classification of Encryption Algorithms: Three Dimensions

- The type of operations used for transforming plaintext to ciphertext:
  - ***Substitution***, which maps each element in the plaintext (bit, letter, group of bits or letters) into another element
  - ***Transposition**,* which re-arranges elements in the plaintext
- The number of keys used:
  - ***Symmetric ciphers**,* which use the same key for en- / decryption
  - ***Asymmetric ciphers**,* which use different keys for en- / decryption
- The way in which the plaintext is processed:
  - ***Stream ciphers*** work on bit streams and encrypt one bit after another:
    - Many stream ciphers are based on the idea of linear feedback shift registers, and there have been detected vulnerabilities of a lot of algorithms of this class, as there exists a profound mathematical theory on this subject.
    - Most stream ciphers do not propagate errors but are sensible to loss of synchronization.
  - ***Block ciphers*** work on blocks of width *b* with *b* depending on the specific algorithm.

Key Management

- Key generation
  - Must use (pseudo) random number generators
  - Key generation for asymmetric encryption depends on the factorization of large integer numbers
- Key distribution
  - Simplest case: personal contact
  - Encrypted channel for key distribution -> Key hierarchies
- Key storage
  - Optimum case: in the brain of the user
  - Alternatively, in secured crypto modules
- Key recovery
  - Simples case: using a saved copy (implicates new security issues)
  - Alternatively, fragment the key into several sub-keys
- Key invalidation
  - Especially required for asymmetric mechanisms
- Key deletion
  - Disablement of old encrypted texts

Cryptographic Algorithms – Outline



Summary (what do I need to know)

- Categories of cryptographic algorithms
  - Symmetric encryption
  - Asymmetric encryption
  - Cryptographic hash functions

- Application of encryption techniques
  - Encryption
  - Signing

- Classification of encryption algorithms
  - Symmetric vs. asymmetric
  - Stream vs. block ciphers