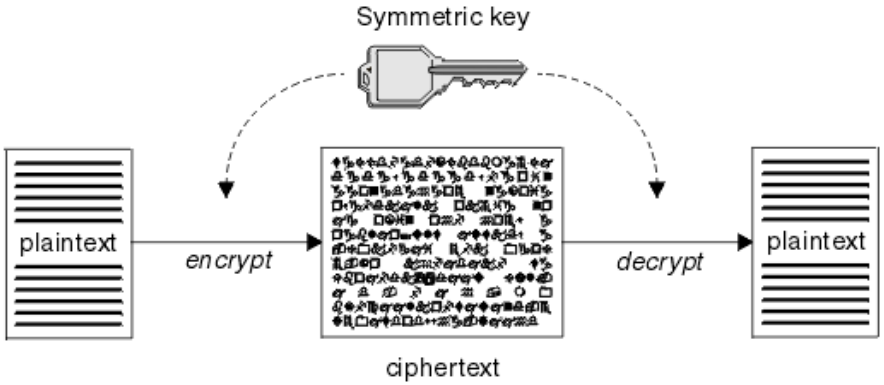

Computer Security

Symmetric Encryption

If you reveal your secrets to the wind, you should not blame the wind for revealing them to the trees.
—Kahlil Gibran

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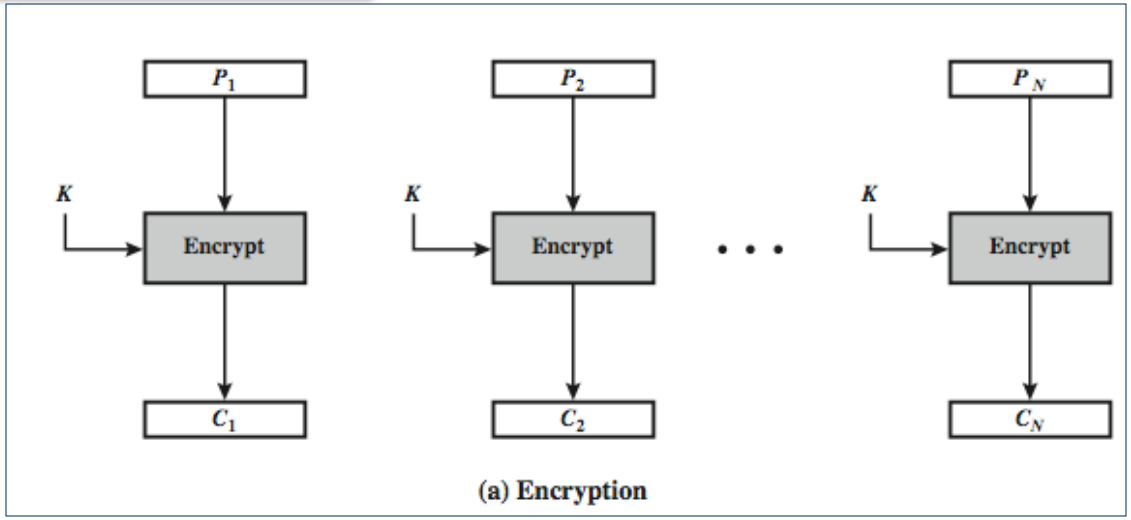
SUNG KYUN KWAN UNIVERSITY

Modes of Operations

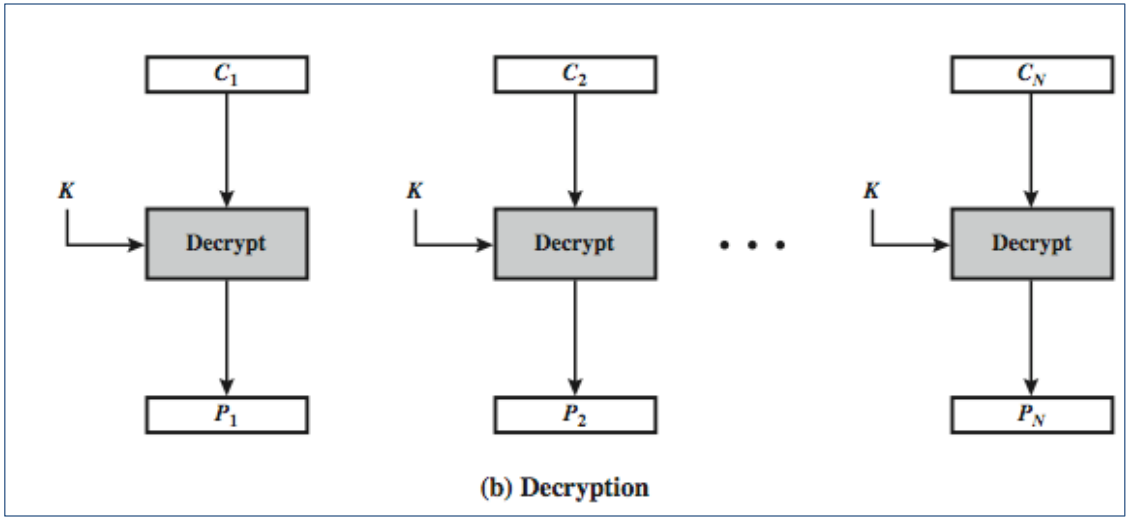
- block ciphers encrypt fixed size blocks
  - DES and 3DES encrypt 64-bit blocks
  - AES uses 128-bit blocks
- in practise, we have arbitrary amount of information to encrypt
  - we use DES, 3DES, AES and other symmetric ciphers in different modes in order to apply to several data blocks
- NIST SP 800-38A defines 5 modes
  - can be used with any block cipher

Electronic Codebook (ECB) Mode

- each block is encrypted independent of the other blocks
  - using the same key
- not so secure for long messages due to repetitions in code



(a) Encryption



(b) Decryption

ECB Mode

- Notation: C = E(P,K)
- Given plaintext $P_0,P_1,\ldots,P_m,\ldots$
- Most obvious way to use a block cipher:

Encrypt	**Decrypt**
$C_0 = E(P_0, K)$	$P_0 = D(C_0, K)$
$C_1 = E(P_1, K)$	$P_1 = D(C_1, K)$
$C_2 = E(P_2, K)$ …	$P_2 = D(C_2, K)$ …

- For fixed key K, this is "electronic" version of a codebook cipher (without additive)
  - With a different codebook for each key

ECB Cut and Paste

- Suppose plaintext is

  `Alice digs Bob. Trudy digs Tom.`

- Assuming 64-bit blocks and 8-bit ASCII:

  P_0 = "`Alice di`", P_1 = "`gs Bob. `",

  P_2 = "`Trudy di`", P_3 = "`gs Tom. `"

- Ciphertext: C_0, C_1, C_2, C_3
- Trudy cuts and pastes: C_0, C_3, C_2, C_1
- Decrypts as

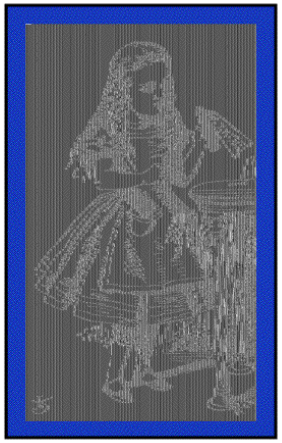
  `Alice digs Tom. Trudy digs Bob.`

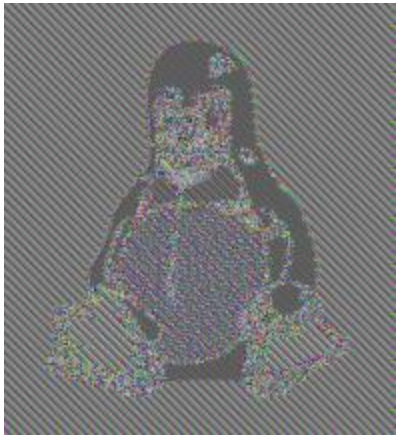
ECB Weakness

- Suppose $P_i = P_j$
- Then $C_i = C_j$ and Trudy knows $P_i = P_j$
- This gives Trudy some information, even if she does not know P_i or P_j
- Trudy might know P_i
- Is this a serious issue?

Alice Hates ECB Mode

- Alice's uncompressed image, and ECB encrypted

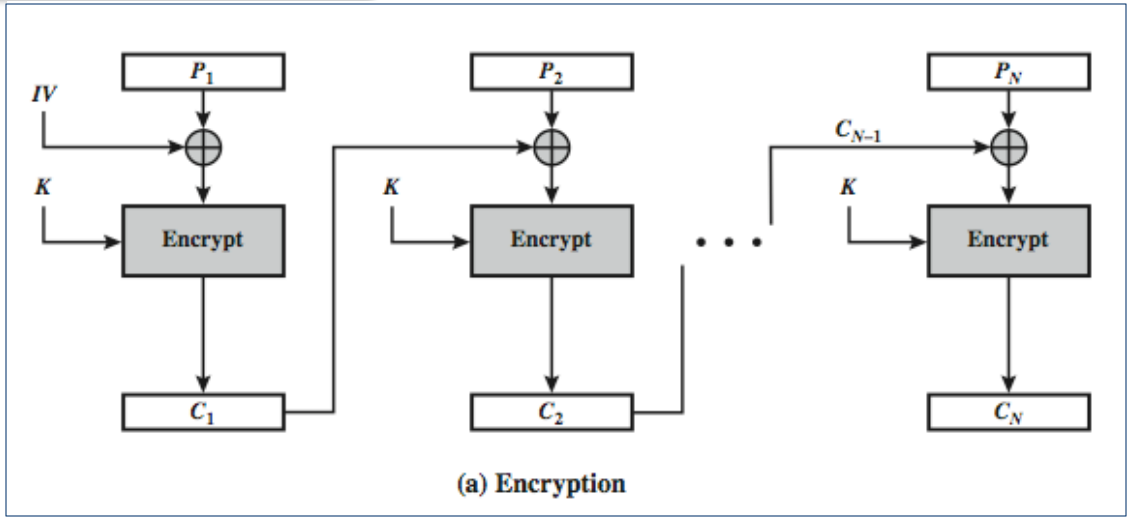



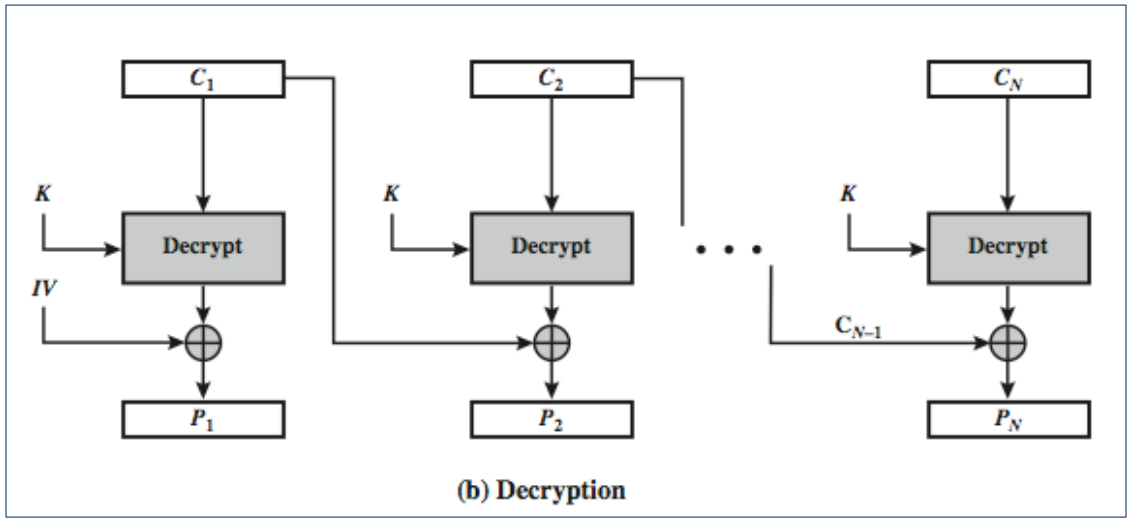


- Why does this happen?
- Same plaintext yields same ciphertext!

Cipher Block Chaining (CBC)

- each previous cipher blocks is XORed with current plaintext
- each ciphertext block depends on all previous blocks
- need Initialization Vector (IV) known to sender & receiver



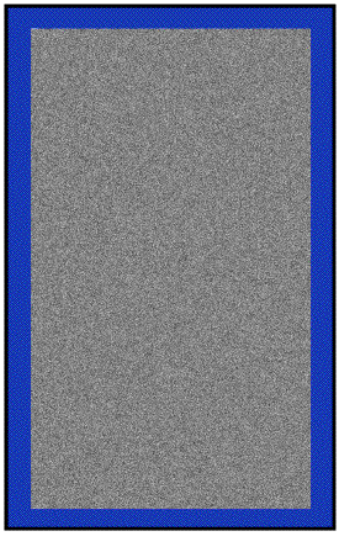


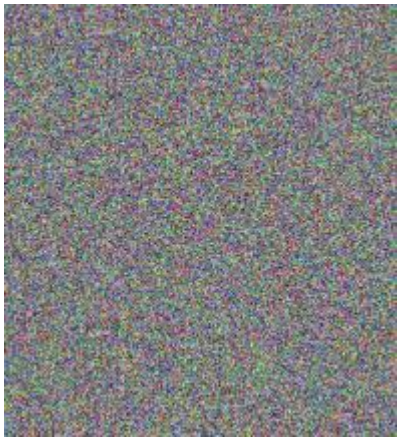
Cipher Block Chaining (CBC)

- Initialization Vector (IV)
  - both parties should agree on an IV
  - for maximum security, IV should be protected for unauthorized changes
  - Otherwise, attacker's change in IV also changes the decrypted plaintext
    - let's see this on board

Alice Likes CBC Mode

- Alice's uncompressed image, Alice CBC encrypted

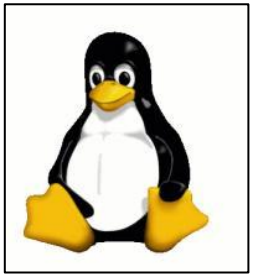


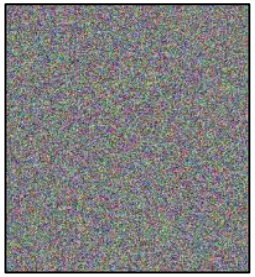
- Why does this happen?
- Same plaintext yields different ciphertext!

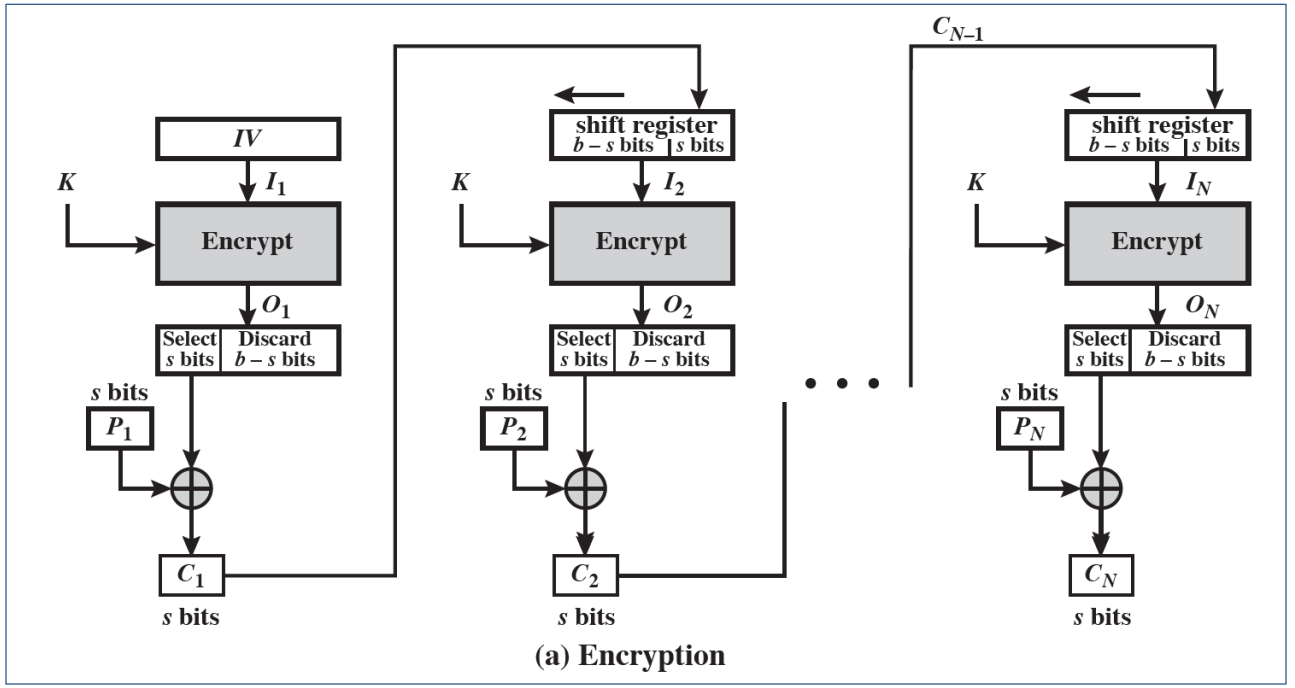
Cipher FeedBack (CFB)

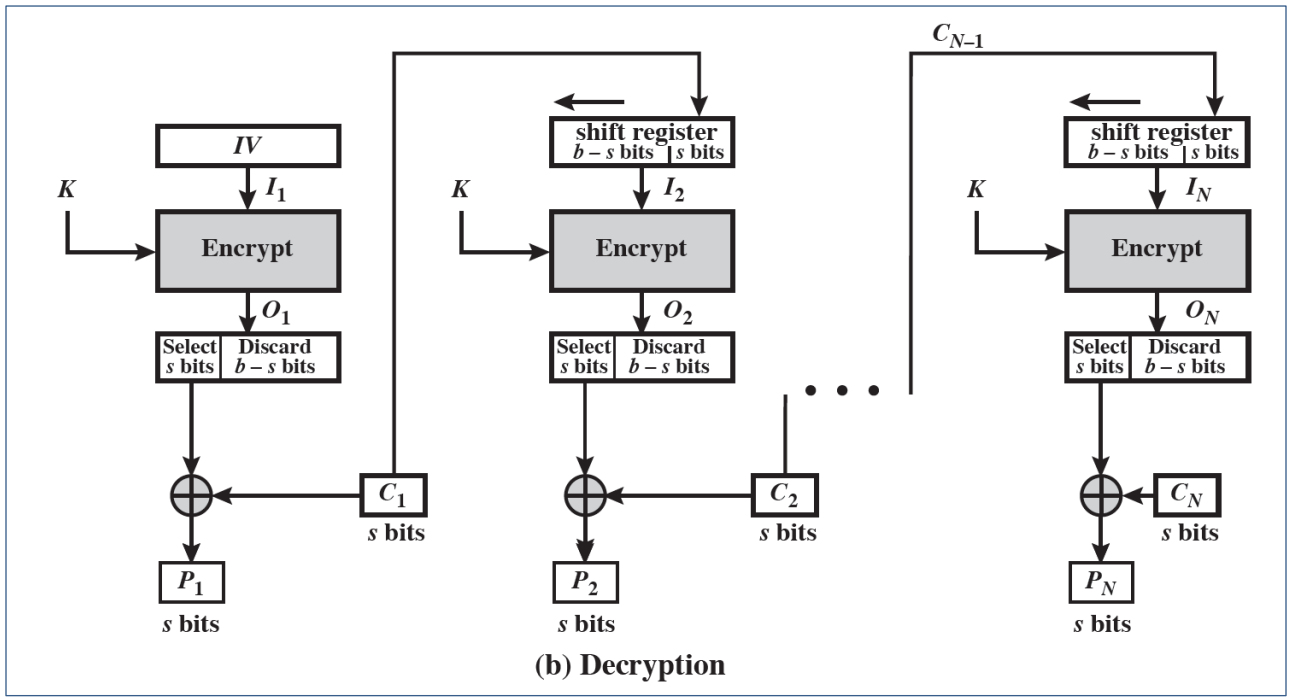
- Message is treated as a stream of bits
  - DES, AES (or any other block cipher) is used as a stream cipher
- standard allows any number of bit, *s*, (1,8 or more until the block size) as the unit of encryption/decryption
  - But common value for *s* is 8.
  - Plaintext is divided into block of *s* bits.
- uses IV
  - as all other stream ciphers
- Result of encryption is fed back to the next stage
- transmission errors propagate

Cipher FeedBack (CFB) Mode





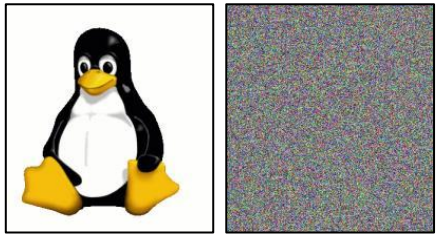


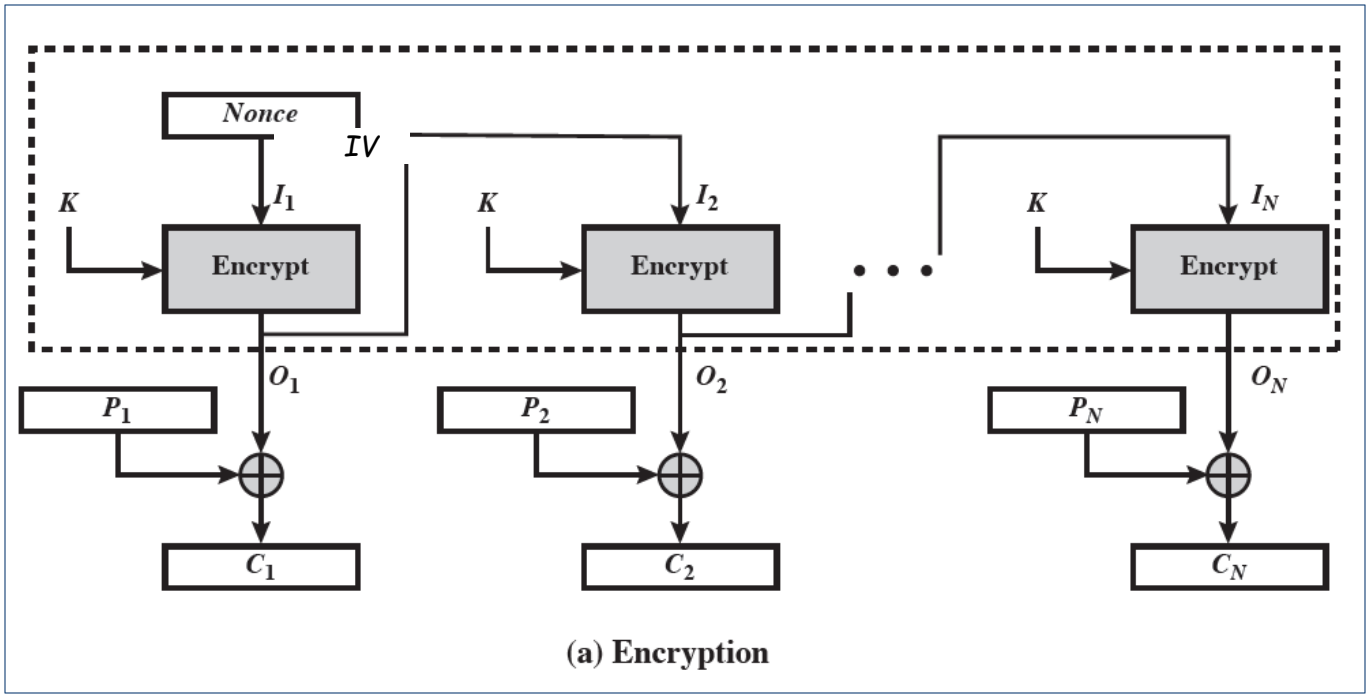


Output FeedBack (OFB)

- another stream mode
  - but, *s*-bit version does not exist anymore
    - Full block is used in the encyption and decryption
- output of cipher is
  - XORed with the message
  - it is also the feedback
- feedback is independent of transmission, so transmission errors do not propagate
- same IV should not be used twice for the same key (general problem of using IV)
  - otherwise, when two ciphertext blocks are XORed the random sequence is cancelled and the attacker obtains XOR of two plaintexts
  - That is why IV is sometimes called as *nonce* (means "*used only once*")

Output FeedBack (OFB)





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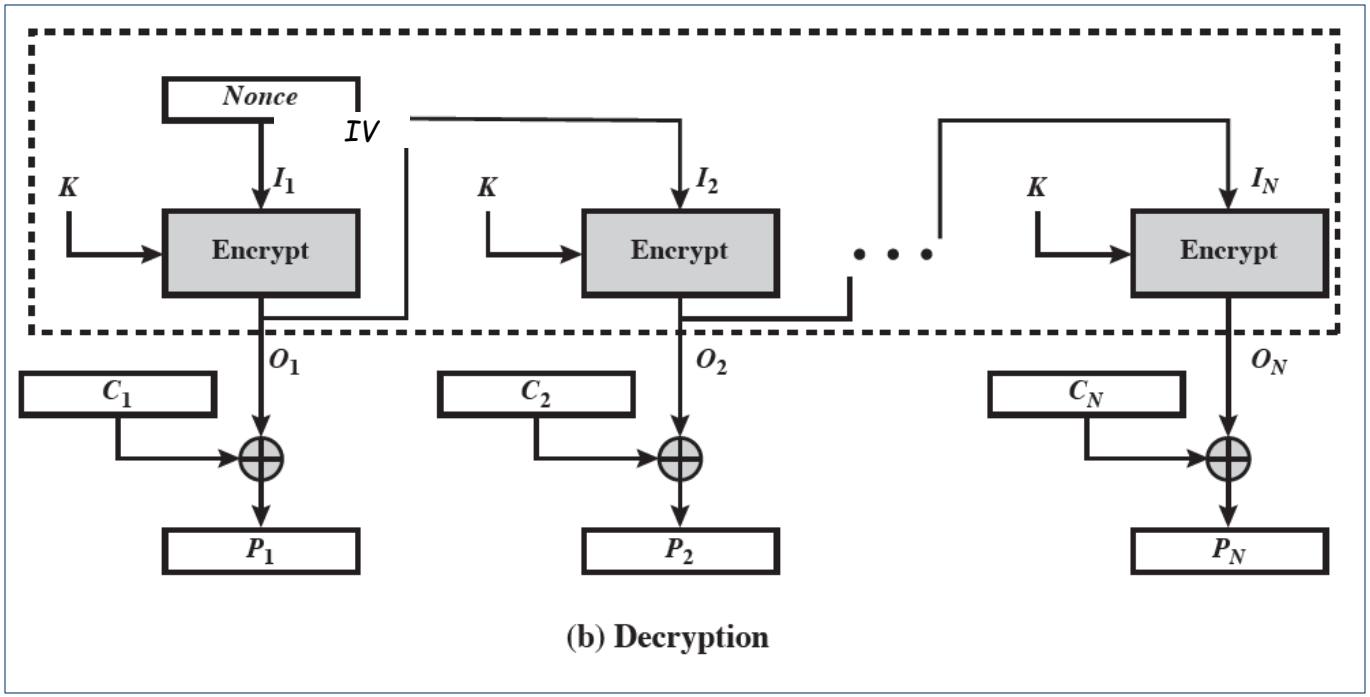
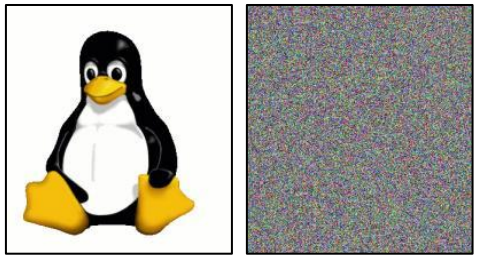


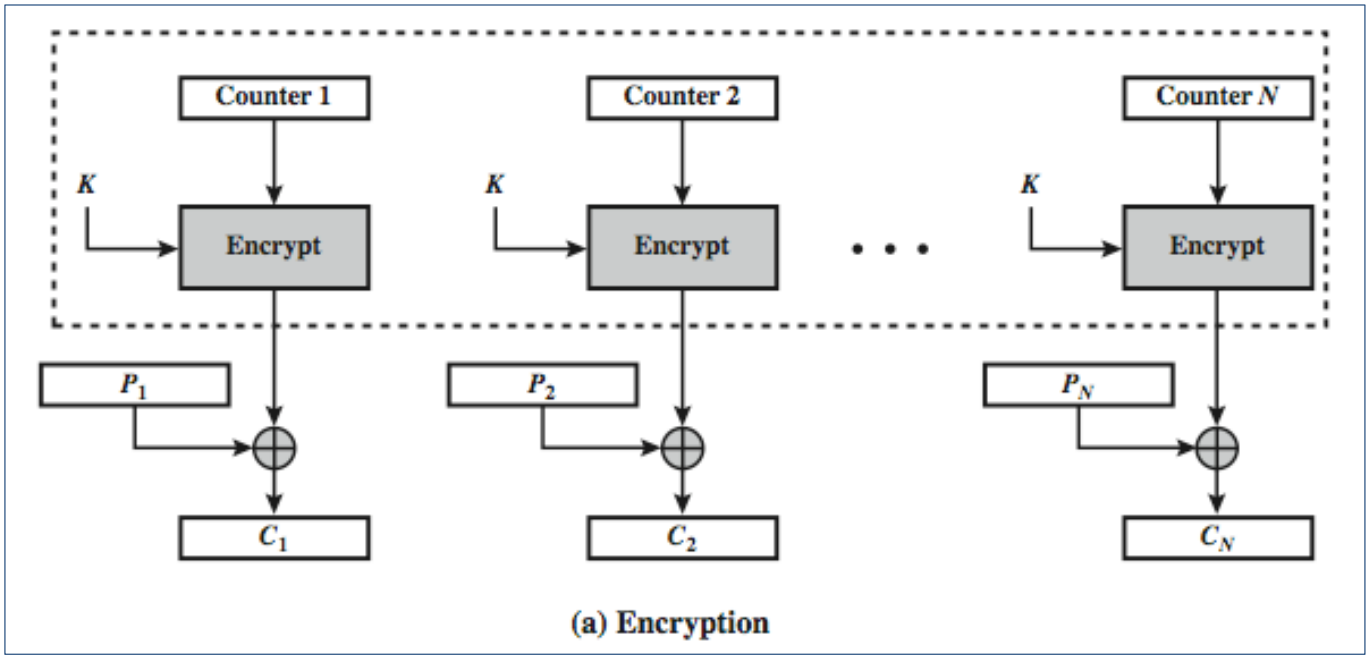
(b) Decryption

Counter (CTR)

- similar to OFB but encrypts counter value rather than any feedback value
- For the same key, the counter value should not repeat
  - same problem as in OFB
- efficient
  - can do parallel encryptions
  - Cryptographic part of the process (encryption blocks) is performed in advance of need
  - good for bursty high speed links

Counter (CTR)





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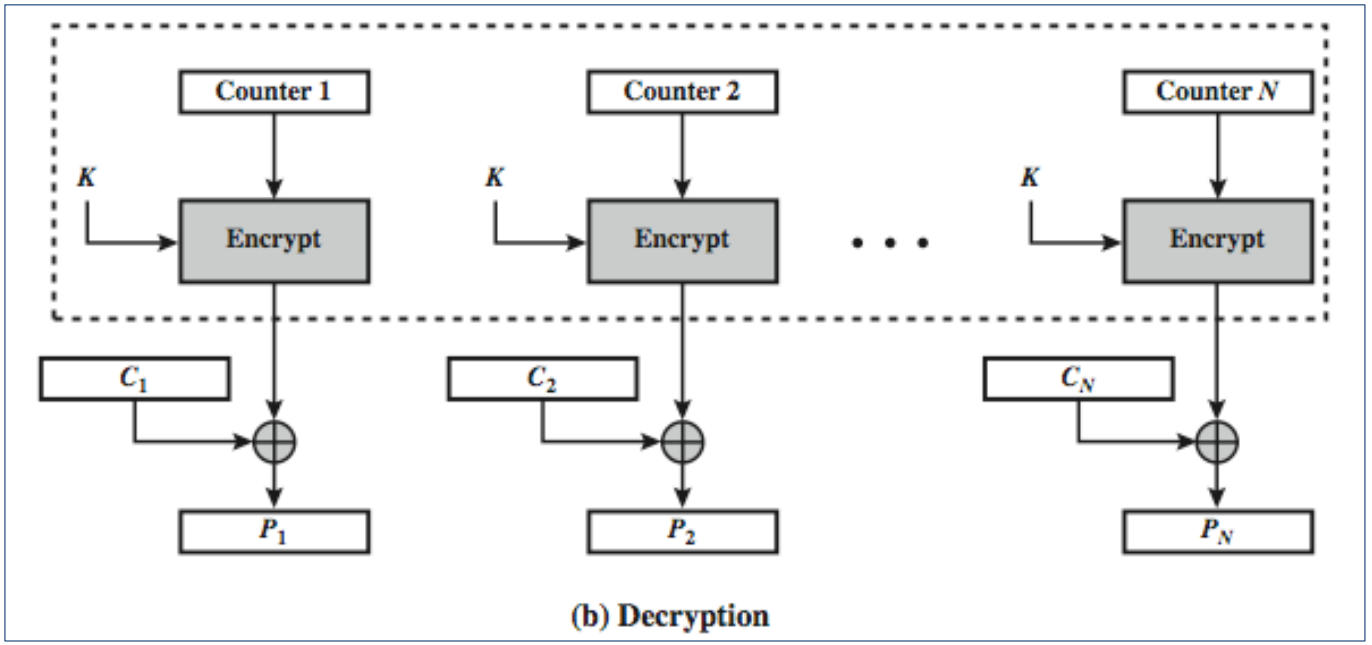

(b) Decryption