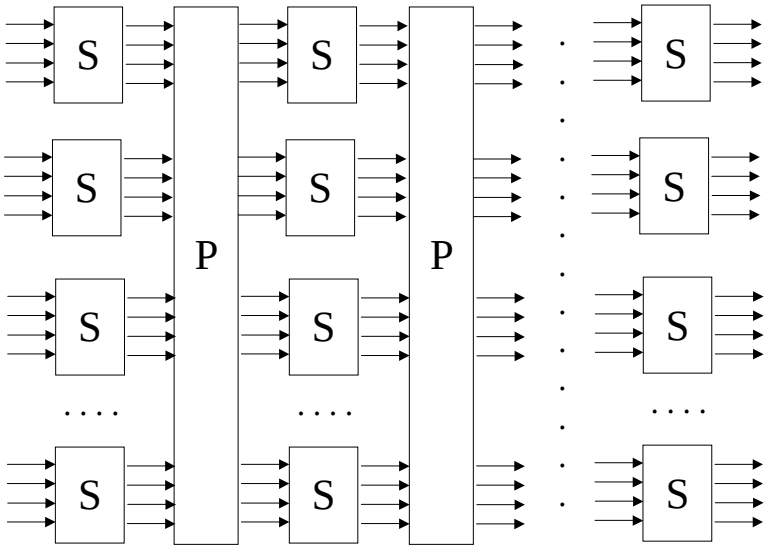
ECE297:11 Lecture 4

Towards modern ciphers: SP networks & DES

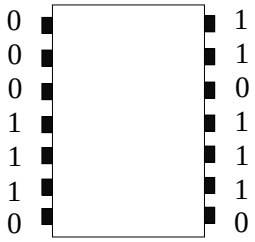
SP Networks

S-P Networks



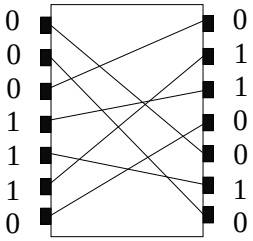
Basic operations of S-P networks

Substitution



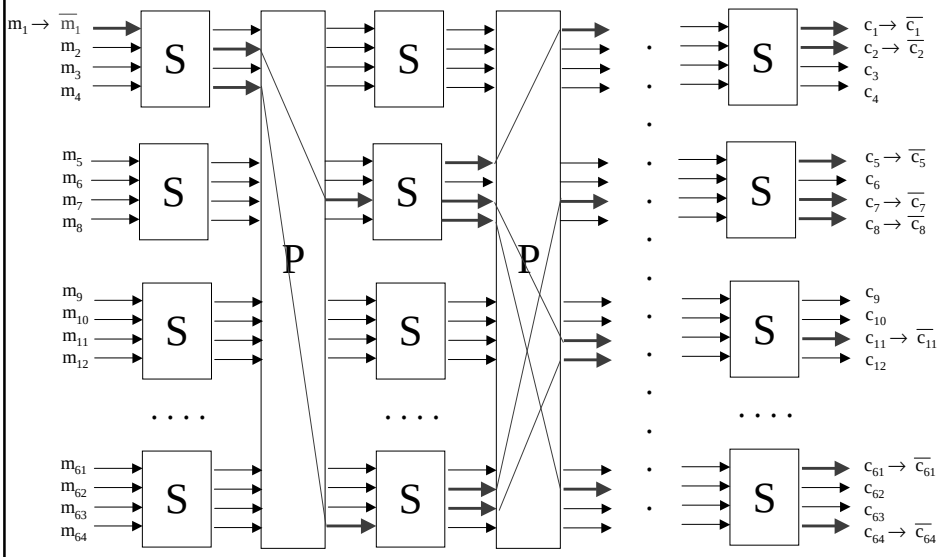
S-box

Permutation



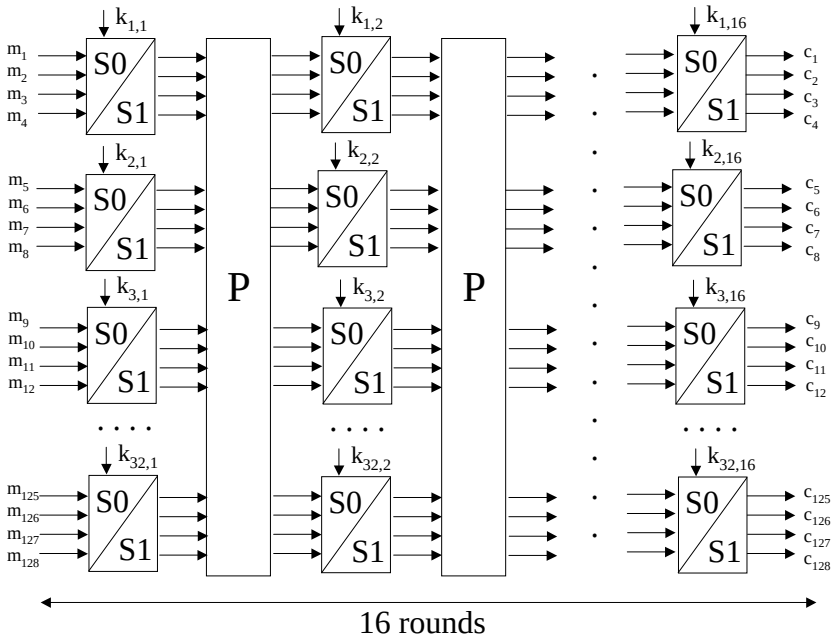
P-box

Avalanche effect

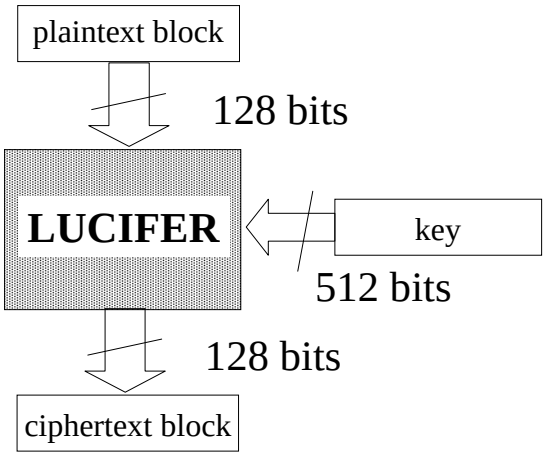


LUCIFER

Horst Feistel, Walt Tuchman
IBM



LUCIFER- external look



History of DES

NBS public request for a standard cryptographic algorithm

May 15, 1973, August 27, 1974

The algorithm must be:

- secure
- public
  - completely specified
  - easy to understand
  - available to all users
- economic and efficient in hardware
- able to be validated
- exportable

DES - chronicle of events

1973 - NBS issues a public request for proposals for a standard cryptographic algorithm

1975 - first publication of the IBM's algorithm and request for comments

1976 - NBS organizes two workshops to evaluate the algorithm

1977 - official publication as FIPS PUB 46: Data Encryption Standard

1983, 1987, 1993 - recertification of the algorithm for another five years

1993 - software implementations allowed to be validated

Controversies surrounding DES

Unknown design criteria

Most criteria reconstructed from cipher analysis

1990

Reinvention of differential cryptanalysis

Slow in software

Only hardware implementations certified

1993

Software, firmware and hardware treated equally

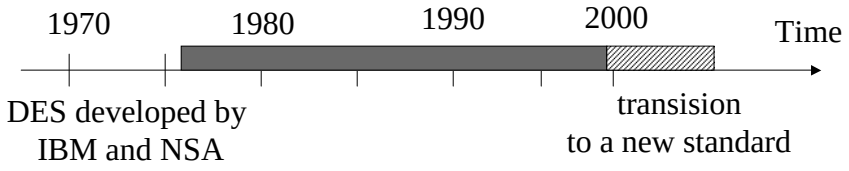
Too short key

Theoretical designs of DES breaking machines

1998

Practical DES cracker built

Life of DES



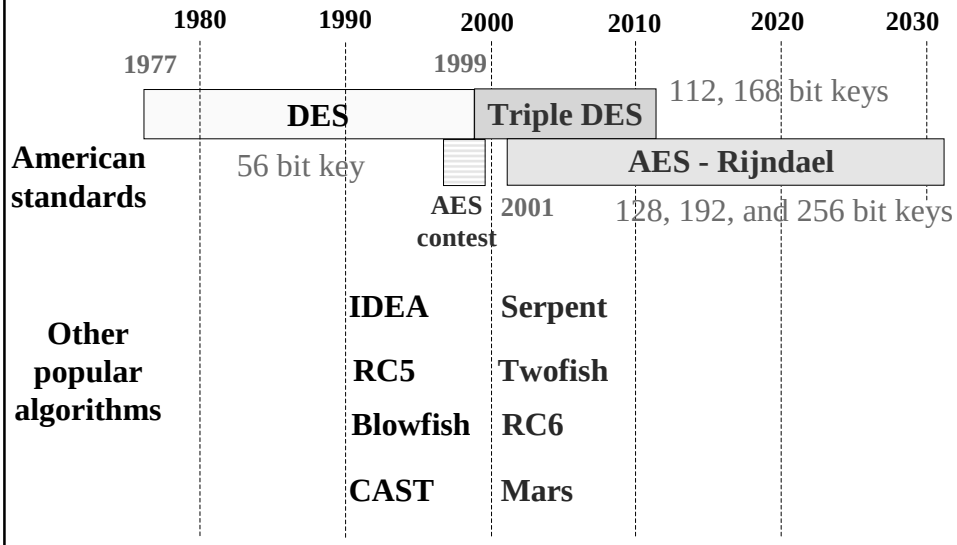
In common use for over 20 years

Federal and banking standard

Over 130 validated implementations

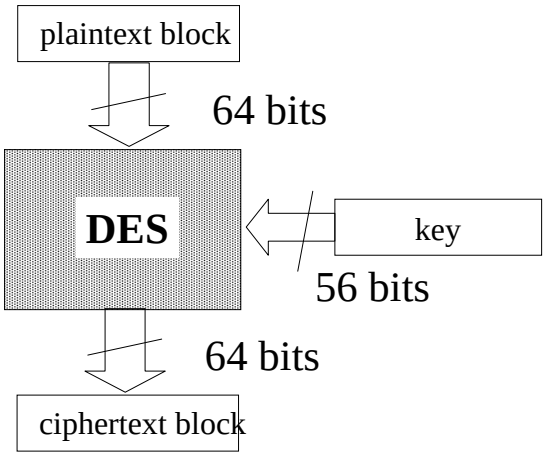
De facto world-wide standard

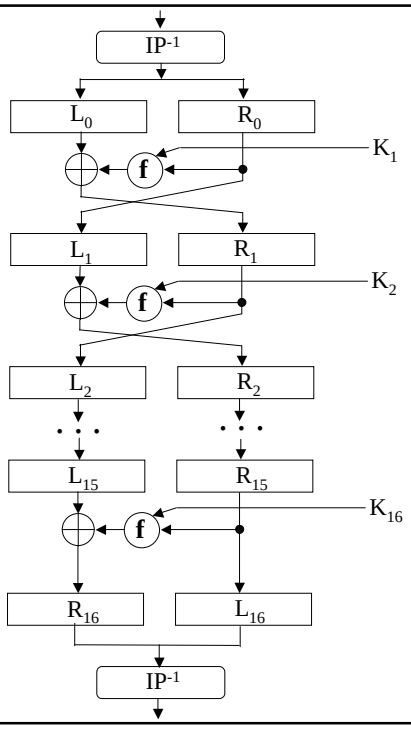
Most popular secret-key ciphers



Specification of DES

DES - external look





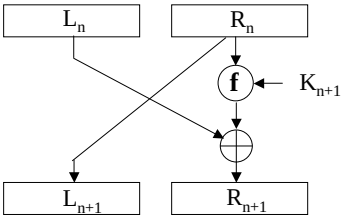
DES Main Loop Feistel Structure

$L_{n+1}=R_n$

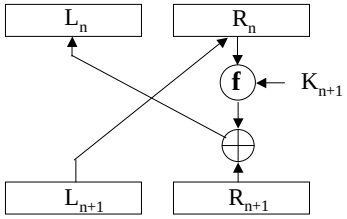
$R_{n+1}=L_n \oplus f(R_n, K_{n+1})$

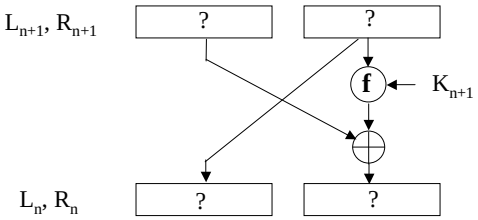
Feistel Structure

Encryption



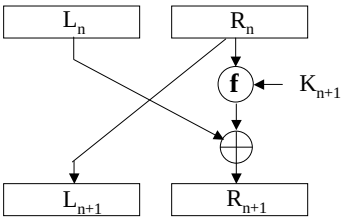
Decryption



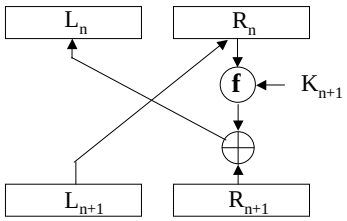


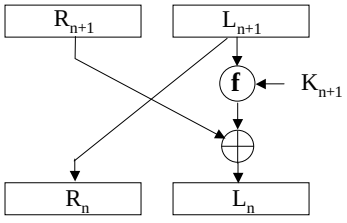
Feistel Structure

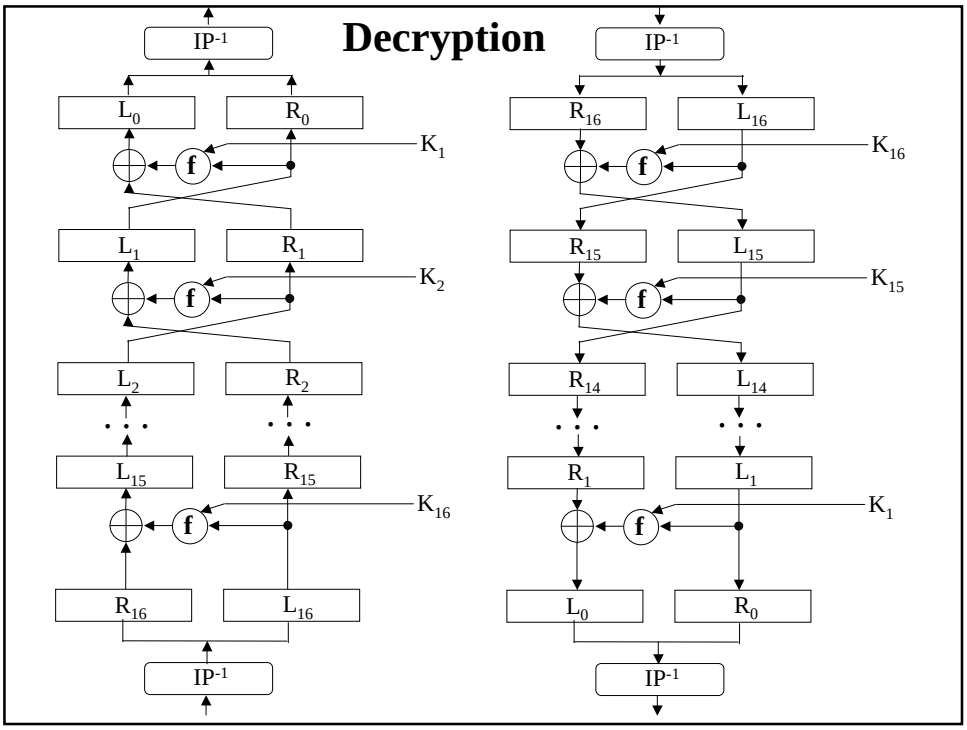
Encryption



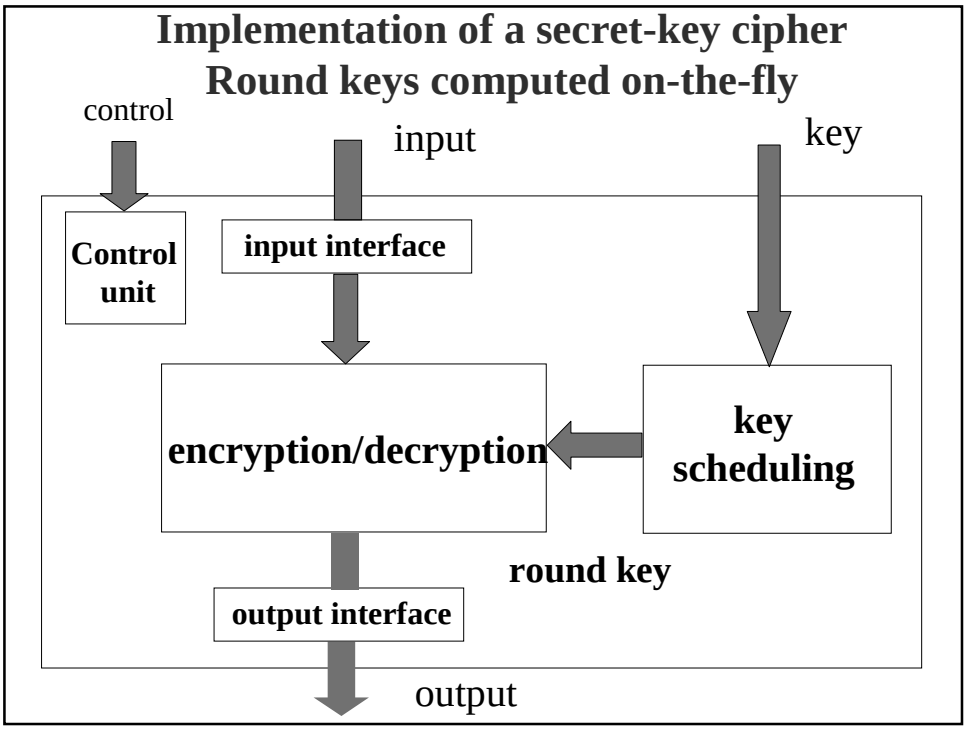
Decryption

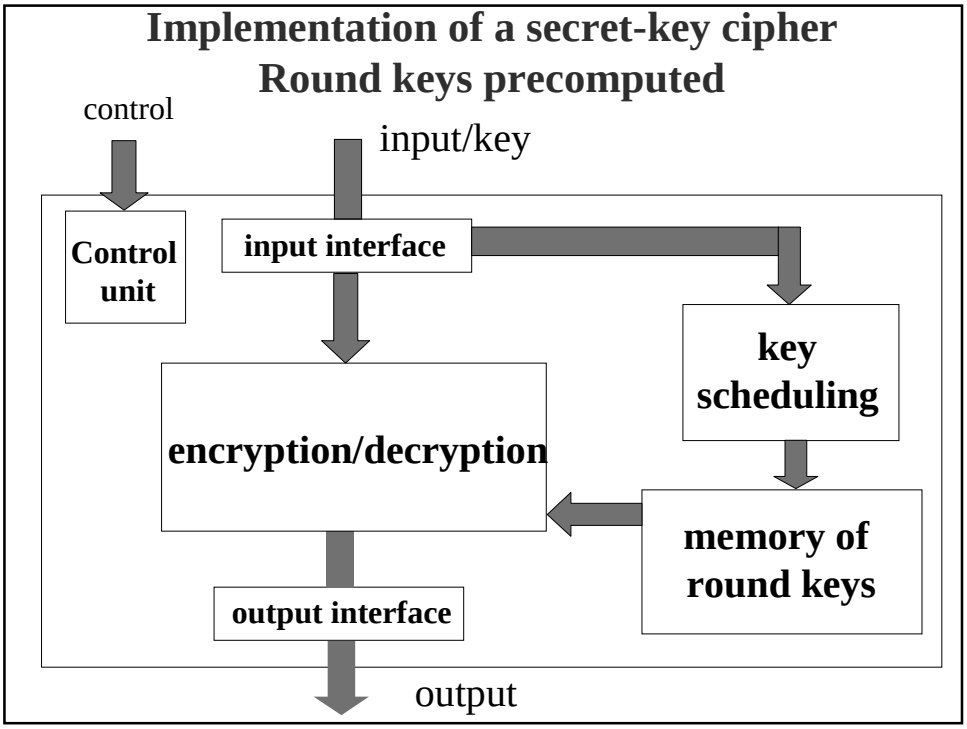




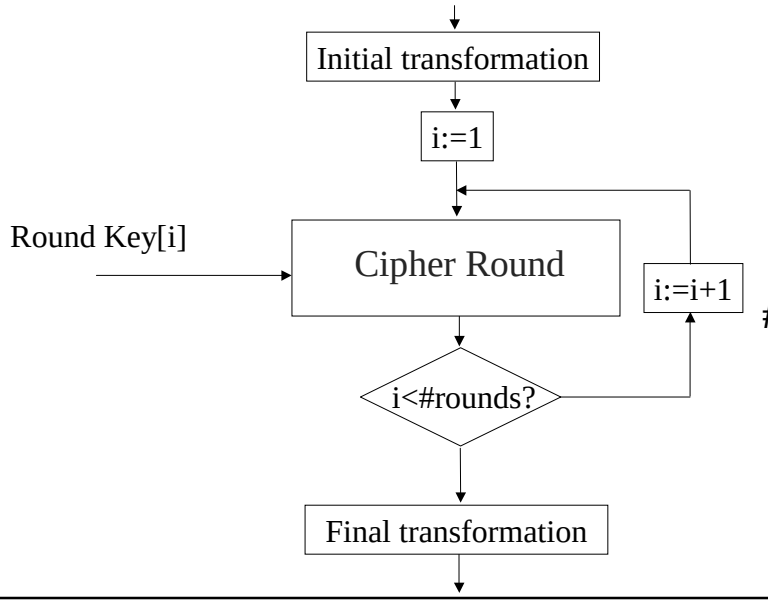


Implementing DES

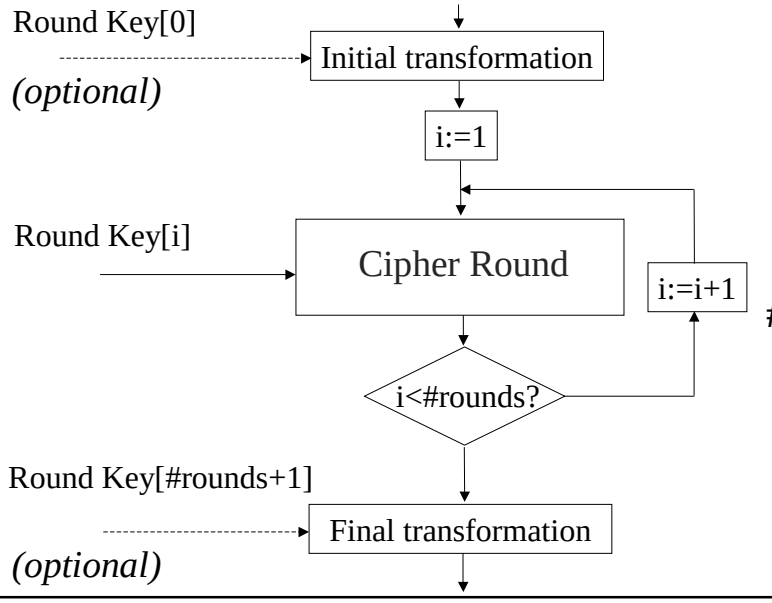

Implementation of a secret-key cipher
Round keys computed on-the-fly
control
input
key
Control unit
input interface
encryption/decryption
key scheduling
round key
output interface
output


Implementation of a secret-key cipher
Round keys precomputed
control
input/key
Control unit
input interface
key scheduling
encryption/decryption
memory of round keys
output interface
output

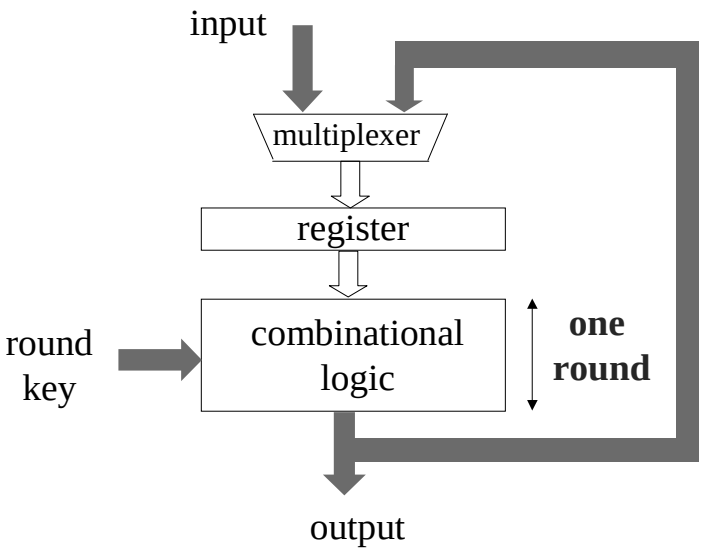
Flow Diagram of the Encryption/Decryption Unit of DES



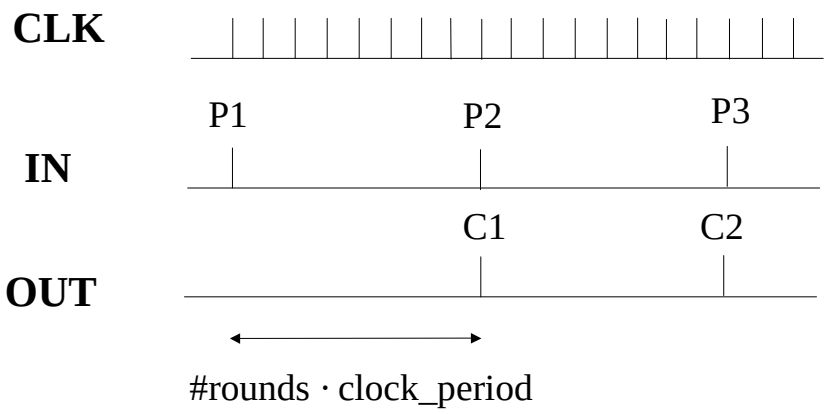
Typical Flow Diagram of a Secret-Key Block Cipher



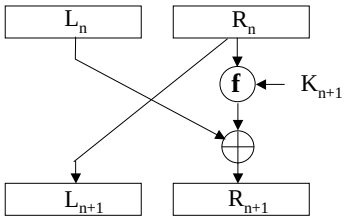
Basic iterative architecture



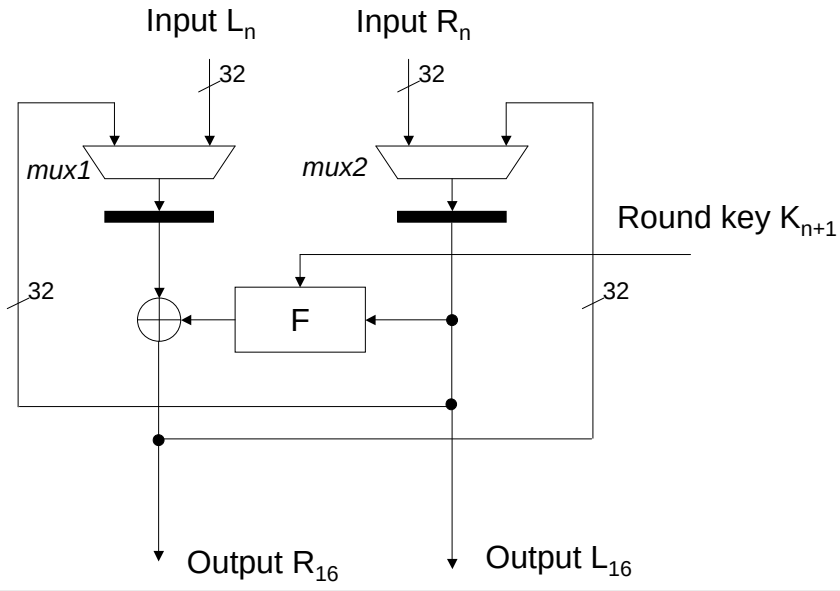
Basic architecture: Timing



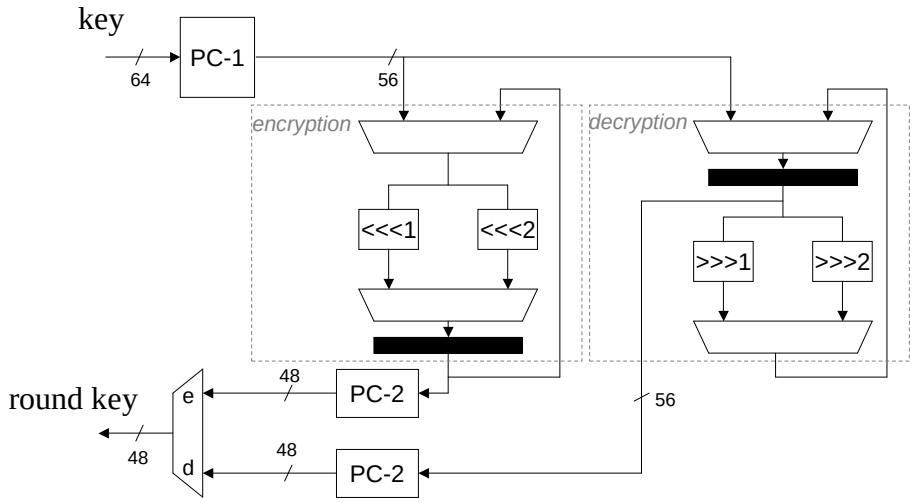
Structure of a single round



DES: Basic Architecture
Encryption/Decryption Unit



DES: Basic Architecture
Key scheduling



Breaking DES

Theoretical design of the specialized machine to break DES

Project: Michael Wiener, Entrust Technologies, **1993, 1997**

Method: **exhaustive key search attack**

Basic component: specialized integrated circuit in CMOS technology, 75 MHz

Checks: **200 mln keys per second**

Costs: $10

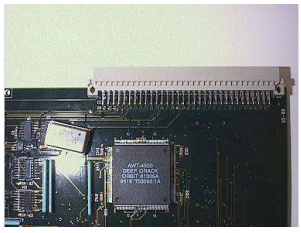
Total cost	Estimated time
$ 1 mln	**35 minutes**
$ 100.000	6 hours

Deep Crack

Electronic Frontier Foundation, 1998

Total cost: $220,000

Average time of search: 4.5 days/key



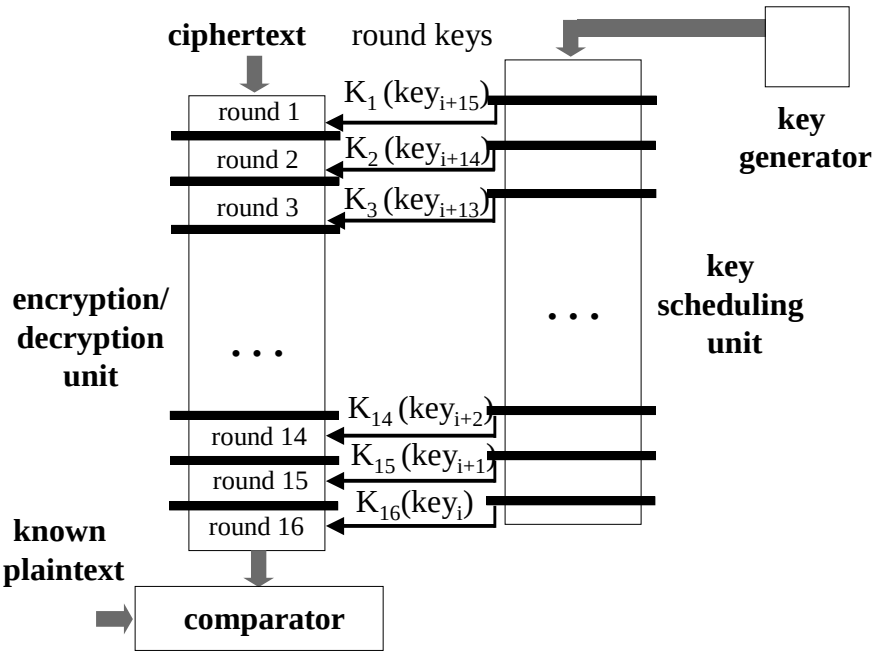
1800 ASIC chips, 40 MHz clock

Deep Crack

Parameters

Number of **ASIC** chips	**1800**
Clock frequency	**40 MHz**
Number of clock cycles per key	16
Number of search units per ASIC	24
Search speed	**90 bln keys/s**
Average time to recover the key	**4.5 days**

DES breaking machine architecture



Minimum length of the key for symmetric ciphers

I. Panel of experts, January 1996

M. Blaze, W. Diffie, R. Rivest, B. Schneier, T. Shimomura, E. Thompson, M. Wiener

Report:

"Minimal Key Lengths for Symmetric Ciphers to Provide Adequate Commercial Security"

II. National Academy of Sciences, National Research Council, May 1996

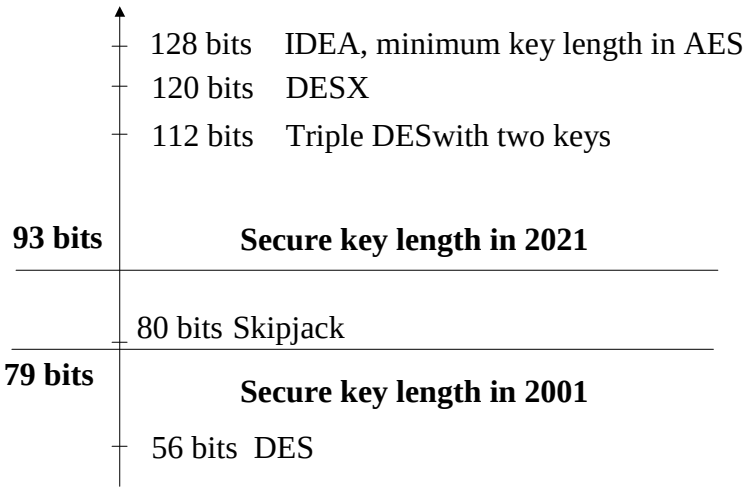
Report**:**

" Cryptography's Role in Securing the Information Society"

Minimum key length for symmetric-key ciphers

Intruder	Budget	Tools	Time		Secure key length
			40 bits	56 bits	
Hacker	tiny	**PC**	**1 week**	infeasible	45
Small business	$400	FPGA	5 hrs	38 years	50
	$10,000	FPGA	12 min	18 months	55
Corporate department	**$300 K**	**FPGA**	**24 sec**	19 days	60
		ASIC	18 sec	**3 hrs**	
Big company	$10 M	FPGA	7 sec	13 hrs	70
		ASIC	5 ms	6 min	
Intelligence agency	$300 M	ASIC	0.2 ms	12 sec	75

Secure key length today and in 20 years



Secure key length - discussion

- increasing key length in a newly developed cipher costs NOTHING
- increasing effective key length, assuming the use of an existing cipher has a limited influence on the efficiency of implementation (DESX, Triple DES)

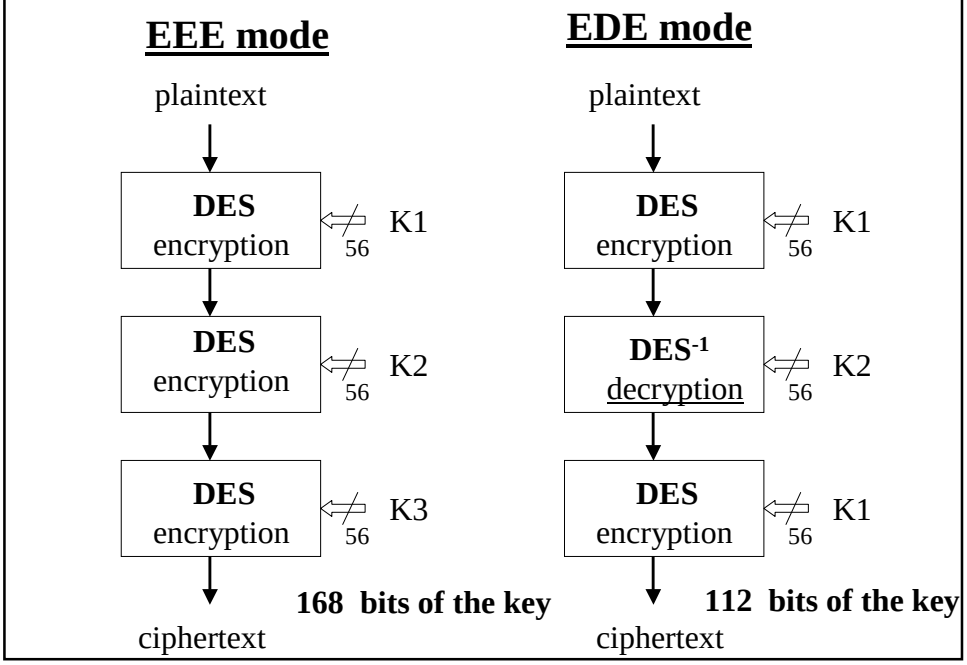
It is economical to use THE SAME secure key length FOR ALL aplications

The primary barriers blocking the use of symmetric ciphers with a secure key length have been of the political nature (e.g., export policy of USA)

Extensions of DES

Triple DES

Diffie, Hellman, 1977



Triple DES

Advantages:

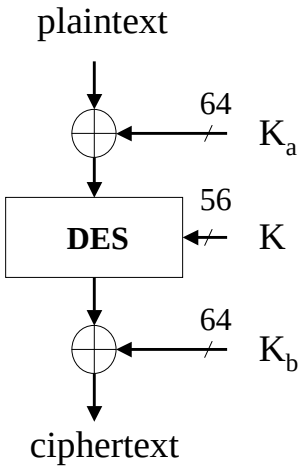
- secure key length (112 or 168 bits)
- increased compared to DES resistance to linear and differential cryptanalysis
- possibility of utilizing existing implementations of DES

Disadvantages:

- relatively slow, especially in software

DESX

Rivest, 1988



KEY = (K, K_a)

120 bits

K_b = hash function(K, K_a)