ECE 297:11 Lecture 5

64-bit Secret-Key Ciphers: IDEA & RC5

IDEA

X. Lai, J. Massey
ETH, 1990-91

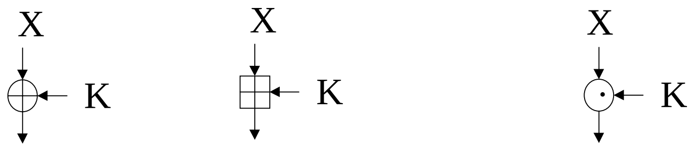
• 128-bit key (**billion machines** each checking **billion keys per second** still would require **10 trillion years**, to check all keys

• used in **PGP** (Pretty Good Privacy) - the most popular public domain program for secure e-mail

• constructed to provide an absolute resistance against **differential cryptanalysis**

IDEA

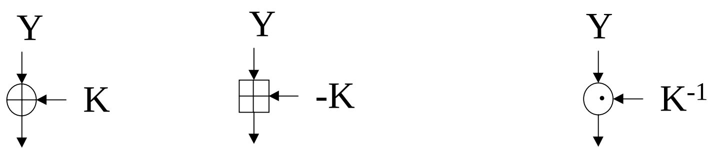
Three basic operations:



$Y = X \oplus K$ $Y = X + K \bmod 2^{16}$ $Y = X \cdot K \bmod (2^{16}+1)$

where 0 represents 2^{16}

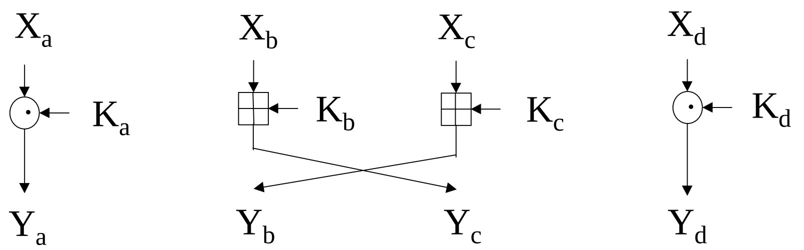
Corresponding inverse operations:



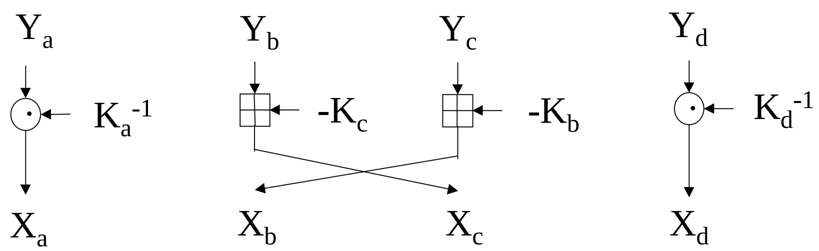
$X = Y \oplus K$ $X = Y+(-K) \bmod 2^{16}$ $X = Y \cdot K^{-1} \bmod (2^{16}+1)$

Half-round of IDEA: Transformation

Forward transformation:

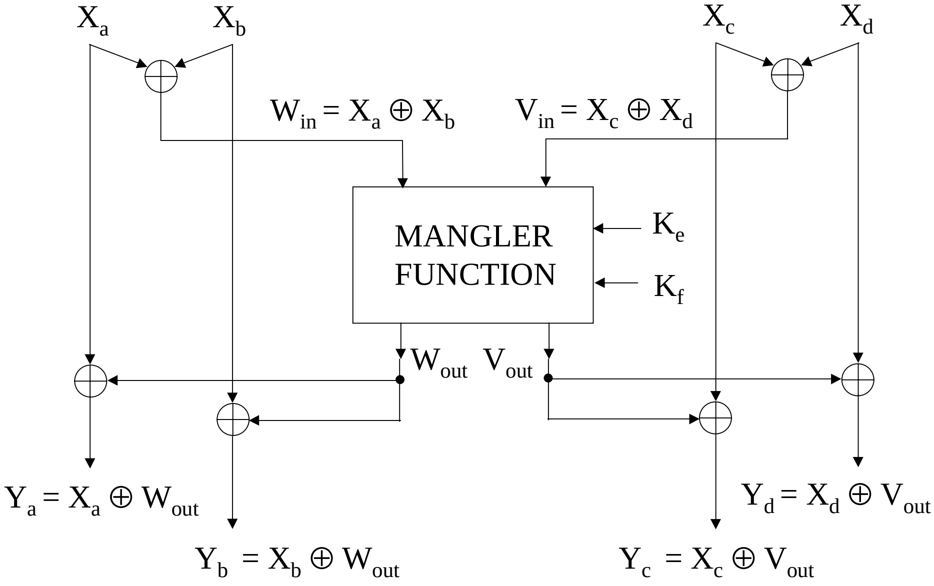


Inverse transformation:



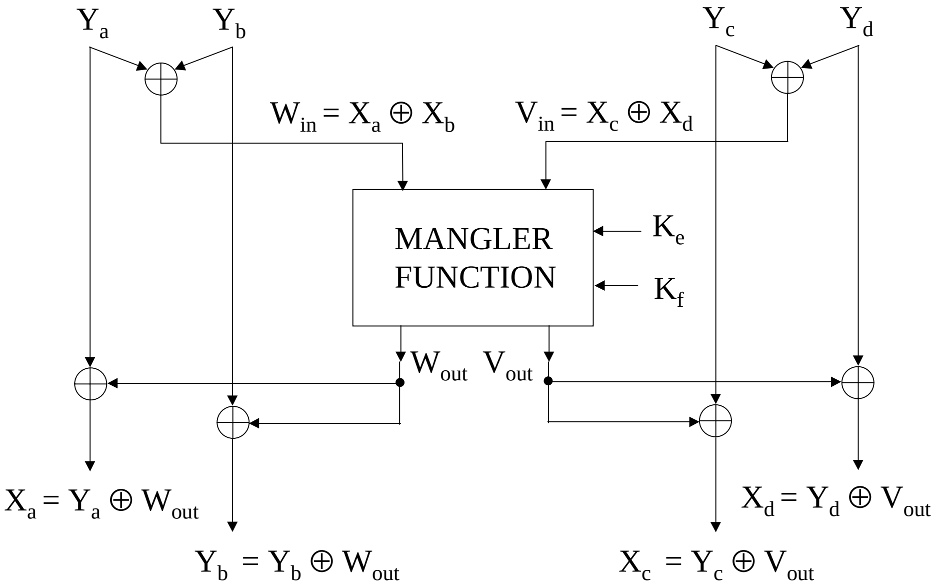
Half-round of IDEA: Sub-encryption

Forward transformation

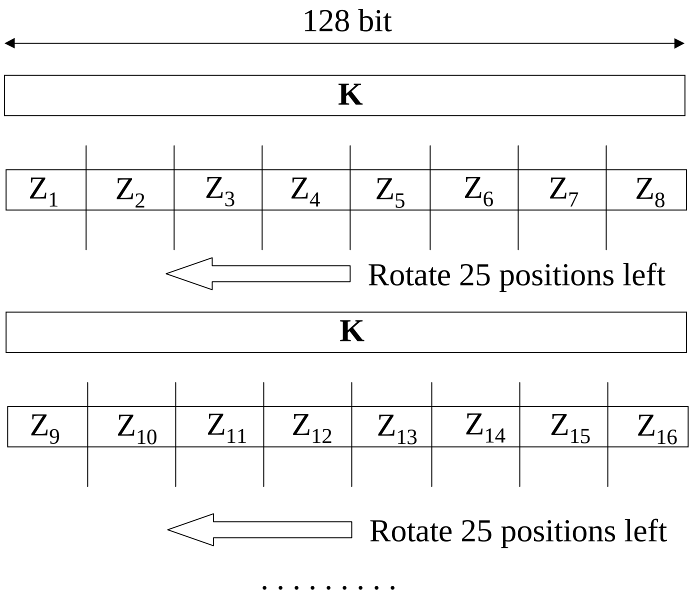


Half-round of IDEA: Sub-encryption

Inverse transformation



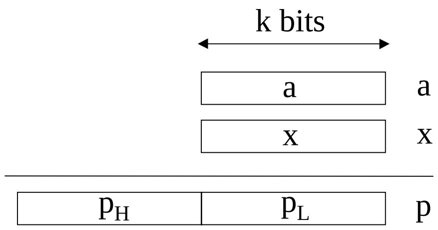
IDEA - Key Scheduling



Implementing IDEA in Hardware

Modular Multiplication

Special Cases



$a\,x = p = p_H\,2^k + p_L$

$a\,x \mod 2^k = p_L$

$a\,x \mod 2^k{+}1 = p_L - p_H - \text{borrow}$

$a\,x \mod 2^k{-}1 = p_L + p_H + \text{carry}$

Modular Multiplication

Special Case (1)

$$
\begin{aligned}
a\,x \mod 2^k{+}1 &= (p_H\,2^k + p_L) \bmod (2^k{+}1) = \\
&= (p_H\,(2^k{+}1{-}1) + p_L) \bmod (2^k{+}1) = \\
&= p_L - p_H \bmod (2^k{+}1) = \\
&= \begin{cases} p_L - p_H & \text{if } p_L - p_H \geq 0 \\ p_L - p_H + (2^k{+}1) & \text{if } p_L - p_H < 0 \end{cases} \\
&= p_L - p_H + \text{borrow}
\end{aligned}
$$

borrow = borrow from subtraction $p_L - p_H$

Modular Multiplication

Special Case (2)

$$a\,x \mod 2^k-1 = (p_H\, 2^k + p_L) \mod (2^k-1) =$$
$$= (p_H\, (2^k \mod 2^k-1) + p_L) \mod (2^k-1) =$$
$$= p_H + p_L \mod (2^k-1) =$$
$$= \begin{cases} p_H + p_L & \text{if } p_H + p_L < 2^k - 1 \\ p_H + p_L - (2^k-1) & \text{if } p_H + p_L \geq 2^k - 1 \end{cases}$$
$$= p_L + p_H + \text{carry}$$

carry = carry from addition $p_L + p_H$

RC5

RC5

Ron Rivest, MIT, 1994

(Ron’s Code 5, Rivest’s Cipher 5)

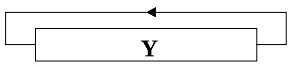
- **variable key length** (40 bits in the former export version, 128 bits to achieve the same strength as IDEA)
- **variable block size** (depends on the processor word length)
- **variable number of rounds** (determines resistance to linear and differential cryptanalysis; for 9 rounds this resistance is greater than for DES)
- **simplicity of description**

RC5

One of the fastest ciphers

Basic operation

Rotation by a variable number of bits



$Y=Y<<X$

RC5 w/r/b

w - word size in bits w = 16, 32, 64

input/output block = 2 words = 2·w bits

Typical value:

w=32 ⇒ 64-bit input/output block

r - number of rounds

b - key size in bytes $0 \le b \le 255$

key size in bits = 8·b bits

Recommended version: RC5 32/12/16

64 bit block
12 rounds
128 bit key

RC5

Encryption

```
A || B = M

A = A + S[0]
B = B + S[1]

for i= 1 to r do
  {
   A= (A⊕B) <<< B + S[2i]
   B= (B⊕A) <<< A + S[2i+1]
  }

C= A || B
```

Decryption

```
A || B = C

for i= r downto 1 do
  {
   B= ((B–S[2i+1]) >>> A) ⊕ A
   A= ((A – S[2i])>>>B) ⊕ B
  }

B = B – S[1]
A = A – S[0]

M= A || B
```

RC5 - Key Scheduling

k bits of the main key

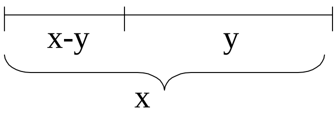
$2 \cdot r + 2$ round keys $= (2 \cdot r + 2) \cdot w$ bits

Two magic constants:

$P_w = \text{Odd}((e-2) \cdot 2^w)$

e - base of natural logarithms
e = 2.7182...

$Q_w = \text{Odd}((\varphi-1) \cdot 2^w)$



φ - golden ratio $= \dfrac{x}{y} = \dfrac{y}{x-y} = 1.6180...$

RC5 - Key Scheduling

Initialize

$S[0] = P_w$
for i=0 to t-1 do
    $S[i] = S[i] + Q_w$

Mix

```
i = j = 0
A = B = 0
do  3 · max{t, c} times
   {
     A = S[i] = (S[i] + A + B) <<< 3
     B = L[j] = (L[j] + A + B) <<< (A+B)
     i = (i+1) mod t
     j = (j+1) mod c
   }
```

$t = 2 \cdot r + 2$

$c = \left\lceil \dfrac{8 \cdot b}{w} \right\rceil$

RC5 - Resistance to differential and linear cryptanalysis

Plaintext requirement

# rounds	4	5	6	7	9	12	13
Differential Cryptanalysis	2^{22}	2^{26}	2^{32}	2^{37}	$\mathbf{2^{46}}$	2^{63}	$>2^{64}$
Linear Cryptanalysis	2^{37}	$\mathbf{2^{47}}$	2^{57}	$>2^{64}$			

Differential cryptanalysis cannot be applied to RC5 with #rounds ≥ 13

Linear cryptanalysis cannot be applied to RC5 with #rounds ≥ 7

Security of Modern Ciphers

Resistance of modern ciphers against known attacks

Proprietary ciphers built in application software	mostly insecure, seconds on PC
Propriatery ciphers with unknown specification	uncertain, impossible to verify
40-bit "international" version of ciphers	Keys recoverable using several hours with a small network of computers
DES	Keys can be recovered within 24 hours using a specialized machine worth about $300,000
Triple DES, DESX, RC5, IDEA	**All known attacks impractical**

State of research regarding the security of secret-key ciphers

- limited number (20-50) of researchers actively involved in cryptanalysis and design of new ciphers
- number of published ciphers > 50
- evaluations of the cipher strength given by designers typically unreliable

"Honest" cipher = the best known attack is an exhaustive key search attack

One can rely only on ciphers analyzed by a large group of qualified researchers