Symmetric Key Cryptosystems

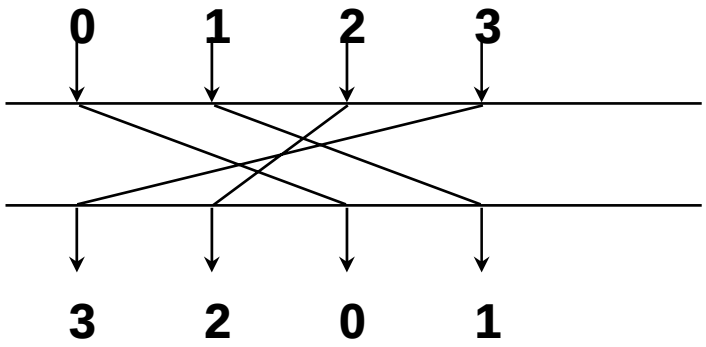
- Based on the sender and the receiver of a message knowing and using
  - The same (secret) key
  - Cryptosystem
- Sender uses the secret key to encrypt the message
  - Receiver uses the same secret key to decrypt the message
- Key management
  - Main problem is the sender and receiver to agree on a secret key without anyone else finding out
  - One of the fundamental issues that has to be addressed in symmetric key cryptosystems
  - In a network of *n* nodes the total number of different symmetric keys needs to be at least $\frac{n(n-1)}{2}$ (assuming that each pair of nodes share a common key)
- Examples of symmetric key algorithms are
  - DES, Triple DES, AES (Rijndael), IDEA

Data Encryption Standard (DES)

- In January 1977 a standard encryption method was adopted by the U.S. government
  - Its origins lay in an internal IBM project codenamed *Lucifer* to develop a cryptographic algorithm
- Though the algorithm used is complex
  - It is easily implemented in hardware
  - Software implementations are also widely available
- DES is a *block cipher*
  - Operates on a single chunk of data at a time
    - 64 bits (8 bytes)
  - Produces a 64 bit output
- The key length is 56 bits
  - Has outlived its usefulness, too small key size and block size
  - Survives in the form of 3DES (three DES encryptions in sequence)
  - This fixes the small key size problem, but not the small block size

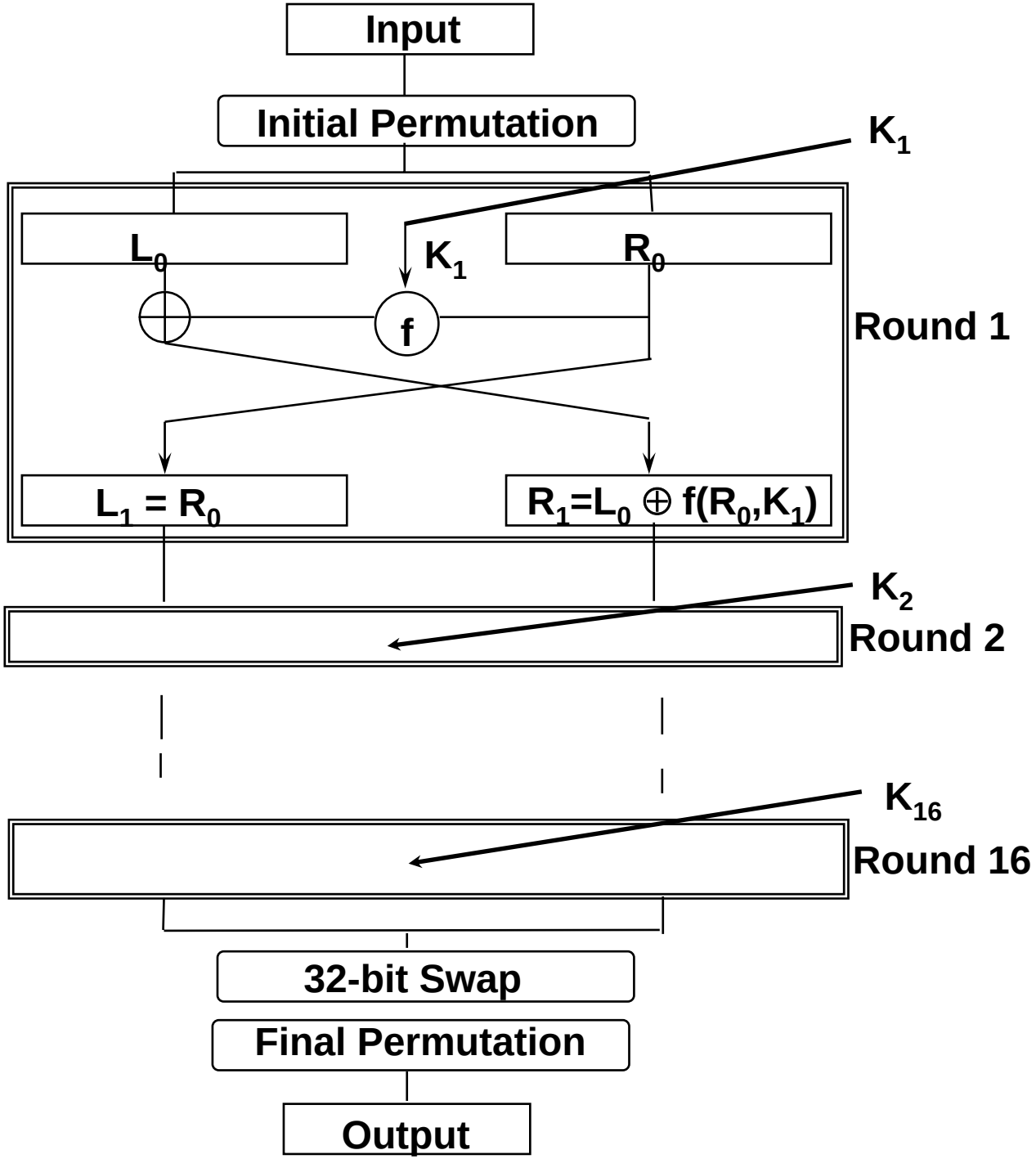
DES Operation

- The algorithm has 19 distinct stages
- The first stage reorders the bits of the 64-bit input block by applying a fixed permutation (nobody seems to know why, no cryptographic effect)



Transpostion of 4 bits (example only)

- The last stage is the exact inverse of this permutation
- The stage penultimate to the last one
  - Exchanges the leftmost 32 bits with the rightmost 32 bits
- The remaining 16 stages are called *rounds*
  - Functionally identical but take as an input a quantity computed from the round key and the round number
  - Round key: 48 bits from the 56-bit key, different at each round


Input
Initial Permutation
K1
L0
K1
R0
f
Round 1
L1 = R0
R1=L0 ⊕ f(R0,K1)
K2
Round 2
K16
Round 16
32-bit Swap
Final Permutation
Output

Cracking DES

- 56 bits is a short key
- *Brute force attack* (try every key)
  - 2^{56} encryptions to try all keys
  - Special chips can check 4 million keys/second
  - $1 million dollar DES cracking machine could break it in a few hours
- June 18 ‘97, DESCHALL group
  - Used spare Internet CPUs
  - 4 months, 18 quadrillion keys (25%), 78,000 computers

Stream Encipherment

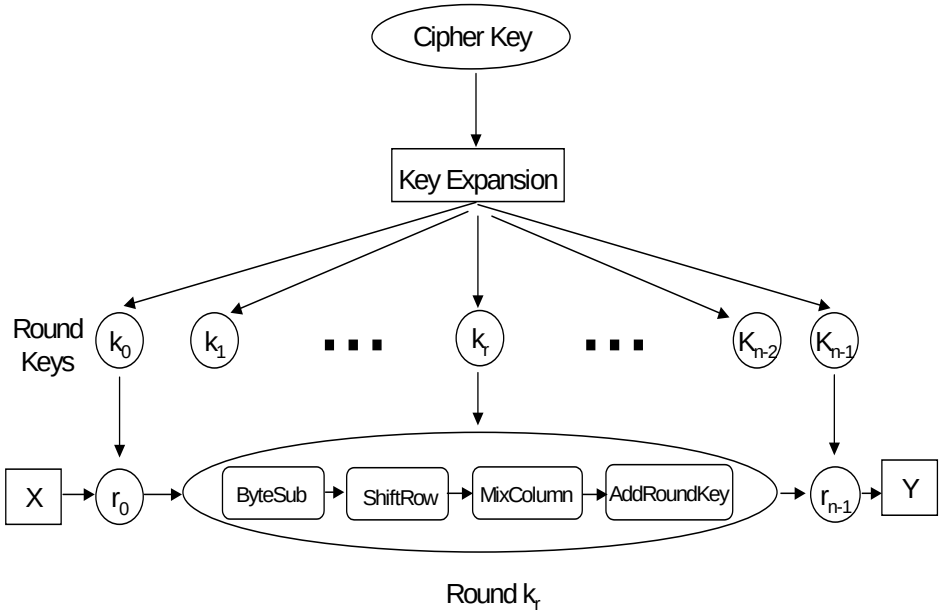
- The above method of operating DES is called Electronic Code Book (ECB) mode
- It does not protect against replay attacks and other attacks that occur on streams of information
- For data communications applications
  - Would like each fragment to depend on what had preceded it
  - One simple way to convert DES into a stream cipher is to XOR plaintext block N with ciphertext block N-1 before it is encrypted - Cipher Block Chaining (CBC) mode

Advanced Encryption Standard (AES)

- In 1997 the U.S. government announced a call for proposals to develop a new Advanced Encryption Standard
  - After a long process 5 algorithms were selected as finalists (out of 15)
- Rijndael was the algorithm that was eventually chosen as the new AES
  - Symmetric cipher with variable key and block sizes of 128, 192 and 256 bits
  - Support for fast encryption and decryption in software (700 Mbps)
  - Can be implemented efficiently in small 8-bit devices e.g. smartcards
  - Serpent (AES finalist) much more secure, the most conservative finalist, about one-third the speed of Rijndael
    * Designed for security instead of elegance and efficiency

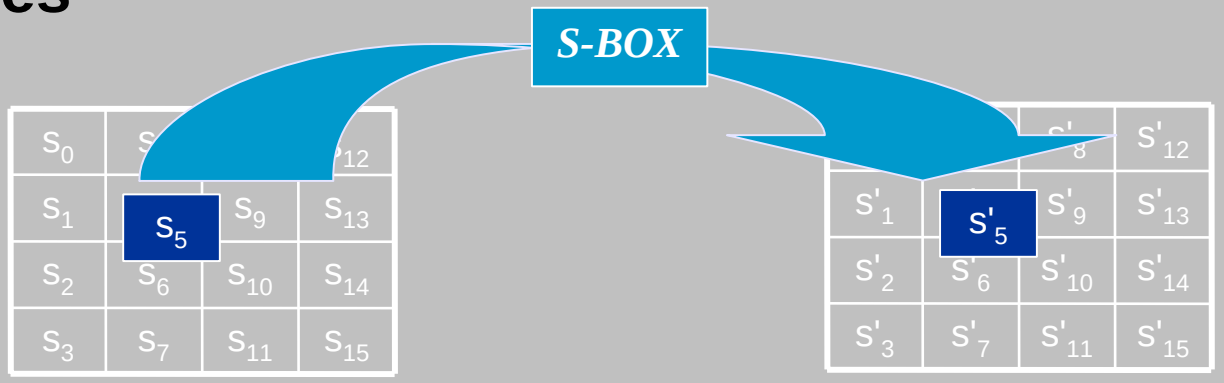
AES Overall Structure

- The cipher consists of between 10 or 14 rounds (Nr)
  - Depending on the key length (Nk) and the block length (Nb)
- A plaintext block *X* undergoes *n* rounds of operations to produce an output block *Y*
  - Each operation is based on the value of the *nth* round key
- The round keys are derived from the cipher key
  - By first expanding the key and then selecting parts of the expanded key for each round



AES Round (1/2)

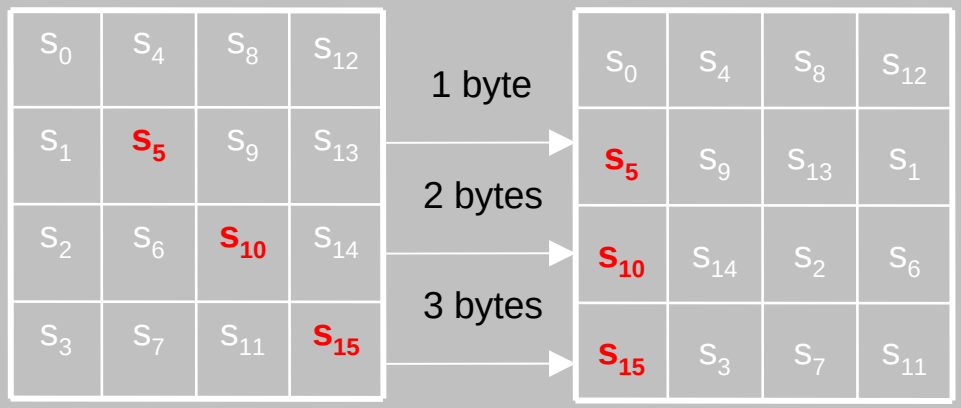
SubBytes



state array

ShiftRows

state array



AES Round (2/2)

MixColumns

s'_0	s'_4	s'_8	s'_{12}
s'_1	s'_5	s'_9	s'_{13}
s'_2	s'_6	s'_{10}	s'_{14}
s'_3	s'_7	s'_{11}	s'_{15}

$=$

coeff.s matrix

$$\begin{bmatrix} 02 & 03 & 01 & 01 \\ 01 & 02 & 03 & 01 \\ 01 & 01 & 02 & 03 \\ 03 & 01 & 01 & 02 \end{bmatrix}$$

$\otimes$

state array

s_0	s_4	s_8	s_{12}
s_1	s_5	s_9	s_{13}
s_2	s_6	s_{10}	s_{14}
s_3	s_7	s_{11}	s_{15}

AddRoundKey

s'_0	s'_4	s'_8	s'_{12}
s'_1	s'_5	s'_9	s'_{13}
s'_2	s'_6	s'_{10}	s'_{14}
s'_3	s'_7	s'_{11}	s'_{15}

$=$

state array

s_0	s_4	s_8	s_{12}
s_1	s_5	s_9	s_{13}
s_2	s_6	s_{10}	s_{14}
s_3	s_7	s_{11}	s_{15}

$\oplus$

round key

k_0	k_4	k_8	k_{12}
k_1	k_5	k_9	k_{13}
k_2	k_6	k_{10}	k_{14}
k_3	k_7	k_{11}	k_{15}

AES Criticism

- Simple algebraic structure

- Possible to write an AES encryption as a formula over the finite field with 256 elements

- Not an attack but a representation

- However, it is a new *avenue* of attack

- For 128-bit keys the best attack we know of covers 70% of the cipher

- AES relies on the hope that future attacks will not give large improvements

Snake Oil

- Snake oil from commercial enterprises is quite common in this area
  - Usually they claim to have developed a revolutionary new algorithm
- Why should you not try to develop your own encryption algorithm?
- How should you debunk such claims?

Message Digest Functions (1/3)

- Also known as cryptographic hashes
- Non-reversible functions
- Take an arbitrary size message and mangle it into a fixed size digest
- It should be impossible to find two messages with the same MD, or come up with a message with a given MD

Message Digest Functions (2/3)

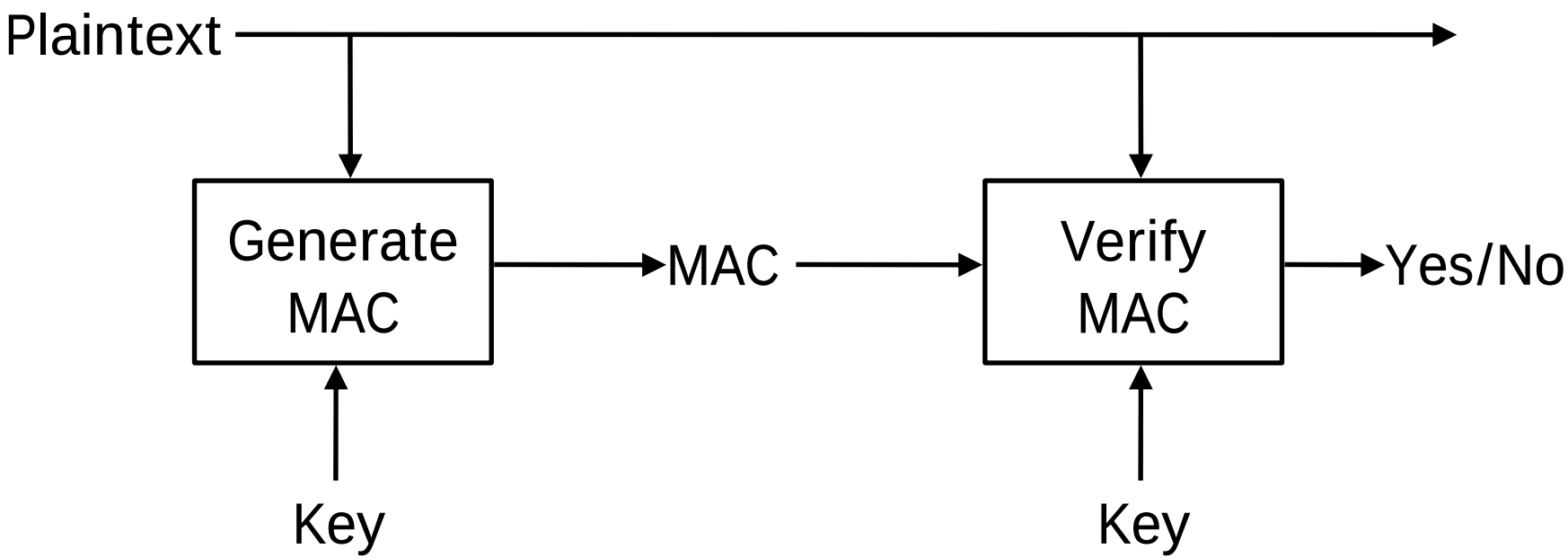
Message Digest Functions (3/3)

- MD2, MD4, and MD5 used to be most popular; SHA-1 next most popular (until a few months ago)
- All produce 128 bit digests
- MD4 and MD2 were recently ``broken'' and MD5 has significant weaknesses
- SHA-1 was proposed by the U.S. government; it produces a 160 bit digest

- Practical collision search attacks very likely to exist according to very recent research

- Message digests are not difficult to design, but most are not secure
- So, for the time being use SHA-256

Secret Key Integrity Protection



Challenge / Response Authentication