CSC 474/574
Information Systems Security

Topic 2.1 Introduction to Cryptography

Cryptography

• Cryptography
  – Original meaning: The art of secret writing
  – Becoming a science that relies on mathematics (number theory, algebra)
  – Process data into intelligible form, reversible, without data loss
  – Usually one-to-one (not compression)
Encryption/Decryption

- Plaintext: a message in its original form
- Ciphertext: a message in the transformed, unrecognized form
- Encryption: the process that transforms a plaintext into a ciphertext
- Decryption: the process that transforms a ciphertext to the corresponding plaintext
- Key: the value used to control encryption/decryption.

Cryptanalysis

- Ciphertext only:
  - Analyze only with the ciphertext
  - Example: Exhaustive search until “recognizable plaintext”
  - Smarter ways available
- Known plaintext:
  - Secret may be revealed (by spy, time), thus <ciphertext, plaintext> pair is obtained
  - Great for mono-alphabetic ciphers
Cryptanalysis (Cont’d)

- Chosen plaintext:
  - Choose text, get encrypted
  - Useful if limited set of messages
- Chosen ciphertext:
  - Choose ciphertext
  - Get feedback from decryption, etc.

Security of An Encryption Algorithm

- Unconditionally secure
  - It is impossible to decrypt the ciphertext
  - One-time pad (the key is as long as the plaintext)
    \[ C_i = P_i \oplus k_i \]
- Computationally secure
  - The cost of breaking the cipher exceeds the value of the encrypted information
  - The time required to break the cipher exceeds the useful lifetime of the information
Secret Keys v.s. Secret Algorithms

• Security by obscurity
  – We can achieve better security if we keep the algorithms secret
  – Hard to keep secret if used widely
  – Reverse engineering, social engineering

• Publish the algorithms
  – Security of the algorithms depends on the secrecy of the keys
  – Less unknown vulnerability if all the smart (good) people in the world are examine the algorithms

Secret Keys v.s. Secret Algorithms (cont’d)

• Commercial world
  – Published
  – Wide review, trust

• Military
  – Keep algorithms secret
  – Avoid giving enemy good ideas
  – Military has access to the public domain knowledge anyway.
Some Trivial Codes

- **Caesar cipher**: substitution cipher:
  - Replace each letter with the one 3 letters later
  - A → D, B → E

- **Captain Midnight Secret Decoder rings**:
  - Shift variable by $n$: IBM → HAL
  - Only 26 possibilities

Some Trivial Codes (Cont’d)

- **Mono-alphabetic cipher**:
  - Generalization, arbitrary mapping of one letter to another
  - $26!$, approximately $4 \times 10^{26}$
  - Statistical analysis of letter frequencies
Some Trivial Codes (Cont’d)

• Hill Cipher
  – Encryption: $C = KP$ or
  – Decryption: $P = K^{-1}C$
  – Problem:
    • Known plaintext attack

Some Trivial Codes (cont’d)

• Poly-alphabetic Ciphers
  – A set of related mono-alphabetic substitution rules is used
  – A key determines which particular rule is chosen for a given transformation
Some Trivial Codes (Cont’d)

- All the previous codes are based on substitution
- Transposition (permutation)

<table>
<thead>
<tr>
<th>Key:</th>
<th>4</th>
<th>3</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaintext:</td>
<td>A</td>
<td>T</td>
<td>T</td>
<td>A</td>
<td>C</td>
<td>K</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>S</td>
<td>T</td>
<td>P</td>
<td>O</td>
<td>N</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>U</td>
<td>N</td>
<td>T</td>
<td>I</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>O</td>
<td>A</td>
<td>M</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
</tbody>
</table>

- Ciphertext: TTNAAPTMTSUOAODWCOIXKNLYPETZ

Types of Cryptography

- Number of keys
  - Hash functions: no key
  - Secret key cryptography: one key
  - Public key cryptography: two keys - public, private

- The way in which the plaintext is processed
  - Block cipher: divides input elements into blocks
  - Stream cipher: process one element (e.g., bit) a time
Secret Key Cryptography

- Same key is used for encryption and decryption
- Also known as
  - Symmetric cryptography
  - Conventional cryptography

Secret Key Cryptography (cont’d)

- Basic technique
  - Product cipher:
  - Multiple applications of interleaved substitutions and permutations
Secret Key Cryptography (cont’d)

- Ciphertext approximately the same length as plaintext
- Examples
  - Stream Cipher: RC4
  - Block Cipher: DES, IDEA, AES

Applications of Secret Key Cryptography

- Transmitting over an insecure channel
  - Challenge: How to share the key?
- Secure Storage on insecure media
- Authentication
  - Challenge-response
  - To prove the other party knows the secret key
  - Must be secure against chosen plaintext attack
- Integrity check
  - Message integrity code (MIC)
Public Key Cryptography

- Invented/published in 1975
- A public/private key pair is used
  - Public key can be publicly known
  - Private key is kept secret by the owner of the key
- Much slower than secret key cryptography
- Also known as
  - Asymmetric cryptography

Public Key Cryptography (Cont’d)

- Another mode: digital signature
  - Only the party with the private key can create a digital signature.
  - The digital signature is verifiable by anyone who knows the public key.
  - The signer cannot deny that he/she has done so.
Applications of Public Key Cryptography

• Data transmission:
  – Alice encrypts $m_a$ using Bob’s public key $e_B$, Bob decrypts $m_a$ using his private key $d_B$.

• Storage:
  – Can create a safety copy: using public key of trusted person.

• Authentication:
  – No need to store secrets, only need public keys.
  – Secret key cryptography: need to share secret key for every person to communicate with.

Applications of Public Key Cryptography (Cont’d)

• Digital signatures
  – Sign hash $H(m)$ with the private key
  • Authorship
  • Integrity
  • Non-repudiation: can’t do with secret key cryptography

• Key exchange
  – Establish a common session key between two parties
Hash Algorithms

- Also known as
  - Message digests
  - One-way transformations
  - One-way functions
  - Hash functions
- Length of $H(m)$ much shorter than length of $m$
- Usually fixed lengths: 128 or 160 bits

Hash Algorithms (Cont’d)

- Desirable properties of hash functions
  - **Performance**: Easy to compute $H(m)$
  - **One-way property**: Given $H(m)$ but not $m$, it’s difficult to find $m$
  - **Weak collision free**: Given $H(m)$, it’s difficult to find $m'$ such that $H(m') = H(m)$.
  - **Strong collision free**: Computationally infeasible to find $m_1, m_2$ such that $H(m_1) = H(m_2)$
Applications of Hash Functions

- Primary application
  - Generate/verify digital signature

\[ m \rightarrow H \rightarrow H(m) \rightarrow \text{Sign} \rightarrow \text{Signature} \rightarrow \text{Sig}(H(m)) \]

- Message integrity
  - Agree on a secrete key \( k \)
  - Compute \( H(m|k) \) and send with \( m \)
  - Doesn’t require encryption algorithm, so the technology is exportable

Applications of Hash Functions (Cont’d)

- Password hashing
  - Doesn’t need to know password to verify it
  - Store \( H(\text{password}+\text{salt}) \) and salt, and compare it with the user-entered password
  - Salt makes dictionary attack more difficult