Cryptography: Introduction

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Cryptography

- cryptography <--> Greek: krupto+grafη (hidden/secret+writing)

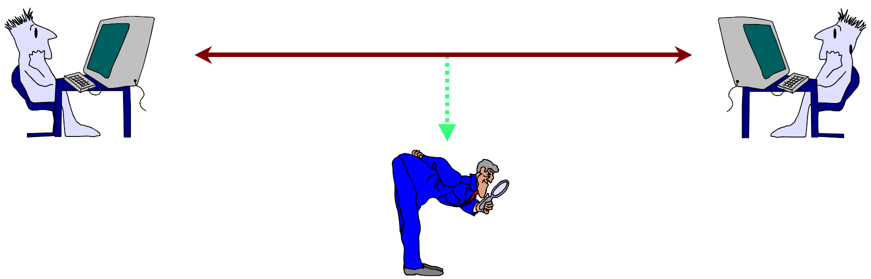
  the study of mathematical techniques related to information security that have the following objectives:
  - **Confidentiality**
    - ensuring information is accessible only by authorized persons
  - **Data integrity**
    - ensuring information is has not been altered by unauthorized or unknown means
  - **Authentication**
    - verification of the identity of an entity
  - **Non-repudiation**
    - preventing the denial of previous commitments or actions
- the most widely used tool for securing information and services
- it is one tool (not the only)

Crittografia e Crittoanalisi

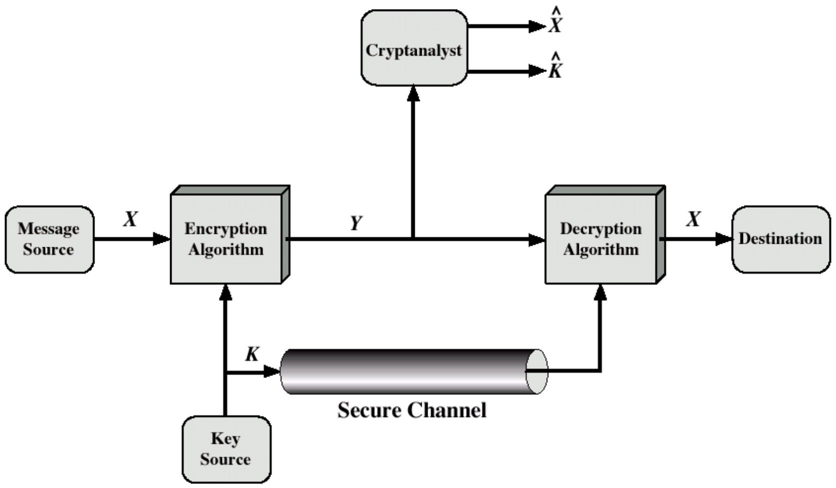
- Crittologia:
  - **scienza che ha lo scopo di studiare comunicazioni sicure**
- Crittografia:
  - **branca della crittologia che ha come scopo la progettazione di algoritmi di cifratura e decifratura, al fine di garantire la segretezza e o l'autenticità dei messaggi**
- Crittoanalisi:
  - **branca della crittologia che ha come scopo l'analisi di un cifrario per risalire all'informazione originaria, e/o la generazione di informazione cifrata contraffatta che possa essere accettata come autentica**

Cryptography

- Consiste nell'alterazione controllata di un messaggio (e.g. sequenza alfanumerica di caratteri) in maniera da renderlo non comprensibile a chi non dispone degli strumenti adeguati



Modello di sistema crittografico tradizionale



Cryptography: Basic Terminology

- **plaintext** - the original message
- **ciphertext** - the coded message
- **cipher** - algorithm for transforming plaintext to ciphertext
- **key** - info used in cipher known only to sender/receiver
- **encipher (encrypt)** - converting plaintext to ciphertext
- **decipher (decrypt)** - recovering ciphertext from plaintext

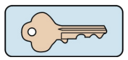
Semplice esempio di algoritmo crittografico operante su testo (cifrario con shift)

Algoritmo: $X \leftarrow M+K \bmod 26$ $K \in \{0,1,\ldots,25\}$

Testo in chiaro: C A S A

Testo cifrato: R P H P

Chiave: K = 15



Caesar cipher:

Chiave K=3

Cryptographic algorithms

- Funzioni matematiche usate per cifrare e decifrare un testo
- Possono essere caratterizzati da:
  - **tipologia di operazioni utilizzate per criptare/decriptare**
    - substitution / transposition / product
  - **numero di chiavi usate**
    - single-key or secret / two-key or private-public
  - **modalità in cui vengono processati i dati**
    - block / stream
  - **altro**
    - velocità, HW/SW, etc.

Security of cryptographic algorithms

- The security of a cipher might rest in the secrecy of its restricted algorithm
  - **c = E(m)**
  - **m = D(c)**

  however:
  - **whenever a users leaves a group, the algorithm must change**
  - **could be scrutinized by people smarter than you**
- Modern cryptography relies on keys, a selected value from a large set (a keyspace), e.g., a 1024-bit number → 2^{1024} values!
  - **C = E(k,m) =** E_k**(m)**
  - **m = D(k,m) =** D_k**(C)**
  - **change of authorized participants requires only a change in key**
  - **"Security should be based on secrecy of the key, not the details of the algorithm"**
    - Jean Guillaume Hubert Victor Francois Alexandre Auguste Kerckhoffs von Nieuwenhof, "La Criptographie Militaire", 1883

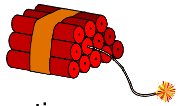
Cryptography Attacks

- Brute-force search
  - **si tenta ogni possibile decifratura (ad esempio provando tutte le possibili chiavi) su un frammento di testo in chiaro**
  - **in media per avere successo occorre provare la metà delle chiavi possibili**
  - **deve essere possibile riconoscere quando si è trovato il testo in chiaro corretto**
- Cryptographic analysis (cryptoanalysis)
  - **Si basa sulla natura dell'algoritmo e sfrutta qualche conoscenza delle caratteristiche generali del testo in chiaro e/o qualche esempio di coppie testo in chiaro/testo cifrato**
    - non richiede necessariamente di scoprire la chiave
- The loss of a key (also without cryptoanalysis or brute-force attack) is called a "compromise"

Brute force attack

- Method of defeating a cryptographic scheme by trying a large number of possibilities
  - **for example, exhaustively working through all possible keys in order to decrypt a message**
- In most schemes, the theoretical possibility of a brute force attack is recognized, but it is set up in such a way that it would be computationally infeasible to carry out
- By obfuscating the data to be encoded, brute force attacks are made less effective as it is more difficult to determine when one has succeeded in breaking the code
- For symmetric-key ciphers, a brute force attack typically means a brute-force search of the key space
  - **testing all possible keys in order to recover the plaintext used to produce a particular ciphertext**

Cryptographic break



- A cryptographic "break" is anything faster than an exhaustive search (brute force attack)
  - **example, an attack against a 128-bit-key cipher requiring 'only'** 2^{120} **operations (compared to** 2^{128} **possible keys) would be considered a break even though it would be, at present, quite infeasible**

Types of Cryptanalytic Attacks

- There are three basic cryptoanalytic attacks:
  - **Ciphertext-only attack**
    - The attacker has to recover the plaintext from only the ciphertext
  - **Known-plaintext attack**
    - Portions of the cipher are known as plaintext. The rest may be easier to recover
  - **Chosen-plaintext attack**
    - The attacker can choose what plaintext to encrypt, again making it easier to recover other ciphertext
  - **Chosen-ciphertext attack**
    - The attacker can choose ciphertext and obtain the plaintext

Ciphertext only - Attack

- The bad guy has seen (and presumably stored) some ciphertext that can be analyzed
- One possible strategy to figure out the plaintext is to try all keys
  - **it is essential that he/she is able to recognize when he/she has succeeded (often called *recognizable plaintext* attack)**
    - for example in case of normal text or known document formats (e.g. PostScript, etc.) with recognizable patterns
    - oppure provando a decriptare le parole più comuni (attacco a parole probabili)
  - **it is necessary to have enough ciphertext**
- E' l'attacco più difficile da realizzare

Known plaintext - Attack

- The bad guy knows a <pliantext, ciphertext> pair
- How it is possible to obtain it...
  - **the secret data does not remain secret forever (e.g. the name of an attacked city)**
- From that pairs, the attacker can try to figure out the mapping of some fraction of the text
- Some cryptographic schemes might be good enough to be secure against *ciphertext only* attacks but not against to *known plaintext* attacks
  - **in these cases, it is important to minimize the possibility for a bad guy to obtain <pliantext, ciphertext> pairs**

Chosen plaintext (or ciphertext) - Attack

- The bad guy can choose any plaintext and get the corresponding ciphertext from the system (or the contrary)
  - **e.g. there is a telegraph service that encrypt and transmit messages; the bad guy can ask the telegraph company to transmit any plaintext he/she wants**
- Some cryptographic schemes might be good enough to be secure against *ciphertext only* attacks and *known plaintext* attacks but not against to *chosen plaintext* attacks

Side channel attack

- Any attack based on information gained from the physical implementation of a cryptosystem, rather than theoretical weaknesses in the algorithms (compare cryptanalysis)
  - **For example, timing information, power consumption, electromagnetic leaks or even sound can provide an extra source of information which can be exploited to break the system**
- General classes of side channel attack include:
  - **Timing attack — attacks based on measuring how much time various computations take to perform**
  - **Power monitoring attack — attacks which make use of varying power consumption by the hardware during computation**
  - **TEMPEST (aka van Eck or radiation monitoring) attack — attacks based on leaked electromagnetic radiation which can directly provide plaintexts and other information**
  - **Acoustic cryptanalysis — attacks which exploit sound produced during a computation (rather like power analysis)**

Side channel attack (cont.)

- In all cases, that physical effects caused by the operation of a cryptosystem can provide useful extra information about secrets in the system, for example, the cryptographic key, partial state information, full or partial plaintexts and so forth
- Many side-channel attacks require considerable technical knowledge of the internal operation of the system on which the cryptography is implemented

Computational Difficulty

- Cryptographic algorithms should be reasonably efficient to compute for good guys (who know the keys)
- Cryptographic algorithms are not impossible to attack without the key: a bad guy can simply try all possible keys until one works
- The security depends on how much work is necessary to break it
  - **It is the *complexity* of launching the attack that secures us**
- Attack complexities:
  - **data complexity: a large number of expected inputs (e.g., ciphertext)**
  - **processing complexity: a large number of operations required**
  - **storage complexity: a large amount of storage units required**
- Often a scheme can be made more secure by making the key longer

Computational and Unconditional Security

- **computational security**
  - **given limited computing resources (e.g. time needed for calculations is greater than age of universe, or the cost required for the attack is not affordable), the cipher cannot be broken**
- **unconditional security**
  - **no matter how much computer power is available, the cipher cannot be broken since the ciphertext provides insufficient information to uniquely determine the corresponding plaintext**
    - e.g. OTP (One Time Pad) chiper

Brute Force Search

- Remarks:
  - **always possible to simply try every key**
  - **most basic attack, proportional to key size**
  - **assume either know / recognise plaintext**

Key Size (bits)	Number of Alternative Keys	Time required at 1 encryption/μs	Time required at 10^6 encryptions/μs
32	$2^{32} = 4.3 \times 10^9$	$2^{31}\ \mu s = 35.8$ minutes	2.15 milliseconds
56	$2^{56} = 7.2 \times 10^{16}$	$2^{55}\ \mu s = 1142$ years	10.01 hours
128	$2^{128} = 3.4 \times 10^{38}$	$2^{127}\ \mu s = 5.4 \times 10^{24}$ years	5.4×10^{18} years
168	$2^{168} = 3.7 \times 10^{50}$	$2^{167}\ \mu s = 5.9 \times 10^{36}$ years	5.9×10^{30} years
26 characters (permutation)	$26! = 4 \times 10^{26}$	$2 \times 10^{26}\ \mu s = 6.4 \times 10^{12}$ years	6.4×10^6 years

Cryptanalysis: Example (Language Redundancy)

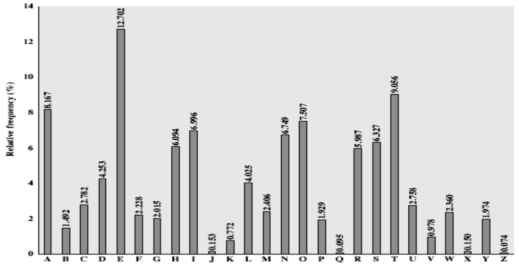
- Example of cryptoanalysis:
  - **cleartext: normal text**
  - **cryptography algorithm: monoalphabetic substitution**
- key concept:
  - **human languages are redundant: do not change relative letter frequencies**
  - **in English e is by far the most common letter**
  - **then T,R,N,I,O,A,S**
  - **other letters are fairly rare (e.g. Z,J,K,Q,X)**
- cryptoanalysis:
  - **based on lenguage redudancy**
  - **discovered by Arabian scientists in 9th century**
  - **calculate letter frequencies for ciphertext**
  - **compare counts/plots against known values**
  - **have tables of single, double & triple letter frequencies**

Cryptanalysis: Example

- given ciphertext:

```
UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ
VUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZUHSX
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ
```

- count relative letter frequencies



- guess P & Z are e and t
- guess ZW is th and hence ZWP is the
- proceeding with trial and error finally get:

```
it was disclosed yesterday that several informal but
direct contacts have been made with political
representatives of the viet cong in moscow
```


Fundamental principle of cryptography

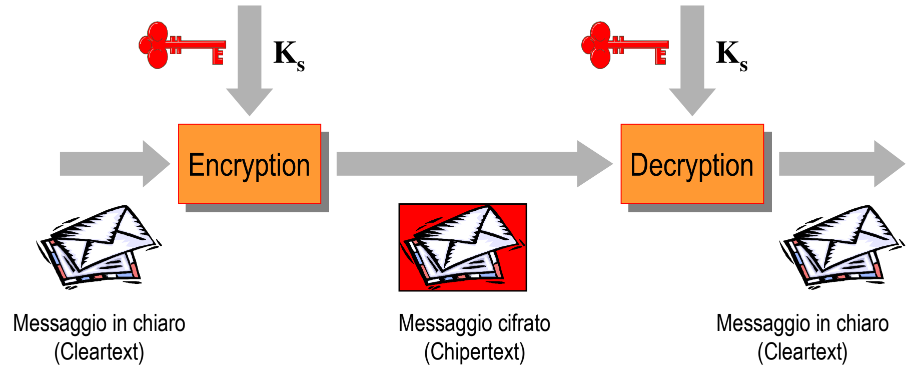
- Fundamental principle of cryptography:
  "If lots of people have failed to solve a problem, then it probably won't be solved (soon)"
  - **cryptographers invent clever secret codes**
  - **cryptoanalysts attempt to break these codes**
  - **the two disciplines help each other!**
- Second fundamental principle of cryptography:
  "Often breaking a cryptographic scheme is not the the only way of getting what you want"

Differenti tipi di crittografia

- A <u>chiave segreta</u> (simmetrica)
  - **le due parti che comunicano condividono un segreto (la chiave crittografica)**
- A <u>chiave pubblica</u> (asimmetrica)
  - **la chiave crittografica è composta da due parti, una che tutti conoscono (chiave pubblica) e una che solo l'interessato conosce (chiave privata)**
- <u>Hash algorithm</u> (message digest/one way transformation)
  - **una funzione hash è una trasformazione matematica in una sola direzione che a partire da un messaggio arbitrario (lunghezza variabile) genera messaggio/numero di dimensione fissata**

Crittografia a chiave segreta (simmetrica)

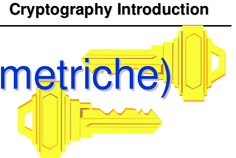
- La chiave utilizzata per cifrare è la <u>medesima</u> chiave utilizzata per decifrare (chiave simmetrica o Secret Key, Ks)
- Alcune volte detta: crittografia convenzionale o simmetrica



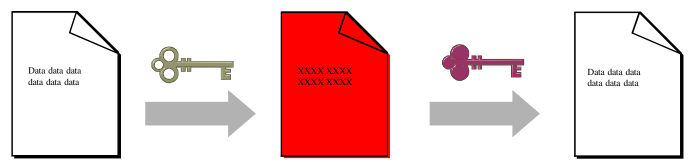
Caratteristiche

- Richiede una fase iniziale in cui ciascuna coppia di interlocutori si scambia la secret key in maniera sicura
- Il numero delle chiavi per realizzare una comunicazione reciproca tra N utenti (dispositivi) è pari a Nx(N-1)/2 (se le chiavi rimangono sempre le stesse)
- Viene generalmente utilizzato per proteggere, mediante codifica, informazioni (file) in un repository locale o trasmessi
- La robustezza dell'algoritmo è normalmente misurata dalla lunghezza delle chiavi: 40 bit (debole), 128 bit (forte)
- Algoritmi più diffusi: DES, 3DES, RC2, RC4, IDEA, AES

Crittografia a chiave pubblica (asimmetriche)



- Spesso detta crittografia asimmetrica
- La chiave utilizzata per cifrare (chiave di cifratura, Ke) è <u>diversa</u> dalla chiave utilizzata per decifrare (chiave di decifratura, Kd)
- Le chiavi si usano in coppie, di cui una detta privata (segreta) e l'altra detta pubblica (disponibile a tutti)
- Un clear-text cifrato con la chiave privata può essere decifrato solo con la chiave pubblica e viceversa
- Ciascuna coppia di chiavi è caratterizzata da proprietà peculiari



Caratteristiche

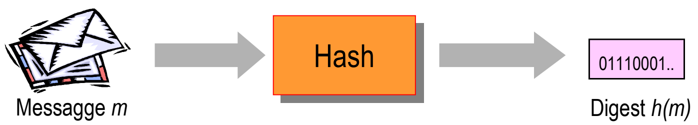
- Può richiedere una fase iniziale in cui gli interlocutori si scambiano le rispettive chiavi pubbliche
- Il numero delle chiavi è proporzionale a N per la comunicazione reciproca tra N utenti (dispositivi)
- Viene generalmente utilizzato per distribuire chiavi simmetriche in un ambiente distribuito
- Algoritmi più diffusi: RSA, Diffie-Hellman, DSA
- La robustezza del sistema dipende anche dal sistema di certificazione delle chiavi di cifratura (se esiste..)
  - **L'impiego della crittografia a chiavi asimmetriche comporta l'implementazione di una PKI (Public Key Infrastructure)**

Algoritmi di cifratura simmetrici e asimmetrici

- Entrambi gli algoritmi, simmetrici o asimmetrici, consentono di cifrare un messaggio; gli algoritmi simmetrici sono preferiti nei casi in cui sia necessaria una certa velocità di esecuzione della cifratura
- Un buon sistema crittografico usa al meglio i due tipi di algoritmo, esempio:
  - **Uso di algoritmo asimmetrico per lo scambio sicuro di chiavi e per l'autenticazione**
  - **Uso di algoritmo simmetrico per lo scambio dei dati**

Hash Algorithms

- Also known as message digests or one way transformations
- Hash function is a mathematical transformation *m* that takes a message of arbitrary length and computes a fixed-length (short) number/string *h(m)*
- Properties:
  - **for any message *m*, it relatively easy to compute *h(m)***
  - **given *h(m)* there is no way to find *m* in a way easier than computing all possibilities**
  - **it is computationally infeasible to to find two values that hash to the same thing**



- Examples of hash algorithms: MD2, MD5, SHS

Dove la crittografia non ci aiuta

- Protezione di sistema:
  - **Accesso non autorizzato alle risorse HW e SW**
  - **Esecuzione di programmi malevoli (virus, ecc.)**
  - **...**
- Protezione dei servizi:
  - **Sfruttamento di bachi nei programmi o protocolli**
  - **Attacchi mirati a rendere indisponibili dei servizi**
  - **Utilizzo illecito di servizi ed informazioni**
  - **Alterazione dei contenuti di DB o altri dispositivi di archiviazione**
  - **...**