Plan of Talk

- Review of topics covered so far.
- Block Ciphers
-     DES
-     AES
- Stream Ciphers
- Symmetric key cryptography in Practice (later after covering public key concepts)

Recap of Secure use of symmetric encryption:

- Two main requirements:
  - A strong encryption algorithm
  - Secret key known only to sender / receiver
- We cannot rely on the obscurity of the cryptosystem. We assume that the attacker knows everything about cryptosystems except the key used in cryptography.

- A secure channel is available for key distribution.

Symmetric key Cryptography

- Unconditional security or Perfect security.
  - Also referred sometimes as information theoretic security.
  - Example: One-time pads.

- Computational Security.
  - Used in Practice.
  - Examples: DES, AES, Stream Ciphers etc.

Perfect Secrecy : One time pad:

- An encryption scheme has the property of *unconditional* security, if the cipher text generated by the algorithm does not reveal enough information to break the scheme even with access to unlimited amount computation.
- In other words, the adversary will not learn any knowledge to reverse the encryption from watching cipher text even with unlimited computing power.

One time pad

- Let X: input, y: output
- Perfect Security implies: $P_{X|Y}(x|y) = P_X(x)$
- One time Pad: This is a method to transmit a message M in $\{0.1\}^n$, an n bit string of binary numbers from a user say A (Alice) to B (Bob). Any intruder (Eve) should not get any information about M by watching the cipher text. A chooses a random key K in $\{0.1\}^n$ and adds it component wise to the message M. The transformed message is then transmitted on insecure channel where Eve can read the message. To decrypt the message Bob should have the copy of the key K which they would have exchanged on a secure channel.

One time pad example

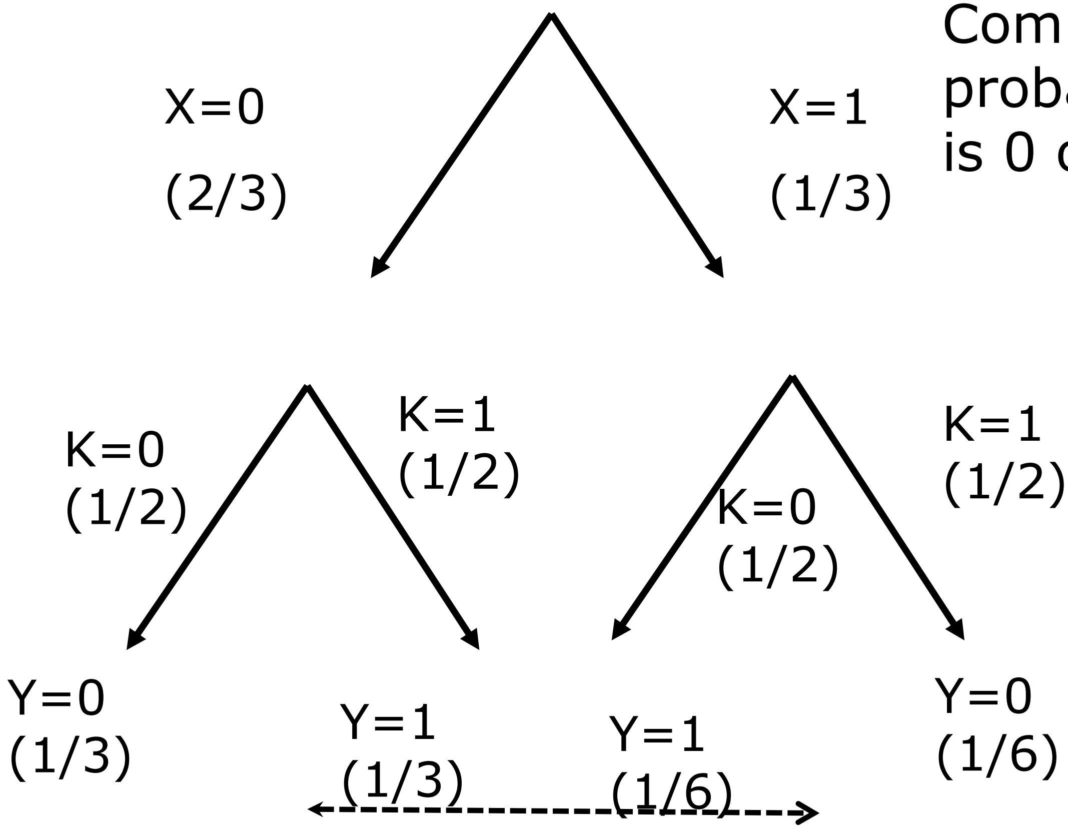
- Let + denote exclusive or symbol.
  - 0 + 0 = 1 + 1 = 0;
  - 0 + 1 = 1 + 0 = 1.
- Suppose A wishes to send a message M=0110111, and suppose they have previously established a shared secret key: K =1011011.
  The cipher text is formed by exclusive-oring the message with the key:
  C = M + K = 1101100.
  Decryption is trivial: the message could be obtained by the same process, i.e. by addition of K to C.
  M = C + K = 0110111.

- The one time pad offers perfect secrecy. Let us make it more precise what this means.
- Let us assume that the message space is binary (0 or 1) and key space is also binary. Assume that A chooses message 0 quarter of the time, i.e Probability that the message is 0 is equal to 1/4, P(M=0) = 1/4.
  Perfect secrecy means knowing this fact, any adversary (E) should not get more information by observing the cipher message (C = M + K).
  i.e. The condition probability, P(M = 0 | C =1) should not be different from apriori probability P(M=0).
- This means that seeing the cipher text C does not increase the adversaries knowledge about the message.

One time pad example

- Let message space be 0 or 1, i.e $X = 0$ or 1
- Assume that the Adversary a priori knows that probability that ($X = 0$) is 2/3.
- i.e, $P(X=0) = 2/3$, then $P(X=1)= 1/3$.
- Suppose $Y =1$ was observed at the output of the cipher
- We want to prove $P(X=0|Y=1) = P(X=0)$
- **This equivalent to : Seeing the cipher text does not increase the adversaries knowledge about the underlying message**.

$P(X=0|Y=1) = P(X=0 \;\Lambda\; Y=1) / P(Y=1 = (2/3 * ½) / (1/2) = 2/3 = P(X=0)$



Computation of probabilities: message is 0 or 1

Key is chosen randomly

P(Y=1)= 1/3+1/6=1/2

Main General Result

- When X and Y are long sequences of 1's and 0's of length n.

- Theorem: $P(X=m|Y=c)= P(X=m)$.
- Proof depends critically on the fact that K is generated according to uniform distribution,
- i.e, $P(K=k_1) =1/2^n$,

Implications of perfect secrecy

- Messages may be biased; could be observed by the adversaries.
- Encryption transformation should distribute messages to cipher space fairly uniformly irrespective of known apriory statistics of the messages.
- One-time pad analysis tells us that if we choose a random secret key pad at least the size as the message, we can achieve the perfect secrecy.
- However, one-time pad is not practical.

Two time pad is bad!

- One time pad is not practical. It demands a key as long as the message.
- If one time pad used twice, it leaks statistics of the plain text. Germans made this mistake in the war times!.
- $C_1=M_1+K$; $C_2=M_2+K$; then
- $C_1+C_2=M_1+M_2+K+K= M_1+M_2$.
- This means that you need a new key for every message.
- This idea is used in attacking Vegenere cipher (same key-pad is added many times)

Computationally Secure Ciphers

- We want a cipher function which is easy to encrypt,
- But hard to invert if the key is unknown.

- It is difficult to precisely define hardness of the inversion function .
- An upper limit is set for computational complexity of inverting the function.

- This definition is derived from practical pragmatism. Let us see what are the practical needs.
- An encryption scheme is computationally secure if
- the cost of breaking the cipher exceeds the value of encrypted information, and the time required to break the cipher exceeds the useful lifetime of the information.

Computationally Secure Ciphers

- How to define strongness of a computationally secure cipher?
  - No precise definition exists.
- Roughly speaking, if the key length n, the complexity of inverting the encryption without the key should be exponential in n.
- For example, 128 bit key cipher should provide 2^{128} work security.
- How to decide minimum key length?
- At least, key should be large enough to withstand a brute force search attack.
- A cipher with a n length key should not have any apparent weakness which helps to break the cipher with less than 2^n computation work.
- A cipher should be secure to withstand the cryptanalytic methods described earlier (Chosen Plaintext Attack(CPA),Chosen Ciphertext Attack(CPA) etc).

Blockciphers and stream ciphers

- These are two major kinds of ciphers, which differ in the way the plaintexts are encrypted.
- Block Cipher: A block cipher takes a fixed length plain text message block (for example, 64 or 128 bits) and a key, and produces a cipher text block of the same length as the original message.
- DES (56), Triple-DES (168), IDEA (128), Blowfish() and AES (128)
- Stream Cipher: Takes a key of fixed size and generates a key stream in a pseudo random fashion with large period; this key stream is then combined with the plain text message stream on a bit by bit basis to form a cipher text stream.
- RC4, A5, BlueTooth cipher etc.

Block Cipher

- Encrypts blocks of n characters/bits of plain text simultaneously outputting blocks of cipher texts.
- Same key is used for many different message blocks.
- Fundamental building blocks for many cryptographical functions.
- Examples include hash functions, preudorandom generators, message authentication codes etc.
- **Confusion and diffusion principles:**
- **Diffusion** dissipates statistical structure of plaintext over bulk of ciphertext.
- **Confusion** makes relationship between ciphertext and key as complex as possible.
- Generally diffusion is created by permutations and confusion is created by substitution.

Product Ciphers and Fiestel Ciphers

- A **product cipher** combines two or more transformations so that resulting cipher is more secure than the individual components by making use of confusion and diffusion principles.
- A **substitution-permutation cipher** is a product cipher made up of number of stages each involving substitution and permutation. The operations of substitution and permutation are responsible for effecting the confusion and diffusion respectively.
- An **iterated block cipher** is a block cipher involving sequential repetition of an iterated function called a round function.

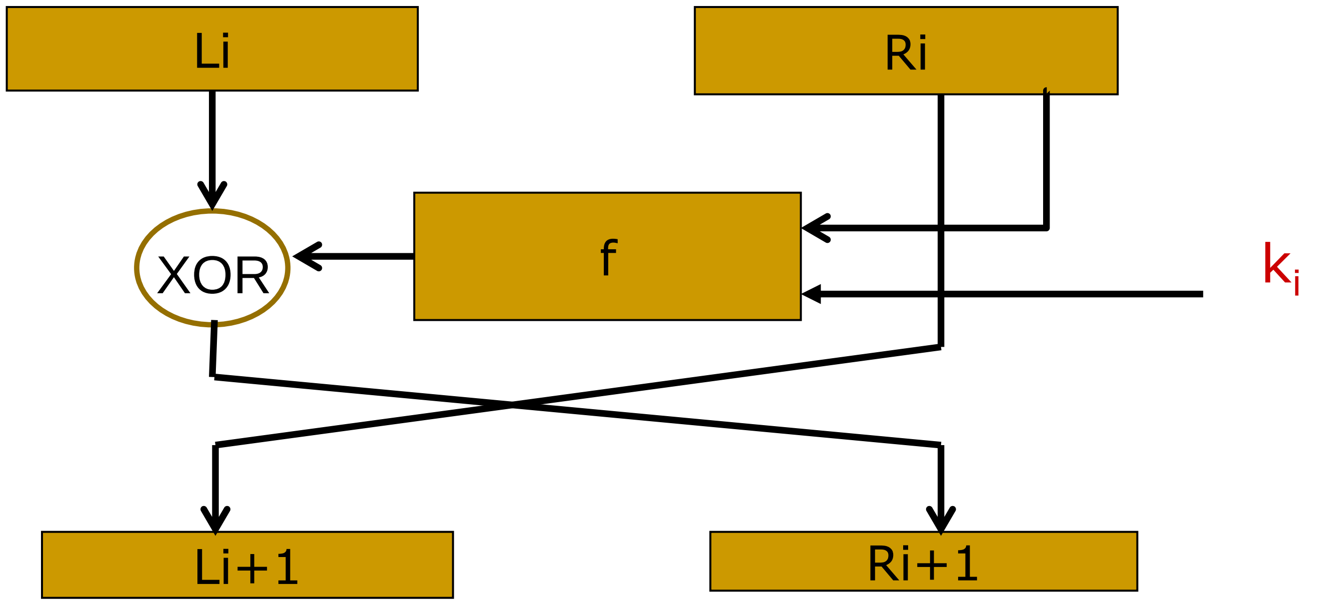
Iterated Block Ciphers

- The parameters of iterated block ciphers are
  r: number of rounds;
  n: block length;k: bit-size of key, K from which r subkeys (round keys) k_i's are derived.

- **Fiestel** ciphers are iterative ciphers; they repeat a given operation several times in rounds.

Iterated Block Ciphers Cont.

- For such a cipher, the input key is used to produce round keys $k_1, k_2, \ldots, k_r$. The message is initially divided into two parts, namely left and right halves, L and R.
  For each of r rounds, the following operations are executed.



After r rounds, the final left and right haves are swapped and concatenated to form the cipher text.

The design of a good function f is partly ``ART'' and partly ``SCIENCE''.

Data Encryption Standard (DES)

- IBM's 1974 submission for a standard.
  A Fiestel cipher
  Block size: $n = 64$,
  keysize $= k = 56$ bits.

  The key is specified with 64 bits containing 8 bits of parity.
  Number of rounds = 16.

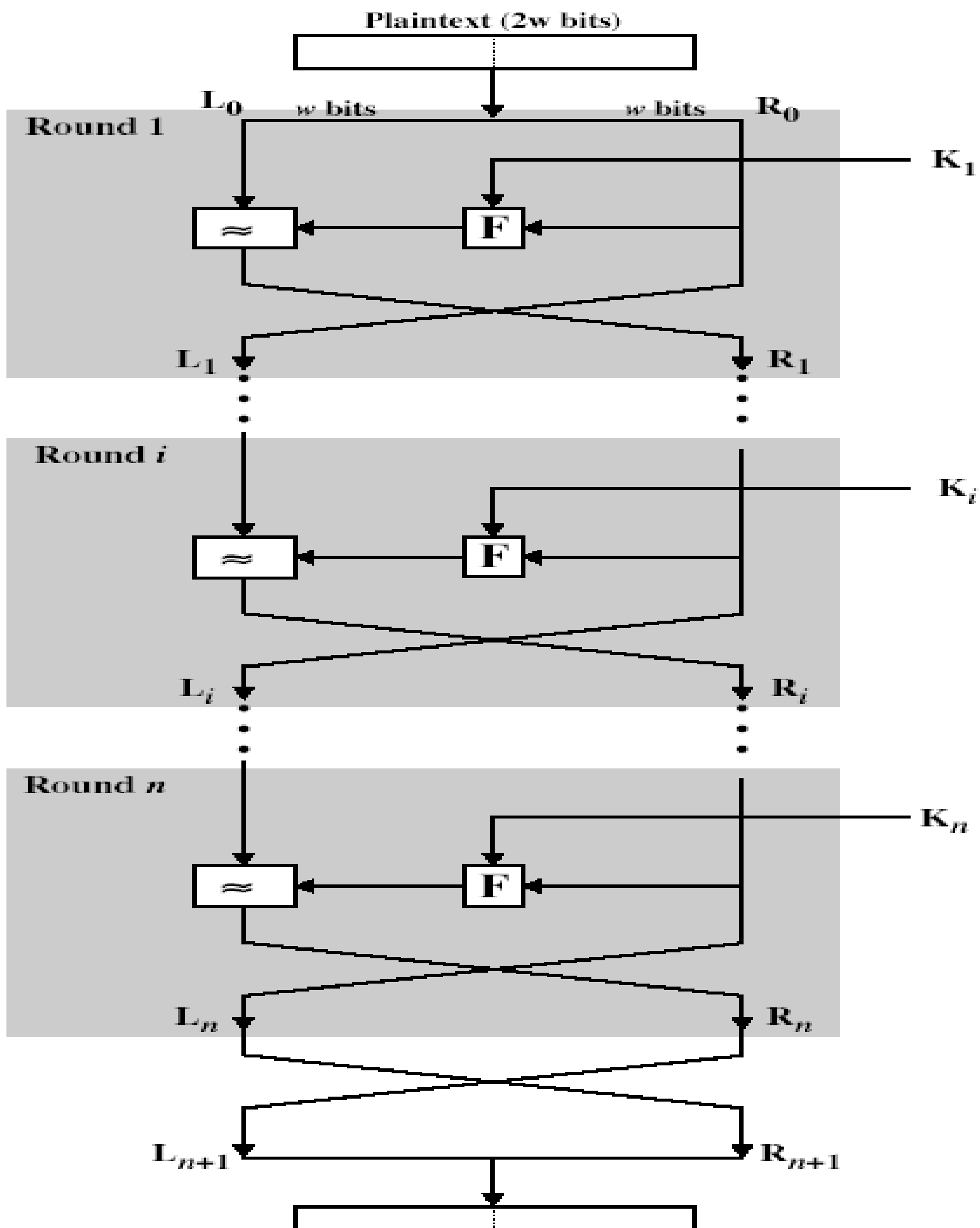
  Strengthening DES:
  DESX: Apart from 56 bit key K, choose two new 64 bit keys
  K_I and K_O, then we encrypt

  C = K_O XOR DES(K, M XOR K_I)

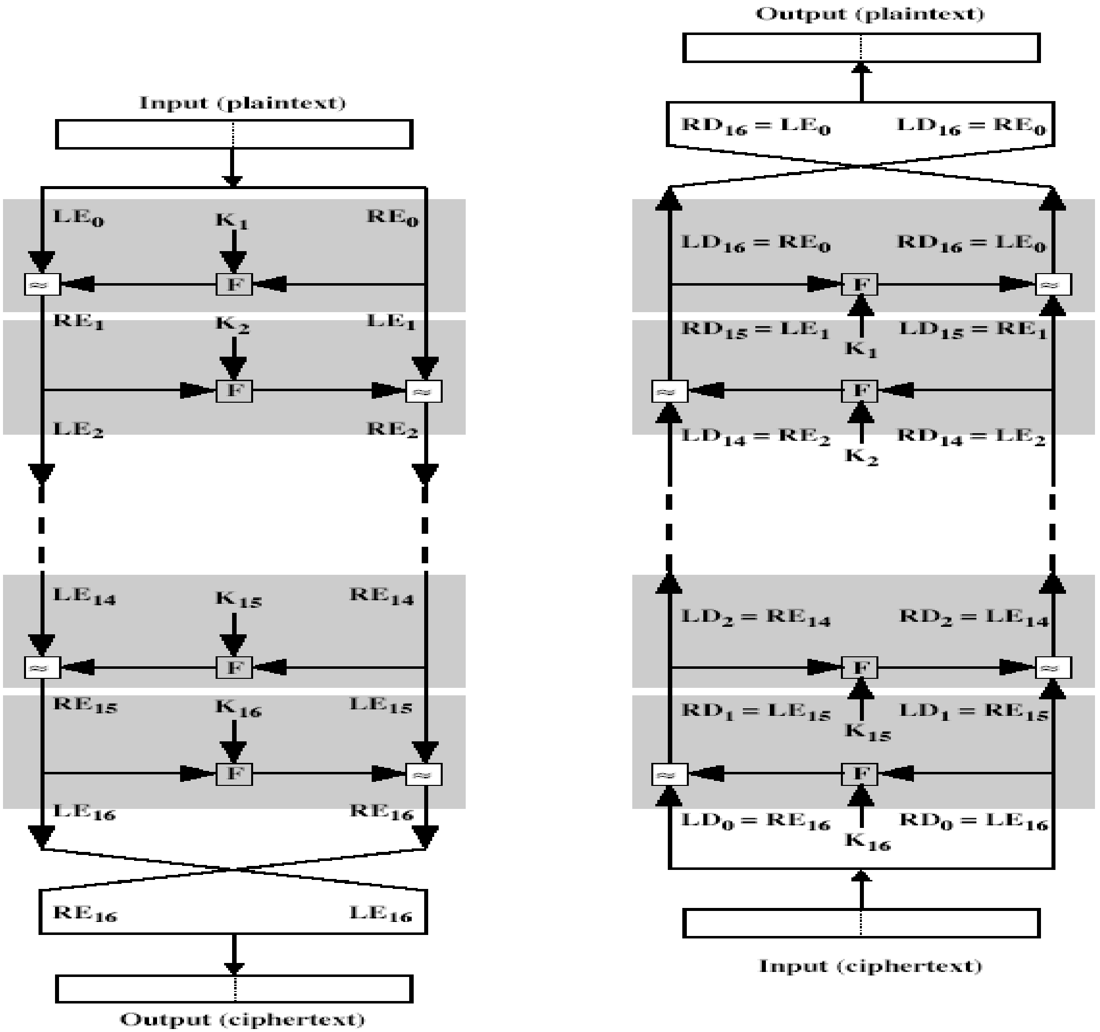
  This method increases effective key length to 199-t, where t is a quantity related to adversaries cryptanalytic assumptions where the adversary is able to collect 2^t matching input-output pairs.

- Read the textbook for more details on DES.

Feistel Cipher Structure



Feistel Cipher Decryption



Strengths, properties and attacks for DES

- Each bit of cipher text depends on all bits of the key and all bits of the plain text.

  No statistical relationship between plain and cipher visible.

  Altering a key bit or a plain text bit should alter each cipher bit with probability close to half.
  Altering a cipher bit should result in unpredictable change in plain text block.

Cryptanalysis of DES

- Empirically it is found that DES is safe.
- Exhaustive search -- Brute force. 2^{64} computations.

  Differential cryptanalysis
- Chosen plain text attack,
- Not realistic -complexity 2^{47} computations.

  Linear cryptanalysis
- Complexity : 2^{43} computations.

- The new standard for encryption now is AES which has key space >= 2^{128}.

Advanced Encryption Standard:Origins

- Reasons for a replacement for DES:
  - have theoretical attacks that can break it
  - have demonstrated exhaustive key search attacks
- Can use Triple-DES – but slow, has small blocks
- US NIST issued call for ciphers in 1997
- 15 candidates accepted in Jun 98
- 5 were shortlisted in Aug-99
- Rijndael was selected as the AES in Oct-2000
- issued as FIPS PUB 197 standard in Nov-2001

AES Requirements

- Private key symmetric block cipher
- 128-bit data, 128/192/256-bit keys
- stronger & faster than Triple-DES
- Active life of 20-30 years (+ archival use)
- Provide full specification & design details
- Both C & Java implementations
- NIST have released all submissions & unclassified analyses

AES Evaluation Criteria

- Initial criteria:
  - security – effort for practical cryptanalysis
  - cost – in terms of computational efficiency
  - algorithm & implementation characteristics
- Final criteria
  - general security
  - ease of software & hardware implementation
  - implementation attacks
  - flexibility (in en/decrypt, keying, other factors)

AES Shortlist

- after testing and evaluation, shortlist in Aug-99:
  - MARS (IBM) - complex, fast, high security margin
  - RC6 (USA) - v. simple, v. fast, low security margin
  - Rijndael (Belgium) - clean, fast, good security margin
  - Serpent (Euro) - slow, clean, v. high security margin
  - Twofish (USA) - complex, v. fast, high security margin
- then subject to further analysis & comment
- saw contrast between algorithms with
  - few complex rounds verses many simple rounds
  - which refined existing ciphers verses new proposals

The AES Cipher - Rijndael

- designed by Rijmen-Daemen in Belgium
- has 128/192/256 bit keys, 128 bit data
- an **iterative** rather than **feistel** cipher
  - processes data as block of 4 columns of 4 bytes
  - operates on entire data block in every round
- designed to be:
  - resistant against known attacks
  - speed and code compactness on many CPUs
  - design simplicity

Rijndael

- data block of 4 columns of 4 bytes is state
- key is expanded to array of words
- has 9/11/13 rounds in which state undergoes:
  - byte substitution (1 S-box used on every byte)
  - shift rows (permute bytes between groups/columns)
  - mix columns (subs using matrix multipy of groups)
  - add round key (XOR state with key material)
  - view as alternating XOR key & scramble data bytes
- initial XOR key material & incomplete last round
- with fast XOR & table lookup implementation
- Read Chapter 5 for more information. We do not study the design of AES in this subject.

Ways to make block encryption more complex and more secure

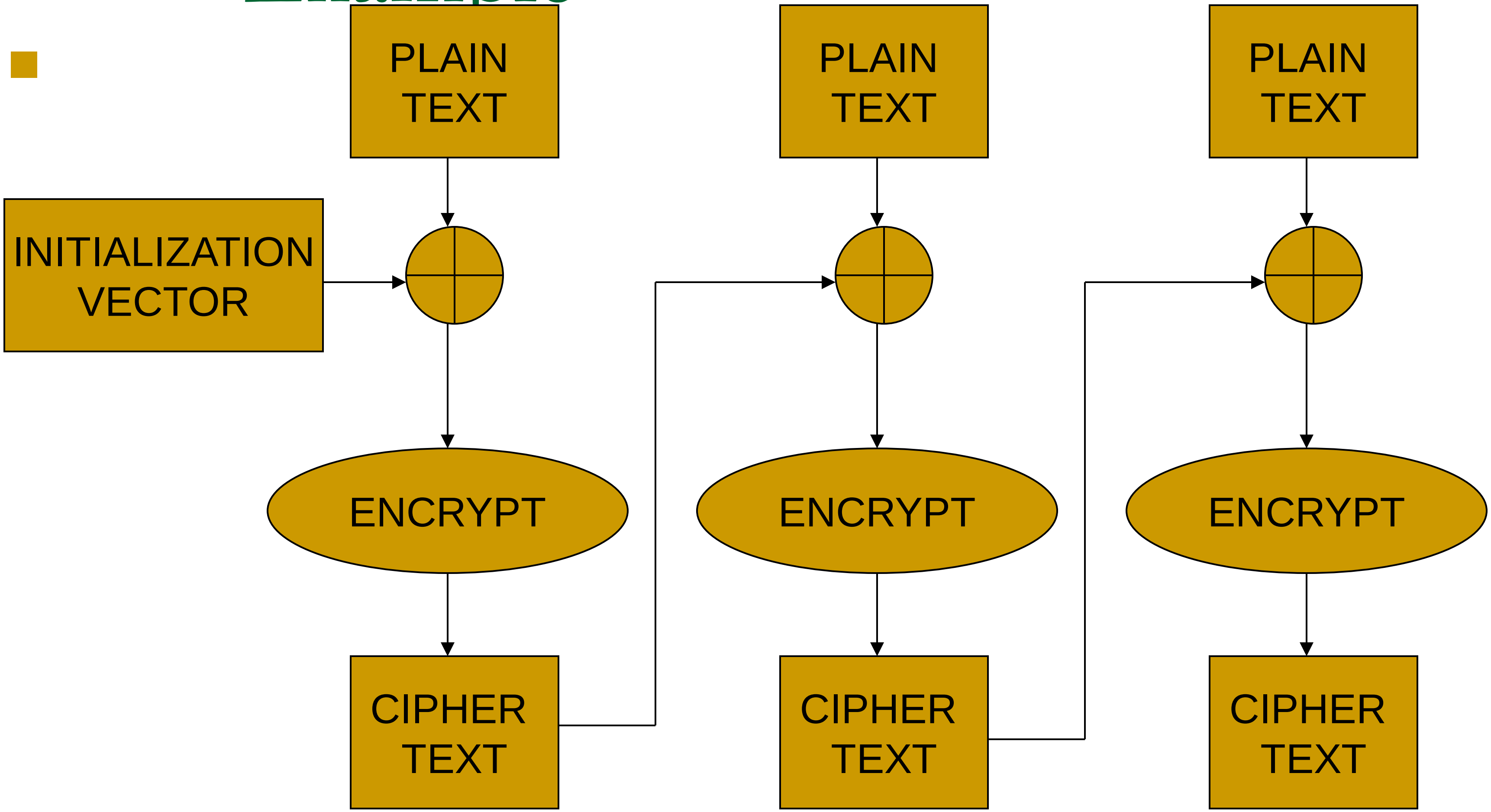
- Increase n, the block length and vary E, encryption function.
  By varying the operating modes of encryption.

- There are four main operating modes of block encryption. Refer Chapter 6 of the text by William Stallings.

Block Cipher Modes

- ECB (electronic codebook) mode simply encrypts each 64-bit block of plaintext one after another under the same 56-bit DES key.
- In CBC (cipher block chaining) mode, each 64-bit plaintext block is bitwise XORed with the previous ciphertext block before being encrypted with the DES key.
- CFB (cipher feedback) mode allows one to use DES with block lengths less than 64 bits.
- The OFB mode essentially allows DES to be used as a stream cipher.

Shared Encryption Modes: Example



Stream Ciphers

- Recently more popular with adhoc wireless network.
- Fast and easy to implement
- Typical examples: Bluetooth, A3, A5.
- Increasingly being used as main building blocks to secure information flow between short range wireless links, mobile phones and other portable devices.