CSE 484: Computer Security and Privacy

Cryptography
[Symmetric Encryption]

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How Cryptosystems Work Today

• **Layered approach:** Cryptographic protocols (like “CBC mode encryption”) built on top of cryptographic primitives (like “block ciphers”)
• **Flavors of cryptography:** Symmetric (private key) and asymmetric (public key)
• Public algorithms (**Kerckhoff’s Principle**)
• Security proofs based on assumptions (**not this course**)

• Be careful about inventing your own! (If you just want to use some crypto in your system, use vetted libraries!)
Flavors of Cryptography

• Symmetric cryptography
  • Both communicating parties have access to a shared random string $K$, called the key.

• Asymmetric cryptography
  • Each party creates a public key $pk$ and a secret key $sk$.
  • *Hard concept to understand, and revolutionary! Inventors won Turing Award 😊*
Symmetric Setting

Both communicating parties have access to a shared random string $K$, called the key.
Asymmetric Setting

Each party creates a public key $pk$ and a secret key $sk$.
Flavors of Cryptography

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Flavors of Cryptography

• Symmetric cryptography
  • Both communicating parties have access to a shared random string $K$, called the key.
  • Challenge: How do you privately share a key?

• Asymmetric cryptography
  • Each party creates a public key $pk$ and a secret key $sk$.
  • Challenge: How do you validate a public key?
Ingredient: Randomness

• Many applications (especially security ones) require randomness

• Explicit uses:
  • Generate secret cryptographic keys
  • Generate random initialization vectors for encryption

• Other “non-obvious” uses:
  • Generate passwords for new users
  • Shuffle the order of votes (in an electronic voting machine)
  • Shuffle cards (for an online gambling site)
C’s rand() Function

• C has a built-in random function: rand()

    ```c
    unsigned long int next = 1;
    /* rand: return pseudo-random integer on 0..32767 */
    int rand(void) {
        next = next * 1103515245 + 12345;
        return (unsigned int)(next/65536) % 32768;
    }
    /* srand: set seed for rand() */
    void srand(unsigned int seed) {
        next = seed;
    }
    
    • Problem: don’t use rand() for security-critical applications!
      • Given a few sample outputs, you can predict subsequent ones
mamajoe: Hey guys, Big B is in!
More details: “How We Learned to Cheat at Online Poker: A Study in Software Security”
PS3 and Randomness

Hackers obtain PS3 private cryptography key due to epic programming fail? (update)

• 2010/2011: Hackers found/released private root key for Sony’s PS3
• Key used to sign software – now can load any software on PS3 and it will execute as “trusted”
• Due to bad random number: same “random” value used to sign all system updates

Another real world example

```c
byte buffer[256];
int index = 0;

setup(){
    for (i=0; i < 256; i++){
        buffer[i] = i;
    }
    shuffle_array(buffer);
}

random(){
    byte ret = buffer[index];
    if(index == 255){
        index = 0;
    } else{
        index++;
    }
}
```
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
  • /dev/urandom - nonblocking, possibly less entropy
  • getrandom() – syscall!

• 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 trick to hide your bits

• 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: ciphertext = plaintext $\oplus$ key

Decrypt by bitwise XOR of ciphertext and key: ciphertext $\oplus$ key = (plaintext $\oplus$ key) $\oplus$ key = plaintext $\oplus$ (key $\oplus$ key) = 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 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
Dangers of Reuse

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
Integrity?

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:
\[ \text{ciphertext} \oplus \text{key} = (\text{plaintext} \oplus \text{key}) \oplus \text{key} = \text{plaintext} \oplus (\text{key} \oplus \text{key}) = \text{plaintext} \]
Problems with One-Time Pad

• (1) Key must be as long as the plaintext
  • Impractical in most realistic scenarios
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• (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
Stream Ciphers

• **One-time pad:** $\text{Ciphertext}(\text{Key,Message}) = \text{Message} \oplus \text{Key}$
  - Key must be a random bit sequence as long as message

• **Idea:** replace “random” with “pseudo-random”
  - Use a pseudo-random number generator (PRNG)
  - PRNG takes a short, truly random secret seed and expands it into a long “random-looking” sequence
    - E.g., 128-bit seed into a $10^6$-bit pseudo-random sequence

• $\text{Ciphertext}(\text{Key,Msg}) = \text{Msg} \oplus \text{PRNG}(\text{Key})$
  - Message processed bit by bit (like one-time pad)

No efficient algorithm can tell this sequence from truly random
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)