Stream Cipher

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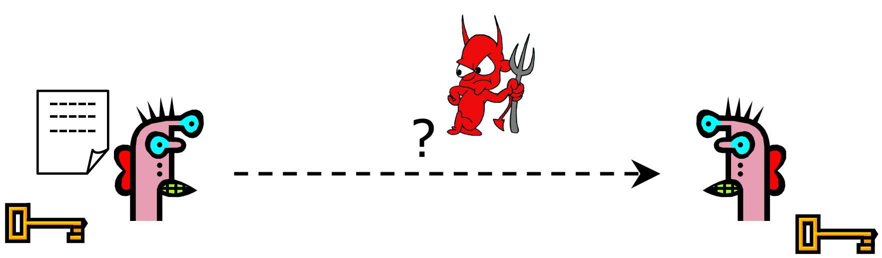
Basic Problem



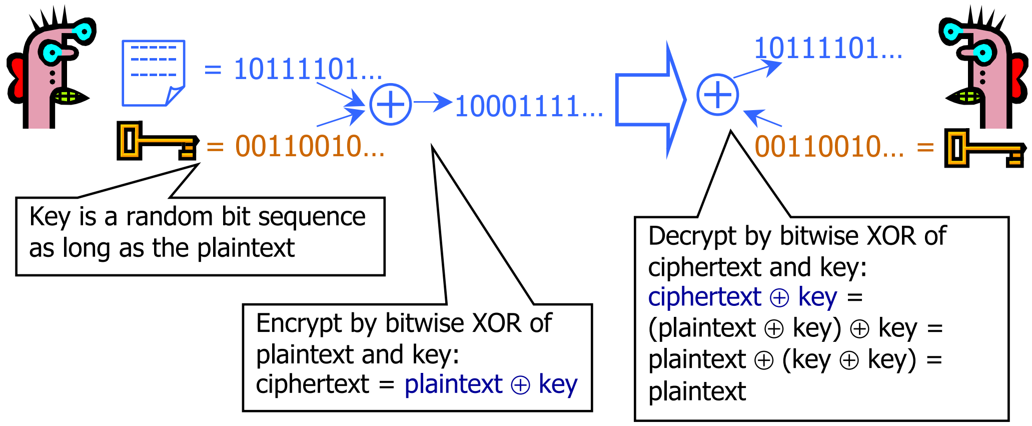
Given: both parties already know the same secret

Goal: send a message confidentially

How is this achieved in practice?

Any communication system that aims to guarantee confidentiality must solve this problem

One-Time Pad



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)

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 the sender communicate the key to receiver?

Problems with One-Time Pad

- Key must be as long as plaintext
  - Impractical in most realistic scenarios
  - Still used for diplomatic and intelligence traffic
- Does not guarantee integrity
  - One-time pad only guarantees confidentiality
  - Attacker cannot recover plaintext, but can easily change it to something else
- Insecure if keys are reused
  - Attacker can obtain XOR of plaintexts

Stream Ciphers

- One-time pad
  Ciphertext(Key,Message)=Message⊕Key
  - Key must be a random bit sequence as long as message
- Idea: replace "random" with "pseudo-random"
  - Encrypt with pseudo-random number generator (PRNG)
  - PRNG takes a short, truly random secret seed (key) and expands it into a long "random-looking" sequence
    - E.g., 128-bit key into a 10^6-bit pseudo-random sequence
- Ciphertext(Key,Message)=Message⊕PRNG(Key)
  - Message processed bit by bit, not in blocks

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Properties of Stream Ciphers

- Usually very fast
  - Used where speed is important: WiFi, SSL, DVD
- Unlike one-time pad, stream ciphers do not provide perfect secrecy
  - Only as secure as the underlying PRNG
  - If used properly, can be as secure as block ciphers
- PRNG must be unpredictable
  - Given the stream of PRNG output (but not the seed!), it's hard to predict what the next bit will be
    - If PRNG(unknown seed)=$b_1 \ldots b_i$, then b_{i+1} is "0" with probability ½, "1" with probability ½

Weaknesses of Stream Ciphers

- No integrity
  - Associativity & commutativity: $(X \oplus Y) \oplus Z = (X \oplus Z) \oplus Y$
  - $(M_1 \oplus PRNG(key)) \oplus M_2 = (M_1 \oplus M_2) \oplus PRNG(key)$
- Known-plaintext attack is very dangerous if keystream is ever repeated
  - Self-cancellation property of XOR: $X \oplus X = 0$
  - $(M_1 \oplus PRNG(key)) \oplus (M_2 \oplus PRNG(key)) = M_1 \oplus M_2$
  - If attacker knows M_1, then easily recovers M_2
    - Most plaintexts contain enough redundancy that knowledge of M_1 or M_2 is not even necessary to recover both from $M_1 \oplus M_2$

Stream Cipher Terminology

- Seed of pseudo-random generator often consists of initialization vector (IV) and key
  - IV is usually sent with the ciphertext
  - The key is a secret known only to the sender and the recipient, not sent with the ciphertext
- The pseudo-random bit stream produced by PRNG(IV,key) is referred to as keystream
- Encrypt message by XORing with keystream
  - ciphertext = message ⊕ keystream

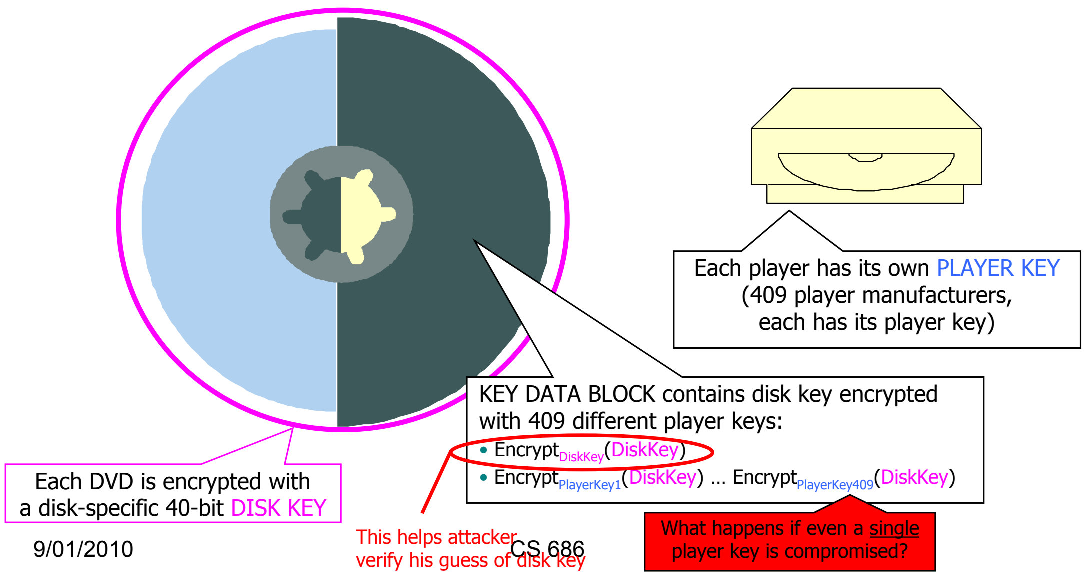
RC4

- Designed by Ron Rivest for RSA in 1987
- Simple, fast, widely used
  - SSL/TLS for Web security, WEP for wireless

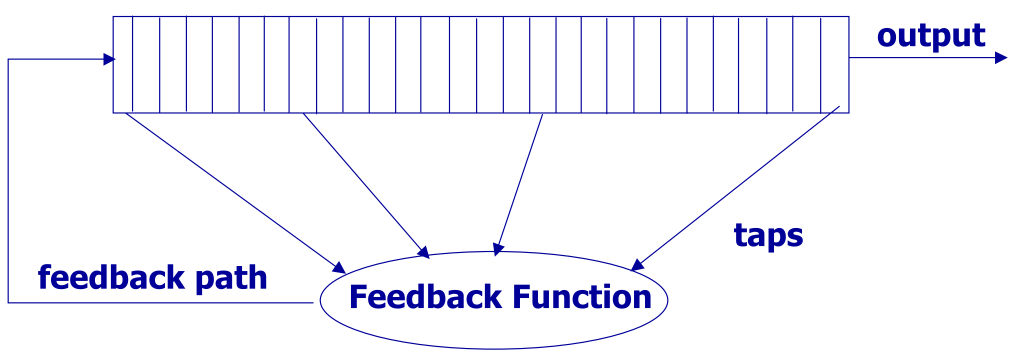
```
Byte array S[256] contains a permutation of numbers from 0 to 255
i = j := 0
loop
    i := (i+1) mod 256
    j := (j+S[i]) mod 256
    swap(S[i],S[j])
    output (S[i]+S[j]) mod 256
end loop
```

Content Scrambling System (CSS)

- DVD encryption scheme from Matsushita and Toshiba



Generic LFSR

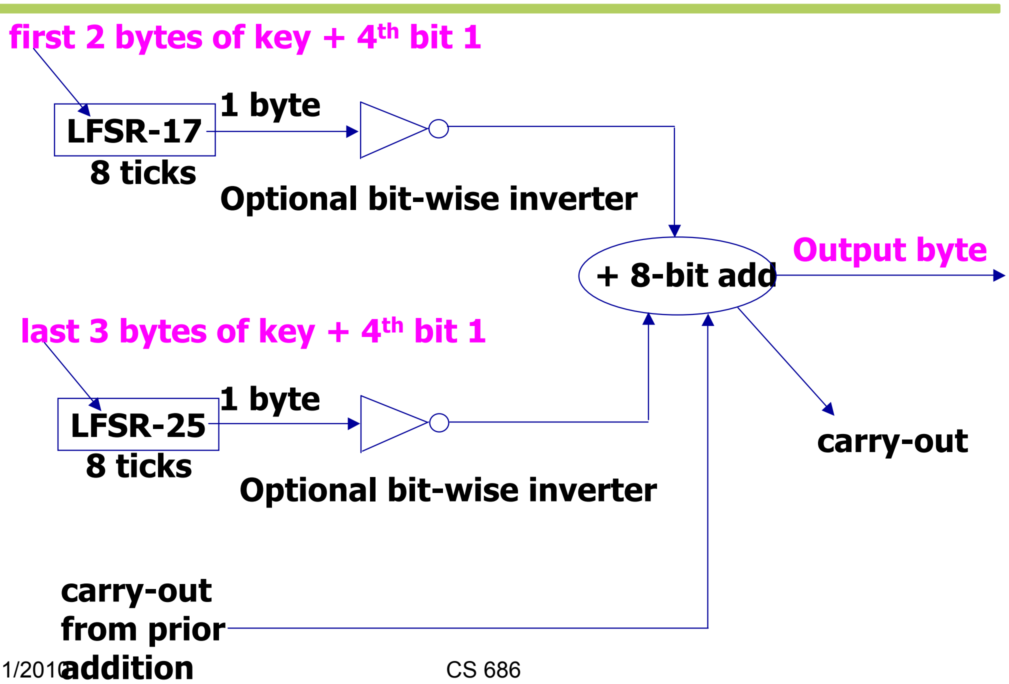


- **The register is *seeded* with an initial value.**
- **At each clock tick, the feedback function is evaluated using the input from the *tapped bits*. The result is shifted into the leftmost bit of the register. The rightmost bit is shifted into the output.**

Linear Feedback Shift Register

- Pseudo-random bit stream
- Linear Feedback Shift Register (LFSR)
  - The LFSR is one popular technique for generating a pseudo-random bit stream. After the LFSR is seeded with a value, it can be *clocked* to generate a stream of bits.
  - Unfortunately, LFSRs aren't truly random – they are periodic and will eventually repeat.
  - In general, the larger the LFSR, the greater its period. There period also depends on the particular configuration of the LFSR.
  - If the initial value of an LFSR is 0, it will produce only 0's, this is sometimes called *null cycling*

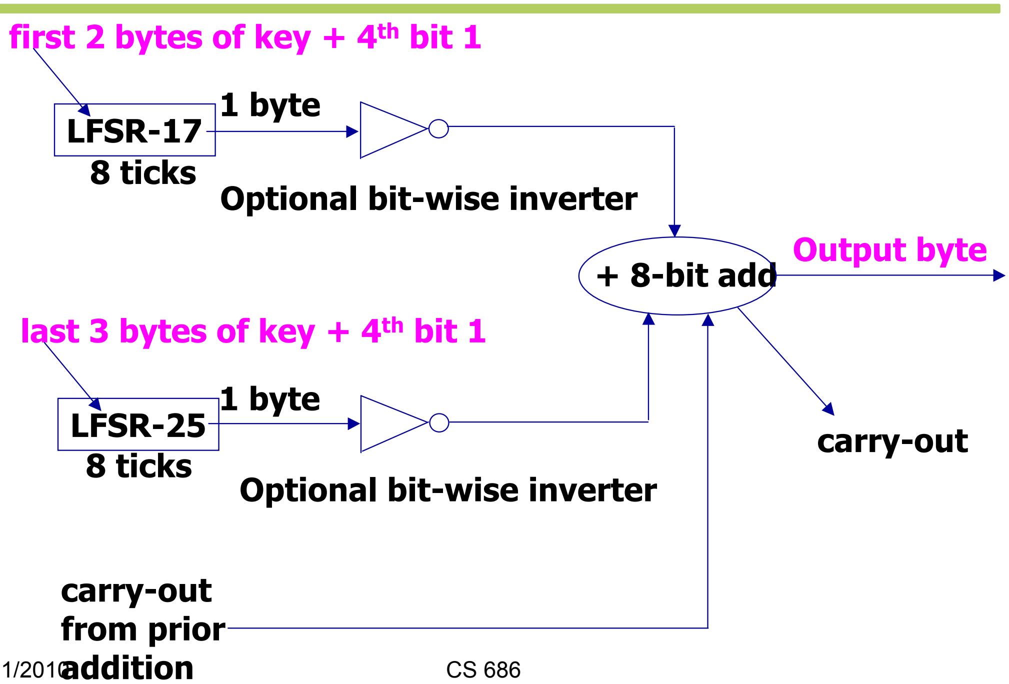
CSS: LFSR Addition



Weakness #1: LFSR Cipher

- Brainless: disk key is 40 bit long
  - 2^{40} isn't really very big – just brainlessly brute-force the keys
- With 6 Output Bytes $O(2^{16})$:
  - Guess the initial state of LFSR-17 $O(2^{16})$.
  - Clock out 4 bytes.
  - Use those 4 bytes to determine the corresponding 4 bytes of output from LFSR-25.
  - Use the LFSR-25 output to determine LFSR-25's state.
  - Clock out 2 bytes on both LFSRs.
  - Verify these two bytes. Celebrate or guess again.

CSS: LFSR Addition



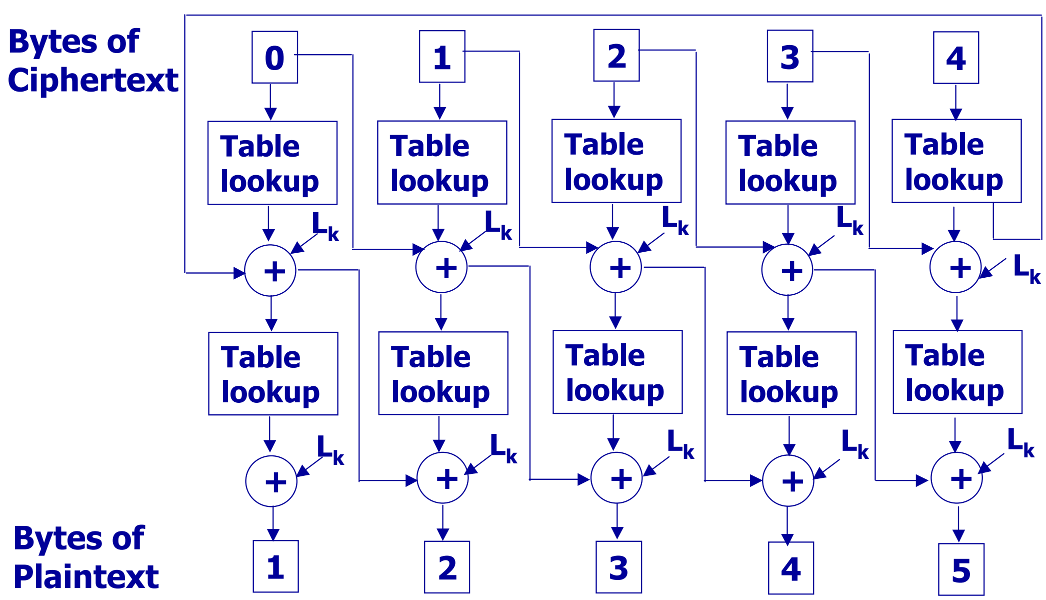
Weakness #1: LFSR Cipher (Cont.)

- With 5 Output Bytes $O(2^{17})$:
  - Guess the initial state of LFSR-17 $O(2^{16})$
  - Clock out 3 bytes
  - Determine the corresponding output bytes from LFSR-25
  - This reveals all but the highest-order bit of LFSR-25
  - Try both possibilities: O(2)
    - Clock back 3 bytes
    - Select the setting where bit 4 is 1 (remember this is the initial case).
    - It is possible that both satisfy this – try both.
  - Clock out 2 bytes on both LFSRs.
  - Verify these two bytes. Celebrate or guess again.

Weakness #2: Mangled Output

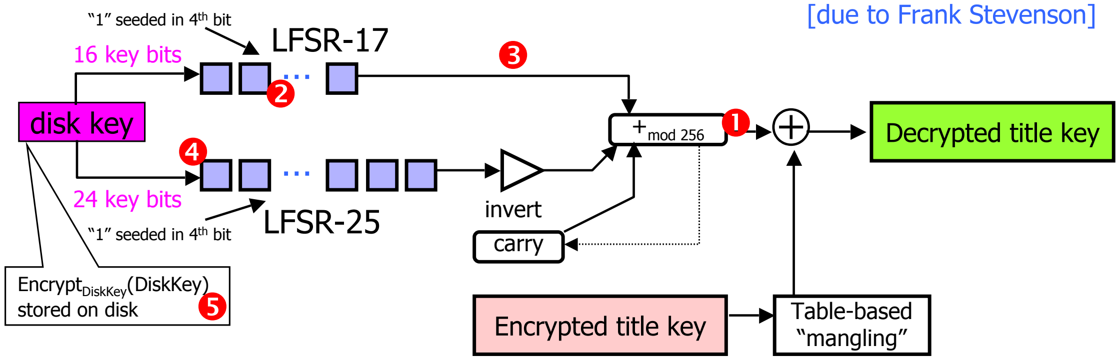
- With Known ciphertext and plainttext
  - Guess L_k (1 byte)
  - Work backward and verify input byte
  - This is a $O(2^8)$ attack.
  - Repeat for all 5 bytes – this gives you the 5 bytes of known output for prior weakness.

CSS decryption algorithm



Attack on CSS Decryption Scheme

[due to Frank Stevenson]



❶ Knowing encrypted and decrypted title key, try 256 possibilities to recover 40 output bits of the LFSRs – this takes O(2^8)

❷ Guess 16 bits of the key contained in LFSR-17 – this takes O(2^{16})

❸ Clock out 24 bits out of LFSR-17, use them to determine the corresponding output bits of LFSR-25 (this reveals all of LFSR-25 except the highest bit)

❹ Clock back 24 bits, try both possibilities – this takes O(2)

❺ Verify the key

This attack takes O(2^{25})

Reading assignment

- Aircrack-ng
  - http://www.aircrack-ng.org/doku.php