Block ciphers, stream ciphers
(start on:) Asymmetric cryptography

CS 161: Computer Security

Prof. Raluca Ada Popa

Sept 15, 2016

Announcements

- Project due Sept 20

Recall: Block cipher

A function $E : \{0, 1\}^k \times \{0, 1\}^n \rightarrow \{0, 1\}^n$. Once we fix the key K, we get

$E_K : \{0,1\}^n \rightarrow \{0,1\}^n$ defined by $E_K(M) = E(K,M)$.

Three properties:

- Correctness:
  - $E_K(M)$ is a permutation (bijective function)
- Efficiency
- Security

Security

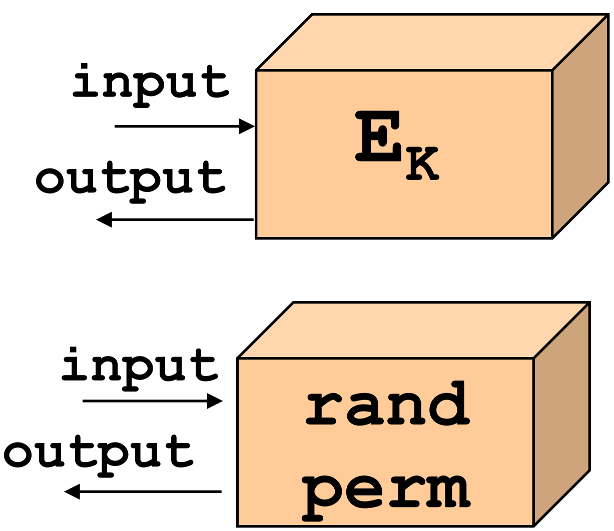
For an unknown key K, E_K “behaves” like a random permutation

For all polynomial-time attackers, for a randomly chosen key K, the attacker **cannot distinguish** E_K from a random permutation

Block cipher: security game

- Attacker is given two boxes, one for E_K and one for a random permutation
- Attacker does not know which is which
- Attacker can give inputs to each box, look at the output
- Attacker must guess which is E_K

??? Which is E_K???



Security game

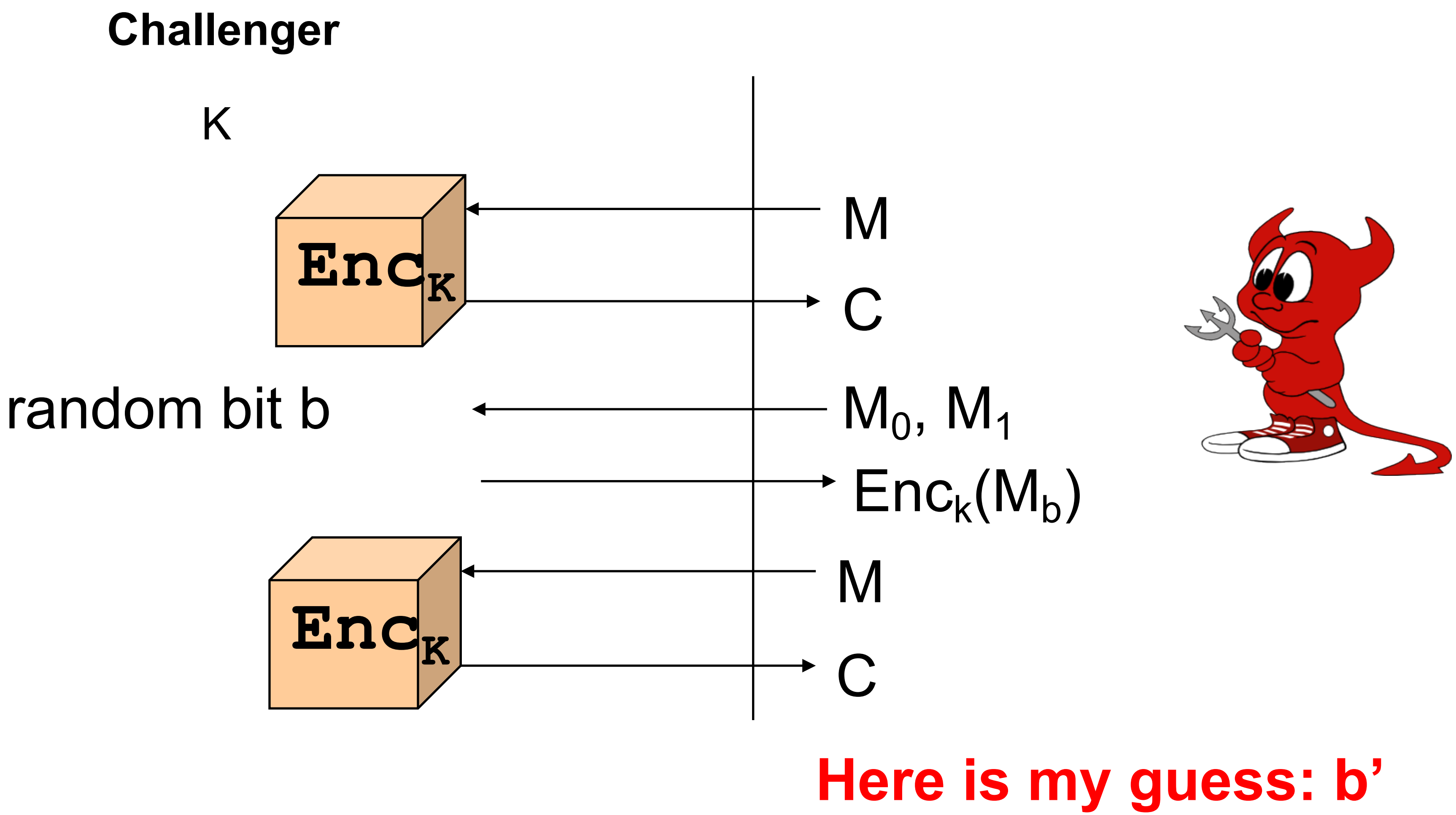
For all polynomial-time attackers,

Pr[attacker wins game] <= ½+negl

Use block ciphers to construct symmetric-key encryption

- Want two properties:
  - IND-CPA security even when reusing the same key to encrypt many messages
  - Can encrypt messages of any length

Desired security: indistinguishability under chosen plaintext attack (IND-CPA)



IND-CPA

An encryption scheme is IND-CPA if
for all polynomial-time adversaries

Pr[Adv wins game] <= ½ + negligible

Note that IND-CPA requires that the encryption scheme is randomized

(An encryption scheme is deterministic if it outputs the same ciphertext when encrypting the same plaintext; a randomized scheme does not have this property)

Difference from known-plaintext attack from last time

- The extra queries to Enc_K
- Why is IND-CPA a stronger security?
  - The attacker is given more capabilities so the IND-CPA scheme resists a more powerful attacker

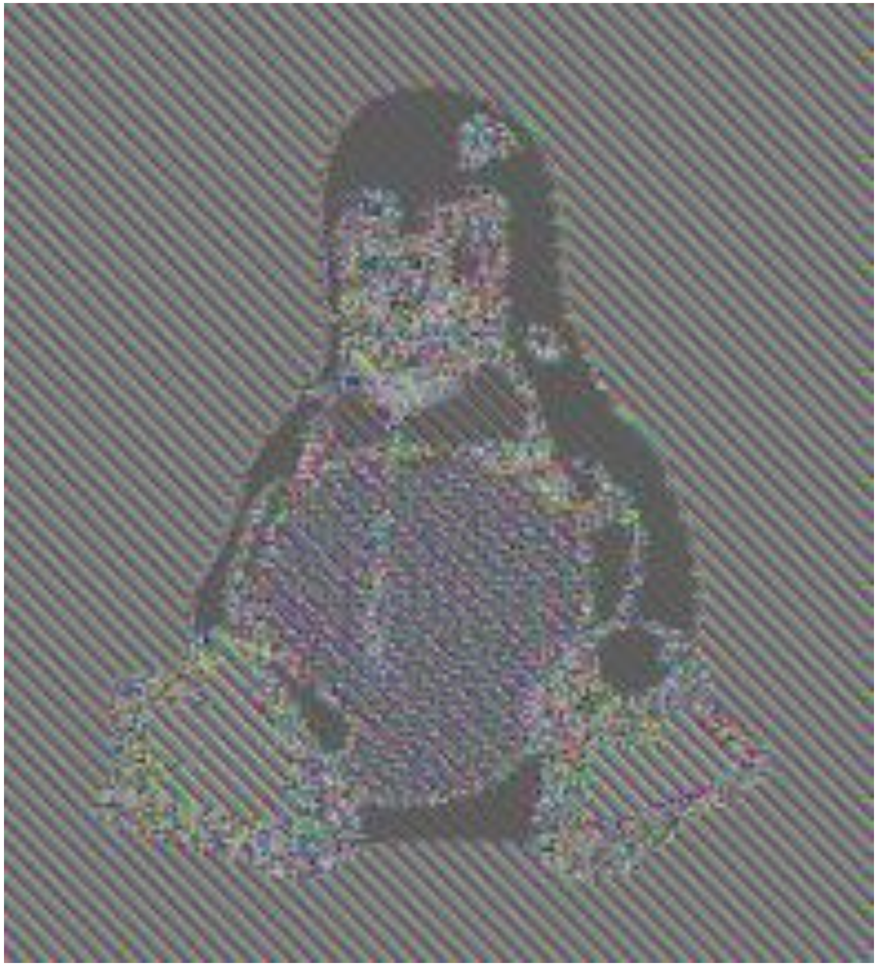
Are block ciphers IND-CPA?

Recall: $E_K : \{0,1\}^n \rightarrow \{0,1\}^n$ is a permutation (bijective)

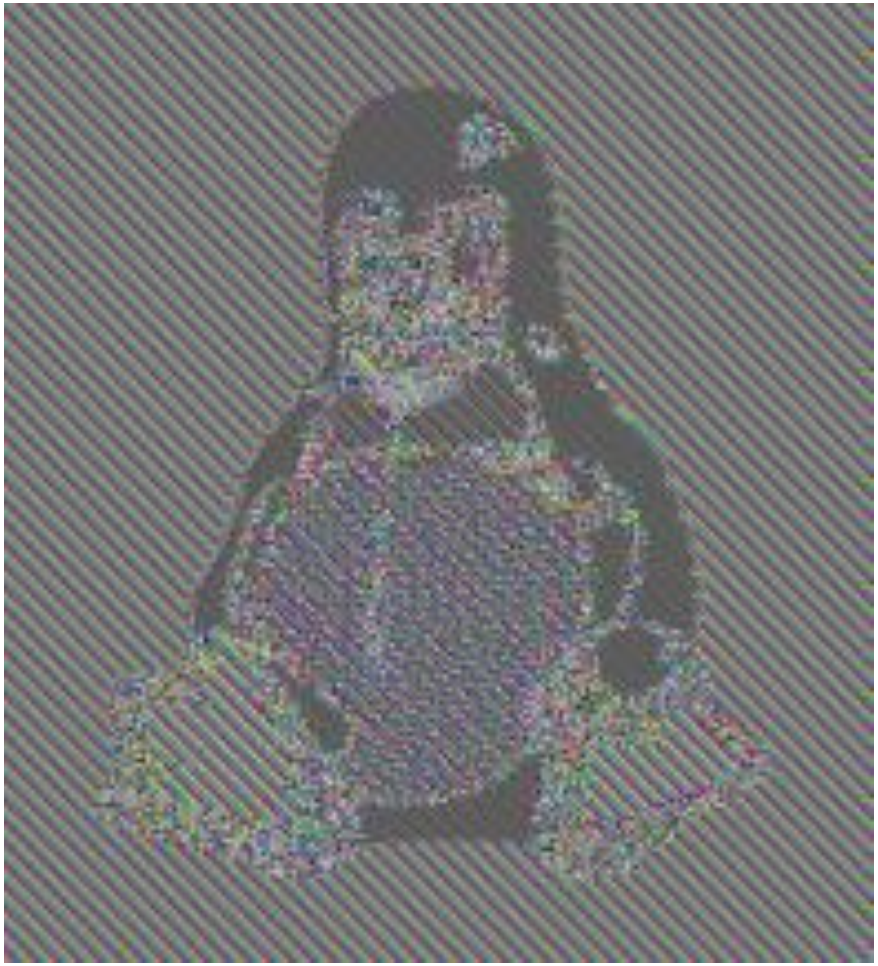
Are block ciphers IND-CPA?

- No, because they are deterministic
- Here is an attacker that wins the IND-CPA game:
  - Adv asks for encryptions of “bread”, receives C_{br}
  - Then, Adv provides (M_0 = bread, M_1 = honey)
  - Adv receives C
  - If $C=C_{br}$, Adv says bit was 0 (for “bread”), else Adv says says bit was 1 (for “honey”)
  - Chance of winning is 1

Original image



Eack block encrypted with a block cipher



Later (identical) message again encrypted

Modes of operation

Chain block ciphers **in certain modes of operation**

- Certain output from one block feeds into next block

Need some **initial randomness IV** **(initialization vector)**

Why? To prevent the encryption scheme from being deterministic

Counter mode (CTR)

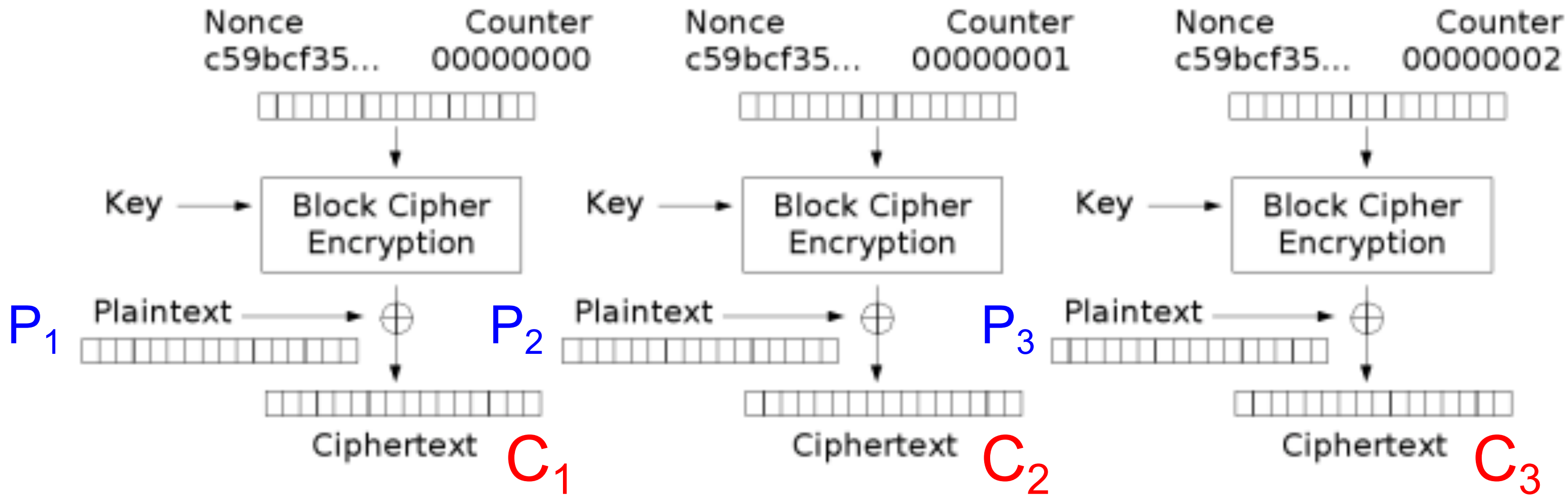
Last time: ECB, CBC

CTR: Encryption

Enc(K, plaintext):

- If n is the block size of the block cipher, split the plaintext in blocks of size n: P_1, P_2, P_3,..
- Choose a random nonce
- Now compute:

(Nonce = Same as IV)
Important that nonce does not repeat across different encryptions



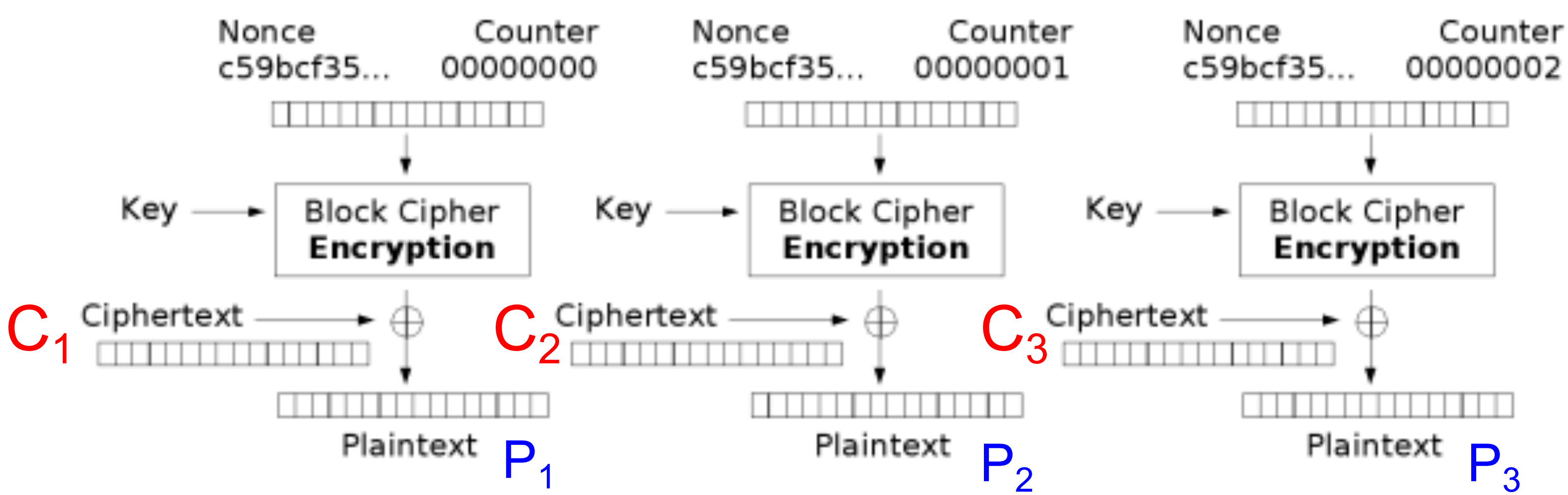
Counter (CTR) mode encryption

- The final ciphertext is (nonce, C_1, C_2, C_3)

CTR: Decryption

Dec(K, ciphertext=[nonce,C_1, C_2, C_3,.].):

- Take nonce out of the ciphertext
- If n is the block size of the block cipher, split the ciphertext in blocks of size n: C_1, C_2, C_3,..
- Now compute this:

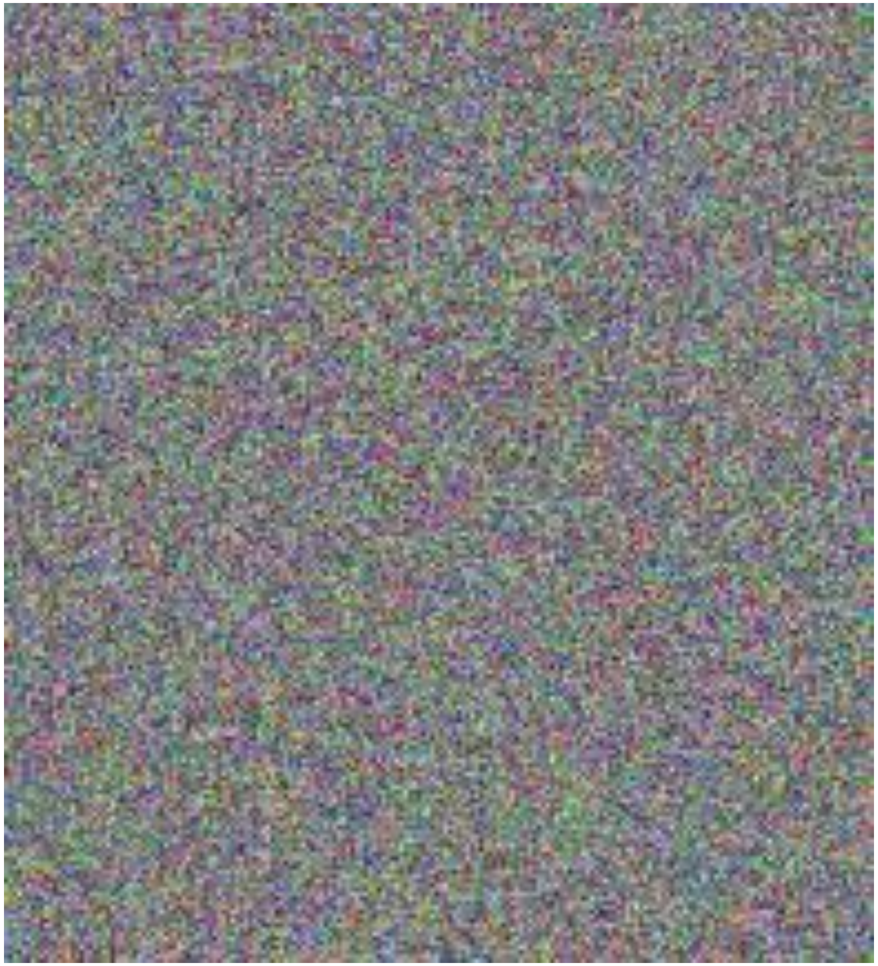


Counter (CTR) mode decryption

- Output the plaintext as the concatenation of P_1, P_2, P_3, ...

Note, CTR decryption uses block cipher's *encryption*, not decryption

Original image



Encrypted with CBC

CBC vs CTR

Security: If no reuse of nonce**, both are IND-CPA.**

Speed: Both modes require the same amount of computation, but CTR is parallelizable

Pseudorandom generator (PRG)

Pseudorandom Generator (PRG)

- Given a seed, it outputs a sequence of random bits

  PRG(seed) -> random bits

- It can output arbitrarily many random bits

PRG security

- Can PRG(K) be truly random?

No. Consider key length k. Have 2^k possible initial states of PRG. Deterministic from then on.

- A secure PRG suffices to “look” random (“pseudo”) to an attacker (no attacker can distinguish it from a random sequence)

Example of PRG: using block cipher in CTR mode

If you want m random bits, and a block cipher with E_k has n bits, apply the block cipher m/n times and concatenate the result:

PRG(K, IV) = E_k(IV, 1), E_k(IV, 2), E_k(IV, 3) … E_k(IV, ceil(m/n))

Application of PRG: Stream ciphers

- Another way to construct encryption schemes
- Similar in spirit to one-time pad: it XORs the plaintext with some random bits
- But random bits are not the key (as in one-time pad) but are output of a pseudorandom generator PRG

Application of PRG: Stream cipher

Enc(K, M):

- Choose a random value IV
- Enc(K,M) = PRG(K, IV) XOR M

Can encrypt any message length because PRG can produce any number of random bits

Summary

- Desirable security: IND-CPA
- Block ciphers have weaker security than IND-CPA
- Block ciphers can be used to build IND-CPA secure encryption schemes by chaining in careful ways
- Stream ciphers provide another way to encrypt, inspired from one-time pads

Start asymmetric cryptography on board