Basics of Cryptography

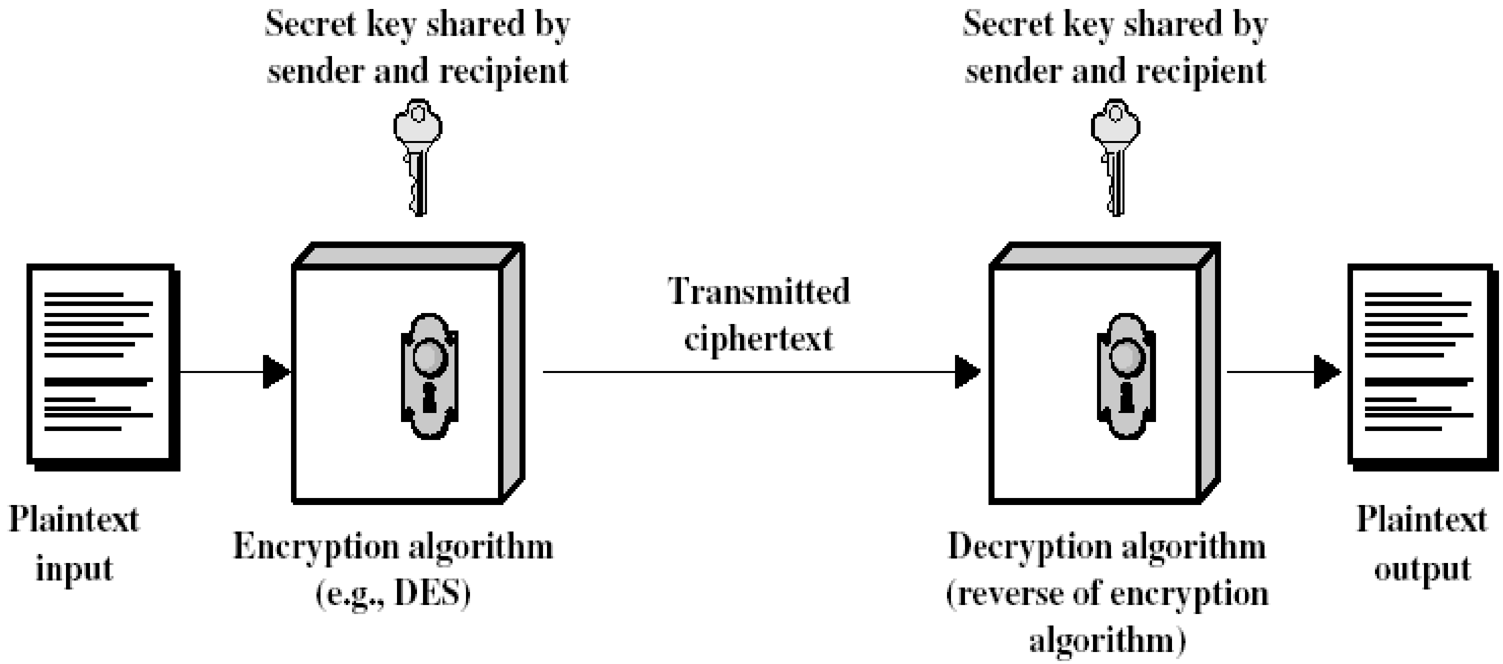
Terminology

- **Plaintext** - the original message
- **Ciphertext** - the coded message
- **Cipher** - algorithm for transforming plaintext to ciphertext
- **key** - info used in cipher known only to sender/receiver
- **Cryptanalysis (codebreaking)** - the study of principles/ methods of deciphering ciphertext *without* knowing key
- **Cryptology** - the field of both cryptography and cryptanalysis

More Terminology

- Symmetric Encryption
  - Both Sender/Receiver use the same algorithms/keys for encryption/decryption
- Asymmetric Encryption
  - Sender/receiver can employ different keys

Symmetric Encryption Model



Encryption Basics

- Gen() algorithm for generating keys
- Encryption algorithm to convert plaintext into ciphertext
  - E(M, keys) = C
- Decryption algorithm to convert ciphertext to plaintext
  - D(C, keys) = M

Some early ciphers

- Substitution (eg., Caesar cipher)
- Security is hard: tfdvsjuz jt ibse
- C = (M+k) mod 26
- M = (C-k) mod 26
- Only 26 possibilities with English Alphabet
- Brute Force search can decrypt

Monoalphabetic cipher

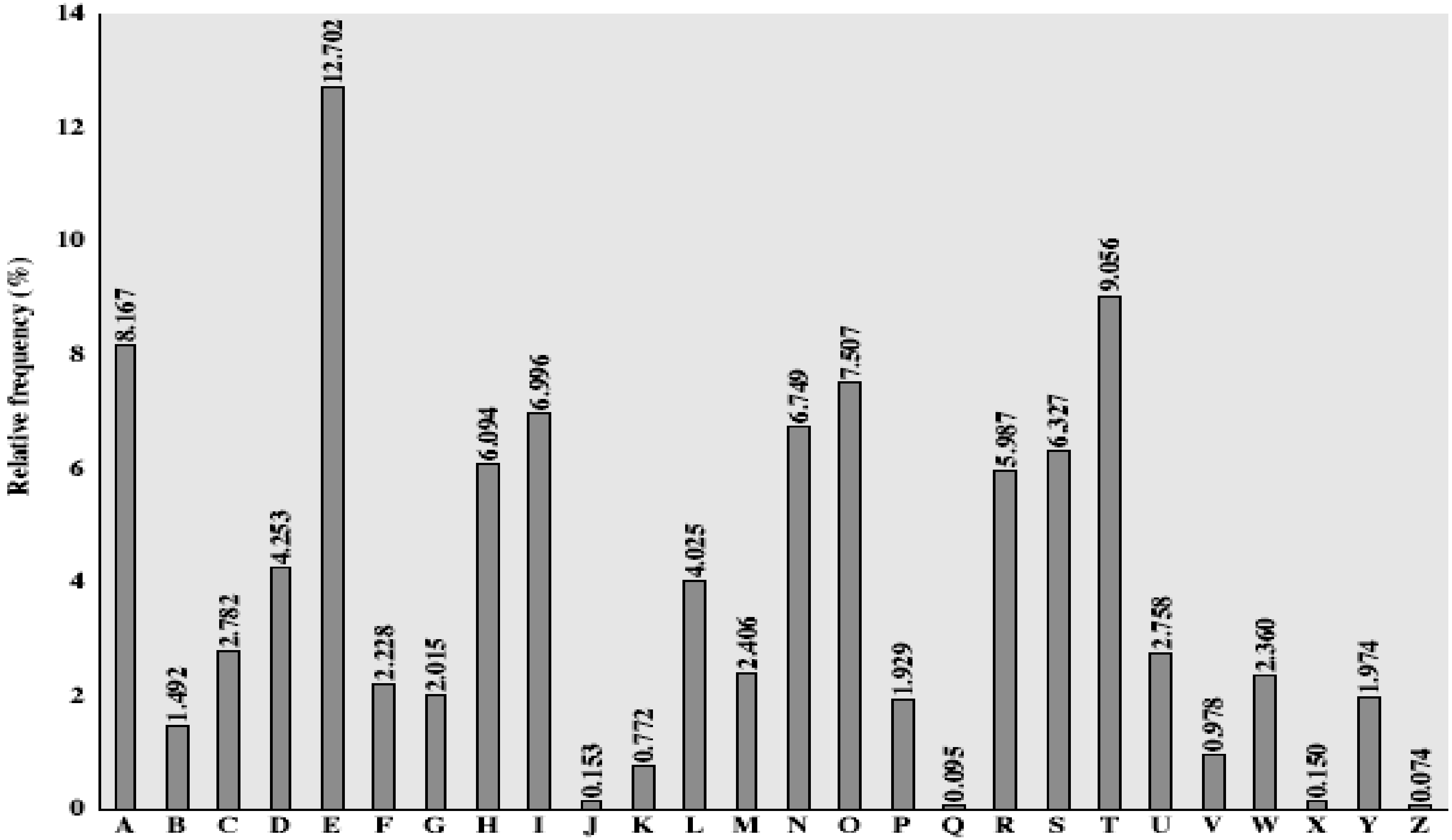
- Instead of plain rotation, use random letter substitution
- Key is 26 letters long

```
Plain:  abcdefghijklmnopqrstuvwxyz
Cipher: DKVQFIBJWPESCXHTMYAUOLRGZN
Plaintext:  security is hard
Ciphertext: AFVOYWUZ WA JDYQ
```

Monoalphabetic cipher

- 26! Combinations
- Difficult to decrypt?
- Not really!
- Language gives lots of hints
  - Single letters are I or A
  - Most common letter E
- Use Lang. characteristics to break

English letter Frequencies



Breaking substitution ciphers

- Use Letter frequencies of ciphertext
- Compare to plaintext frequencies
- These don't change –enable analysis
- Use common two-letter words etc.

Measures of ciphers

- Shannon Secrecy
- $Pr(M = m | E(K,m) = c) = Pr(M = m)$
  - Probability of guessing the plaintext knowing the ciphertext = probability of guessing plaintext without knowing ciphertext

Perfect Secrecy

- $Pr(E(K, m) = c) = Pr(E(K, m') = c)$
- Probability of any message giving a ciphertext is the same

Block vs. Stream ciphers

- Block ciphers encrypt block at a time
- Message is broken into blocks and encrypted
- Stream ciphers process a bit or byte at a time during encryption/decryption

Shannon and ciphers

- Claude Shannon introduced idea of substitution-permutation (S-P) networks (1949)
  - the basis of modern block ciphers
- S-P networks are based on the two primitive cryptographic operations:
  - *substitution* (S-box)
  - *permutation* (P-box)
- Provide *confusion* and *diffusion* of message

Confusion and Diffusion

- Cipher needs to completely obscure statistical properties of original message
- Shannon suggested confusion & diffusion
- **Diffusion** – dissipates statistical structure of plaintext over bulk of ciphertext
- **Confusion** – makes relationship between ciphertext and key as complex as possible

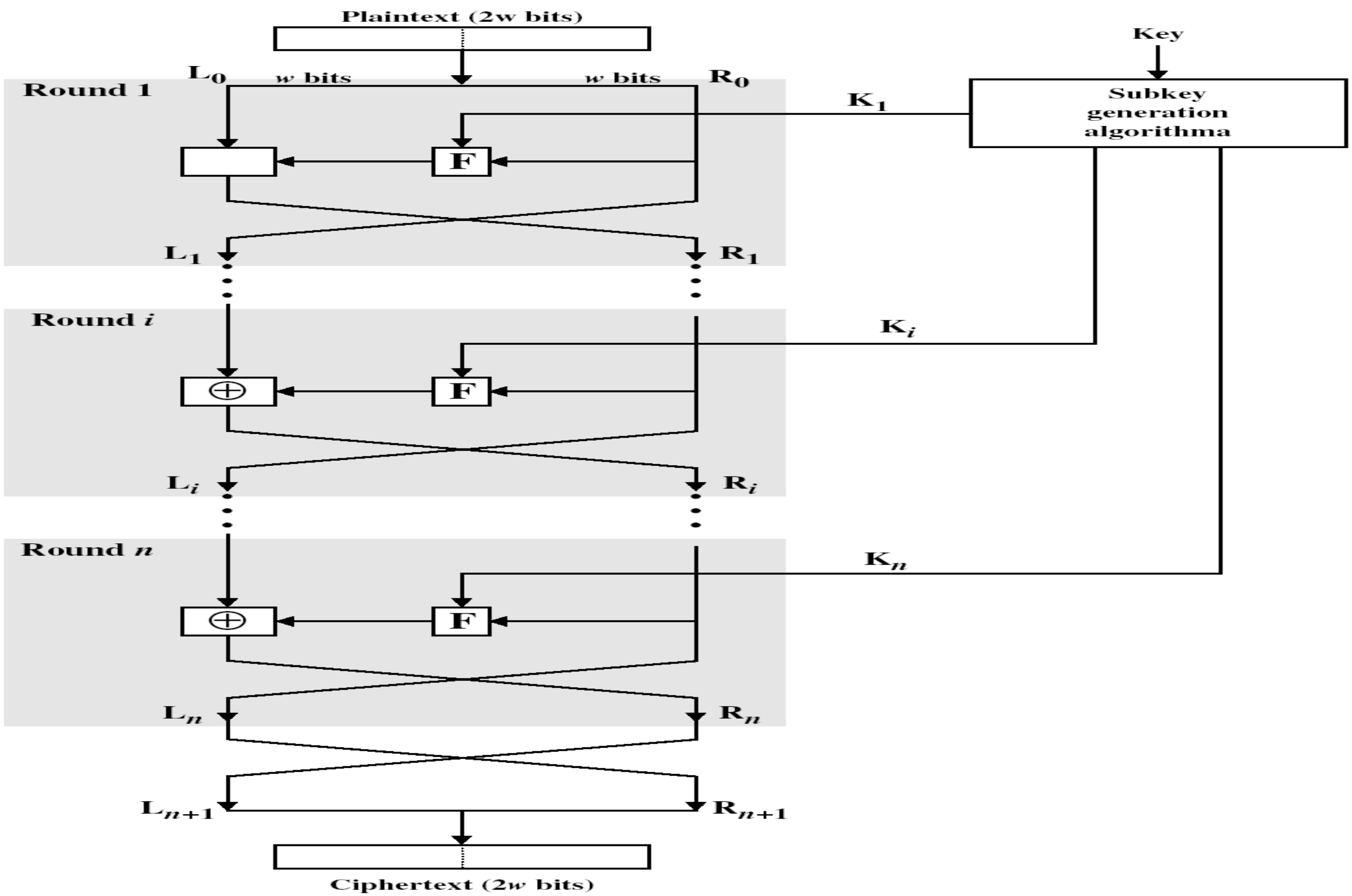
Shannon's one-time pad

- Choose a key as long as the message
- E (M, k) = k XOR M = C
- D (C, k) = k XOR C = M
- Choose k randomly (uniformly distributed in $\{0,1\}^l$), l = message length
- One-time pad has perfect secrecy
  - Pr (m xor k = c) = Pr (m' xor k = c) = 2^{-l}

One time pad

- Each key works only once
- Works with fixed length messages
- Key length = message length
- Not very practical

Fiestel Cipher



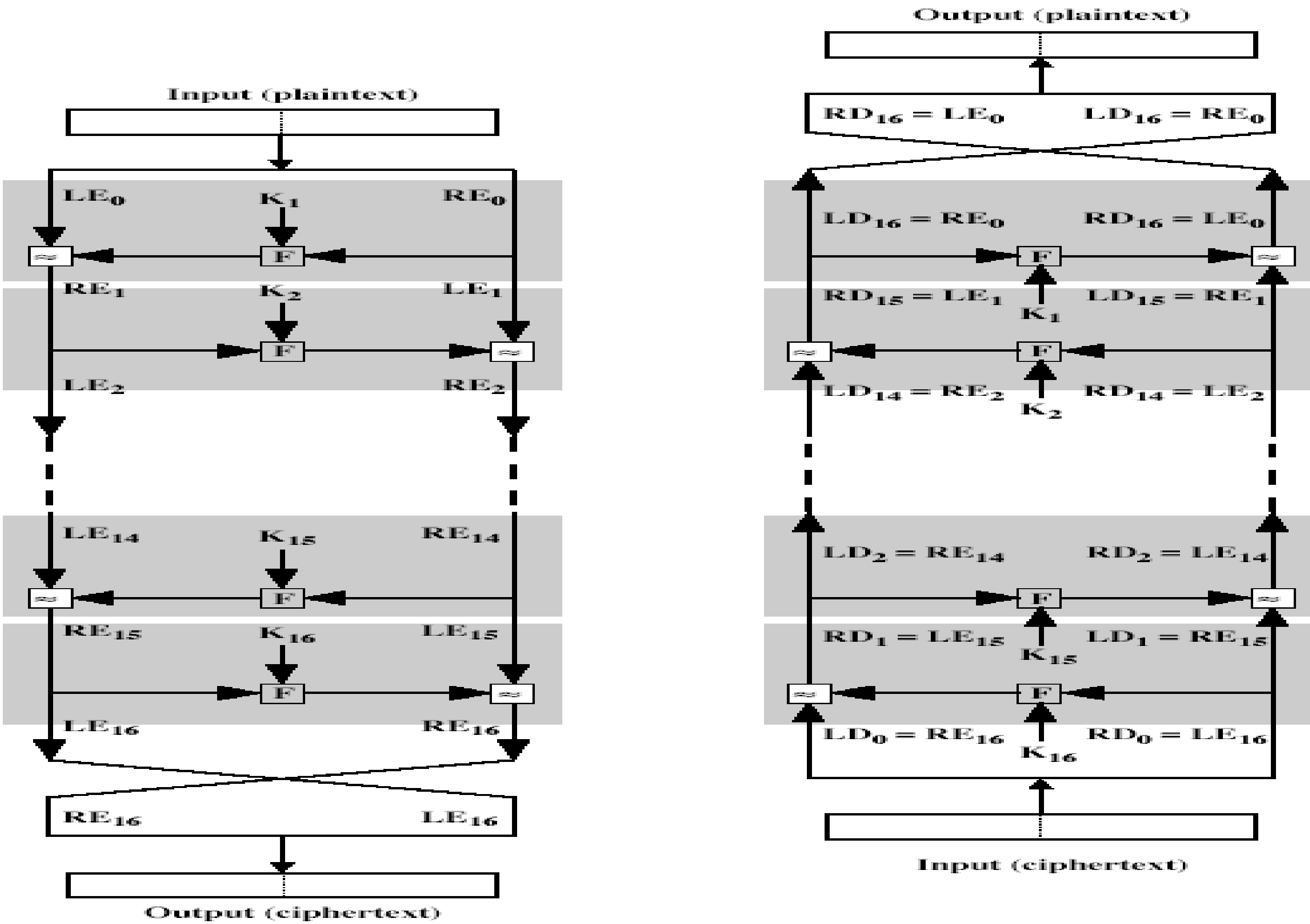
Fiestel Cipher (IBM, 70s)

- Partitions input block into two halves
  - Employs multiple rounds of processing
  - Performs a substitution on left data half based on a fn. of right half & subkey
  - Employs permutation swapping halves
- Implements Shannon's substitution-permutation network concept

Cipher parameters

- **Block size**
  - increasing size improves security, but slows cipher
- **key size**
  - increasing size improves security, makes exhaustive key searching harder, but may slow cipher
- **Number of rounds**
  - increasing number improves security, but slows cipher
- **Subkey generation**
  - greater complexity can make analysis harder, but slows cipher
- **Round function**
  - greater complexity can make analysis harder, but slows cipher

Decryption

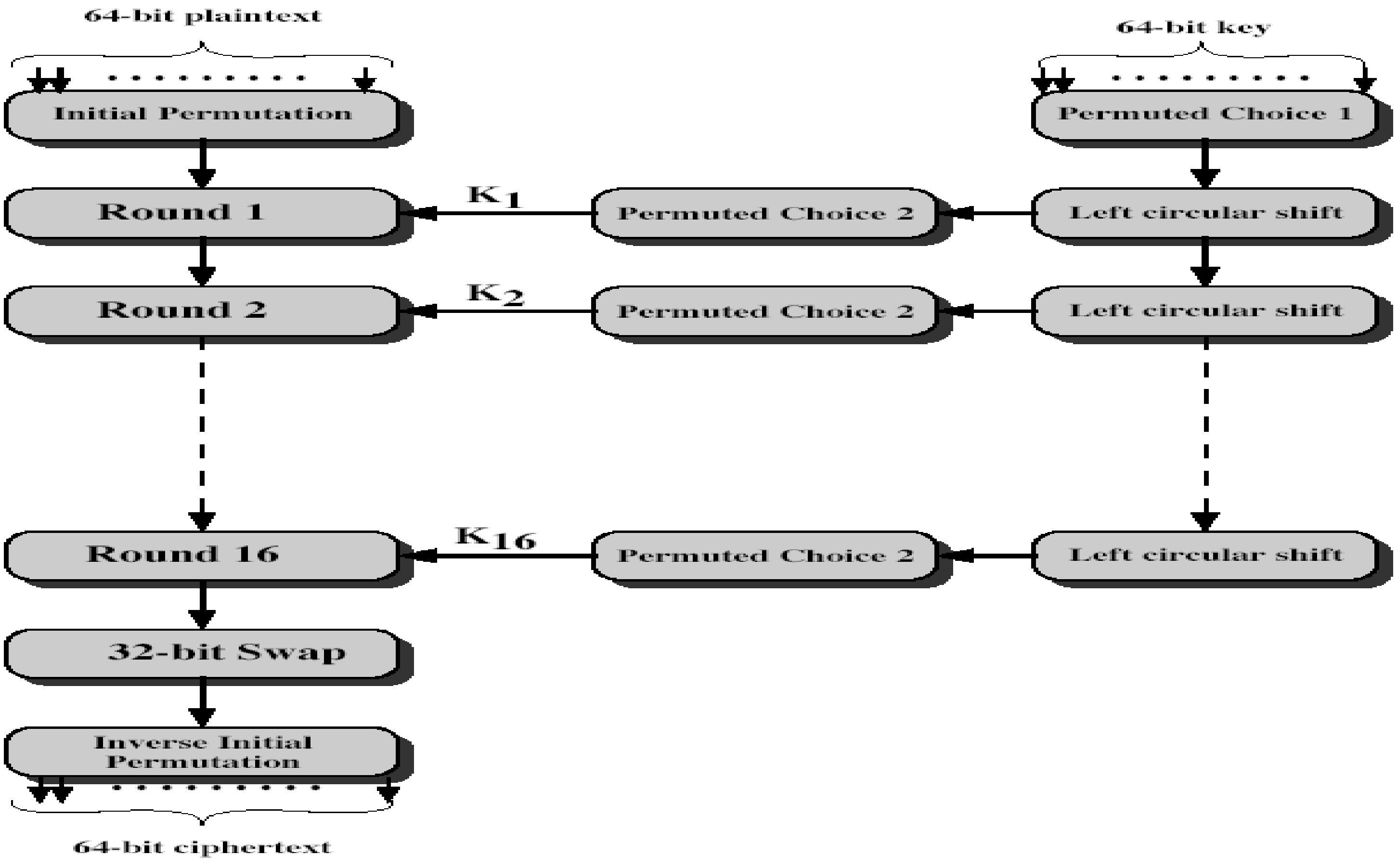


Input (plaintext)
LE0
K1
RE0
F
RE1
K2
LE1
F
LE2
RE2
LE14
K15
RE14
F
RE15
K16
LE15
F
LE16
RE16
RE16
LE16
Output (ciphertext)
Output (plaintext)
RD16 = LE0
LD16 = RE0
LD16 = RE0
RD16 = LE0
F
RD15 = LE1
K1
LD15 = RE1
F
LD14 = RE2
K2
RD14 = LE2
LD2 = RE14
RD2 = LE14
F
RD1 = LE15
K15
LD1 = RE15
F
LD0 = RE16
K16
RD0 = LE16
Input (ciphertext)

DES cipher

- Data Encryption Standard
- Most widely used block cipher in world
- Adopted in 1977 by NIST as a standard
- Encrypts 64-bit data using 56-bit key
- Based on IBM's Lucifer cipher (128-bit key)

DES Encryption



Initial permutation

- First step of the data computation
- IP reorders the input data bits
- Even bits to LH half, odd bits to RH half
- Quite regular in structure
  - easy to build h/w

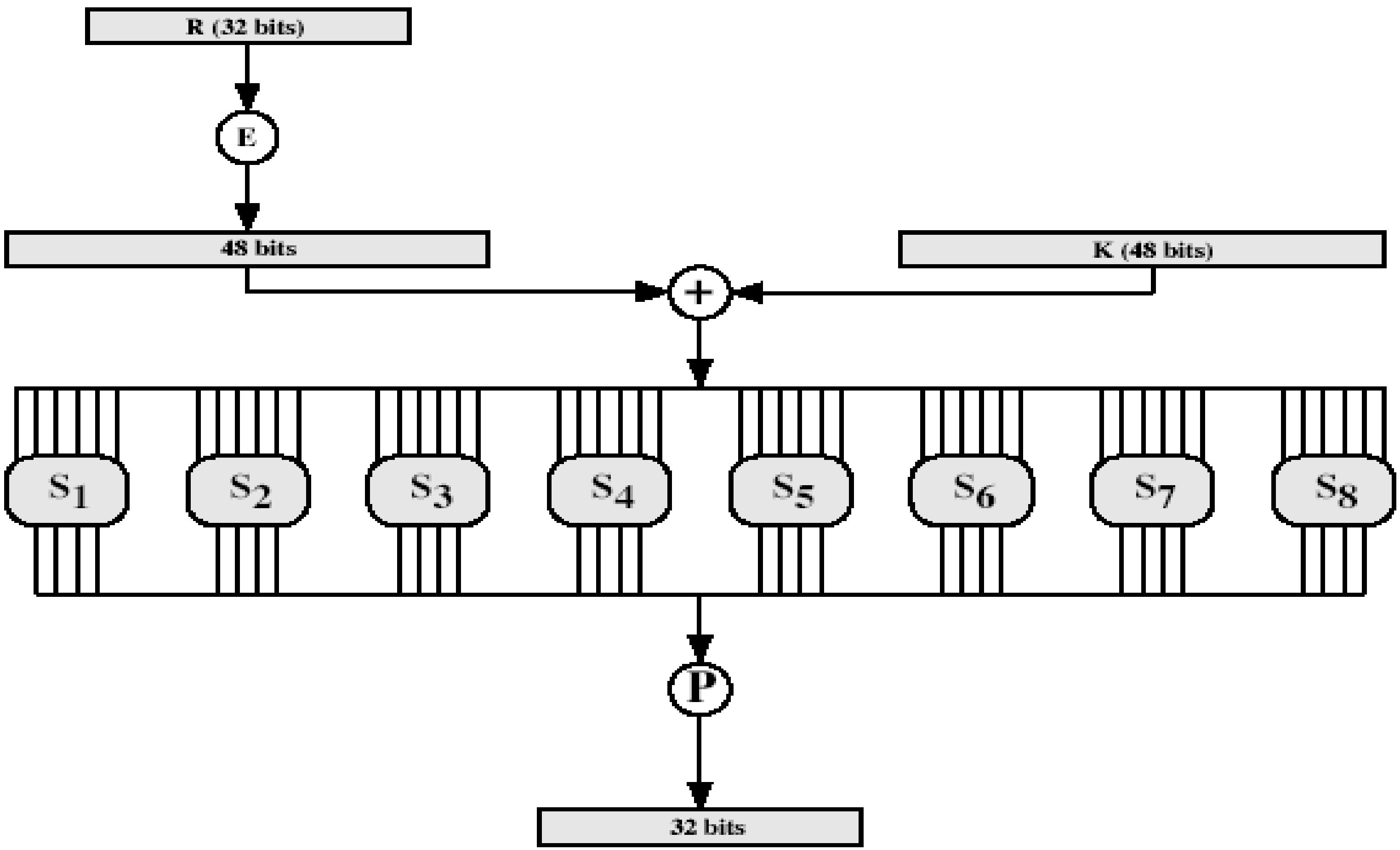
DES Rounds

- Uses two 32-bit L & R halves
- Similat to Feistel cipher can describe as:

  $L_i = R_{i-1}$

  $R_i = L_{i-1}$ xor $F(R_{i-1}, K_i)$
- Takes 32-bit R half and 48-bit subkey and:
  - expands R to 48-bits using perm E
  - adds to subkey
  - passes through 8 S-boxes to get 32-bit result
  - finally permutes this using 32-bit perm P

DES Round



Strength of DES

- 56-bit keys have $2^{56} = 7.2 \times 10^{16}$ values
- Brute force search requires lot of work
- But, possible
  - in 1997 on Internet in a few months
  - in 1998 on dedicated h/w in a few days
  - in 1999 above combined in 22hrs!
- Must be able to recognize plaintext
- Alternatives to DES being considered

References

- [1] Network Security Essentials, Applications and Standards, 2nd edition by William Stallings –Chapter2