Symmetric-Key Cryptography

CS 161: Computer Security

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Announcements

- Project due Sept 20

Special guests

- Alice 
- Bob 
- The attacker (Eve - "eavesdropper", Malice)  
- Sometimes Chris too

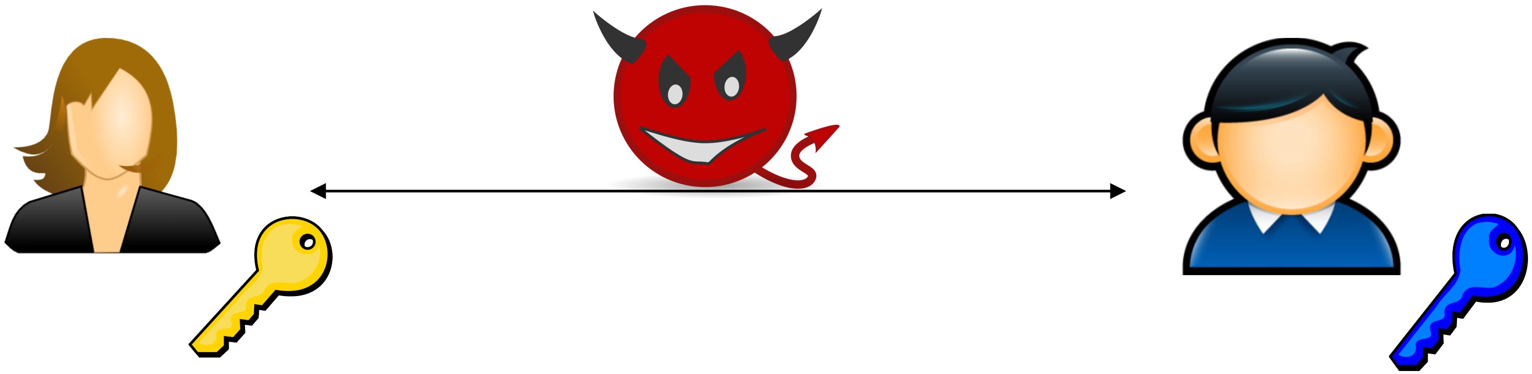
Cryptography

- Narrow definition: secure communication over insecure communication channels
- Broad definition: a way to provide formal guarantees in the presence of an attacker

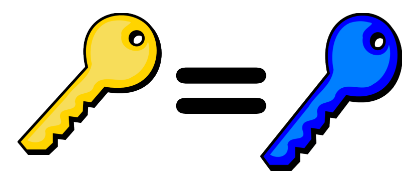
Three main goals

- Confidentiality: preventing adversaries from reading our private data,
- Integrity: preventing attackers from altering some data,
- Authenticity: determining who created a given document

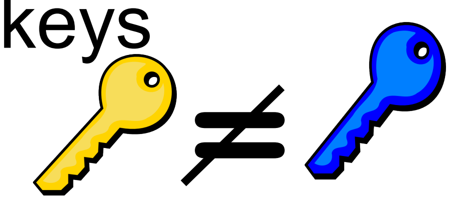
Modern Cryptography



- Symmetric-key cryptography
  - The same secret key is used by both endpoints of a communication



- Public-key (asymmetric-key) cryptography
  - Sender and receiver use different keys



Today: Symmetric-key Cryptography

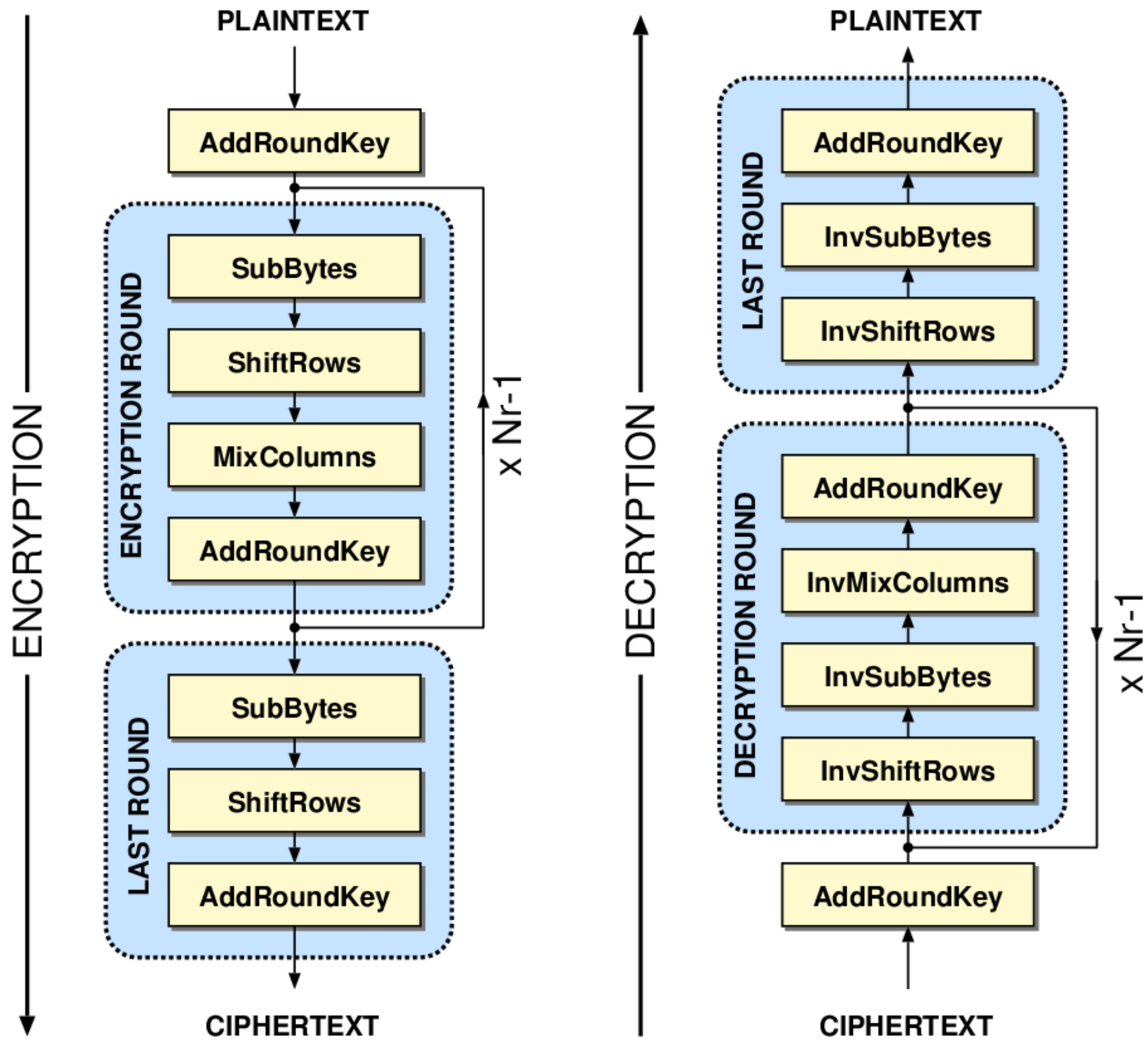
Whiteboard & notes:

- Symmetric encryption definition
- Security definition
- One time pad (OTP)
- Block cipher

Advanced Encryption Standard (AES)

- Block cipher developed in 1998 by Joan Daemen and Vincent Rijmen
- Recommended by US National Institute for Standard and Technology (NIST)
- Block length $n = 128$, key length $k = 256$

AES ALGORITHM

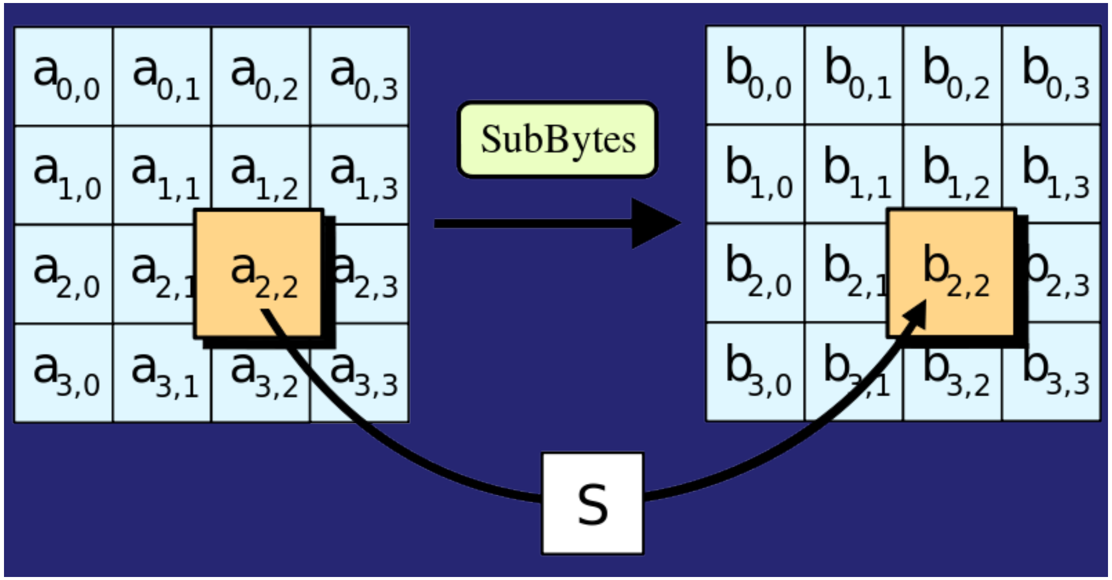


- 14 cycles of repetition for 256-bit keys.

AES slides, credit Kevin Orr

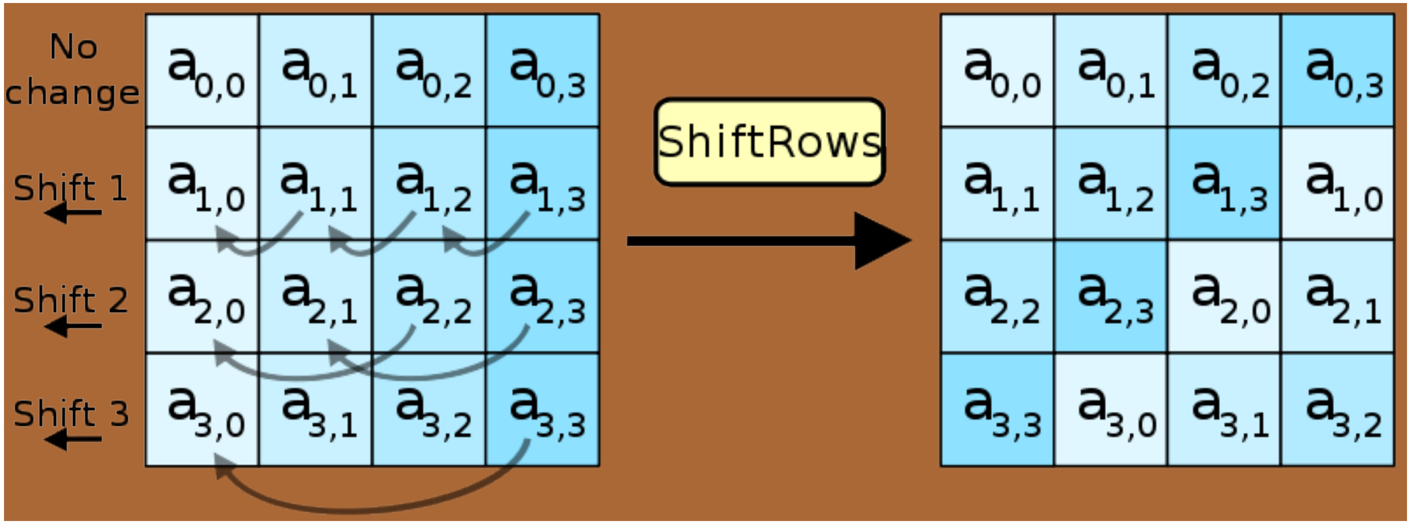
Algorithm Steps - Sub bytes

- each byte in the *state* matrix is replaced with a SubByte using an 8-bit substitution box
- $b_{ij} = S(a_{ij})$



Shift Rows

- Cyclically shifts the bytes in each row by a certain offset
- The number of places each byte is shifted differs for each row



Uses

- Government Standard
  - AES is standardized as Federal Information Processing Standard 197 (FIPS 197) by NIST
  - To protect classified information
- Industry
  - SSL / TLS
  - SSH
  - WinZip
  - BitLocker
  - Mozilla Thunderbird
  - Skype

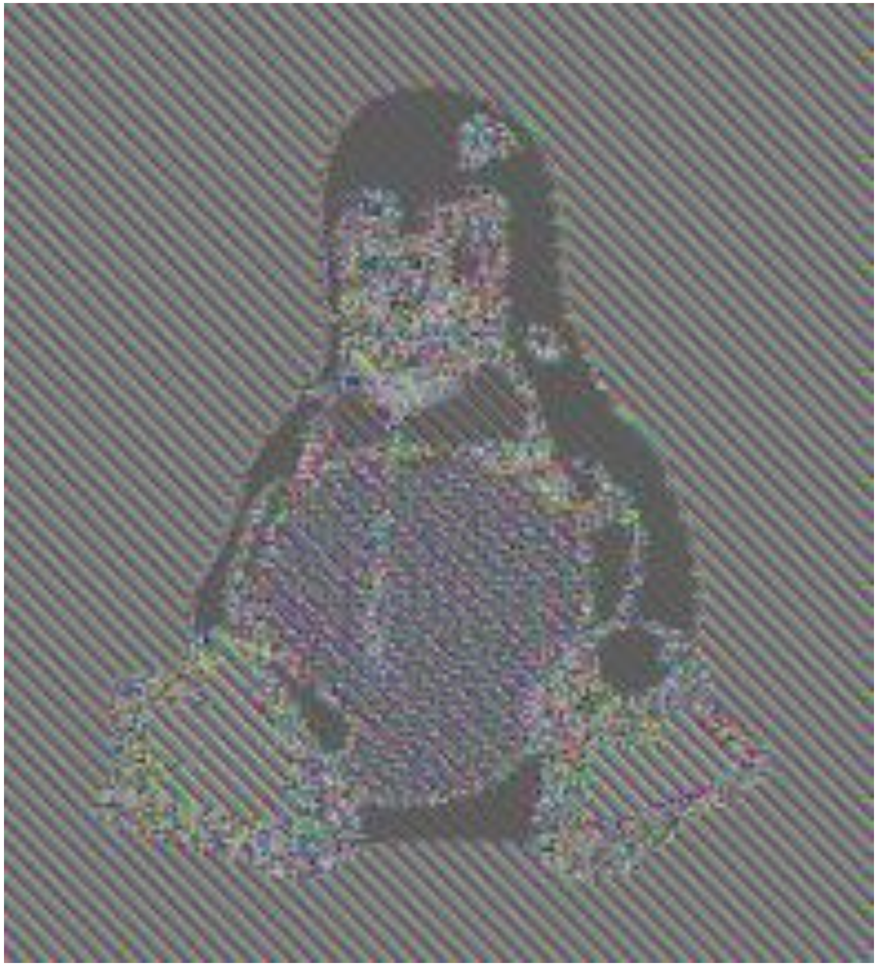
But used as part of symmetric-key encryption or other crypto tools

Symmetric-key encryption from block ciphers

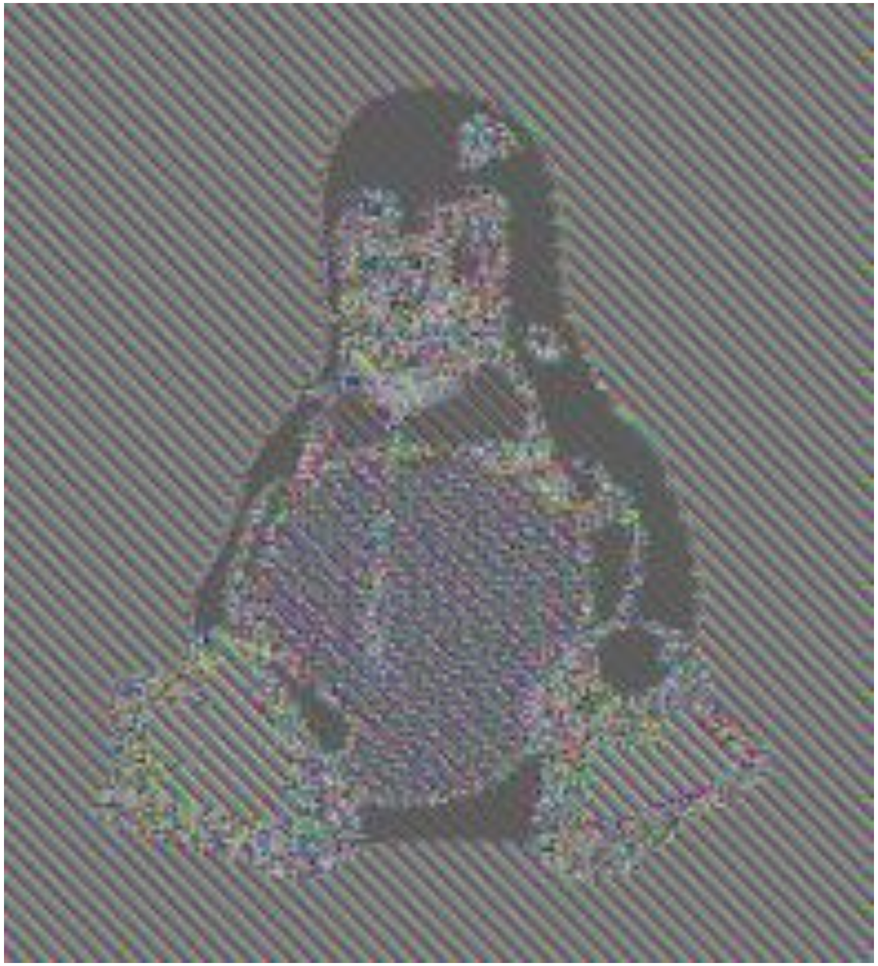
Why block ciphers not enough for encryption by themselves?

- Can only encrypt messages of a certain size
- If message is encrypted twice, attacker knows it is the same message

Original image



Eack block encrypted with a block cipher



Later (identical) message again encrypted

Symmetric key encryption scheme

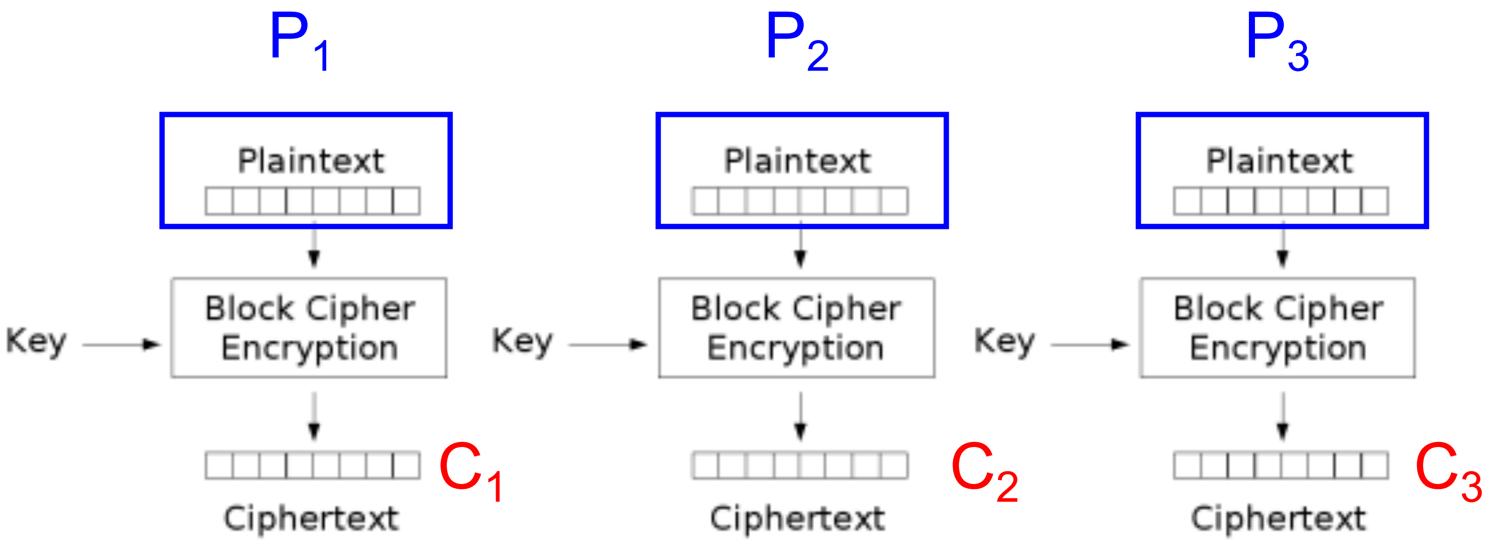
- Can be reused (unlike OTP)
- Builds on block ciphers:
  - Can be used to encrypt long messages
  - Wants to hide that same block is encrypted twice
- Uses block ciphers in certain modes of operation

Electronic Code Book (ECB)

- Split message M in blocks P_1, P_2, …
- Each block is a value which is substituted, like a codebook
- Each block is encoded independently of the other blocks

$$C_i = EK(Pi)$$

Encryption



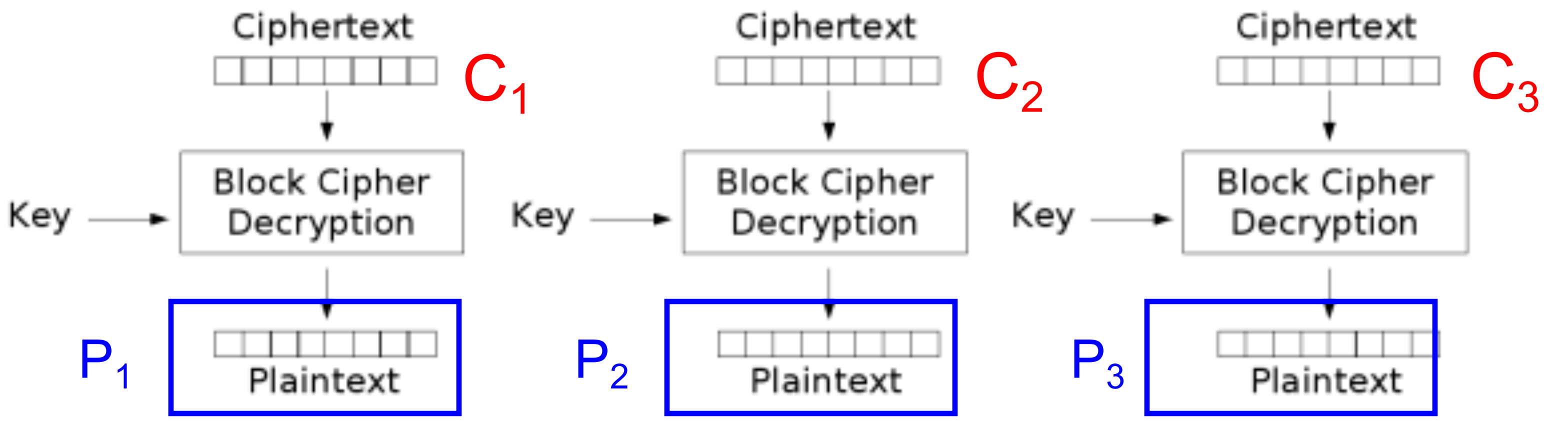
Electronic Codebook (ECB) mode encryption

`KeyGen = key gen of block cipher`

`Enc(K, P1|P2|P3) = (IV, C1, C2, C3)`

`Dec(K, (IV,C1,C2,C3)) = (P1, P2, P3)`

Decryption



Electronic Codebook (ECB) mode decryption

What is the problem with ECB?

Does this achieve IND-KPA?

No, attacker can tell if $P_i = P_j$

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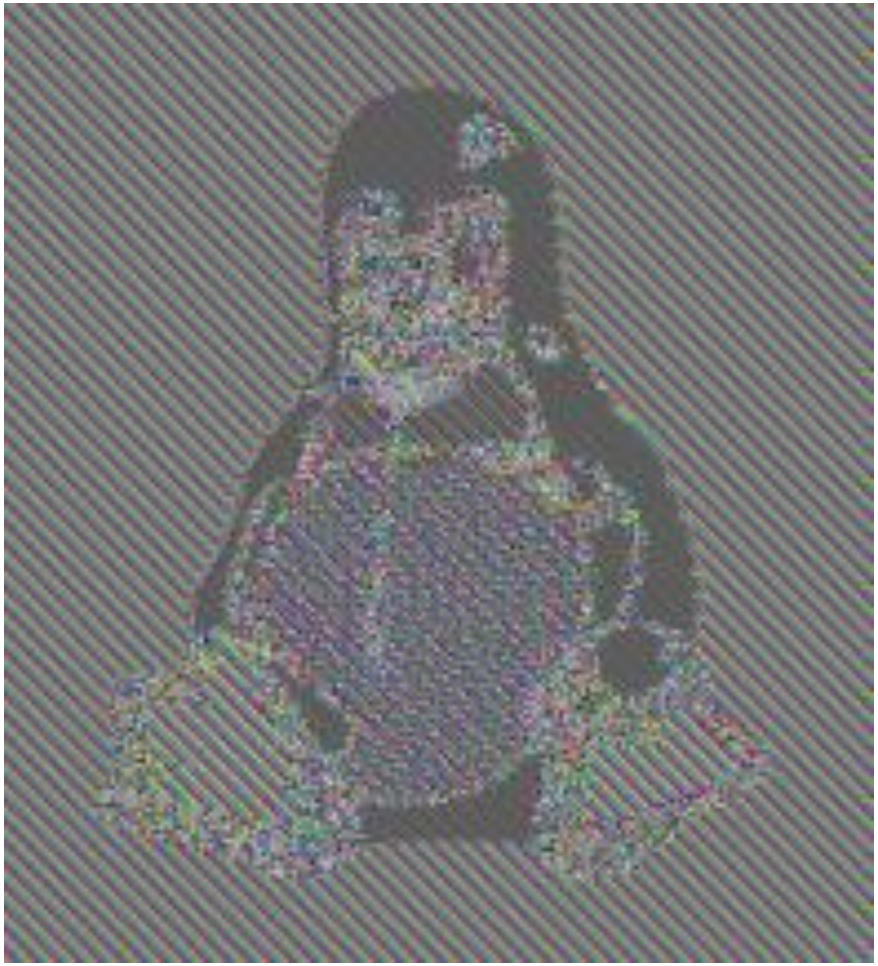
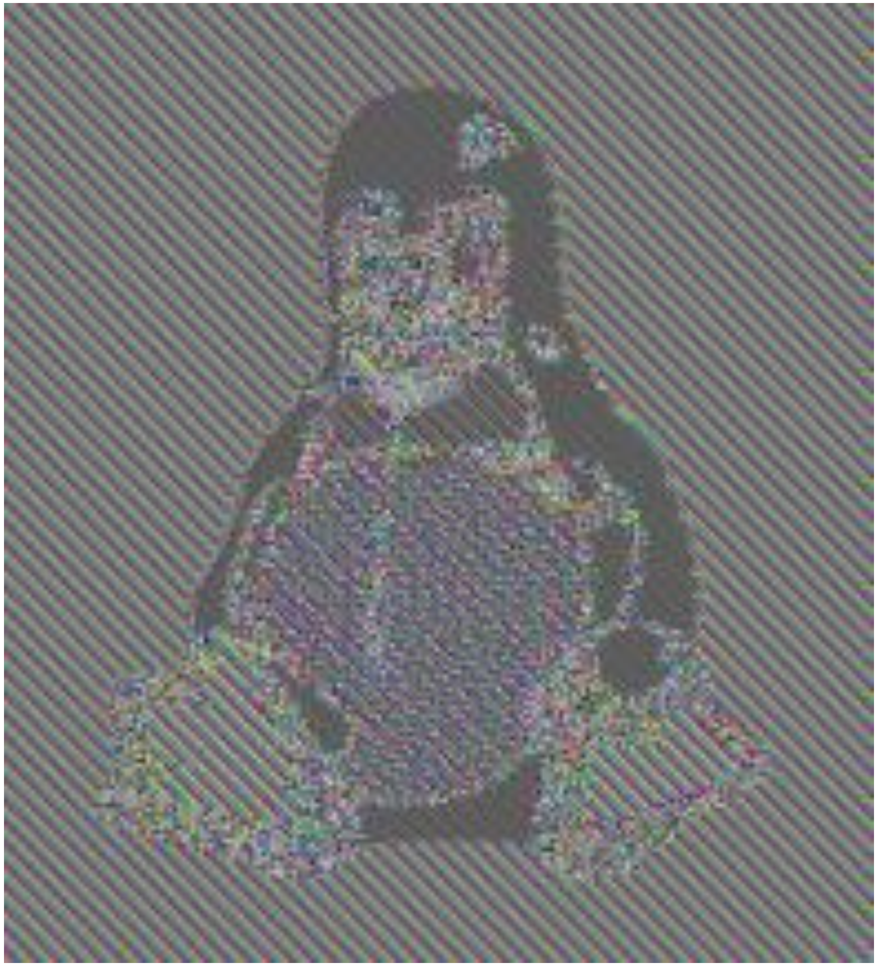
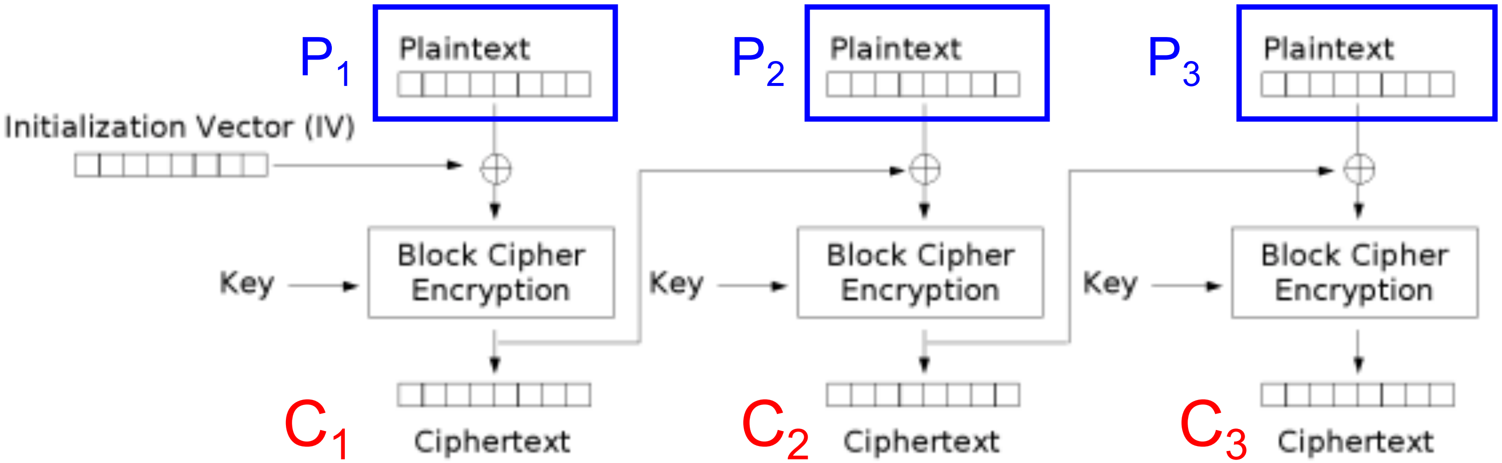


Encrypted with ECB



Later (identical) message again encrypted with ECB

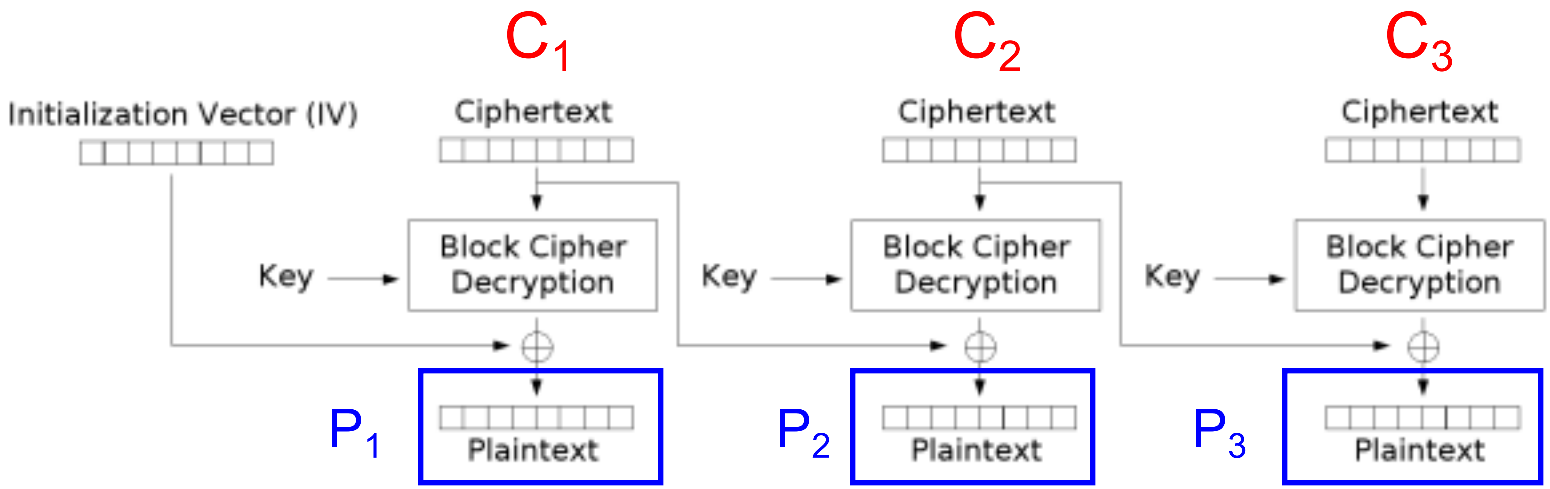
CBC: Encryption



Cipher Block Chaining (CBC) mode encryption

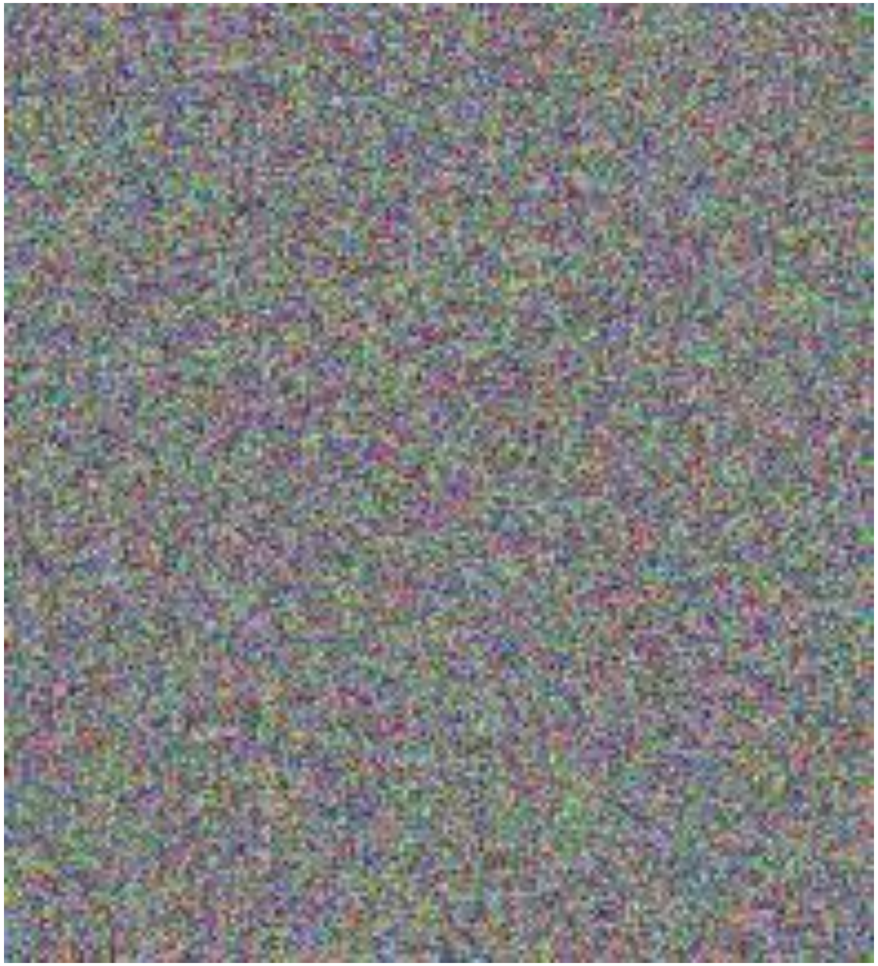
IV may not repeat for messages with same P_1, choose it at random

CBC: Decryption



Cipher Block Chaining (CBC) mode decryption

Original image



Encrypted with CBC

CBC

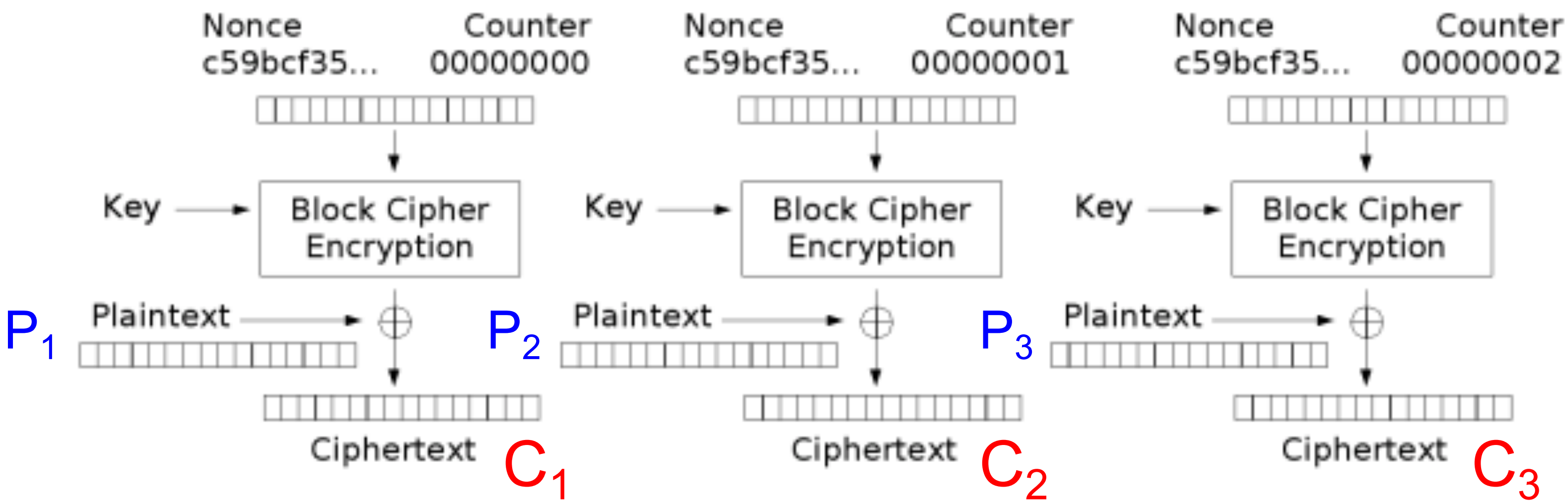
Popular, still widely used
Achieves IND-KPA, and more (IND-CPA)

Caveat: sequential encryption, hard to parallelize

CTR mode gaining popularity

CTR: Encryption

Enc(K, P1|P2|P3) = (nonce, C1, C2, C3)



Counter (CTR) mode encryption

Nonce is similar to IV for CBC, one should not use the same nonce for two messages; choose it at random

CTR: Decryption

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Dec(K, (nonce,C1,C2,C3)) = (P1, P2, P3)
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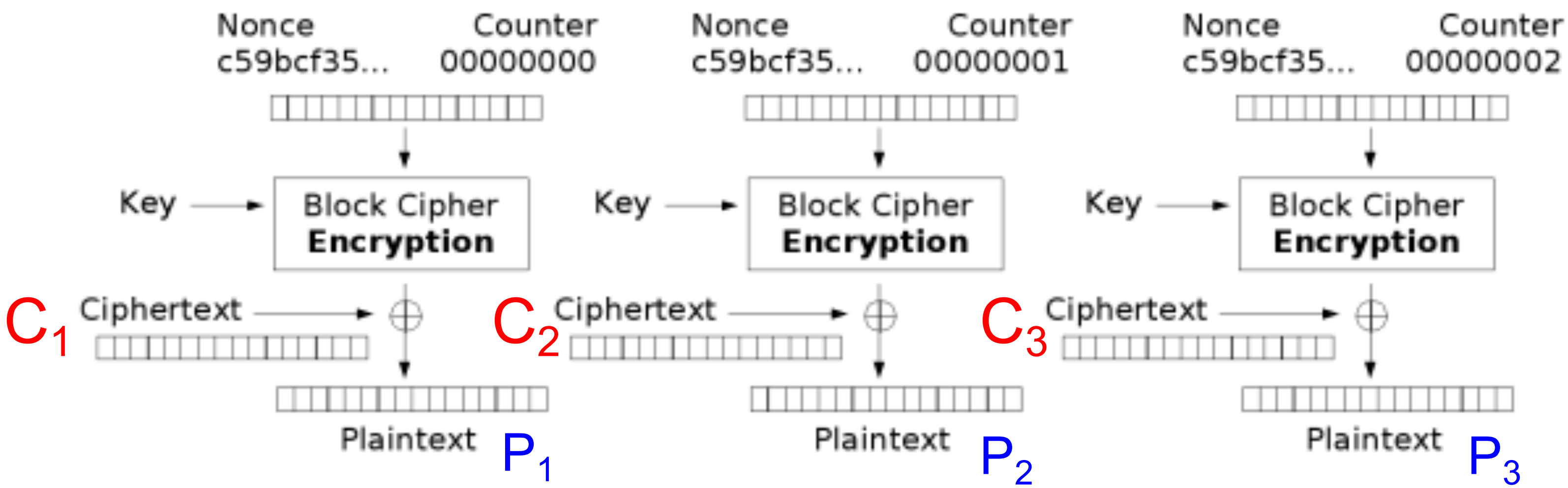

Counter (CTR) mode decryption

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

CBC vs CTR

Security: Both IND-KPA, and even IND-CPA
If you ever reuse the same nonce, CBC might leak some information about the initial plaintext blocks up to a first difference between two messages. CTR can leak information about various blocks in the message.

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

Summary

- Encryption protects confidentiality
- IND-KPA is a security game expressing message indistinguishability
- OTP is secure if used only once
- Block ciphers help build symmetric-key encryption schemes with reusable sizes and arbitrary message lengths by chaining them in cipher modes