# Block Ciphers and the Data Encryption Standard

*All the afternoon Mungo had been working on Stern's code, principally with the aid of the latest messages which he had copied down at the Nevin Square drop. Stern was very confident. He must be well aware London Central knew about that drop. It was obvious that they didn't care how often Mungo read their messages, so confident were they in the impenetrability of the code.*

**—*Talking to Strange Men,* Ruth Rendell**

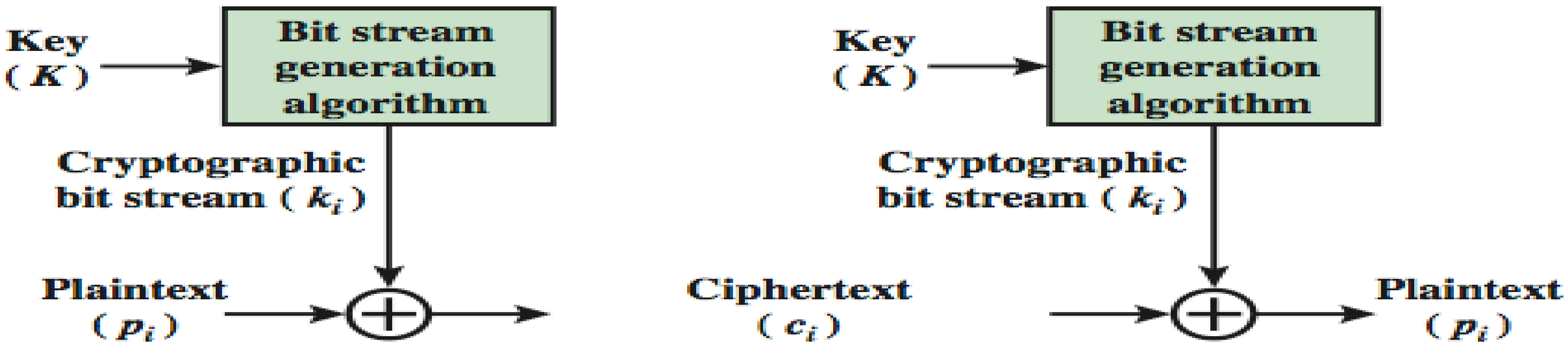
# Modern Block Ciphers

- one of the most widely used types of cryptographic algorithms
- provide secrecy /authentication services
- focus on DES (Data Encryption Standard)
- to illustrate block cipher design principles

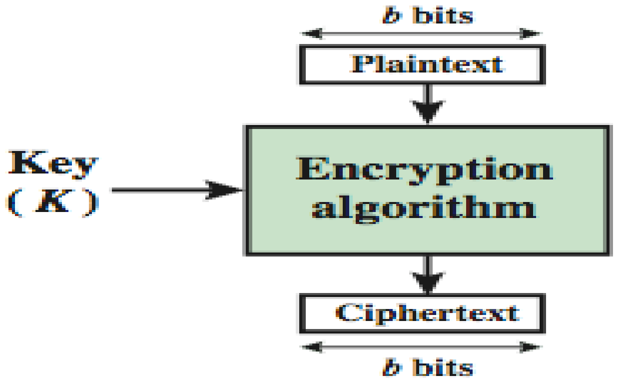
# Block vs Stream Ciphers

- block ciphers process messages in blocks, each of which is then en/decrypted
- like a substitution on very big characters
  - 64-bits or more
- stream ciphers process messages a bit or byte at a time when en/decrypting
- many current ciphers are block ciphers
  - better analysed
  - broader range of applications

# Block vs Stream Ciphers




(a) Stream Cipher Using Algorithmic Bit Stream Generator

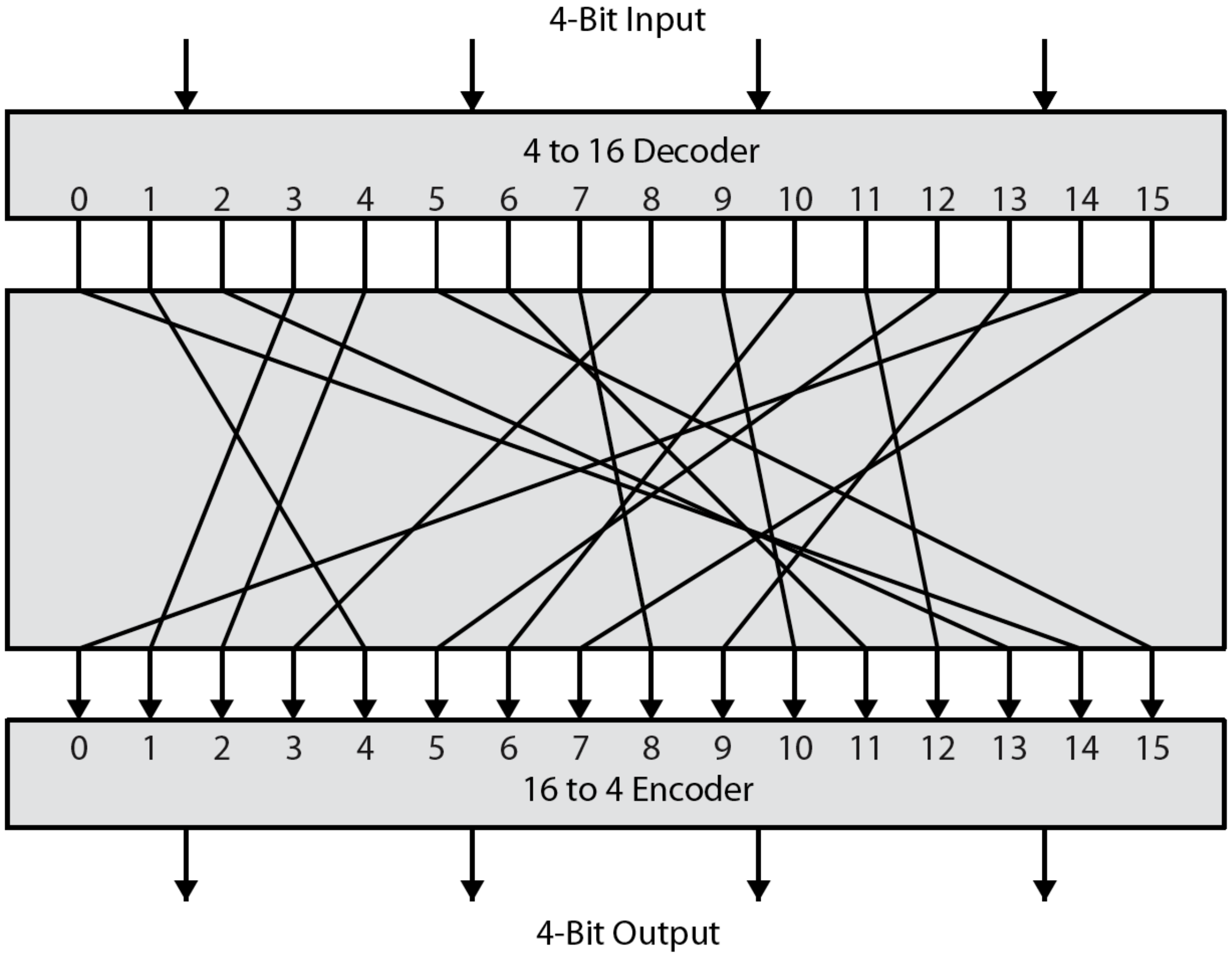



(b) Block Cipher

# Block Cipher Principles

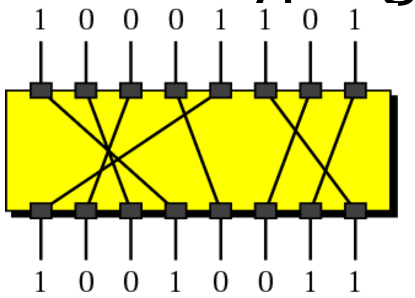
- most symmetric block ciphers are based on a **Feistel Cipher Structure**
- needed since must be able to **decrypt** ciphertext to recover messages efficiently
- block ciphers look like an extremely large substitution
- would need table of $2^{64}$ entries for a 64-bit block
- instead create from smaller building blocks
- using idea of a product cipher

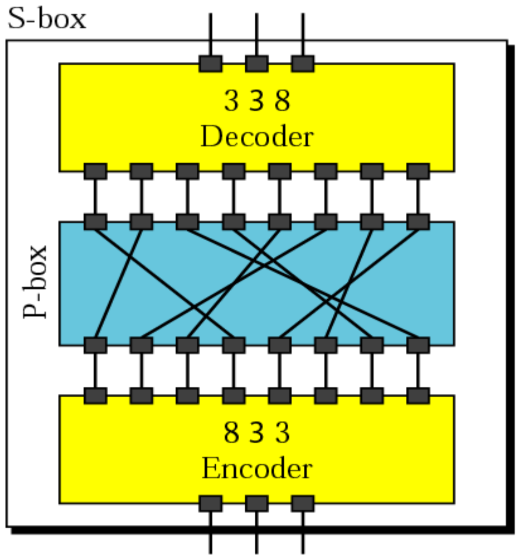
# Ideal Block Cipher

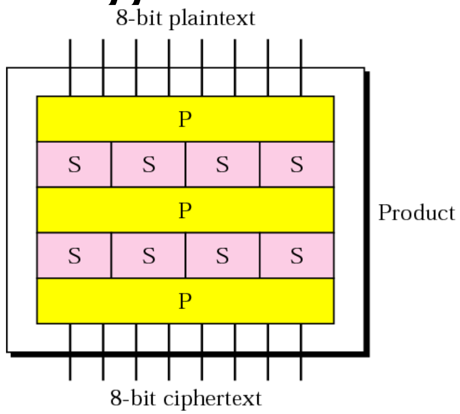


# Claude Shannon and Substitution-Permutation Ciphers

- Claude Shannon introduced idea of substitution-permutation (S-P) networks in 1949 paper
- form basis of modern block ciphers
- S-P nets are based on the two primitive cryptographic operations seen before:
  - *substitution* (S-box)
  - *permutation* (P-box)
- provide *confusion* & *diffusion* of message & key



# Confusion and Diffusion

- cipher needs to completely obscure statistical properties of original message
- a one-time pad does this
- more practically Shannon suggested combining S & P elements to obtain:
- **diffusion** – dissipates statistical structure of plaintext over bulk of ciphertext
- **confusion** – makes relationship between ciphertext and key as complex as possible

# Feistel Cipher Structure

- Horst Feistel devised the **feistel cipher**
  - based on concept of invertible product cipher
- partitions input block into two halves
  - process through multiple rounds which
  - perform a substitution on left data half
  - based on round function of right half & subkey
  - then have permutation swapping halves
- implements Shannon's S-P net concept

# Feistel Cipher Design Elements

- block size
- key size
- number of rounds
- subkey generation algorithm
- round function
- fast software en/decryption
- ease of analysis

# Data Encryption Standard

# Data Encryption Standard (DES)

- most widely used block cipher in world
- adopted in 1977 by NBS (now NIST)
  - as FIPS PUB 46
- encrypts 64-bit data using 56-bit key
- has widespread use
- has been considerable controversy over its security
- Now deprecated due to short key

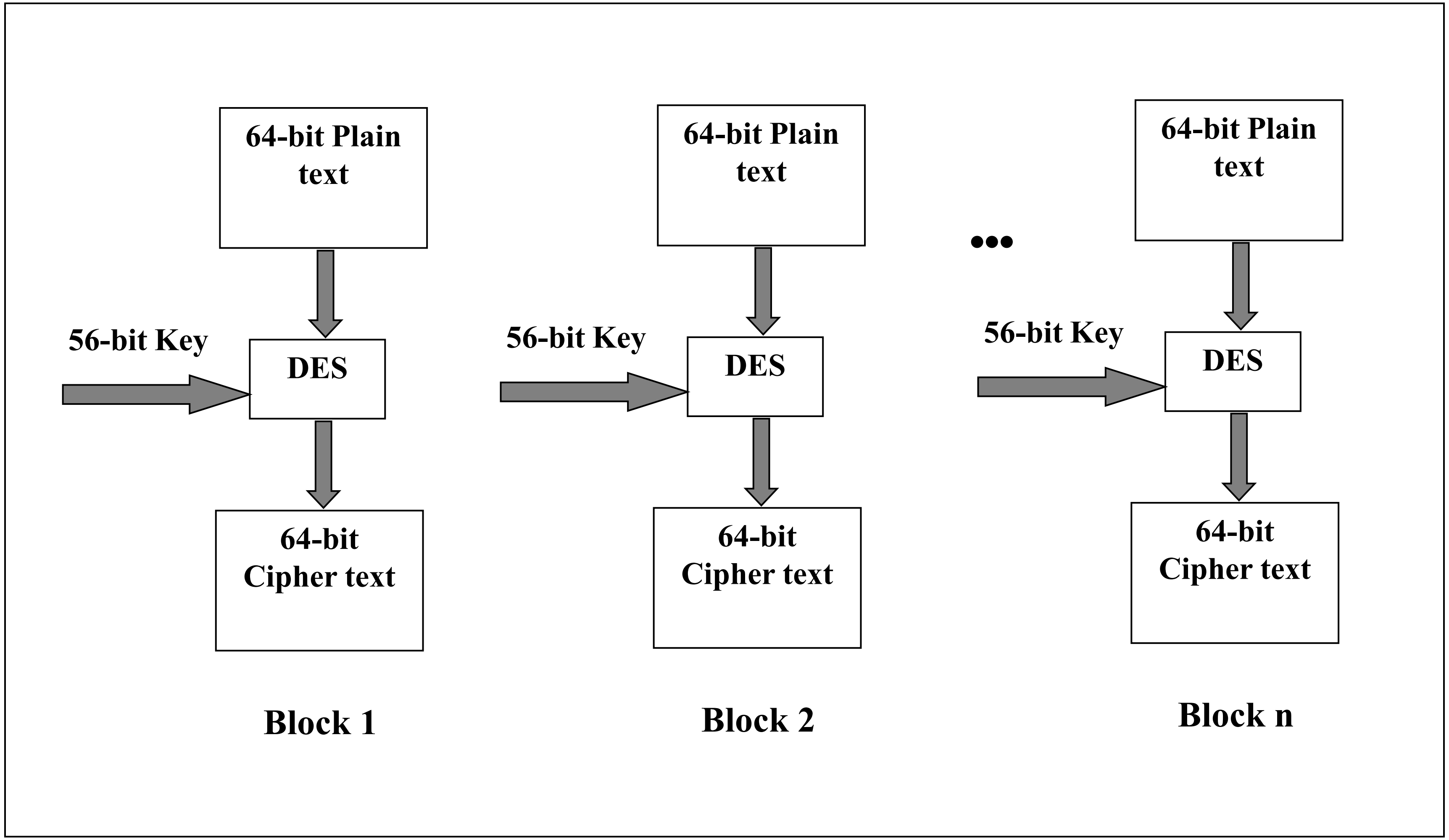
# DES History

- IBM developed Lucifer cipher
  - by team led by Feistel in late 60's
  - used 64-bit data blocks with 128-bit key
- then redeveloped as a commercial cipher with input from NSA and others
- in 1973 NBS issued request for proposals for a national cipher standard
- IBM submitted their revised Lucifer which was eventually accepted as the DES

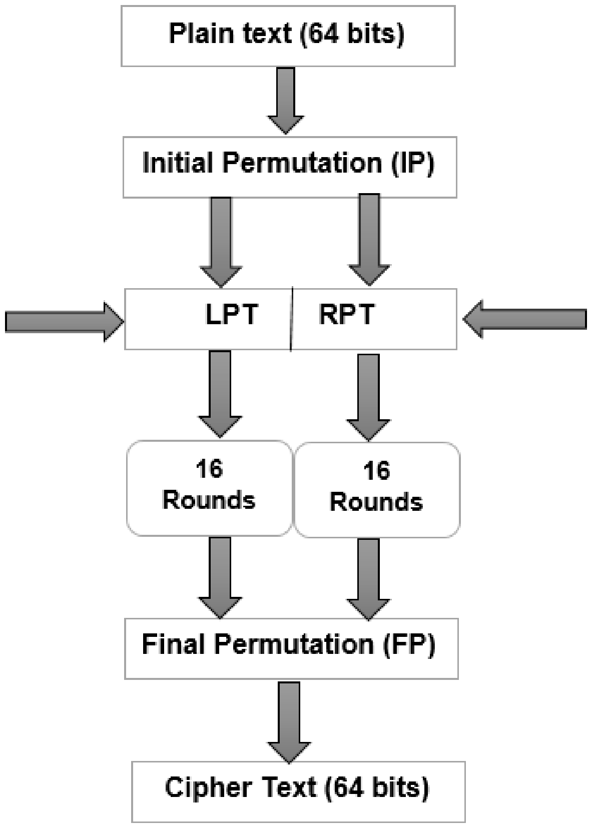
# DES Design Controversy

- although DES standard is public
- was considerable controversy over design
  - in choice of 56-bit key (vs Lucifer 128-bit)
  - and because design criteria were classified
- subsequent events and public analysis show in fact design was appropriate
- use of DES has flourished
  - especially in financial applications
  - still standardized for legacy application use
  - 3DES still strong (112 bit key)

# Conceptual View of DES



# Data Encryption Standard



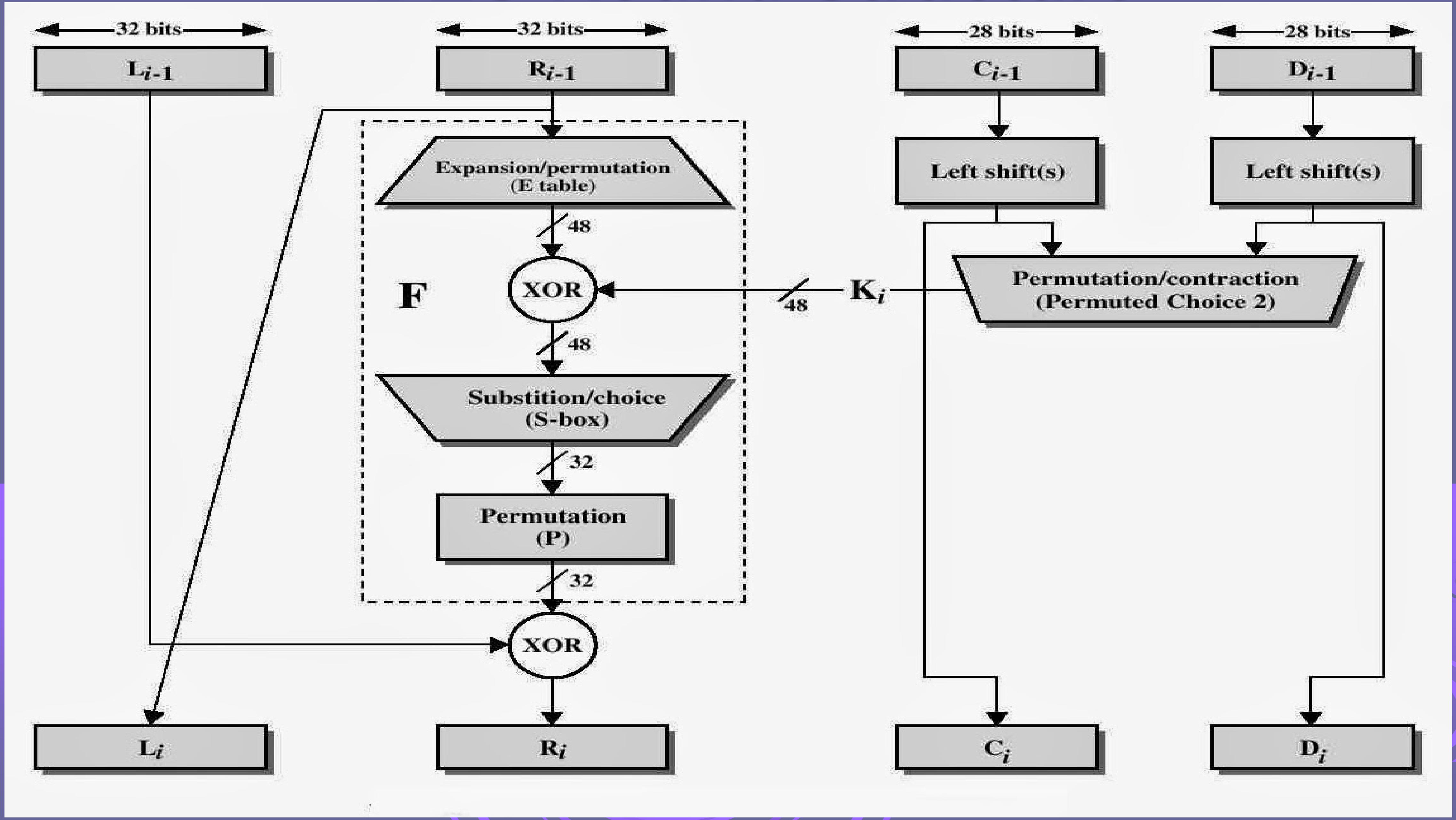

[Figure: Broad level steps in DES]

# Initial Permutation IP

**Table 6.1** *Initial and final permutation tables*

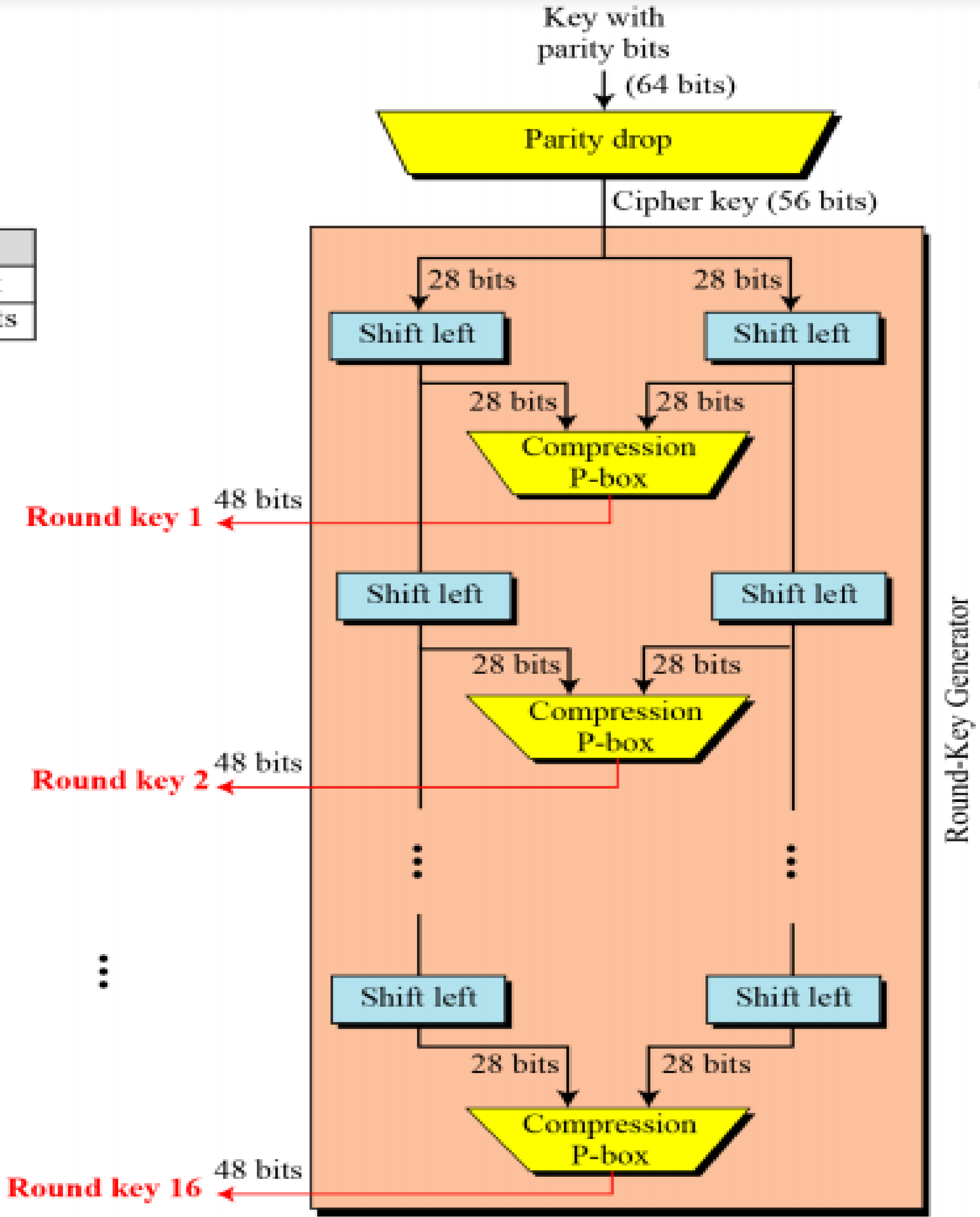
| Initial Permutation | | | | | | | | Final Permutation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 | 50 | 42 | 34 | 26 | 18 | 10 | 02 | 40 | 08 | 48 | 16 | 56 | 24 | 64 | 32 |
| 60 | 52 | 44 | 36 | 28 | 20 | 12 | 04 | 39 | 07 | 47 | 15 | 55 | 23 | 63 | 31 |
| 62 | 54 | 46 | 38 | 30 | 22 | 14 | 06 | 38 | 06 | 46 | 14 | 54 | 22 | 62 | 30 |
| 64 | 56 | 48 | 40 | 32 | 24 | 16 | 08 | 37 | 05 | 45 | 13 | 53 | 21 | 61 | 29 |
| 57 | 49 | 41 | 33 | 25 | 17 | 09 | 01 | 36 | 04 | 44 | 12 | 52 | 20 | 60 | 28 |
| 59 | 51 | 43 | 35 | 27 | 19 | 11 | 03 | 35 | 03 | 43 | 11 | 51 | 19 | 59 | 27 |
| 61 | 53 | 45 | 37 | 29 | 21 | 13 | 05 | 34 | 02 | 42 | 10 | 50 | 18 | 58 | 26 |
| 63 | 55 | 47 | 39 | 31 | 23 | 15 | 07 | 33 | 01 | 41 | 09 | 49 | 17 | 57 | 25 |

# DES Round Structure



Shifting

| Rounds | Shift |
|---|---|
| 1, 2, 9, 16 | one bit |
| Others | two bits |




***Key generation***

# Compression Permutation of Key

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 17 | 11 | 24 | 1 | 5 | 3 | 28 | 15 | 6 | 21 | 10 |
| 23 | 19 | 12 | 4 | 26 | 8 | 16 | 7 | 27 | 20 | 13 | 2 |
| 41 | 52 | 31 | 37 | 47 | 55 | 30 | 40 | 51 | 45 | 33 | 48 |
| 44 | 49 | 39 | 56 | 34 | 53 | 46 | 42 | 50 | 36 | 29 | 32 |

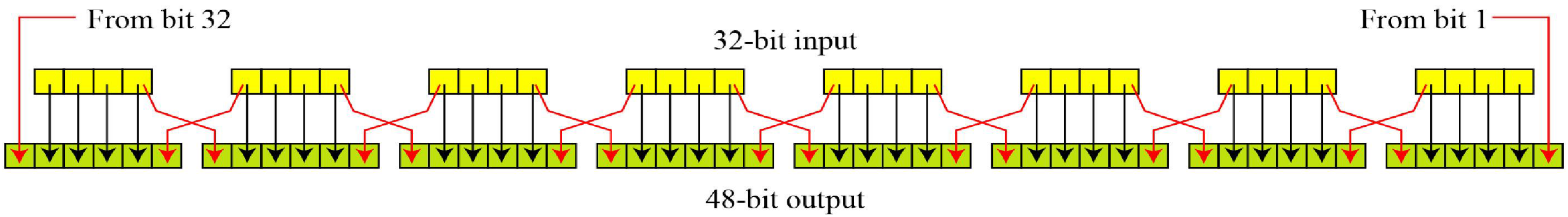
**Figure** - compression permutation

# Continue

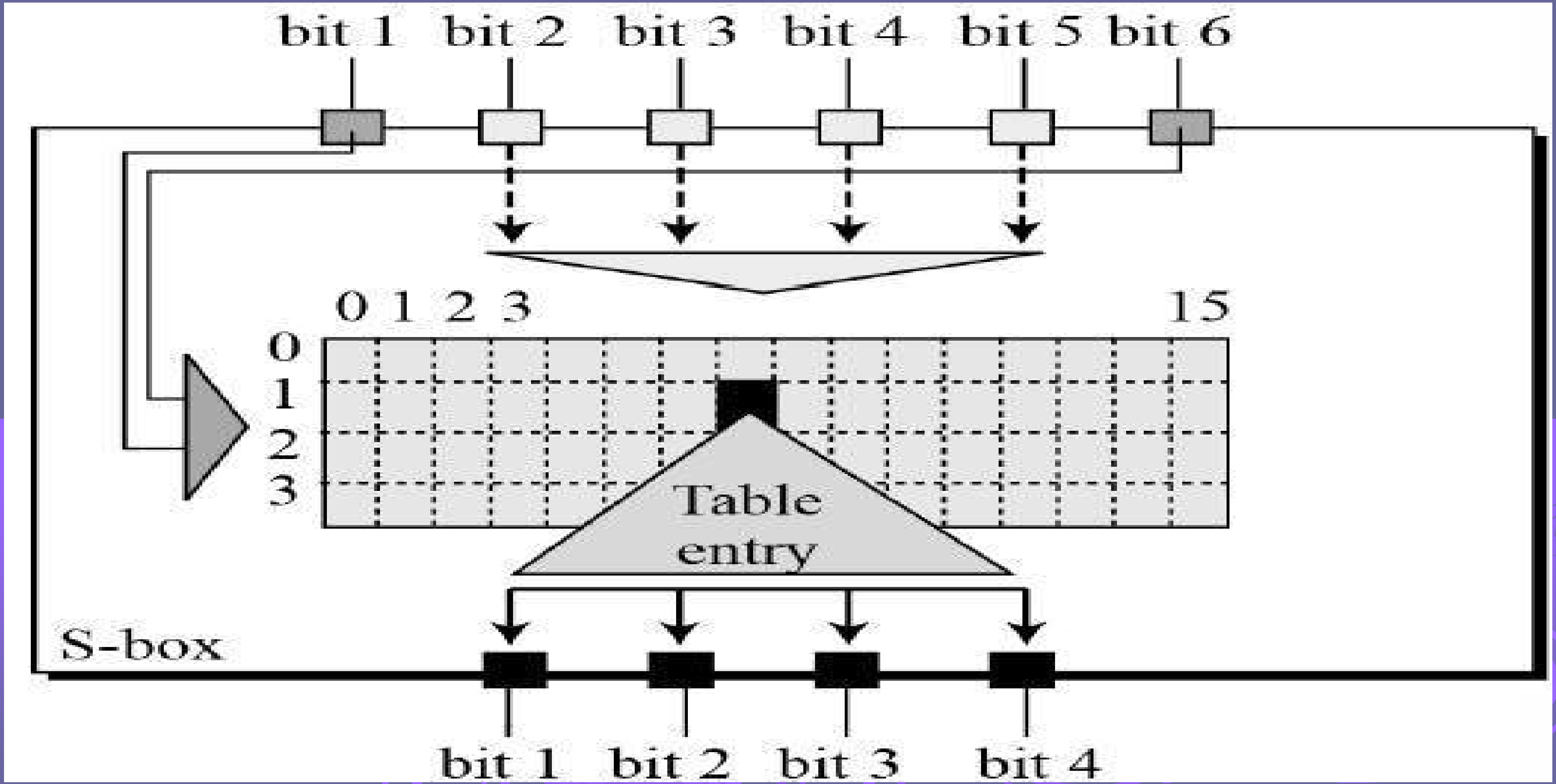
## Expansion P-box

***Since $R_{I-1}$ is a 32-bit input and $K_I$ is a 48-bit key, we first need to expand $R_{I-1}$ to 48 bits.***

***Expansion permutation***



# S-box


bit 1 bit 2 bit 3 bit 4 bit 5 bit 6
0 1 2 3 15
0
1
2
3
Table entry
S-box
bit 1 bit 2 bit 3 bit 4

# S-box

## Continue

***Table shows the permutation for S-box 1. For the rest of the boxes see the textbook.***

***S-box 1***

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 14 | 04 | 13 | 01 | 02 | 15 | 11 | 08 | 03 | 10 | 06 | 12 | 05 | 09 | 00 | 07 |
| 1 | 00 | 15 | 07 | 04 | 14 | 02 | 13 | 10 | 03 | 06 | 12 | 11 | 09 | 05 | 03 | 08 |
| 2 | 04 | 01 | 14 | 08 | 13 | 06 | 02 | 11 | 15 | 12 | 09 | 07 | 03 | 10 | 05 | 00 |
| 3 | 15 | 12 | 08 | 02 | 04 | 09 | 01 | 07 | 05 | 11 | 03 | 14 | 10 | 00 | 06 | 13 |

The input to S-box 1 is 100011. What is the output?

If we write the first and the sixth bits together, we get 11 in binary, which is 3 in decimal. The remaining bits are 0001 in binary, which is 1 in decimal. We look for the value in row 3, column 1 (S-box 1). The result is 12 in decimal, which in binary is 1100. So the input 100011 yields the output 1100.

# F and Key Transformation involves…

# Avalanche Effect

- key desirable property of encryption alg
- where a change of **one** input or key bit results in changing approx **half** output bits
- making attempts to “home-in” by guessing keys impossible
- DES exhibits strong avalanche