# IND-CPA

intuition: adversary can query encryption oracle

## Game

challenger | | adversary
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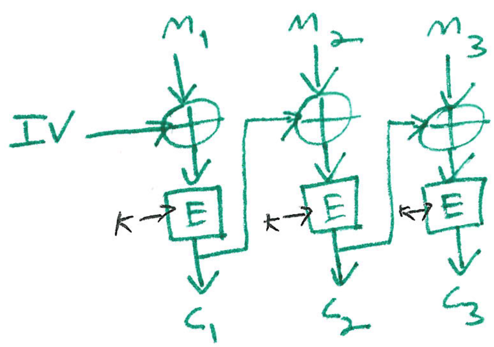
1. $\xleftarrow{\ m_0,\ m_1\ }$
2. $b$ = coin flip
3. $\xrightarrow{\ c = E_k(m_b)\ }$
4. $\xleftarrow{\ m_2\ }$
   $\xrightarrow{\ c_2 = E_k(m_2)\ }$

⋮       ⋮

n. $\xleftarrow{\ b\ }$

## CBC mode

Recall:




**Theorem**: CBC with incremental IV is not CPA secure.

Proof sketch:

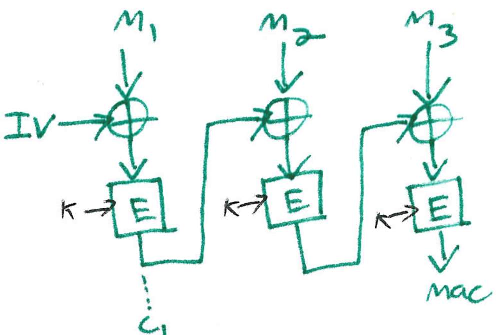
- Adv. gets $c = E_k(m_0 \oplus 1)$ or $c = E_k(m_1 \oplus 1)$
- Adv. queries $m_2 = m_0 \oplus 1 \oplus 2$
- Adv gets $c_2 = E_k(m_2 \oplus 2) = E_k(m_0 \oplus 1 \oplus 2 \oplus 2)$
  $= E_k(m_0 \oplus 1)$
- $b = c_2 == c$

## Integrity:

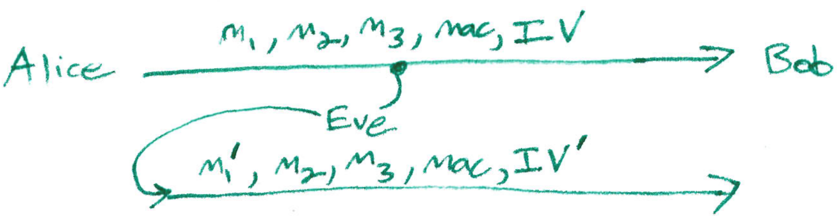
Alice $\xrightarrow{m_1, m_2, m_3, mac}$ Bob

## Recall: CBC-MAC

**Theorem:** CBC-MAC with randomized IV is not secure.




## Proof sketch:




- $c_1 = E_k(m_1 \oplus IV)$
- $c_1' = E_k(m_1' \oplus IV')$
- want $c_1 = c_1'$
- solve for $IV'$: $m_1' \oplus IV' = m_1 \oplus IV$

$$\Rightarrow IV' = m_1' \oplus m_1 \oplus IV$$

# Padding oracle attacks

## Padding scheme

$n$ bytes of padding: $\overbrace{n, n, n, n \ldots n}^{n \text{ times}}$

✓ 0x04, 0x04, 0x04, 0x04

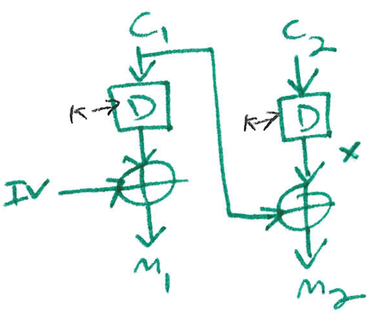
✓ 0x01

✗ 0x49, 0x02

## Padding oracle

Given ciphertext, return "ok" if decrypted message has valid padding or "error" otherwise.

## Recall: CBC decryption




## Padding oracle attack

$$m_2[15] = x[15] \oplus c_1[15]$$

$$c_1'[15] = c_1[15] \oplus g \oplus 0x01$$

$$\begin{aligned} m_2'[15] &= x[15] \oplus c_1'[15] \\ &= x[15] \oplus c_1[15] \oplus g \oplus 0x01 \\ &= 0x01 \text{ if } g = m_2[15] \end{aligned}$$

same for $2^{nd}$ to last byte:

0x02, 0x02

... $16 \times 256$ queries to decrypt whole block!