CSE 484: Computer Security and Privacy

Cryptography
[Symmetric Encryption]

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Admin

• Lab 1 checkpoint on Wednesday
How might we get “good” random numbers?
Obtaining Pseudorandom Numbers

• For security applications, want “cryptographically secure pseudorandom numbers”

• Libraries include cryptographically secure pseudorandom number generators (CSPRNG)
Obtaining Pseudorandom Numbers

• **Linux:**
  • `/dev/random` – blocking (waits for enough entropy)
  • `/dev/urandom` – nonblocking, possibly less entropy
  • `getrandom()` – syscall! – by default, blocking

• **Internally:**
  • *Entropy pool* gathered from multiple sources
    • e.g., mouse/keyboard/network timings
  • **Challenges with embedded systems, saved VMs**
Obtaining *Random* Numbers

• Better idea:
  • AMD/Intel’s *on-chip random number generator*
    • RDRAND
• Hopefully no hardware bugs!
Now: Symmetric Encryption
Confidentiality: Basic Problem

Given (Symmetric Crypto): both parties know the same secret.
Goal: send a message confidentially.

Ignore for now: How is this achieved in practice??
One weird bit-level trick

• XOR!
  • Just XOR with a random bit!

• Why?
  • Uniform output
  • Independent of ‘message’ bit
One-Time Pad

Key is a random bit sequence as long as the plaintext

Encrypt by bitwise XOR of plaintext and key:
\[ \text{ciphertext} = \text{plaintext} \oplus \text{key} \]

Decrypt by bitwise XOR of ciphertext and key:
\[ \text{plaintext} = (\text{ciphertext} \oplus \text{key}) \oplus \text{key} = \text{plaintext} \oplus (\text{key} \oplus \text{key}) = \text{plaintext} \]

Cipher achieves **perfect secrecy** if and only if there are as many possible keys as possible plaintexts, and every key is equally likely  
(Claude Shannon, 1949)
Advantages of One-Time Pad

• Easy to compute
  • Encryption and decryption are the same operation
  • Bitwise XOR is very cheap to compute

• As secure as theoretically possible
  • Given a ciphertext, all plaintexts are equally likely, regardless of attacker’s computational resources
  • ...as long as the key sequence is truly random
    • True randomness is expensive to obtain in large quantities
  • ...as long as each key is same length as plaintext
    • But how does sender communicate the key to receiver?
Problems with the One-Time Pad?

• Breakout Discussions
• What potential security problems do you see with the one-time pad?
• (Try not to look ahead and next slides)
• Recall two key goals of cryptography: confidentiality and integrity
Problems with One-Time Pad

• (1) Key must be as long as the plaintext
  • Impractical in most realistic scenarios
  • Still used for diplomatic and intelligence traffic

• (2) Insecure if keys are reused
Learn relationship between plaintexts

\[ C_1 \oplus C_2 = (P_1 \oplus K) \oplus (P_2 \oplus K) = (P_1 \oplus P_2) \oplus (K \oplus K) = P_1 \oplus P_2 \]
Problems with One-Time Pad

• (1) Key must be as long as the plaintext
  • Impractical in most realistic scenarios
  • Still used for diplomatic and intelligence traffic

• (2) Insecure if keys are reused
  • Attacker can obtain XOR of plaintexts
Key is a random bit sequence as long as the plaintext

Encrypt by bitwise XOR of plaintext and key: ciphertext = plaintext ⊕ key

Decrypt by bitwise XOR of ciphertext and key: ciphertext ⊕ key = (plaintext ⊕ key) ⊕ key = plaintext
Problems with One-Time Pad

• (1) Key must be as long as the plaintext
  • Impractical in most realistic scenarios
  • Still used for diplomatic and intelligence traffic

• (2) Insecure if keys are reused
  • Attacker can obtain XOR of plaintexts

• (3) Does not guarantee integrity
  • One-time pad only guarantees confidentiality
  • Attacker cannot recover plaintext, but can easily change it to something else
Reducing Key Size

• What to do when it is infeasible to pre-share huge random keys?
  • When one-time pad is unrealistic...

• Use special cryptographic primitives: block ciphers, stream ciphers
  • Single key can be re-used (with some restrictions)
  • Not as theoretically secure as one-time pad
Block Ciphers

- Operates on a single chunk ("block") of plaintext
  - For example, 64 bits for DES, 128 bits for AES
  - Each key defines a different permutation
  - Same key is reused for each block (can use short keys)
Keyed Permutation

<table>
<thead>
<tr>
<th>input</th>
<th>possible output (K=00)</th>
<th>possible output (K=01)</th>
<th>etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>010</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>001</td>
<td>111</td>
<td>110</td>
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<td>010</td>
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<td>011</td>
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<tr>
<td>111</td>
<td>000</td>
<td>110</td>
<td></td>
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</tbody>
</table>

For N-bit input, $2^N!$ possible permutations
For K-bit key, $2^K$ possible keys
Keyed Permutation

• Not just shuffling of input bits!
  • Suppose plaintext = “111”.
  • Then “111” is not the only possible ciphertext!
• Instead:
  • Permutation of possible outputs
  • Use secret key to pick a permutation
Block Cipher Security

• Result should look like a random permutation on the inputs
  • Recall: not just shuffling bits. N-bit block cipher permutes over $2^N$ inputs.

• Only computational guarantee of secrecy
  • Not impossible to break, just very expensive
    • If there is no efficient algorithm (unproven assumption!), then can only break by brute-force, try-every-possible-key search
  • Time and cost of breaking the cipher exceed the value and/or useful lifetime of protected information
  • “Break” could mean recovering key, or it could mean distinguishing the block cipher’s behavior from that of a randomly selected permutation over the $2^N$ possible inputs