

CSE 484/M584: Computer Security (and Privacy)





Spring 2025

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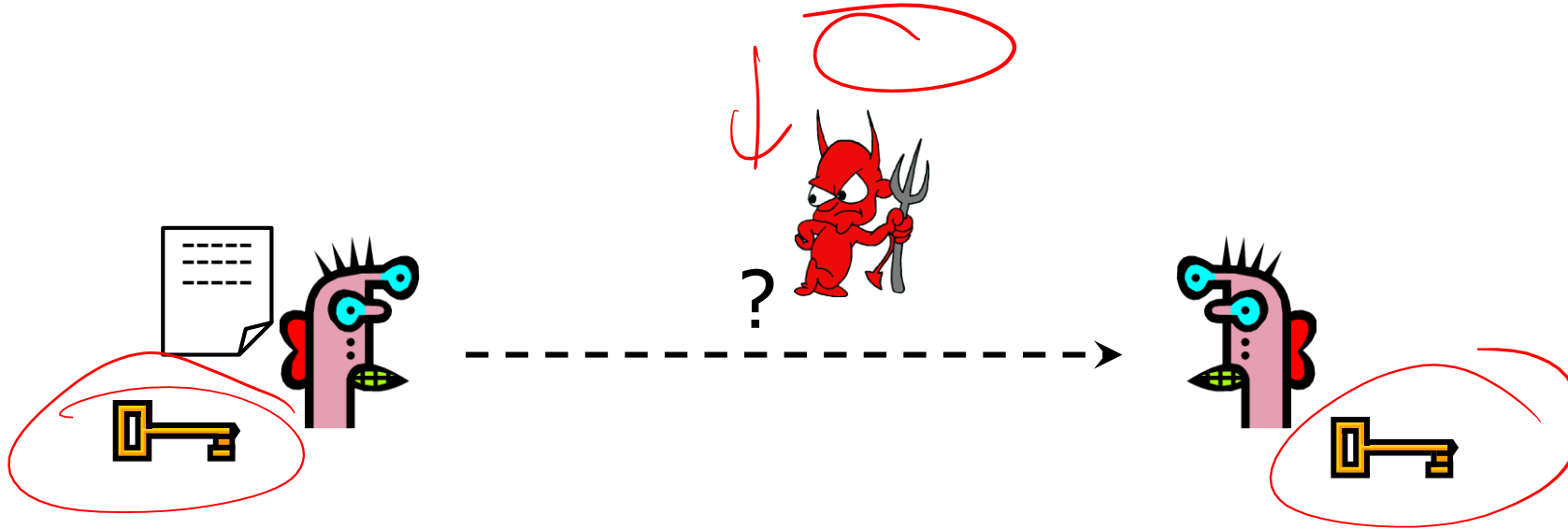
Admin



- Lab 1b due tonight.
- Lab1a Writeup grades are out!
 - Regrade requests close on May 7th (hard deadline)
 - Exploit grades will be fixed later today.
- HW1 due next Wednesday
- Lab 2 (Cryptolab) goes out today!
 - We won't have covered everything, but worth reading through ASAP.

Symmetric Encryption

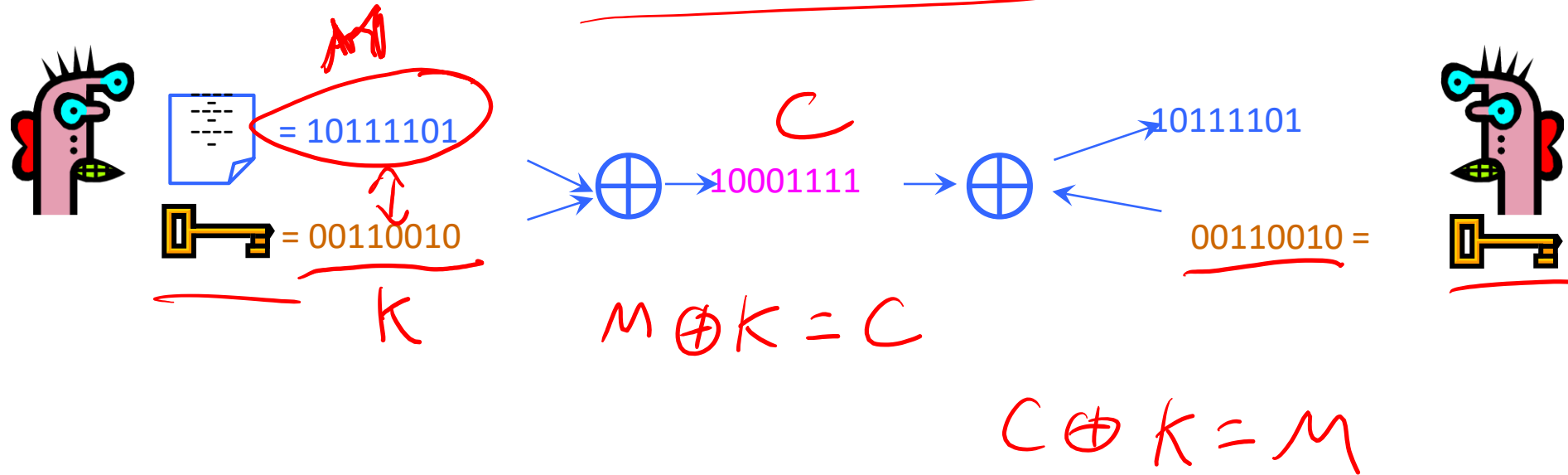
Goal: Confidentiality



Given: Both parties know a shared random key

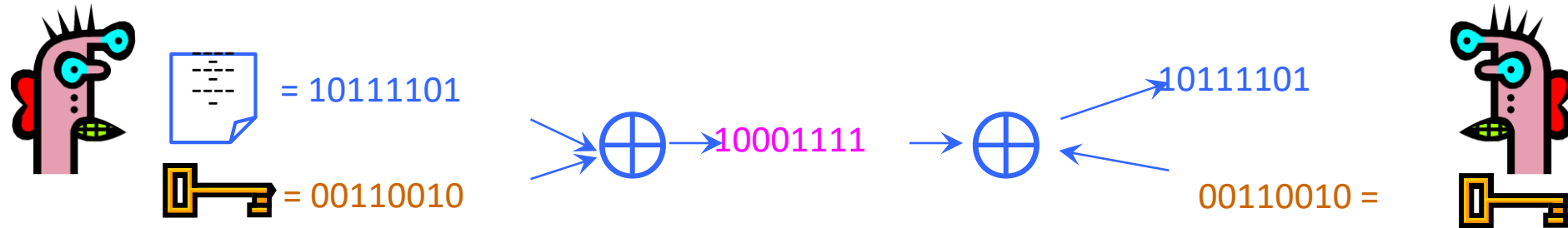
Goal: Send a message without revealing information about the message

One-Time Pad (Simple XOR Encryption)



Cipher achieves **perfect secrecy** if key is chosen uniformly at random (Claude Shannon, 1949)

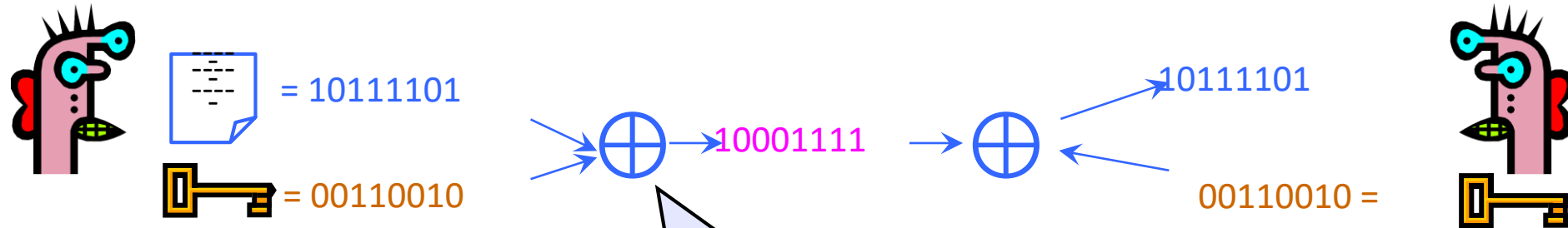
One-Time Pad (Simple XOR Encryption)



Key is a random bit sequence
as long as the plaintext

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One-Time Pad (Simple XOR Encryption)

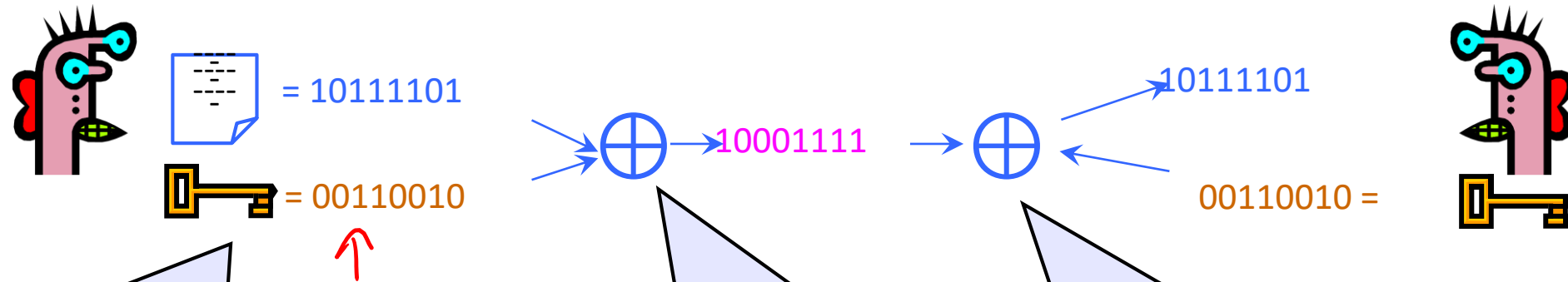


Key is a random bit sequence
as long as the plaintext

Encrypt by bitwise XOR of
plaintext and key

Cipher achieves **perfect secrecy** if key is chosen uniformly at random (Claude Shannon, 1949)

One-Time Pad (Simple XOR Encryption)



Key is a random bit sequence as long as the plaintext

Encrypt by bitwise XOR of plaintext and key

Decrypt by bitwise XOR of ciphertext and key

$$K = \{0, 1\}$$
$$M = \{0, 1\}$$

Handwritten XOR table:

	1	0
1	0	1
0	1	0

Labels: $C \rightarrow$ (for ciphertext), $M \rightarrow$ (for message/plaintext), k (for key).

Cipher achieves **perfect secrecy** if key is chosen uniformly at random (Claude Shannon, 1949)

Advantages of One-Time Pad

- Easy to compute
 - Encryption and decryption are the same operation
 - Bitwise XOR is very cheap to compute
- Perfect secrecy
 - Given a ciphertext, all plaintexts are equally likely, regardless of attacker's computational resources
 - ...as long as the key sequence is truly random
 - True randomness is expensive to obtain in large quantities
 - ...as long as each key is same length as plaintext
 - But how does sender communicate the key to receiver?

Problems with the One-Time Pad?

Gradescope

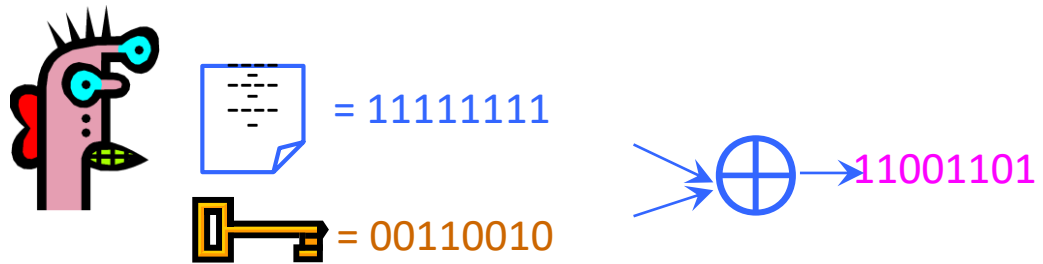
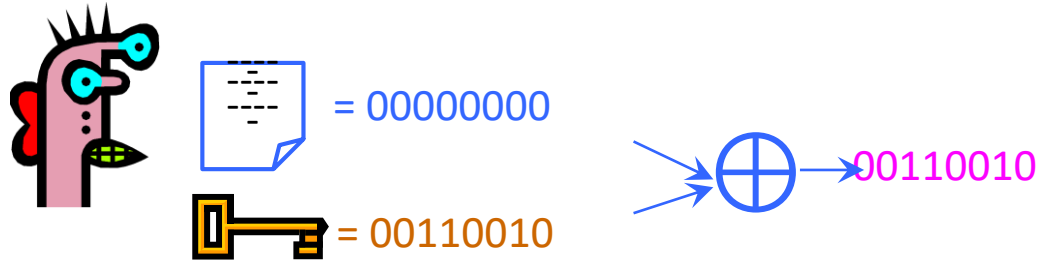
- What potential security problems do you see with the one-time pad?
- Q1: Confidentiality: What if key is reused?
- Q2: Integrity: Any protection against corruption?

k_1

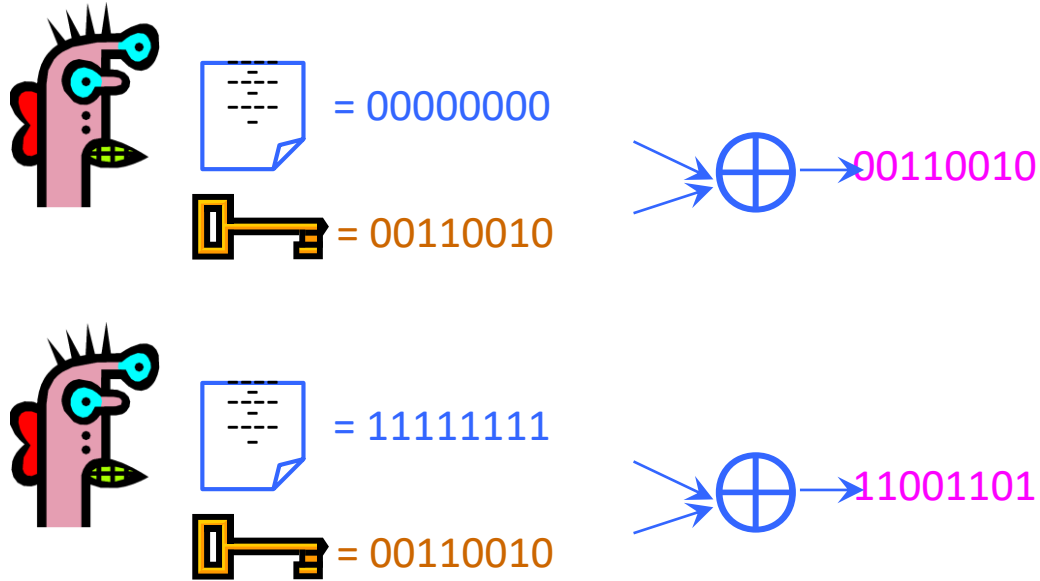
$$\begin{aligned}M_1 \oplus k_1 &= C_1 \\M_2 \oplus k_1 &= C_2\end{aligned}$$

$$\begin{aligned}C_1 \oplus C_2 &= \\M_1 \oplus M_2\end{aligned}$$

Dangers of Reuse



Dangers of Reuse



Learn relationship between plaintexts

$$\begin{aligned} C1 \oplus C2 &= (P1 \oplus K) \oplus (P2 \oplus K) = \\ &= (P1 \oplus P2) \oplus (K \oplus K) = P1 \oplus P2 \end{aligned}$$




Problems with One-Time Pad

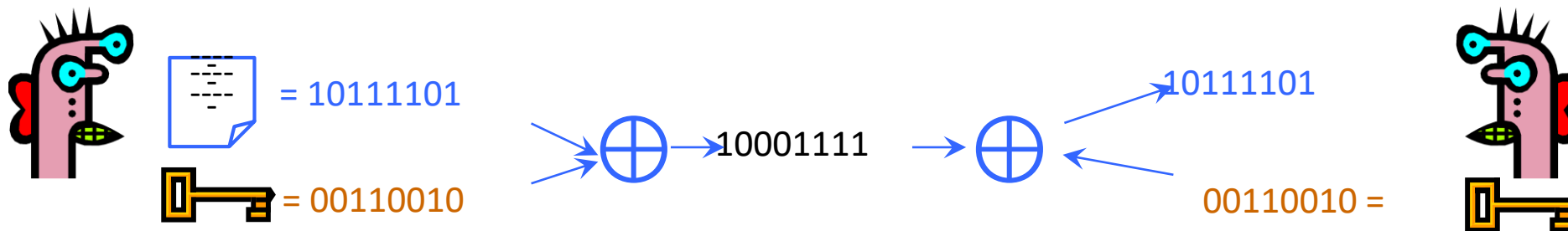


- (1) Key must be as long as the plaintext
 - Impractical in most realistic scenarios

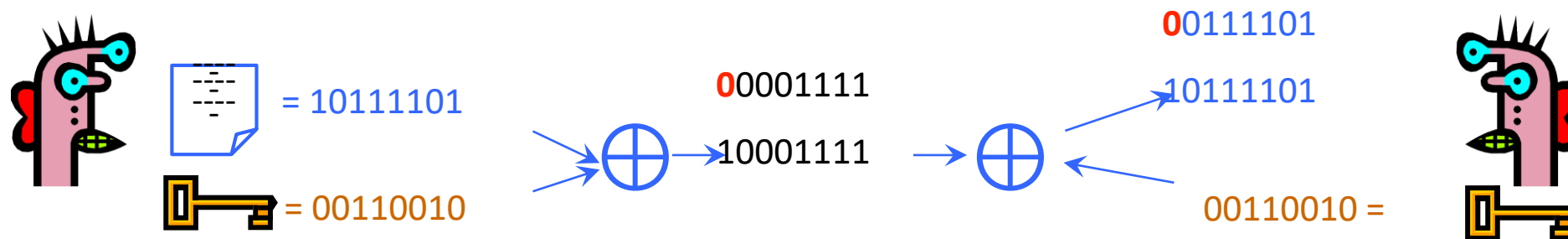
Problems with One-Time Pad

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 - (2) Insecure if keys are reused
 - Attacker can obtain XOR of plaintexts
- 


One-Time Pad Integrity?



One-Time Pad Integrity?



Problems with One-Time Pad

- (1) Key must be as long as the plaintext
 - Impractical in most realistic scenarios
- (2) Insecure if keys are reused
 - Attacker can obtain XOR of plaintexts
- **(3) Does not guarantee integrity**
 - One-time pad only guarantees confidentiality 
 - Attacker cannot recover plaintext, but can easily change it to something else

Reducing Key Size

- What to do when it is infeasible to pre-share huge random keys?
 - When one-time pad is unrealistic...
- Use special cryptographic primitives: **block ciphers**
 - Single key can be re-used (with some restrictions)
 - Not as theoretically secure as one-time pad

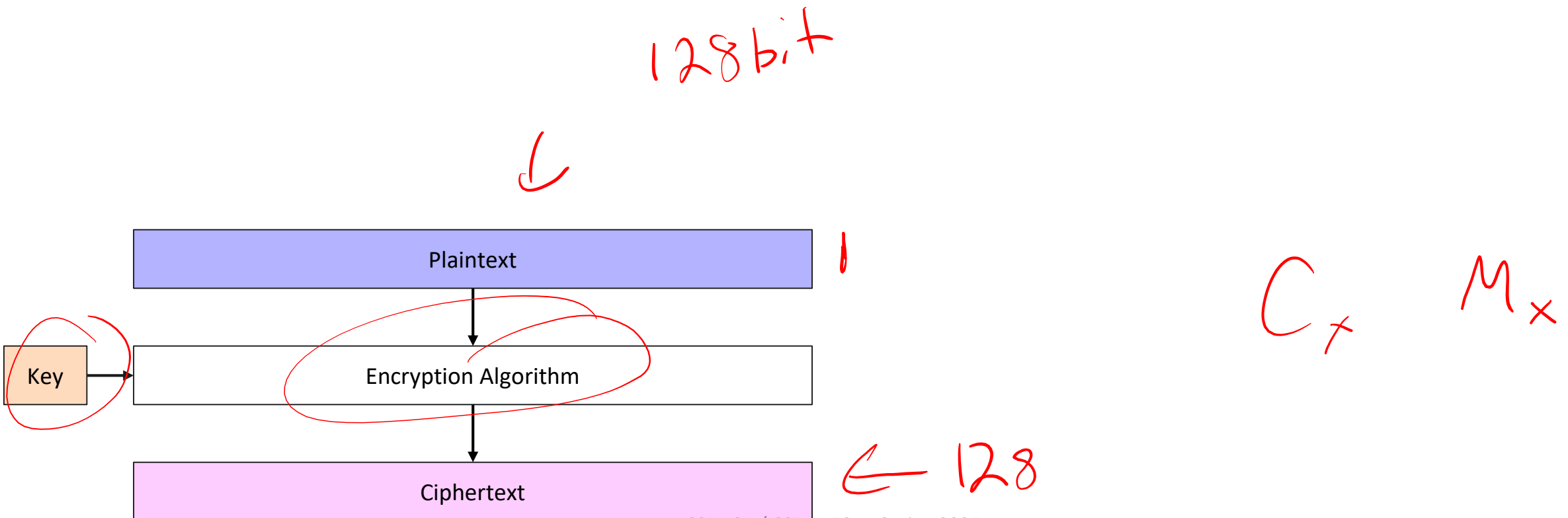
m_1
 m_2

$$E_K(m_1) = c_1$$

$$E_K(m_2) = c_2 \mid |K| = 256 \text{ bits}$$

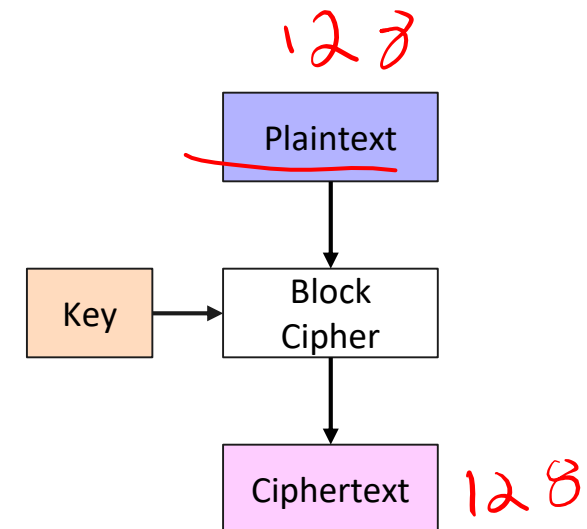
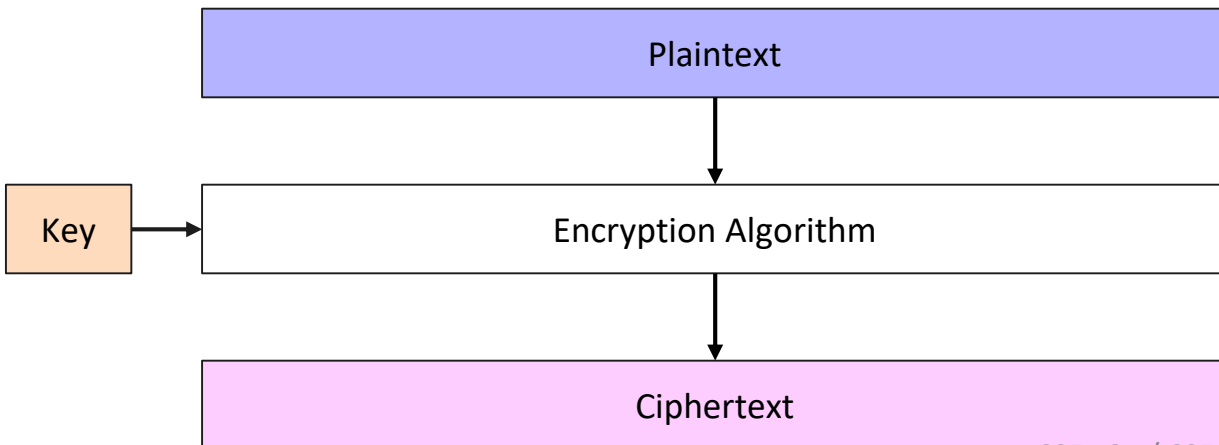
Symmetric Encryption Goal

- Operates on an arbitrary size plaintext
 - Each key defines a random and invertible mapping from plaintext space to ciphertext space

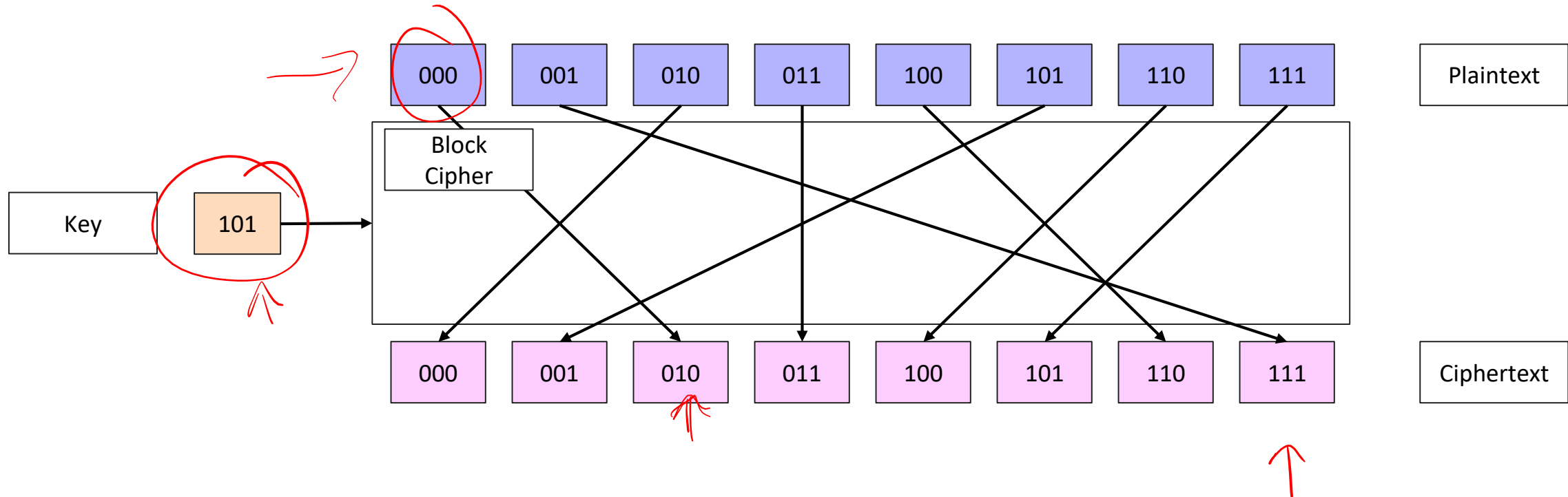


Symmetric Encryption Goal

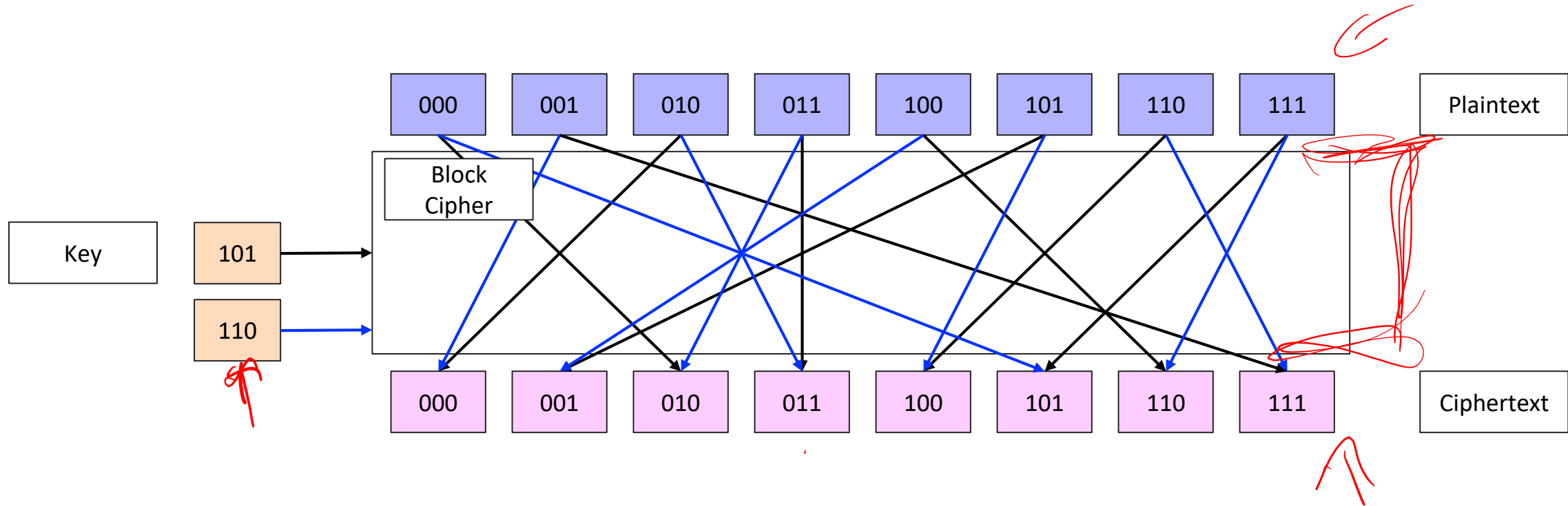
- Operates on an arbitrary size plaintext
 - Each key defines a random and invertible mapping from plaintext space to ciphertext space
- Block ciphers operate on a single chunk (“block”) of plaintext
 - Block sizes on the order of 64 bits, 128 bits, 256 bits
 - Each key defines a “random” invertible **permutation** of inputs to possible outputs
 - Plan: Build encryption algorithm from block cipher building block



Keyed Permutation

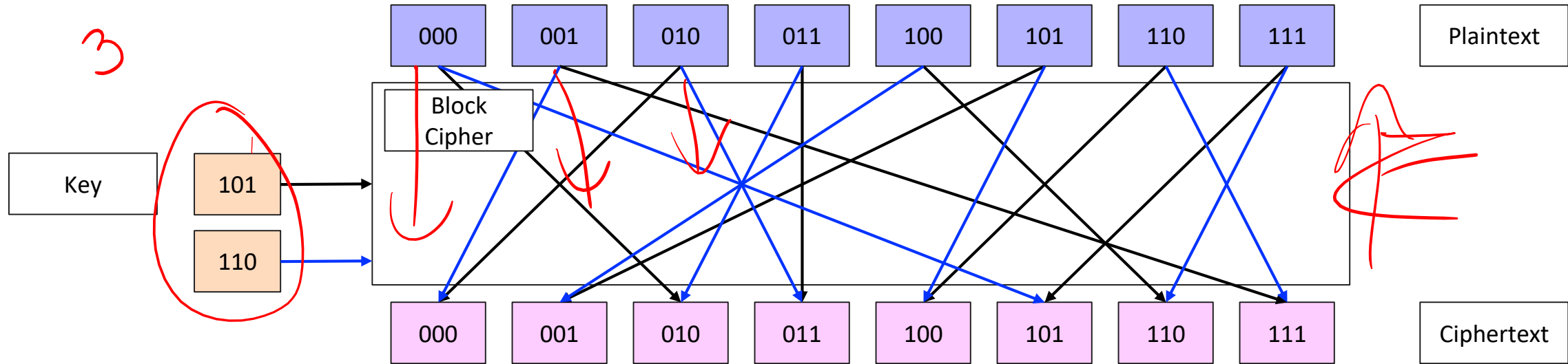


Keyed Permutation



- Each key defines a permutation from the plaintext space to the ciphertext space
- Ideal: Permutation looks “random” if you don’t know the key
 - Is that possible?
 - How many permutations exist?
- Next best: Computationally indistinguishable from random!

Keyed Permutation



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For N-bit input:
2^N! possible permutations

For K-bit key:
2^K possible keys

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

M, C
 \uparrow

$$E_k(M) = C$$
$$\text{rand}() = C$$

- 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

2^{128}

AES
9 rounds

Standard Block Ciphers

Handwritten diagram showing the relationship between plaintext (M) and ciphertext (C).
Top row: M, C with arrows pointing down to them.
Bottom row: M, C with arrows pointing up to them.

- **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

Handwritten: 2^{56}

- **AES: Advanced Encryption Standard**

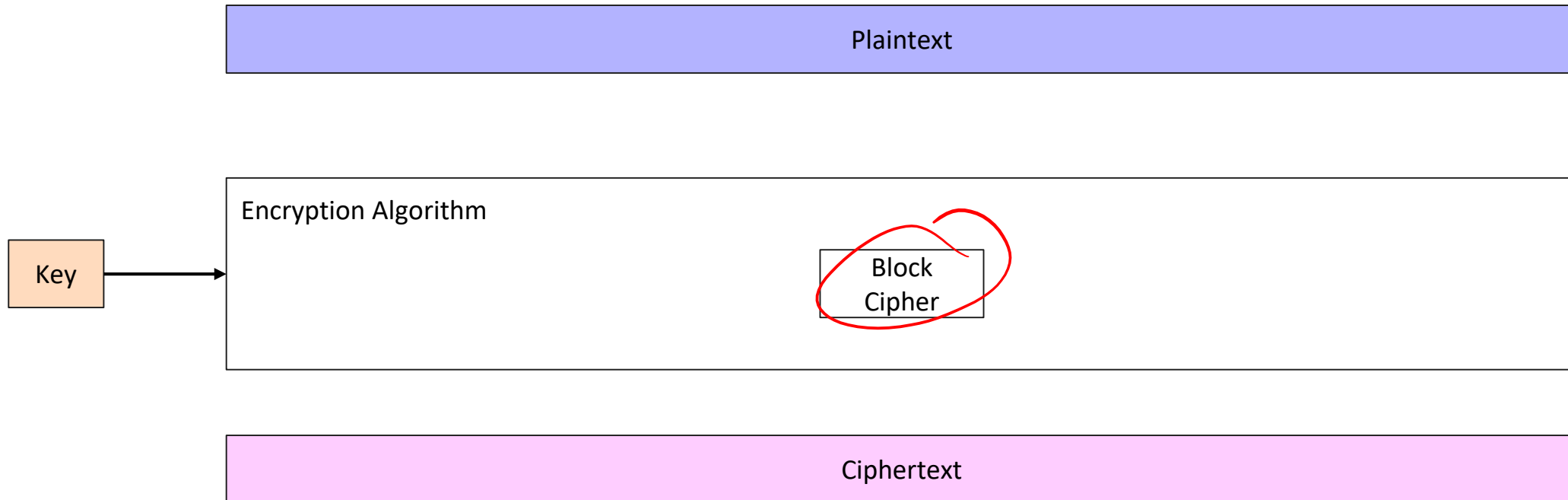
- New federal standard as of 2001
 - NIST: National Institute of Standards & Technology
- Based on the Rijndael algorithm
 - Selected via an open process
- 128-bit blocks, keys can be 128, 192 or 256 bits

Handwritten: 2^{57}

Handwritten: 2^{128}

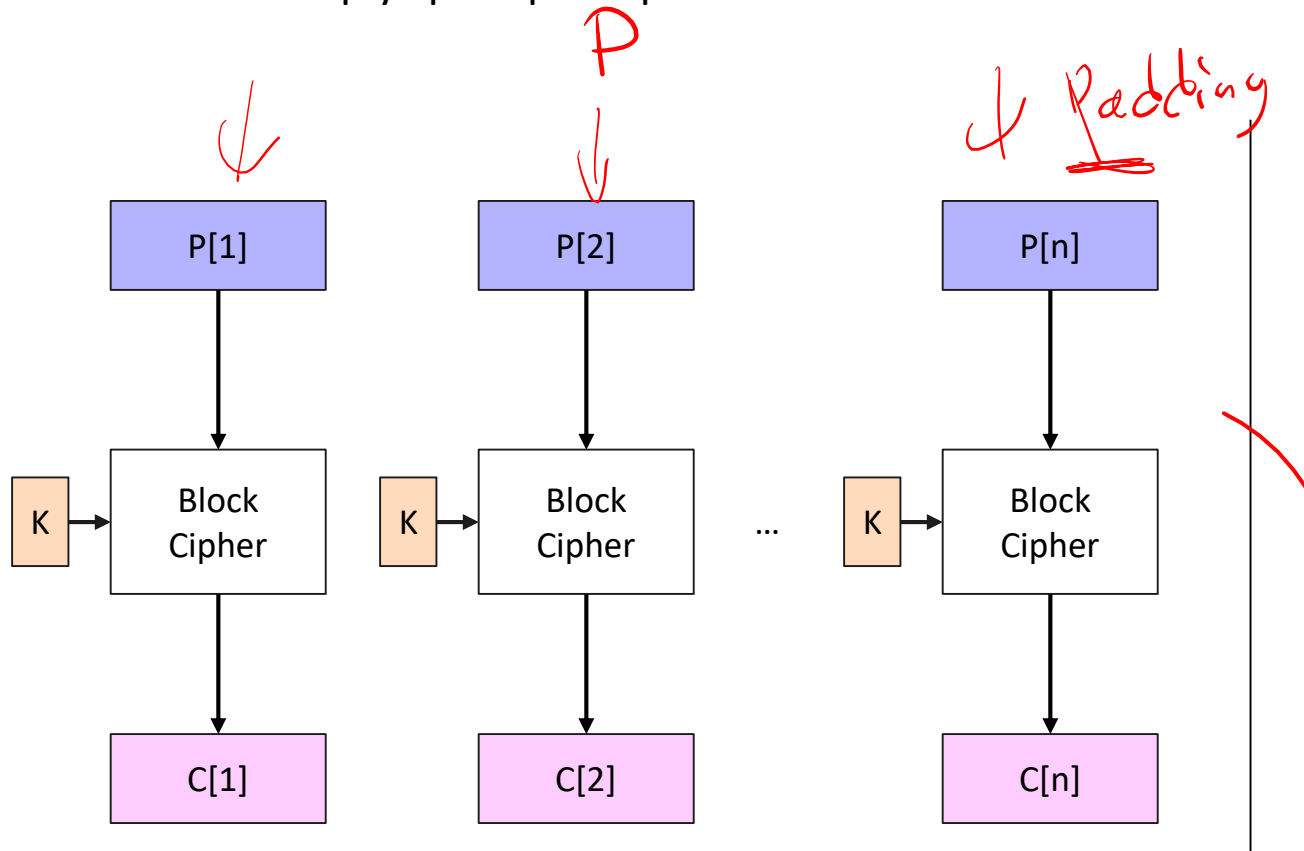
Encrypting a Large Message

- How do we use block ciphers to encrypt larger messages?
- Plan: Build an encryption “mode” from a block cipher



Electronic Code Book (ECB) Mode

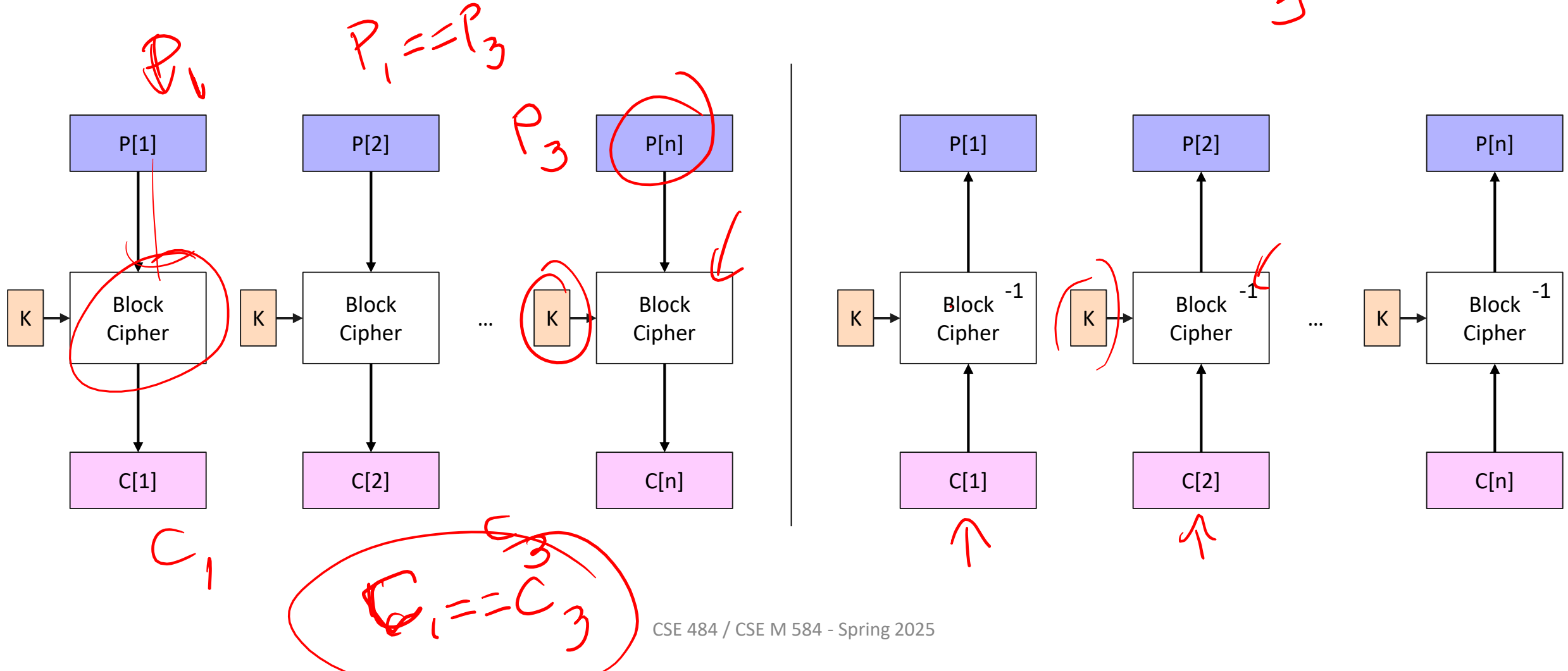
- Idea: Simply split up the plaintext into block-sized chunks!



Electronic Code Book (ECB) Mode

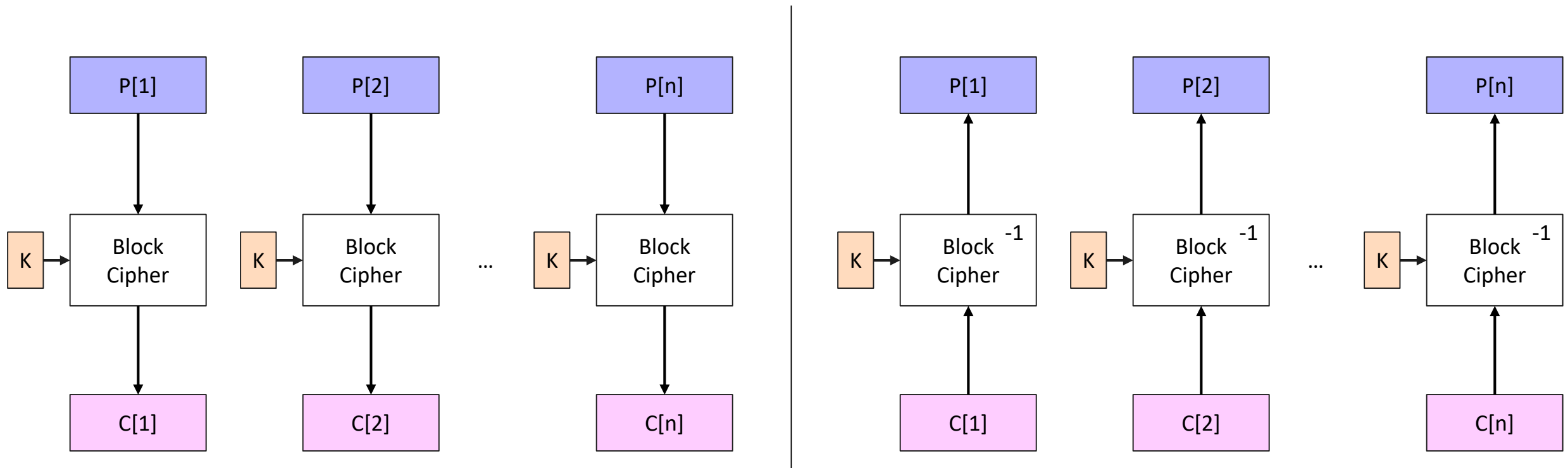
- Idea: Simply split up the plaintext into block-sized chunks!

$$E_K(P) = C$$



Electronic Code Book (ECB) Mode

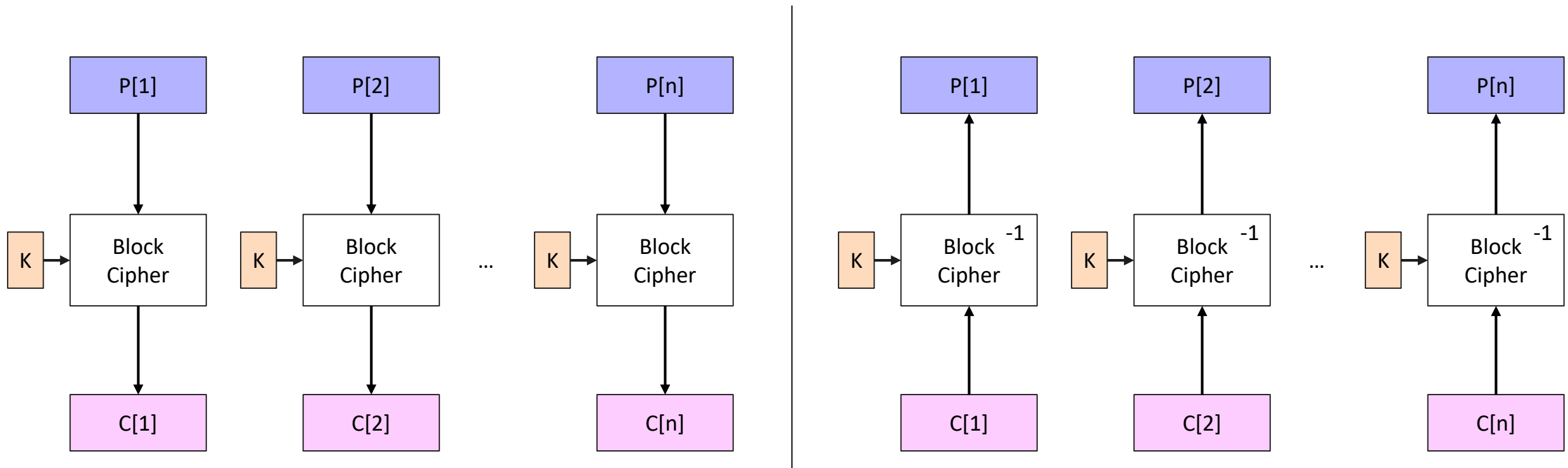
- Idea: Simply split up the plaintext into block-sized chunks!



In-class Activity 1/29: Good idea?

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

Information Leakage in ECB Mode

