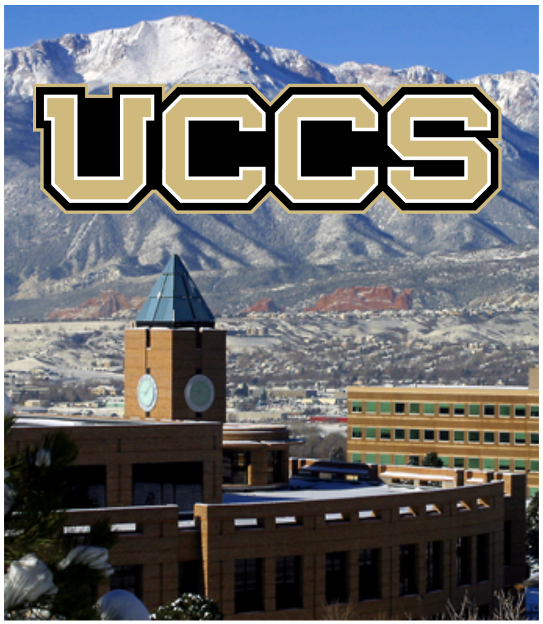


Symmetric Cryptography

**3-DES and AES**

Sang-Yoon Chang, Ph.D.

**Module: 3-DES and AES**

Double-DES

Meet-in-the-Middle Attack

Triple Data Encryption Standard (3-DES)

Advanced Encryption Standard (AES)

**DES Security**

Brute Force attacks in practice

Cryptanalytic attacks that can further reduce the complexity

Timing attacks on computation

**Double-DES**

DES Encryption (Enc) and Decryption (Dec)

Double-DES has two encryption stages
and two different keys ($K_1$, $K_2$):
$C = Enc(K_2, Enc(K_1, P));$
$P = Dec(K_1, Dec(K_2, C));$

**Double-DES**

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Two keys (112 bits) ➔ 112 bits of entropy?

**Meet in the Middle Attack**

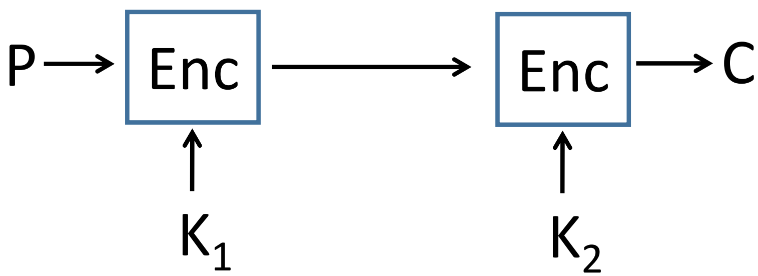
Applies for any block encryption cipher

$C = Enc(K_2, Enc(K_1, P))$

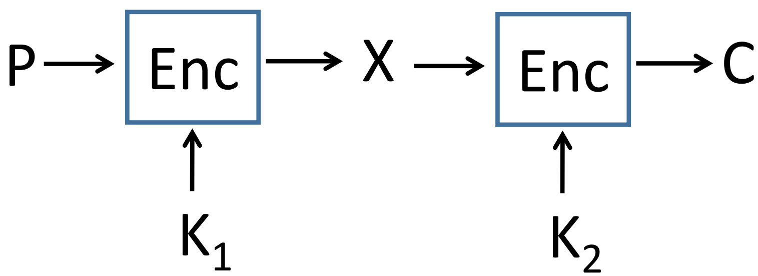
➔ $X = Enc(K_1, P) = Dec(K_2, C)$

Known plaintext attack

# Meet in the Middle Attack



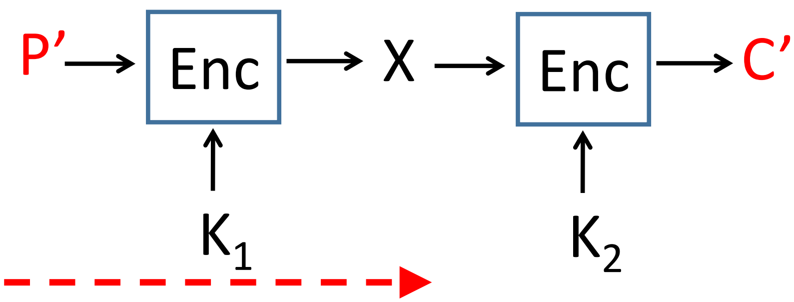
# Meet in the Middle Attack



# Meet in the Middle Attack

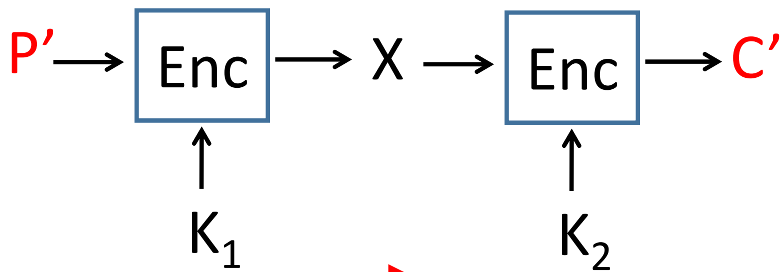
$$\begin{tikzcd}
P' \arrow[r] & \boxed{\text{Enc}} \arrow[r] & X \arrow[r] & \boxed{\text{Enc}} \arrow[r] & C' \\
 & K_1 \arrow[u] & & K_2 \arrow[u] &
\end{tikzcd}$$

# Meet in the Middle Attack




Compute and store $2^{56}$ P’→X mappings using different $K_1$’s

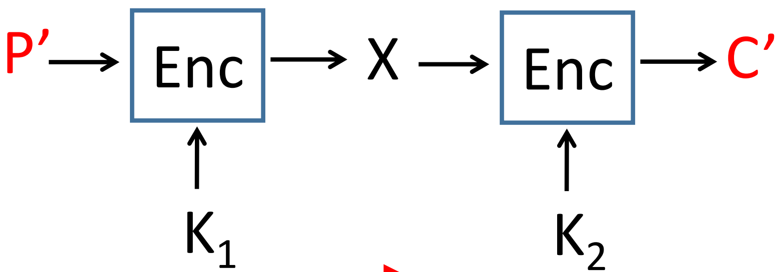
# Meet in the Middle Attack




Compute and store $2^{56}$ P’→X mappings using different $K_1$’s

Compute $2^{56}$ C’→X decryptions using $K_2$’s

# Meet in the Middle Attack




Compute and store
$2^{56}$ P'→X mappings
using different $K_1$'s

Compute $2^{56}$ C'→X
decryptions using $K_2$'s

Compare X's from two directions;
If the same, try with different
known plaintexts (P'',C'')

**Meet in the Middle Attack** 

Attacker effort is $O(2^{56})$ and not $O(2^{112})$,

c.f., DES is $O(2^{55})$

**Triple-DES**

Triple-DES has three encryption stages:

$C = Enc(K_3, Dec(K_2, Enc(K_1, P)))$

$P = Dec(K_1, Enc(K_2, Dec(K_3, C)))$

**Triple-DES**

Triple-DES has three encryption stages:

$C = Enc(K_3, Dec(K_2, Enc(K_1, P)))$

$P = Dec(K_1, Enc(K_2, Dec(K_3, C)))$

Supports compatibility with single-DES

(Not recommended)

**Triple-DES Keys**

Key option 1: $K_1$, $K_2$, $K_3$ are independent

Key option 2: $K_1$, $K_2$ independent; $K_3 = K_1$

Key option 3: $K_3 = K_2 = K_1$
Equivalent to single-DES (ill-advised)

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Makes the meet-in-the-middle attack
effort $O(2^{112})$, c.f., double-DES $O(2^{56})$

**Triple-DES Keys**

Key option 1: $K_1$, $K_2$, $K_3$ are independent

Key option 2: $K_1$, $K_2$ independent; $K_3 = K_1$

➔ $C = Enc(K_1, Dec(K_2, Enc(K_1, P)))$

Makes the meet-in-the-middle attack effort $O(2^{112})$, c.f., double-DES $O(2^{56})$

**Advanced Encryption Standard (AES)**

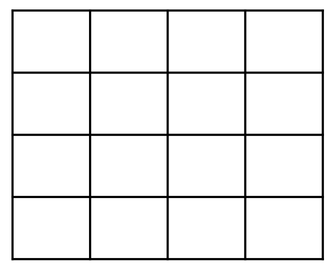
In 1997, US NIST call for ciphers
In 2001, standardized (FIPS PUB 197)

Replace DES and resist known attacks
Design simplicity
Speed and code compactness in CPU

# **Advanced Encryption Standard (AES)**

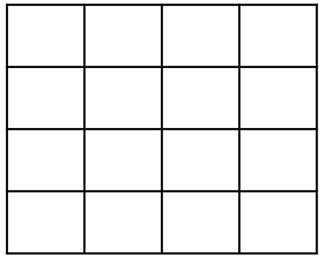
Byte-based processing and operations

128-bit (16B) block size with
128/192/256 bit key size



Not based on Feistel Cipher but based
on substitution and transposition

## AES Rounds

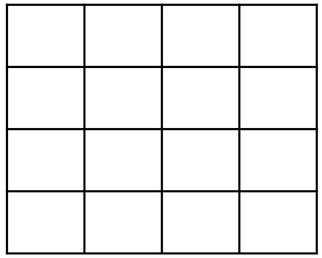


←Processes the data as 4x4 matrix of 16 bytes total (Each element is a Byte) "State array"

Iterated block cipher with rounds (different round keys)

In addition to the initial round (XOR),
10 rounds for 128-bit key
12 rounds for 192-bit key
14 rounds for 256-bit key

## AES Rounds

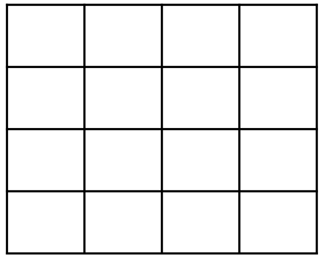


←Processes the data as 4x4 matrix of 16 bytes total (Each element is a Byte) "State array"

Except for initial (AddRoundKey only) and final round (excluding MixColumns), all rounds go through the following steps:

- SubBytes: Substitution using look-up table
- ShiftRows: Row-based transposition
- MixColumns: Column-based mapping
- AddRoundKey: XOR w/ 16B round key (KeyExapnsion: Round key generated)

# AES



←Processes the data as 4x4
matrix of 16 bytes total
(Each element is a Byte)
"State array"

Only AddRoundKey uses key
(the cipher starts and ends with the step)

Additional AddRoundKey at the start,
and the final round is different

Each step is reversible

**AES Decryption**

Uses the round key in the reverse order

Reverse the steps order one-by-one

Except for AddRoundKey (XOR), the
inverse functions are different for
different steps
(Different decryption and encryption)