Computer Security
Theory

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Abstract

The course topics are:

- Introduction to information security.
- A short introduction to cryptography.
- Authentication.
- Authorization and access control.
- Software vulnerabilities.
- Secure networking architectures.
- Malicious software.

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CHAPTER 1

Introduction

1.1 Basic security requirements

The fundamental security principles, known as the CIA paradigm for information security, outline three key requirements:

- *Confidentiality*: only authorized entities can access information.
- *Integrity*: information can only be modified by authorized entities in authorized ways.
- *Availability*: information must be accessible to all authorized parties within specified time limits.

It's worth noting that the availability requirement can sometimes conflict with the other two, as higher availability exposes the system for longer durations.

1.2 Definitions

Definition (*Vulnerability*)**.** A vulnerability is a flaw that can be exploited to violate one of the constraints of the CIA paradigm.

Definition (*Exploit*)**.** An exploit is a specific method of leveraging one or more vulnerabilities to achieve a particular objective that breaches the constraints.

Definition (*Asset*)**.** An asset is anything of value to an organization.

Definition (*Threat*)**.** A threat is a potential event that could lead to a violation of the CIA paradigm.

Definition (*Attack*)**.** An attack is a deliberate use of one or more exploits with the aim of compromising a system's CIA.

Definition (*Threat agent*)**.** A threat agent is any entity or factor capable of causing an attack.

Definition (*Hacker*)**.** A hacker is an individual with advanced knowledge of computers and networks, driven by a strong curiosity and desire to learn.

Definition (*Black hats*)**.** Malicious hackers are commonly referred to as black hats.

1.3 Ethical hacking

White hats, also known as security professionals or ethical hackers, are tasked with:

- *Identifying vulnerabilities.*
- *Developing exploits.*
- *Creating attack-detection methods.*
- *Designing countermeasures against attacks.*
- *Engineering security solutions.*

Since no system is invulnerable, it's crucial to assess its risk level. This involves evaluating the potential damage due to vulnerabilities and threats through the concept of risk:

Definition (*Risk*)**.** Risk is a statistical and economic evaluation of potential damage resulting from the presence of vulnerabilities and threats:

$$\text{Risk} = \text{Asset} \times \text{Vulnerabilities} \times \text{Threats}$$

Assets and vulnerabilities can be managed, but threats are independent variables.

To ensure system security, a balance must be struck between cost and reducing vulnerabilities and containing damage. The costs of securing a system can be categorized as direct and indirect. Direct costs include management, operational, and equipment expenses, while indirect costs, which often form the larger portion, stem from:

- *Reduced usability.*
- *Slower performance.*
- *Decreased privacy* (due to security controls).
- *Lower productivity* (as users may be slower).

It's important to note that simply spending more money on security may not always resolve the issue.

In real-world systems, setting boundaries is essential, meaning that a portion of the system must be assumed as secure. These secure parts consist of trusted elements determined by the system developer or maintainer. For example, the level of trust in a particular system can be determined at the software, compiler, or hardware level.

CHAPTER 2

Cryptography

2.1 Introduction

Definition (*Cryptography*)**.** Cryptography refers to the field of study concerned with developing techniques that enable secure communication and data storage in the presence of potential adversaries.

Cryptography offers several essential features, including:

- *Confidentiality*: ensures that data can only be accessed by authorized entities.
- *Integrity/freshness*: detects or prevents tampering or unauthorized replays of data.
- *Authenticity*: certifies the origin of data and verifies its authenticity.
- *Non-repudiation*: ensures that the creator of data cannot deny their responsibility for creating it.
- *Advanced features*: includes capabilities such as proofs of knowledge or computation.

2.1.1 History

Cryptography has a history as ancient as written communication itself, originating primarily for commercial and military purposes. Initially, cryptographic algorithms were devised and executed manually, using pen and paper.

The early approach to cryptography involved a contest of intellect between cryptographers, who devised methods to obscure messages, and cryptanalysts, who sought to break these ciphers.

A significant development occurred in 1553 when Bellaso pioneered the idea of separating the encryption method from the key.

In 1883, Kerchoff formulated six principles for designing robust ciphers:

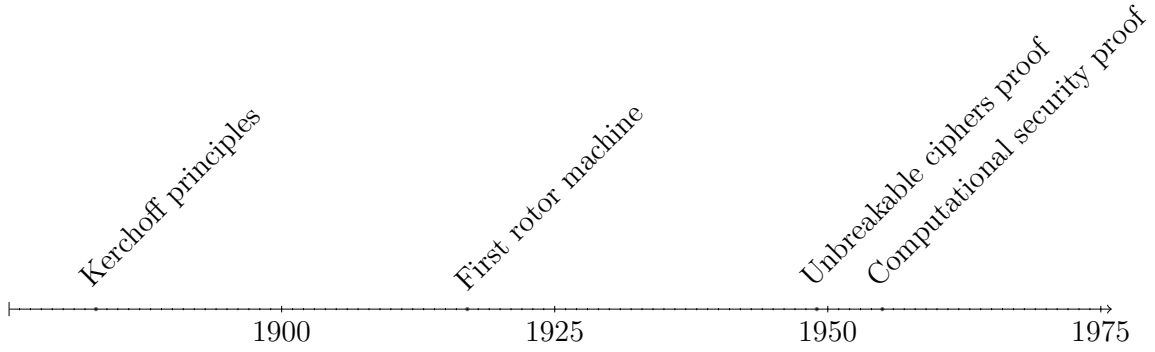
1. The cipher should be practically, if not mathematically, unbreakable.
2. It should be possible to disclose the cipher to the public, including enemies.

3. The key must be communicable without written notes and changeable at the discretion of correspondents.
4. It should be suitable for telegraphic communication.
5. The cipher should be portable and operable by a single person.
6. Considering the operational context, it should be user-friendly, imposing minimal mental burden and requiring a limited set of rules.

The landscape of cryptography underwent a significant transformation in 1917 with the introduction of mechanical computation, exemplified by Hebern's rotor machine, which became commercially available in the 1920s. This technology evolved into the German Enigma machine during World War II, whose encryption methods were eventually deciphered by cryptanalysts at Bletchley Park, contributing significantly to the Allied victory.

After World War II, in 1949 Shannon proved that a mathematically secure ciphers exists.

Following World War II, in 1949, Shannon demonstrated the existence of mathematically secure ciphers. Subsequently, in 1955, Nash proposed the concept of computationally secure ciphers, suggesting that if the interaction of key components in a cipher's determination of ciphertext is sufficiently complex, the effort required for an attacker to break the cipher would grow exponentially with the length of the key ($\mathcal{O}(2^\lambda)$), surpassing the computational capabilities of the key owner ($\mathcal{O}(\lambda^2)$) for sufficiently large key lengths (λ).



2.1.2 Definitions

Definition (*Plaintext space*)**.** A plaintext space P is the set of possible messages $ptx \in P$.

Definition (*Ciphertext space*)**.** A ciphertext space C is the set of possible ciphertext $ctx \in P$.

It's worth noting that the ciphertext space C may have a larger cardinality than the plaintext space P.

Definition (*Key space*)**.** A key space K is the set of possible keys.

The length of the key often correlates with the desired level of security.

Definition (*Encryption function*)**.** An encryption function $\mathbb{E}$ is a mapping that takes an element from the plaintext space P and a key from the key space K, and produces an element from the ciphertext space C:

$$\mathbb{E} : P \times K \to C$$

Definition (*Decryption function*)**.** A decryption function $\mathbb{D}$ is a mapping that takes an element from the ciphertext space C and a key from the key space K, and yields an element from the plaintext space P:

$$\mathbb{D} : C \times K \to P$$

2.2 Computational security

The objective of ensuring confidentiality is to prevent unauthorized individuals from comprehending the data. Various methods can compromise confidentiality:

- Passive interception by an attacker.
- Knowledge of a set of potential plaintexts by the attacker.
- Data manipulation by the attacker to observe the reactions of an entity capable of decryption.

Definition (*Perfect cipher*)**.** In a perfect cipher, for any plaintext ptx in the plaintext space P and any corresponding ciphertext ctx in the ciphertext space C, the probability of the plaintext being sent is equal to the conditional probability of that plaintext given the observed ciphertext:

$$\mathrm{P}(ptx\ sent = ptx) = \mathrm{P}(ptx\ sent = ptx | ctx\ sent = ctx)$$

In other words, observing a ciphertext $c \in C$ provides no information about the corresponding plaintext it represents.

Theorem 2.2.1 (Shannon 1949)**.** *Any symmetric cipher* $\langle P, K, C, \mathbb{E}, \mathbb{D} \rangle$ *with* $|P| = |K| = |C|$*, achieves perfect security if and only if every key is utilized with equal probability* $\frac{1}{|K|}$*, and each plaintext is uniquely mapped to a ciphertext by a unique key:*

$$\forall\, (ptx, ctx) \in P \times C, \exists! k \in K \text{ such that } \mathbb{E}\,(ptx, k) = ctx$$

Example:
Let's consider P, K, and C as sets of binary strings. The encryption function selects a uniformly random, fresh key k from K each time it's invoked and computes the ciphertext as $ctx = ptx \oplus k$.

Gilbert Vernam patented a telegraphic machine in 1919 that implemented $ctx = ptx \oplus k$ using the Baudot code. Joseph Mauborgne proposed utilizing a random tape containing the key k.

Combining Vernam's encryption machine with Mauborgne's approach results in a perfect cipher implementation.

It's crucial to understand that while a cipher may achieve perfect security, this doesn't necessarily mean it's practical or user-friendly. Managing key material and regularly changing keys can be exceptionally challenging.

In practice, perfect ciphers often face vulnerabilities due to issues such as key theft or reuse. Additionally, the generation of truly random keys has historically been problematic, leading to potential vulnerabilities and breaches.