CSE 484/M584: Computer Security (and Privacy)

Spring 2025

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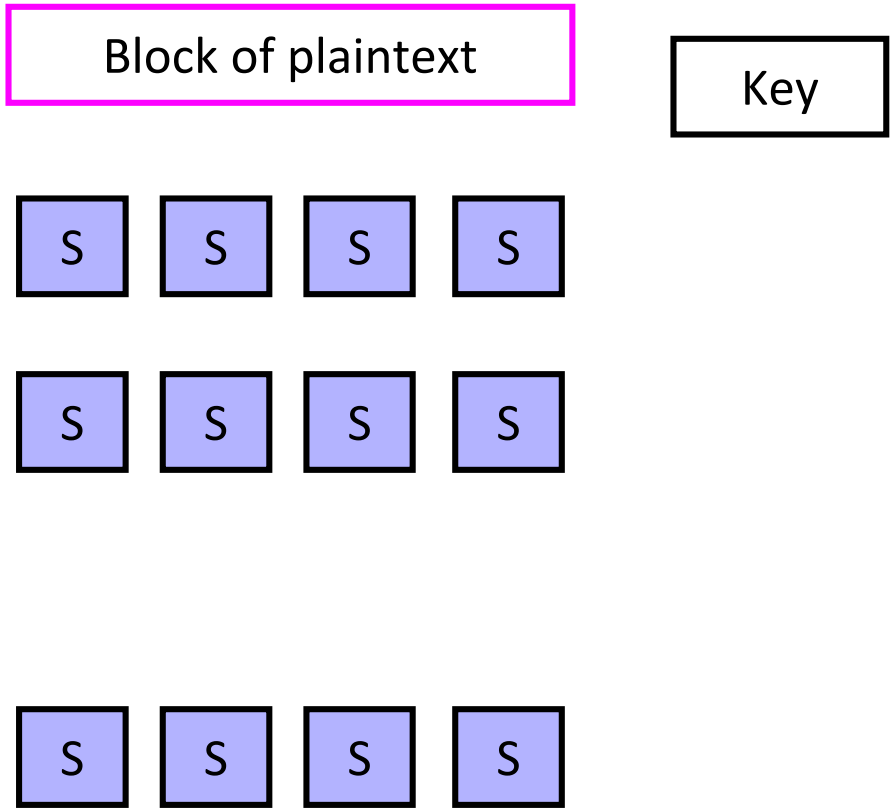
Admin

- Lab1a Grades are out
  - File regrades BEFORE May 7
- HW1 due next wednesday
- Lab 2 (Cryptolab) is out

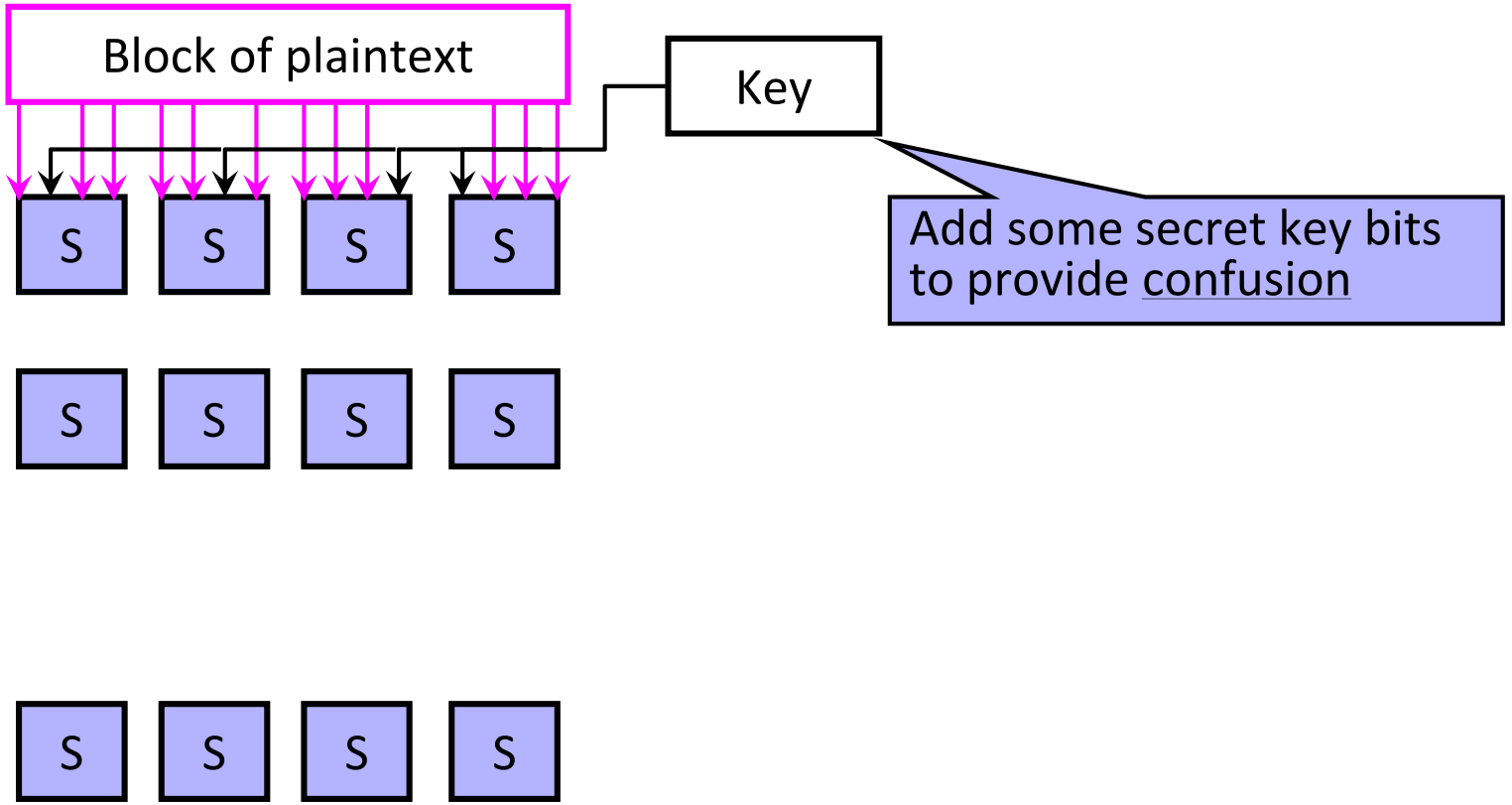
Crosswalk ‘hack’

Symmetric Encryption

Block Cipher Operation (Simplified)



Block Cipher Operation (Simplified)



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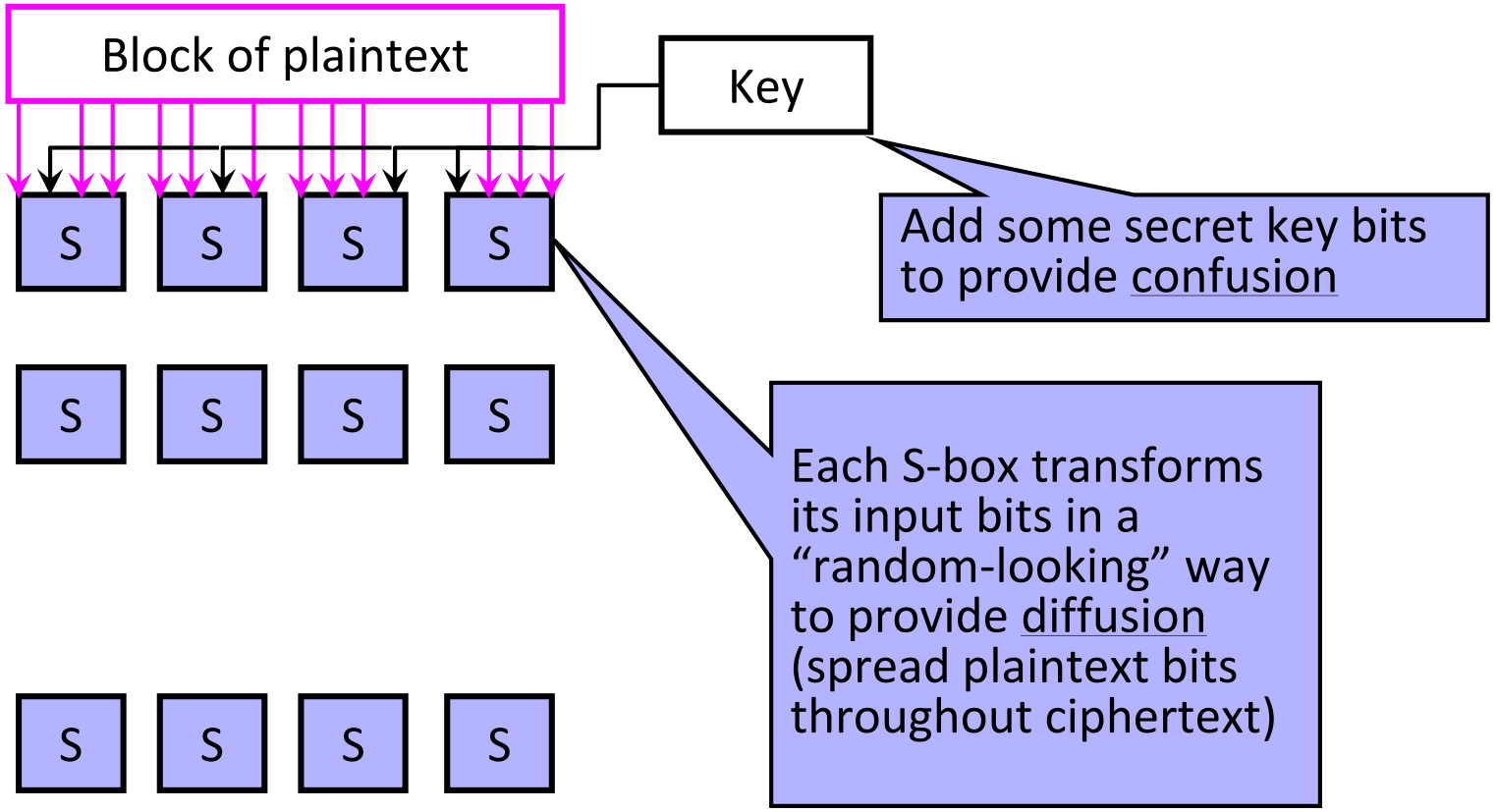

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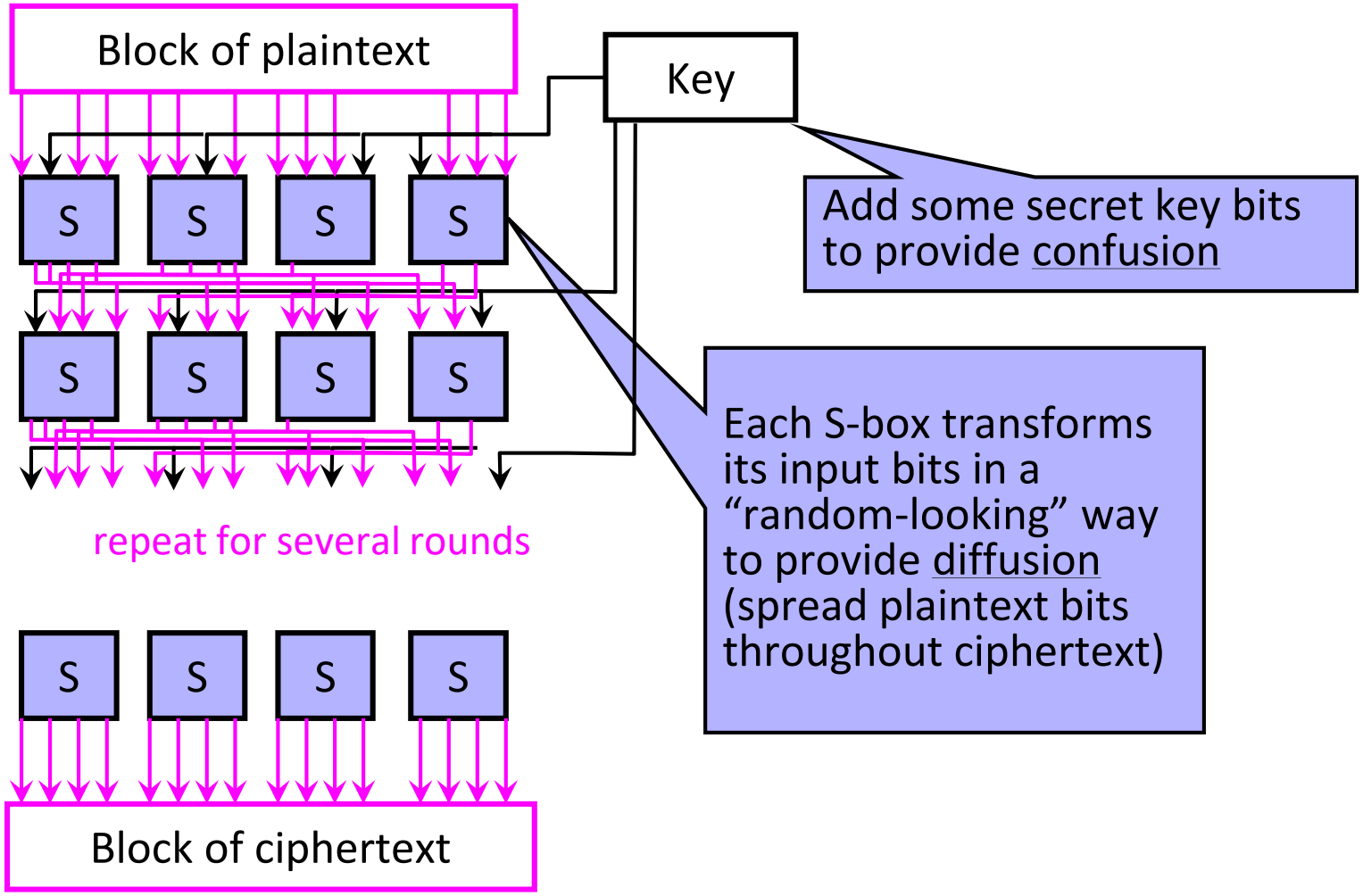
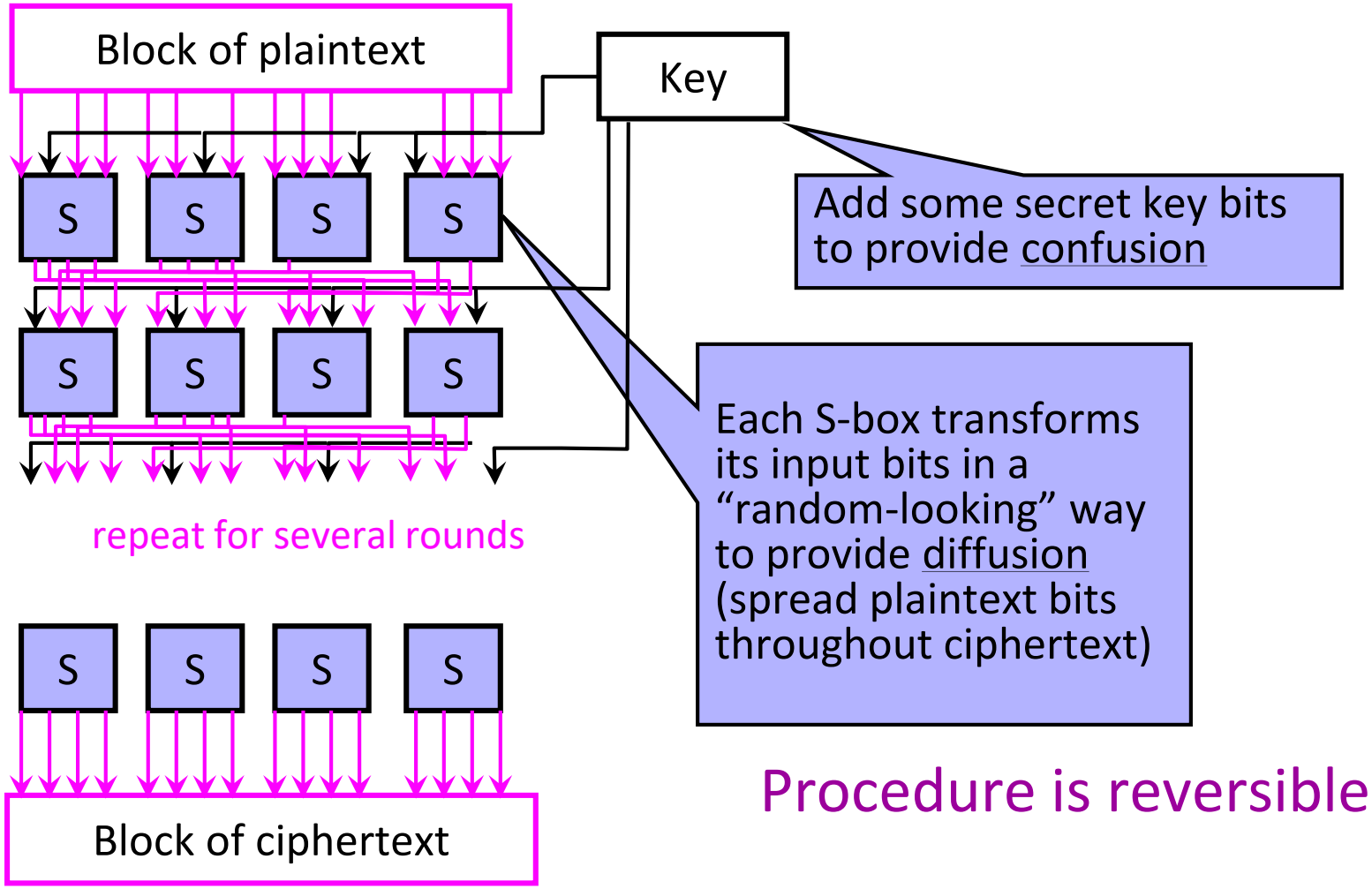


Block Cipher Operation (Simplified)



Procedure is reversible!

Block Cipher Security

- Security: For a randomly selected key: Computationally hard to distinguish outputs of the block cipher from outputs of a truly random permutation

- Popular block ciphers (e.g., AES) do not have proofs of security!
  - Design is open and standard is created through public competition
  - Current best attacks against AES-128 take 2^{126} time
  - Block ciphers with proofs of security exist but are less efficient

Standard Block Ciphers

- **DES: Data Encryption Standard**
  - Feistel structure: builds invertible function using non-invertible ones
  - Invented by IBM, issued as federal standard in 1977
  - 64-bit blocks, 56-bit key + 8 bits for parity

DES and 56 bit keys

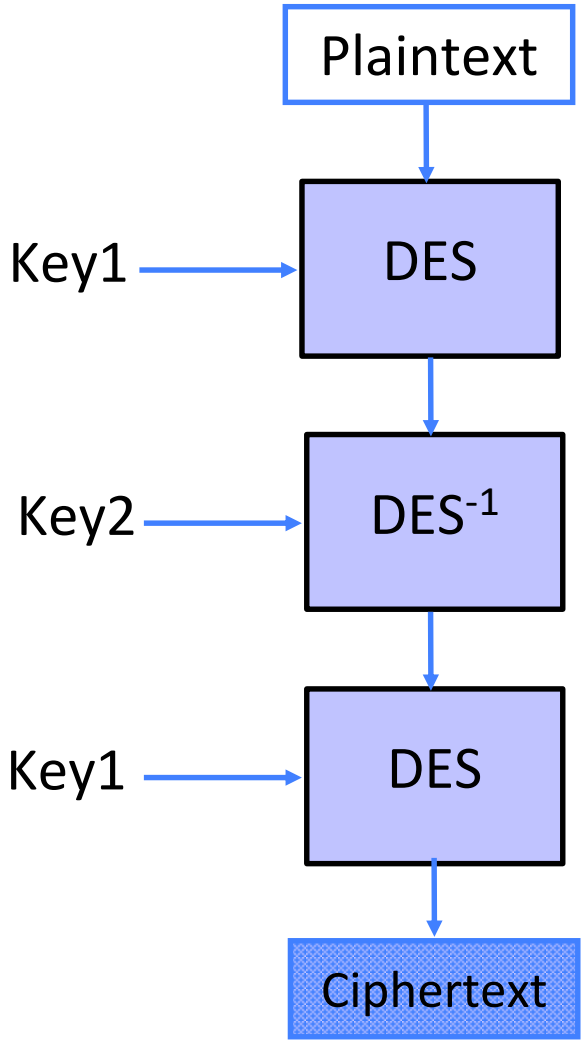
- 56 bit keys are quite short

Key Size (bits)	Number of Alternative Keys	Time required at 1 encryption/μs	Time required at 10^6 encryptions/μs
32	$2^{32} = 4.3 \times 10^9$	$2^{31}\ \mu s = 35.8$ minutes	2.15 milliseconds
56	$2^{56} = 7.2 \times 10^{16}$	$2^{55}\ \mu s = 1142$ years	10.01 hours
128	$2^{128} = 3.4 \times 10^{38}$	$2^{127}\ \mu s = 5.4 \times 10^{24}$ years	5.4×10^{18} years
168	$2^{168} = 3.7 \times 10^{50}$	$2^{167}\ \mu s = 5.9 \times 10^{36}$ years	5.9×10^{30} years
26 characters (permutation)	$26! = 4 \times 10^{26}$	$2 \times 10^{26}\ \mu s = 6.4 \times 10^{12}$ years	6.4×10^{6} years

- 1999: EFF DES Crack + distributed machines
  - < 24 hours to find DES key
- DES ---> 3DES
  - 3DES: DES + inverse DES + DES (with 2 or 3 diff keys)

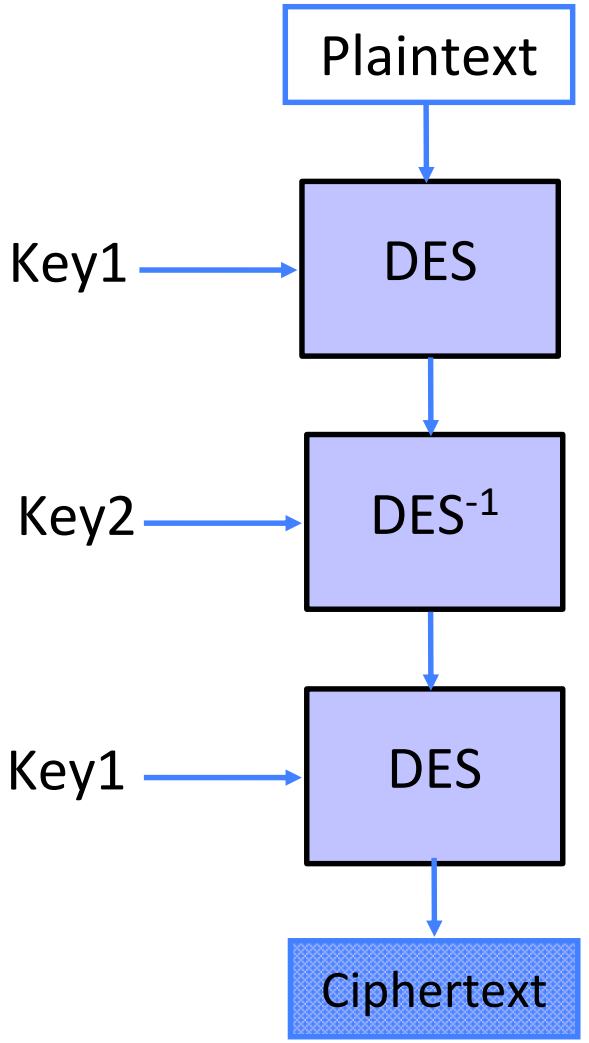
3DES

- Two-key 3DES increases security of DES by doubling the key length
- Why 3DES and not cool-new-scheme?

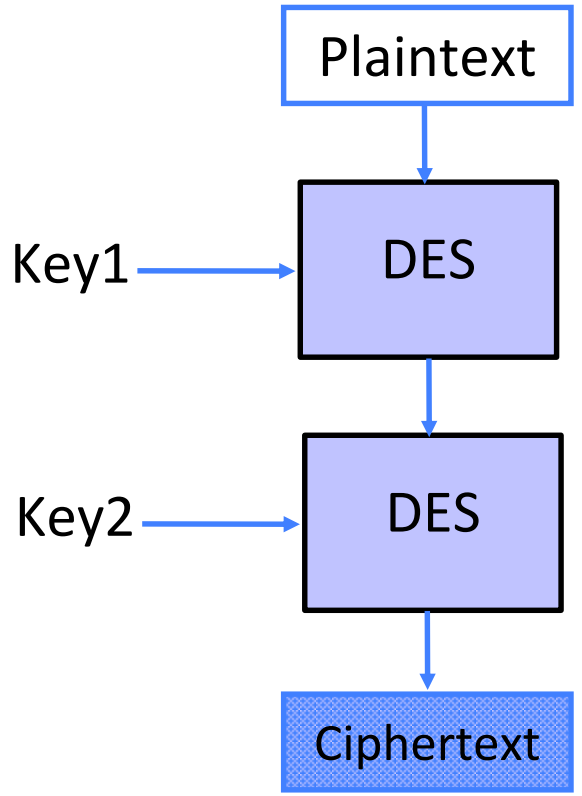


3DES

- Two-key 3DES increases security of DES by doubling the key length
- Why 3DES and not cool-new-scheme?
- Why not 2DES?



Meet-in-the-middle



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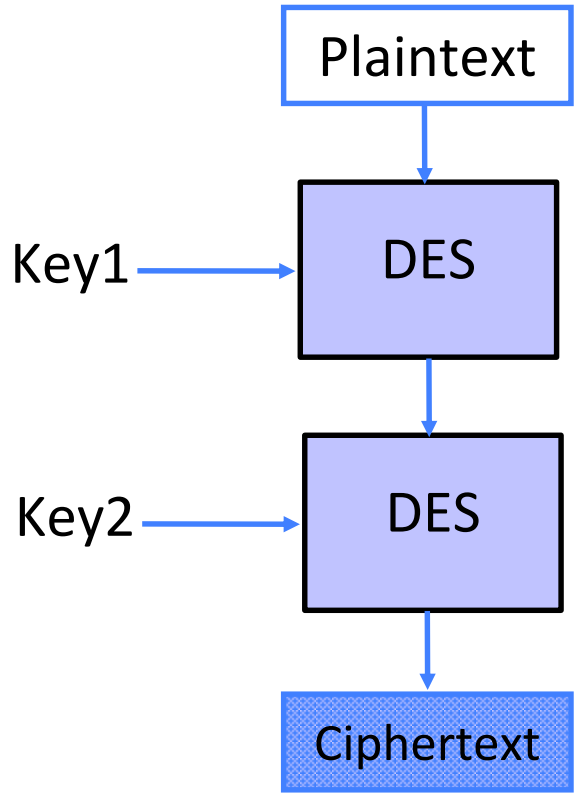
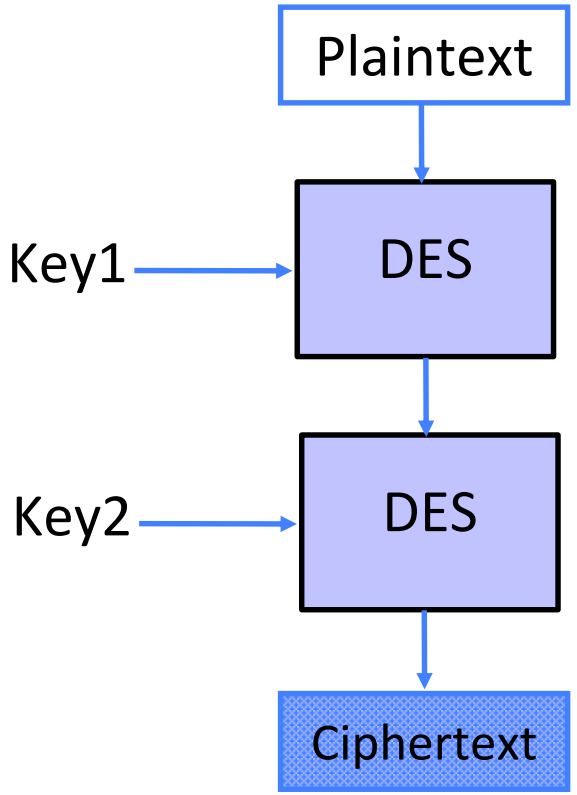


Meet-in-the-Middle Attack

- Guess 2^{56} values for Key1, and create a table from P1 to a middle value M1 for each key guess ($M1^{G1}$, $M1^{G2}$, $M1^{G3}$, …)
- Guess 2^{56} values for Key2, and create a table from C1 to a middle value M'1 for each key guess ($M'1^{G1}$, $M'1^{G2}$, $M'1^{G3}$, …)
- Look for collision in the middle values → if only one collision, found Key1 and Key2; otherwise repeat for (P2,C2), …



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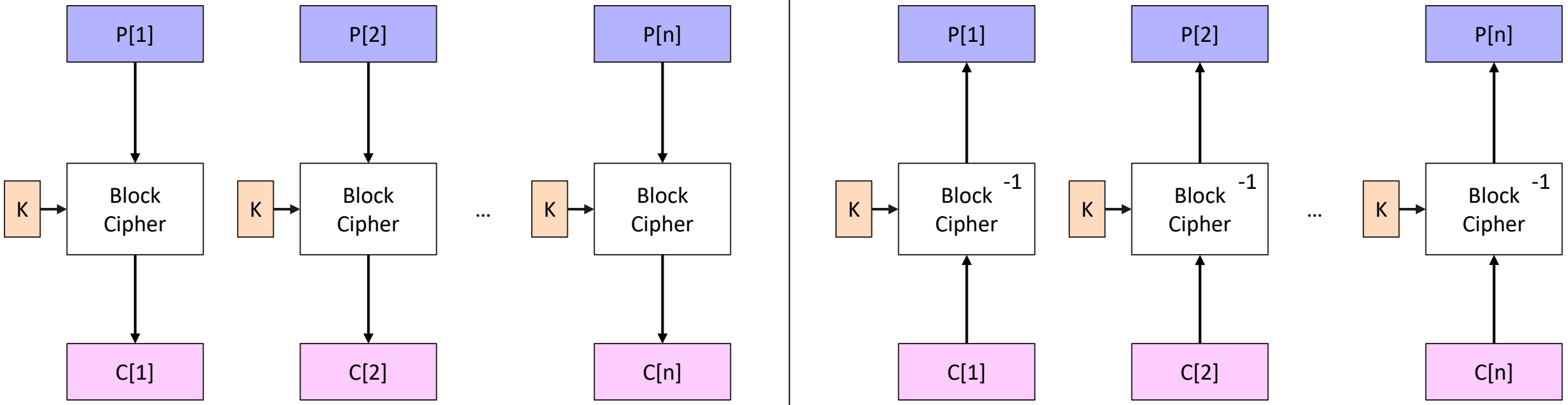
- **AES: Advanced Encryption Standard**
  - New federal standard as of 2001
    - NIST: National Institute of Standards & Technology
  - Based on the Rijndael algorithm
    - Selected via an open process
  - 128-bit blocks, keys can be 128, 192 or 256 bits

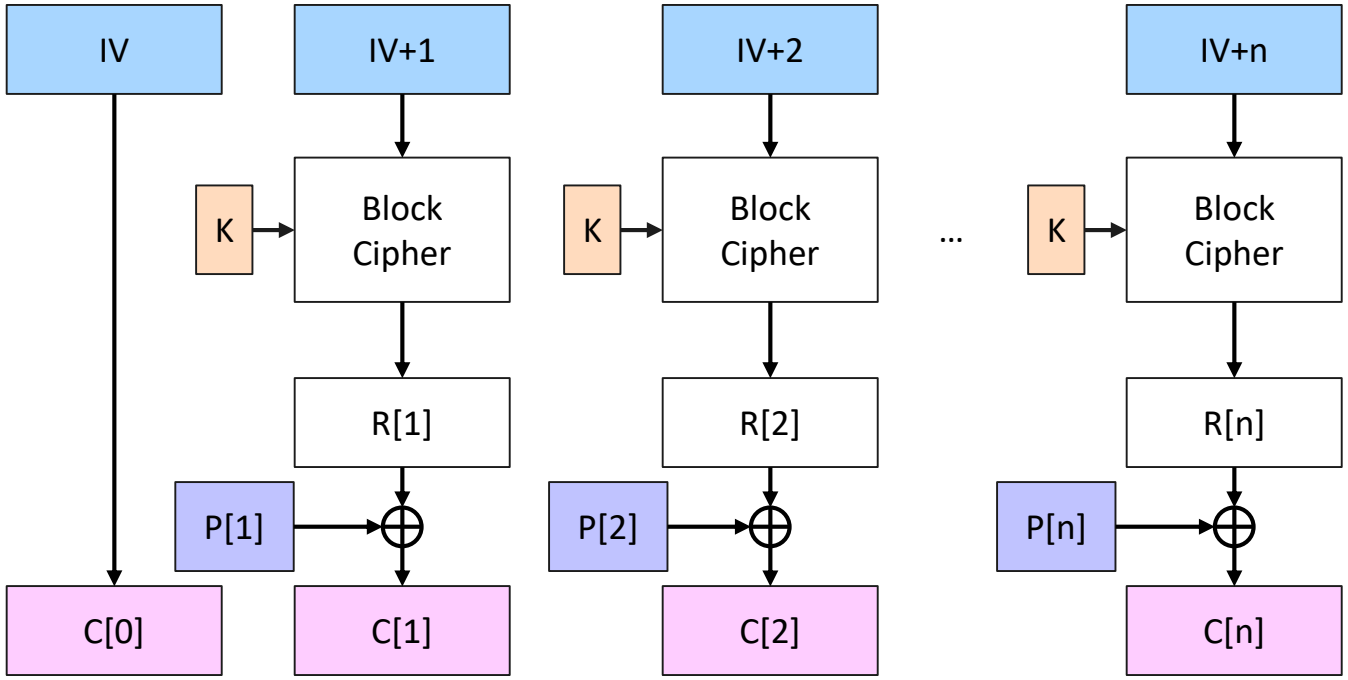
Electronic Code Book (ECB) Mode

- Idea: Simply split up the plaintext into block-sized chunks!



- Identical blocks of plaintext produce identical blocks of ciphertext
- No integrity checks: can mix and match blocks

Counter (CTR) Mode



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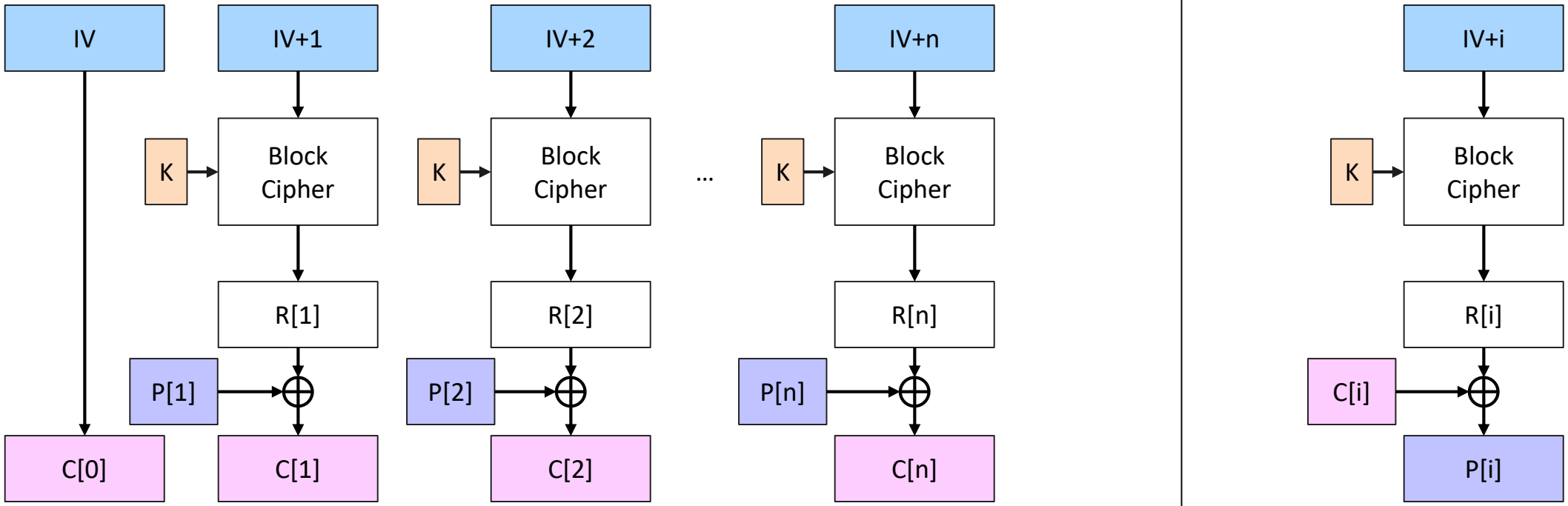

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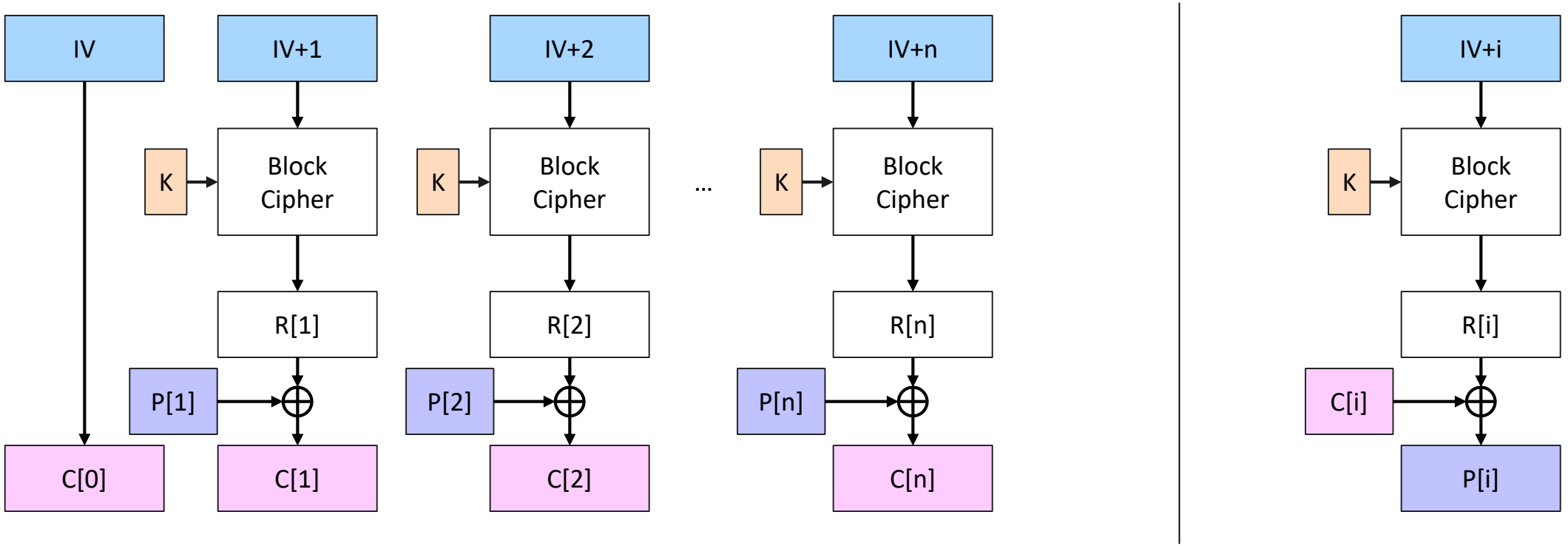
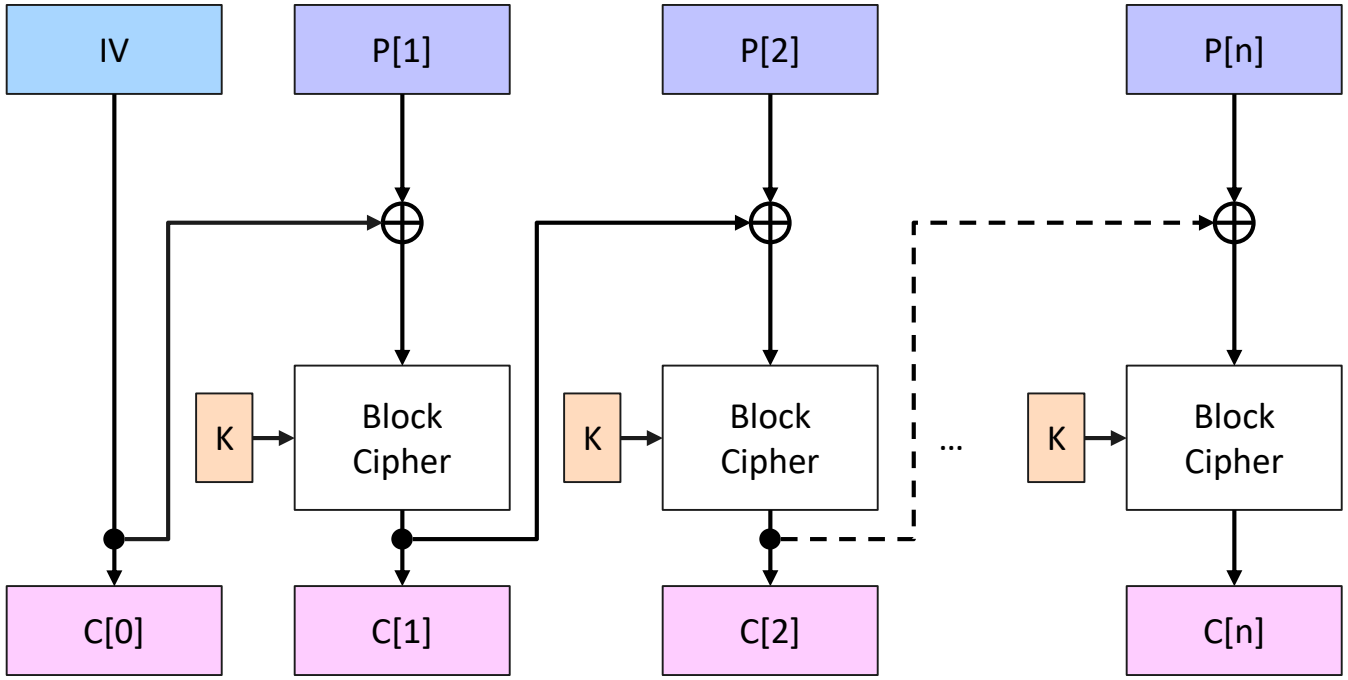
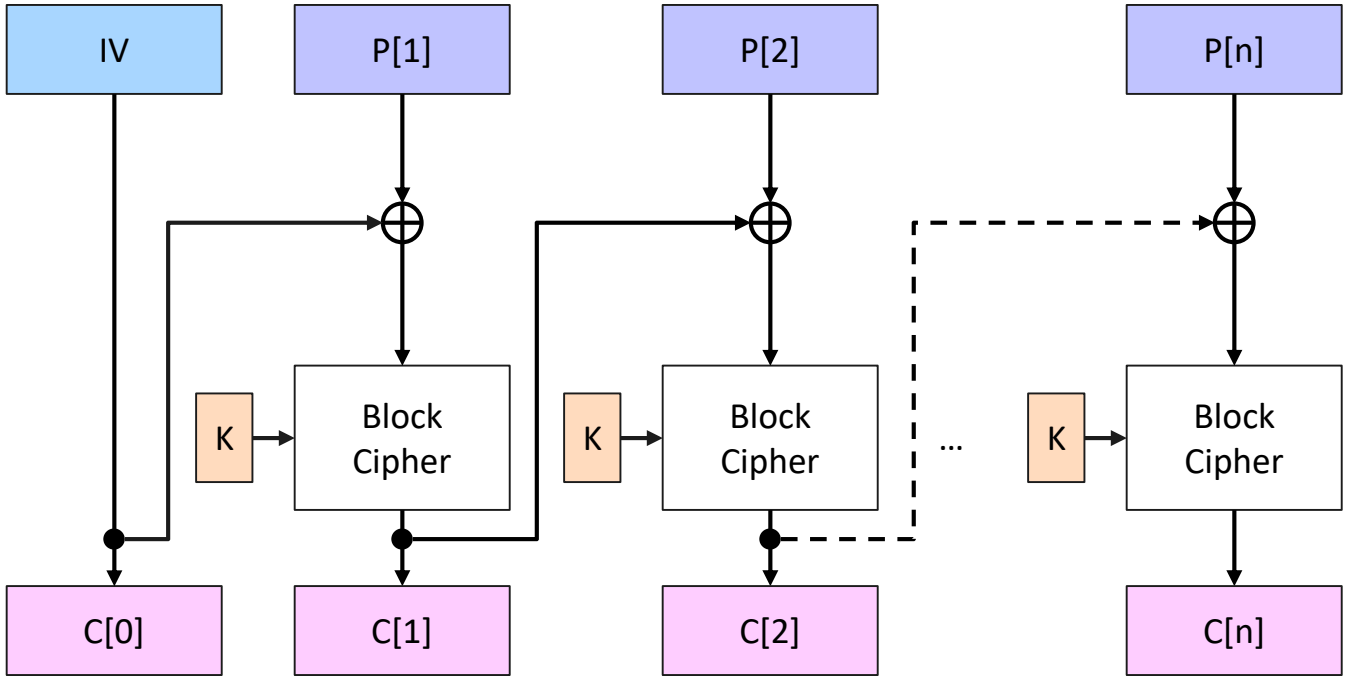


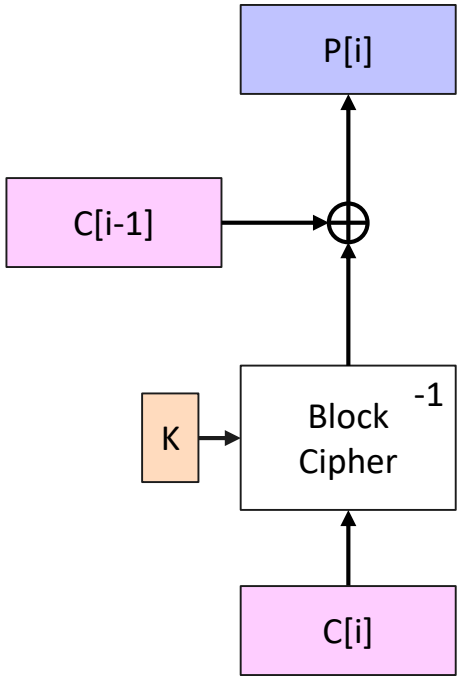
- Security intuition: Outputs of block cipher look like a “random” one-time-pad!
  - As long as initialization vector (IV) is never reused then one-time-pad is never reused
- Parallelizable
- Decryption doesn’t require block cipher inverse (connection to stream cipher and PRNGs)

Cipher Block Chaining (CBC) Mode



Cipher Block Chaining (CBC) Mode





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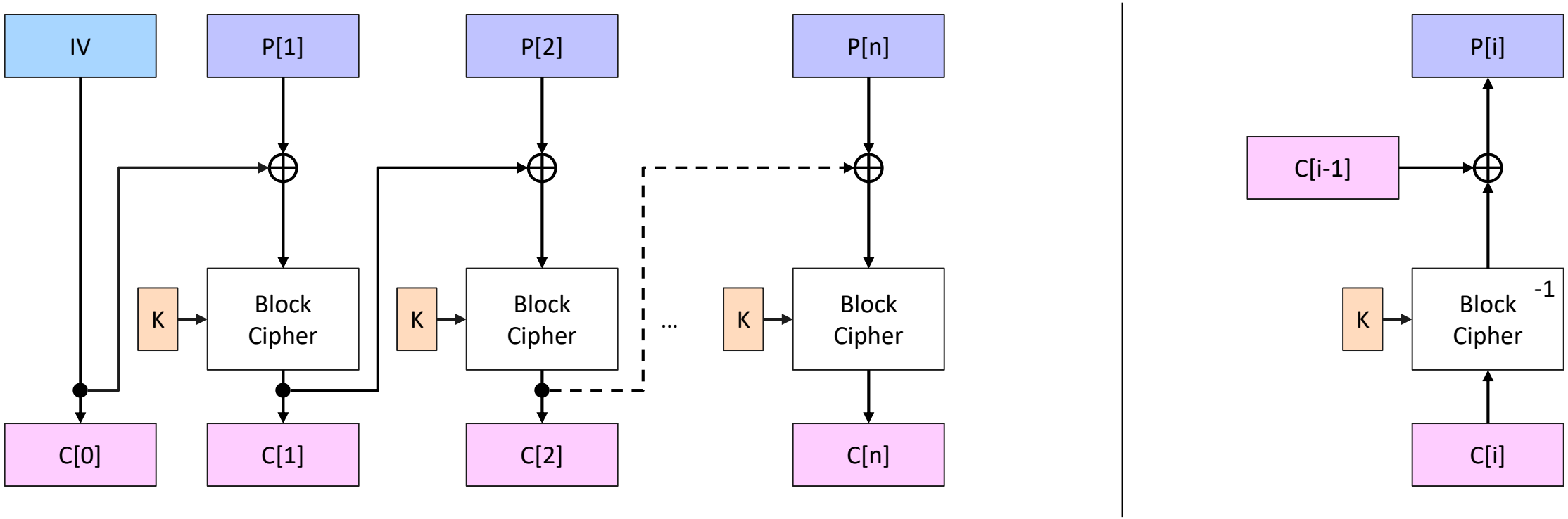
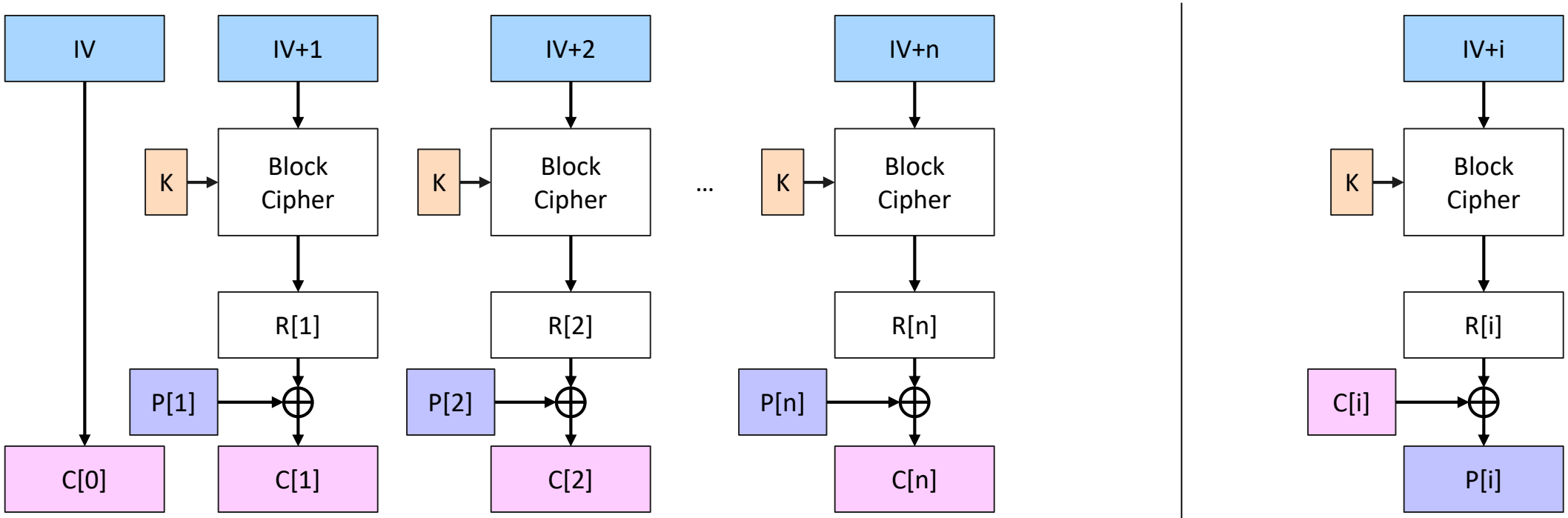


- Security intuition: Ciphertext blocks appear random, and thus produce unpredictable inputs to block cipher
  - Also requires IV to not be reused
- Encryption is serial
- Decryption requires block cipher inverse

IV Reuse?


IV
IV+1
IV+2
IV+n
K
Block Cipher
K
Block Cipher
...
K
Block Cipher
R[1]
R[2]
R[n]
P[1]
P[2]
P[n]
C[0]
C[1]
C[2]
C[n]
IV+i
K
Block Cipher
R[i]
C[i]
P[i]

When is an Encryption Scheme “Secure”?

- Hard to recover the key?
  - What if attacker can learn plaintext without learning the key?
- Hard to recover plaintext from ciphertext?
  - What if attacker learns some bits or some function of bits?

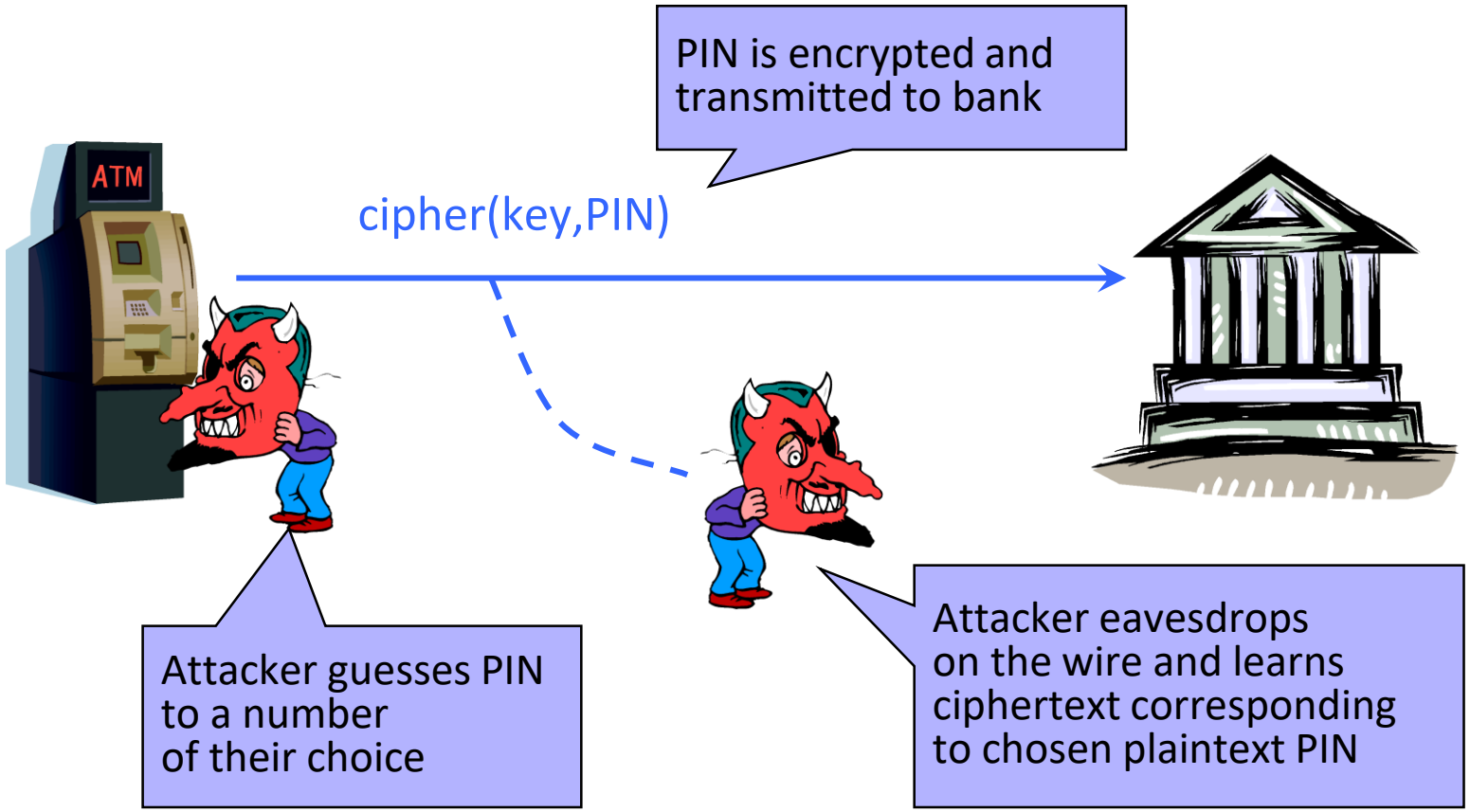
When is an Encryption Scheme “Secure”?

Gradescope!

How Can a Cipher Be Attacked?

- Attackers knows ciphertext and encryption algorithm
  - What else does the attacker know? Depends on the application in which the cipher is used!
- Ciphertext-only attack
- KPA: Known-plaintext attack (stronger)
  - Knows some plaintext-ciphertext pairs
- CPA: Chosen-plaintext attack (even stronger)
  - Can obtain ciphertext for any plaintext of his choice

Chosen Plaintext Attack



… repeat for any PIN value

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- CPA: Chosen-plaintext attack (even stronger)
  - Can obtain ciphertext for any plaintext of his choice
- CCA: Chosen-ciphertext attack (very strong)
  - Can decrypt any ciphertext except the target

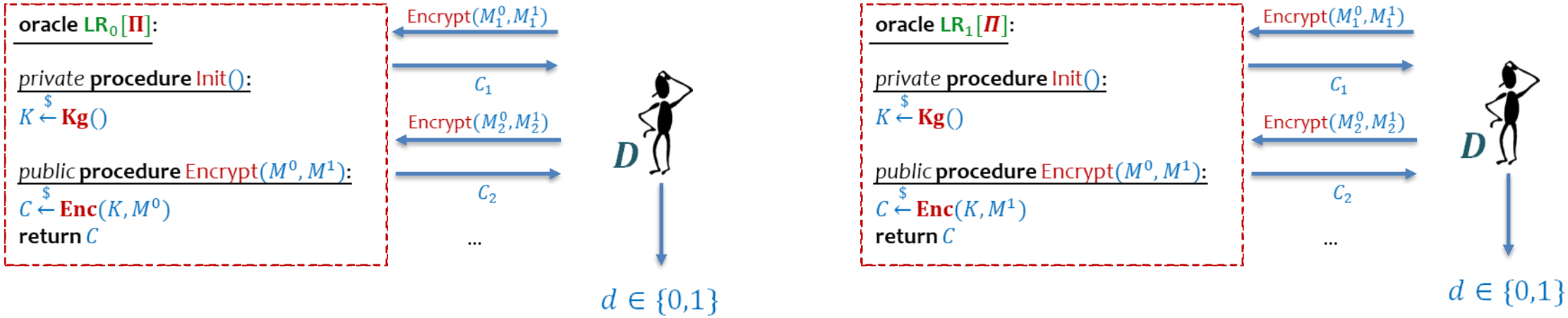
Very Informal Intuition

Minimum security requirement for a modern encryption scheme

- Security against chosen-plaintext attack (CPA)
  - Ciphertext leaks no information about the plaintext
  - Even if the attacker correctly guesses the plaintext, they cannot verify their guess
  - Every ciphertext is unique, encrypting same message twice produces completely different ciphertexts
    - Implication: encryption must be randomized or stateful

The Shape of the Formal Approach

- INDistinguishability under Chosen Plaintext Attack ("IND-CPA")
- Formalized cryptographic game
  - Adversary submits pairs of plaintexts (M_0, M_1)
  - Gets back ONE of the ciphertexts (C_b)
  - Adversary must **guess** which ciphertext this is (C_0 or C_1)
  - If they can do better than 50/50, they win



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- Security against chosen-ciphertext attack (CCA)
  - Integrity protection – it is not possible to change the plaintext by modifying the ciphertext