ΥΣ13 - Computer Security

Symmetric Cryptography

Κώστας Χατζηκοκολάκης
Context

• **Goal**
  - Confidentiality
  - Alice wants to send a message $P$(plaintext) to Bob
  - Only Bob should be able to read it

• **Solution**: symmetric encryption
  - Share a key $K$ with Bob
  - Only Alice and Bob should know the key
  - Alice constructs an (encrypted) message $C$(ciphertext) from $P$, $K$
  - Bob uses $K$ to decrypt $C$ and obtain $P$
Correctness: $P = \text{Dec}(K, \text{Enc}(K, P))$
Adversary model

- Knows **everything** except $P, K$
- Including all **algorithms**, protocols, conventions
  - **Important**: obscurity is not security
- Having all information public actually makes the system **more secure**
First attempt

• Caesar’s cipher (50 BC)
  - Replace A→D, B→E, …
  - In other words $C_i = P_i + K \mod 26$
  - $K = 3$ (or $K = "D"$) is the key
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• ROT13
  - \( K = 13 \) (decrypt is the same as encrypt)
  - Win XP registry keys!
First attempt

- Generally: mono-alphabetic substitution cipher
  - use a single permutation of the alphabet
  - How can we break this?

Frequency analysis
- observe the frequency of each symbol in the ciphertext

How can we do better?
- Stream cipher: substitution depends on the character's position
- Block cipher: encrypt many letters at once in a block
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Vigenère cipher

An early *stream* cipher (1553)

- **Idea**
  - Key: **CCCCCCCCCCCCC...** change to
  - Key: **WORDWORDWORD...**

- **Frequency analysis much harder**
  - Unbreakable for 300 years
Vigenère cipher

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- Problem
  - Repeated patterns at multiples of the keyword length
  - Find out the keyword length
  - Then?
One time pad

- Repeating key letters was problematic
- Solution?
One time pad

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- Solution?
  - Key at least as big as the plaintext
  - Randomly chosen (uniformly)
  - Key: AFEMIONOASNEPOZLMOIUW…

How good is this cipher?
- Perfect! unconditional security

Idea: choose $P = 0, K = 0$ arbitrarily, choose $K = 0$ uniformly

What is the probability that $P = 0$?

Why “one time”?

Drawbacks?
One time pad

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  - \( p(P|C) = p(P) \)  \( \)  equivalently \( p(C|P) = p(C|P') \)
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    • $p(P|C) = p(P)$  equivalently $p(C|P) = p(C|P')$
  - Idea: choose $P = 0|1$ arbitrarily, choose $K = 0|1$ uniformly
    • What is the probability that $P \oplus K = 0$?
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- Drawbacks?
Playfair Cipher

An early block cipher (1854)

• Key: 5x5 permutation of all letters (I/J combined)

• Encrypt pairs of letters (blocksize: 2 letters)

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- Much better than Vigenère
  - But how much better?
  - Change a single letter of plaintext?

\[
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  R & S & T & O & N \\
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Random Oracle

• Reverse question
  - what is an ideal cipher?
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- Ideal ciphers
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- Good real cipher
  - indistinguishable from a suitable oracle
  - given certain abilities of the adversary
How can we create a good block cipher?

Principles

• Confusion
  - Drastic (non-linear) change to the input
  - Basic tool: substitution
  - Invertible function \( \{0, 1\}^n \rightarrow \{0, 1\}^n \) (permutation of \( \{0, 1\}^n \))
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- **Diffusion**
  - Changing a single character of the input will change many characters of the output.
  - Basic tool: permutation of bits
How can we create a good block cipher?

- **Substitution** (confusion)
- **Permutation** (diffusion)
Substitution–permutation network
Feistel cipher

- No need for invertible $F$!
- IF $F$ is a random function then
  - indist. from random permutation
  - 3 rounds: chosen plaintext
  - 4 rounds: chosen plaintext/ciphertext
Data Encryption Standard (DES)

- IBM, 1975
- Feistel cipher
- 56bit keys
- 64bit block size
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Weaknesses
- Brute force (< day)
- Linear cryptanalysis
Advanced Encryption Standard (AES)

- NIST, 2001
  - Key: 128, 192, 256 bits
  - Block: 128 bits

- **SP-network**: multiple rounds of
  - Substitution
    - SubBytes
  - Permutation
    - MixColumns
    - ShiftRows

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Mode of operation

Problem?

Electronic Codebook (ECB) mode encryption

Electronic Codebook (ECB) mode decryption
Mode of operation

Patterns!
Mode of operation

Cipher Block Chaining (CBC) mode encryption

Cipher Block Chaining (CBC) mode decryption
References

- Ross Anderson, Security Engineering, Sections 5.1 - 5.5
- https://blog.filippo.io/the-ecb-penguin/