CSE 484/M584: Computer Security (and Privacy)

Spring 2025

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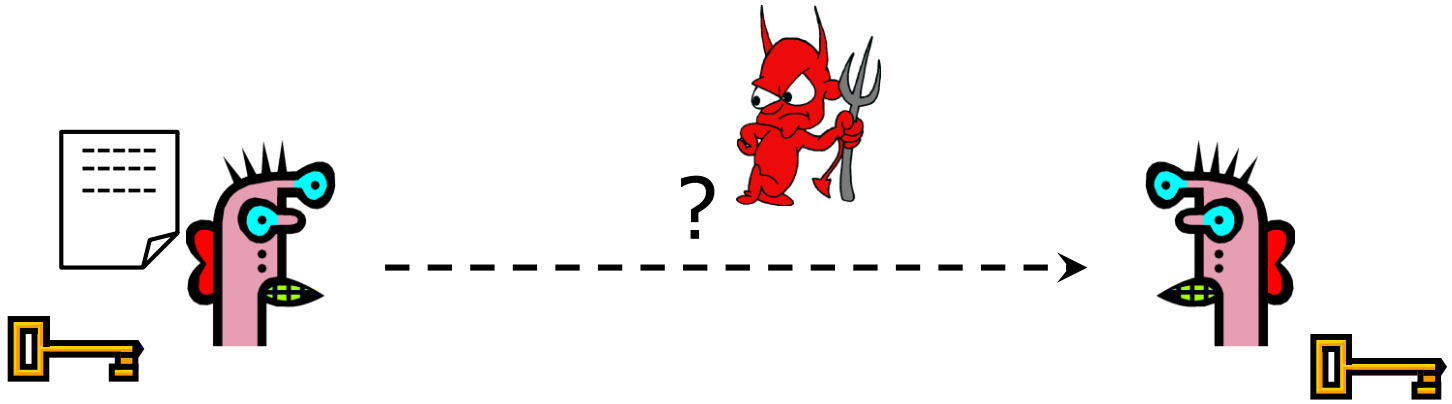
Admin

- 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

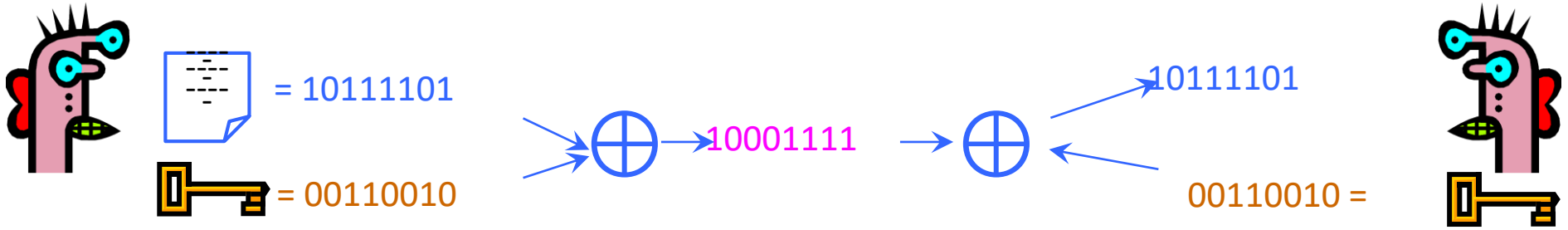
Goal: Confidentiality



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)

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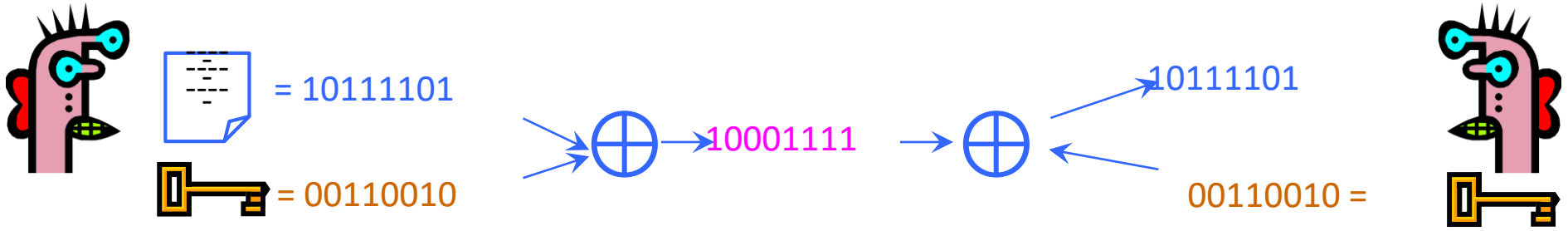

Key is a random bit sequence as long as the plaintext

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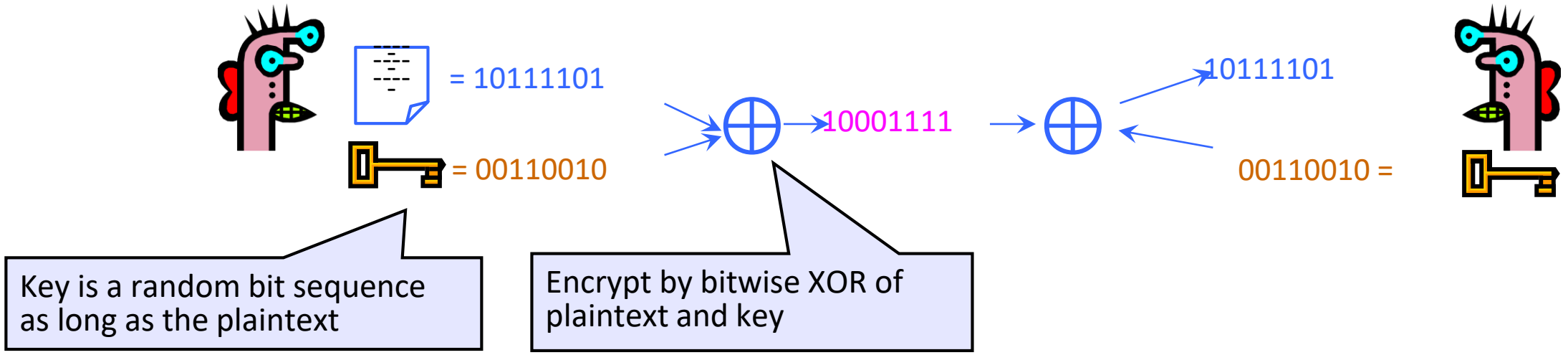

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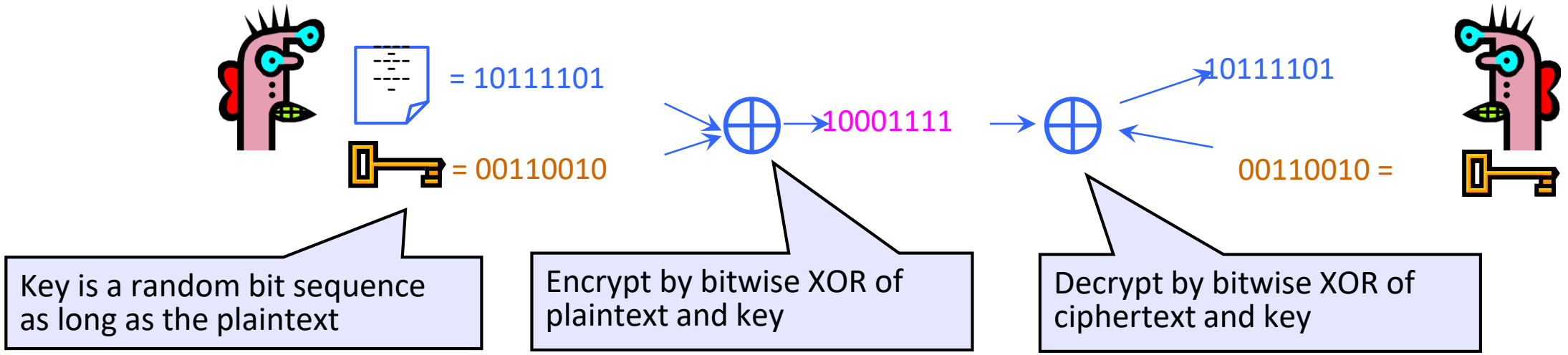

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Advantages of One-Time Pad

- Easy to compute
  - Encryption and decryption are the same operation
  - Bitwise XOR is very cheap to compute

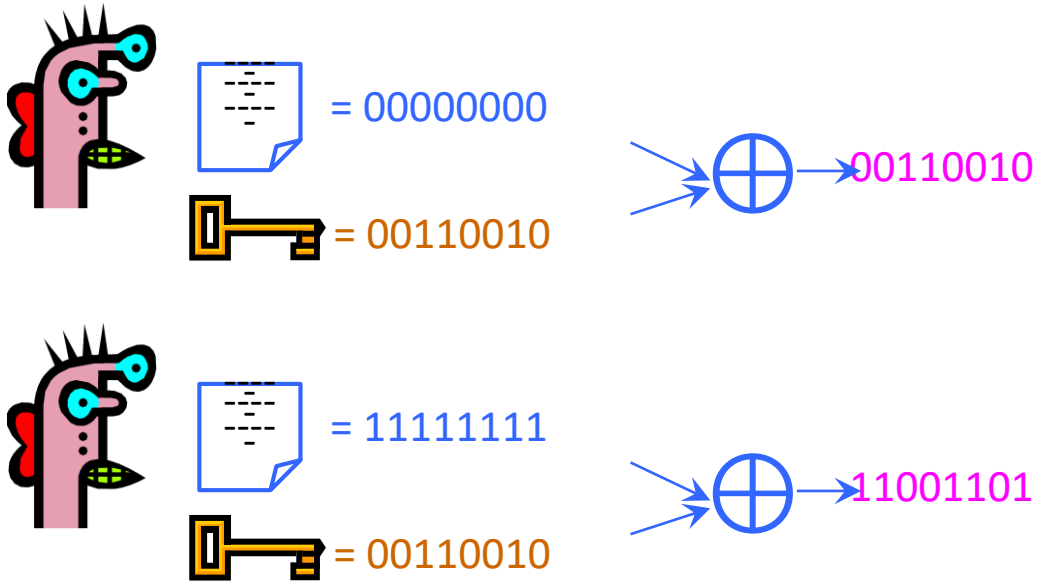
- Perfect secrecy
  - Given a ciphertext, all plaintexts are equally likely, regardless of attacker's computational resources
  - …as long as the key sequence is truly random
    - True randomness is expensive to obtain in large quantities
  - …as long as each key is same length as plaintext
    - But 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?

Dangers of Reuse



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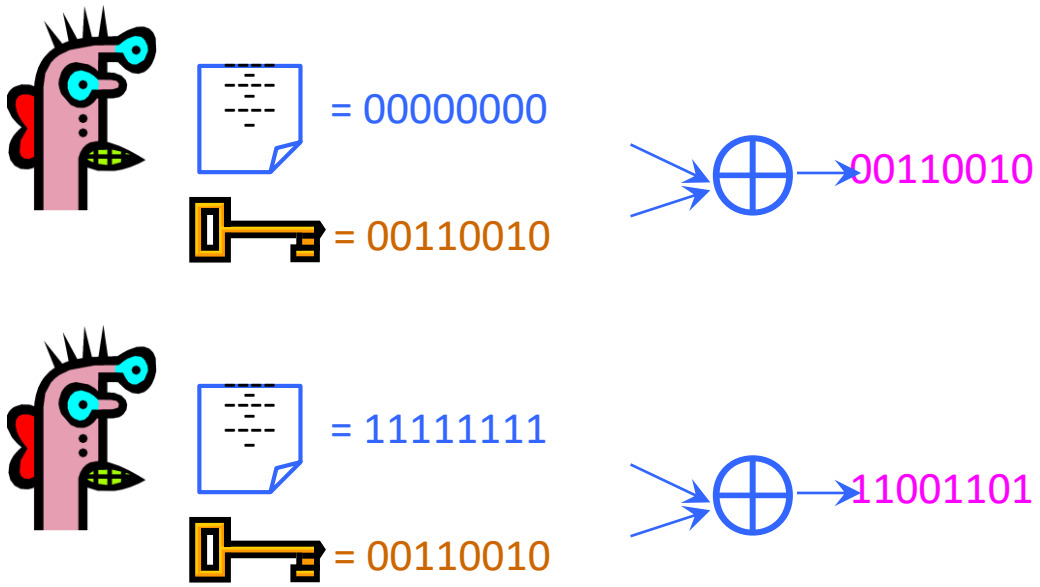

Learn relationship between plaintexts

C1⊕C2 = (P1⊕K)⊕(P2⊕K) =

(P1⊕P2)⊕(K⊕K) = P1⊕P2

Problems with One-Time Pad

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

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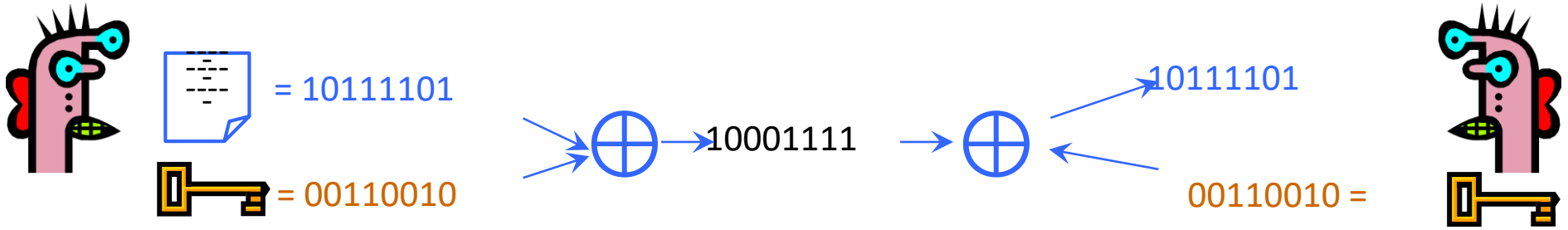
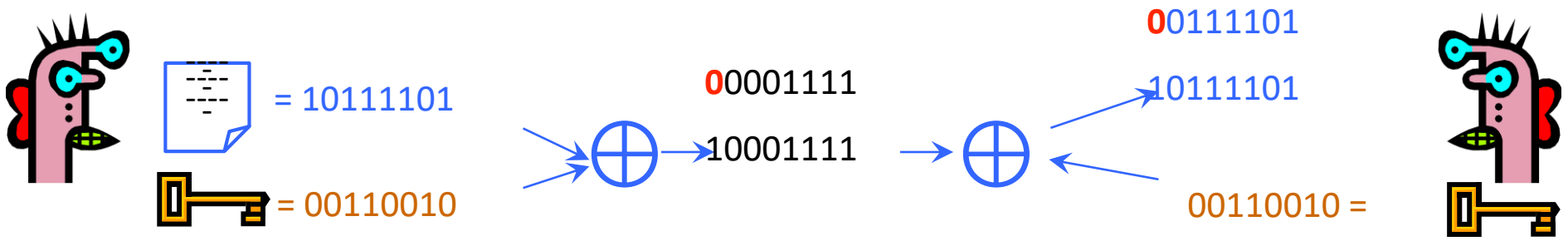
  - **Attacker can obtain XOR of plaintexts**

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**

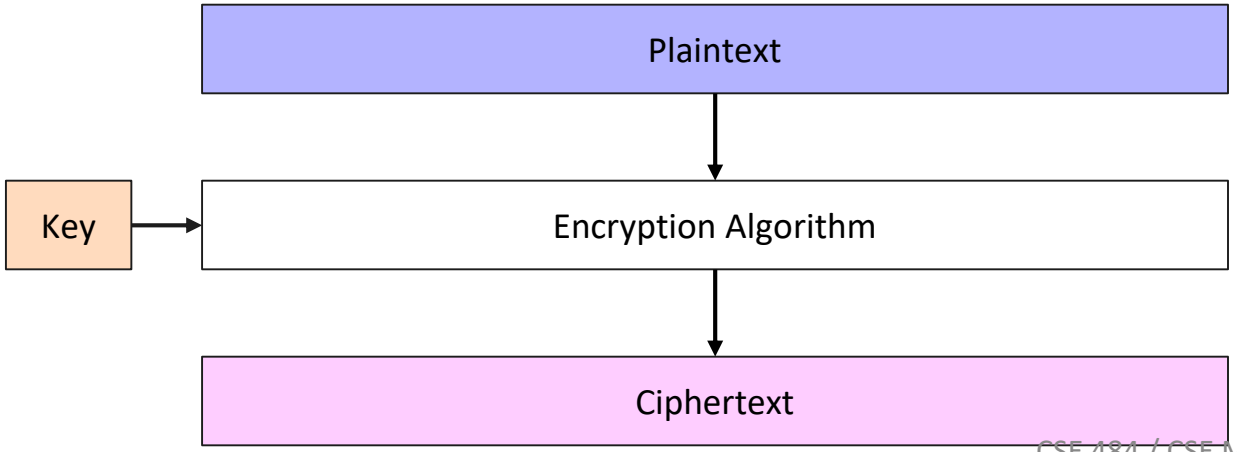
Reducing Key Size

- 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

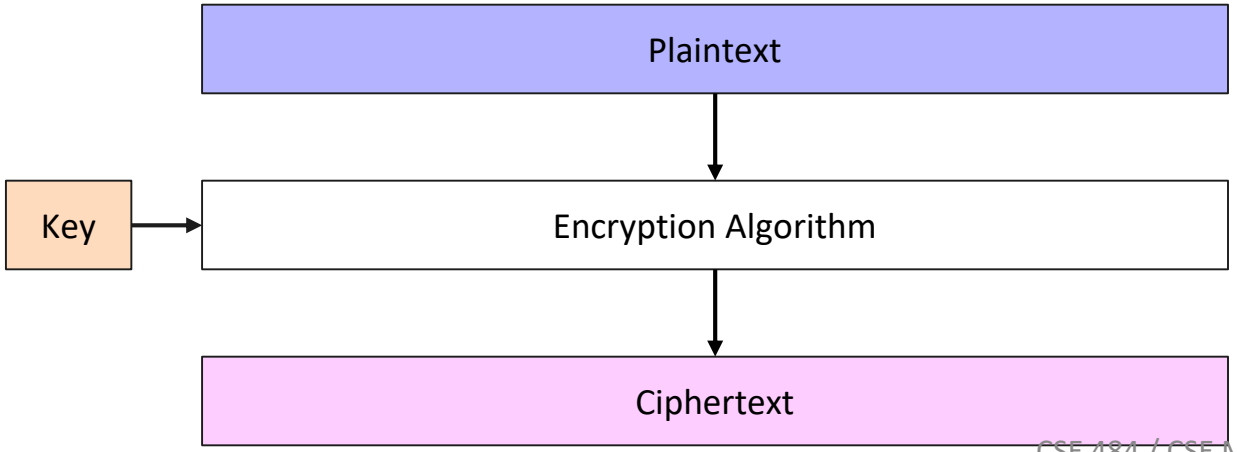
Symmetric Encryption Goal

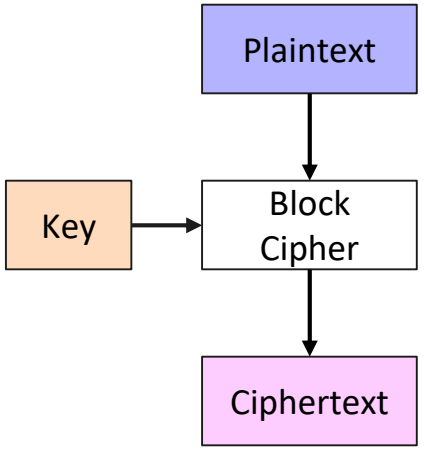
- Operates on an arbitrary size plaintext
  - Each key defines a random and invertible mapping from plaintext space to ciphertext space



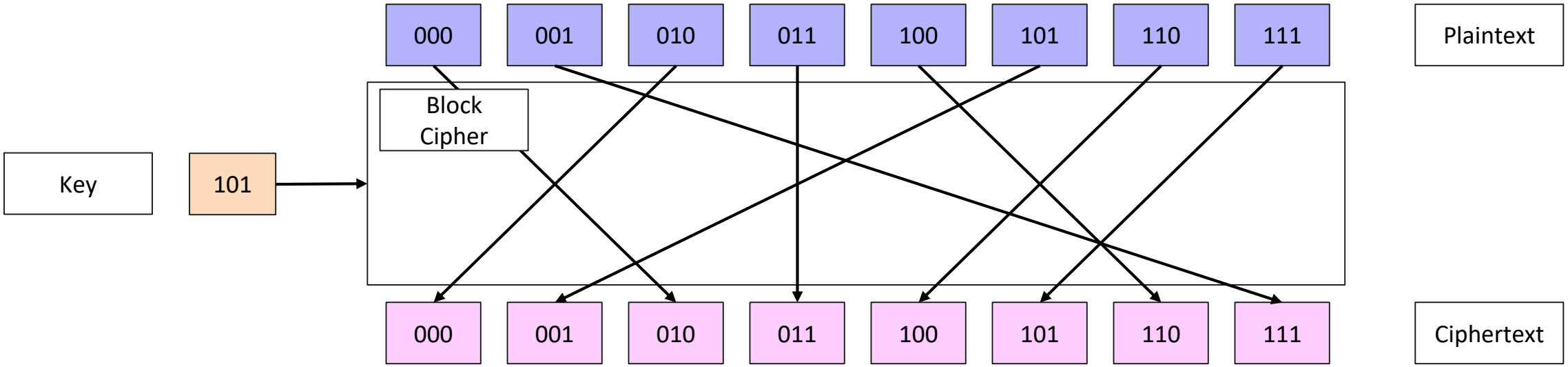
Symmetric Encryption Goal

- 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



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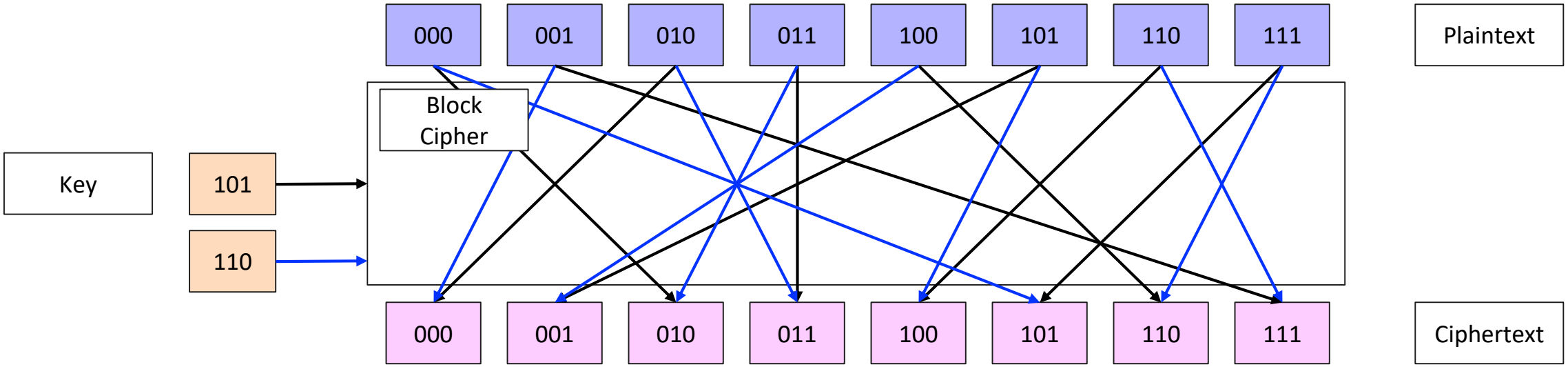
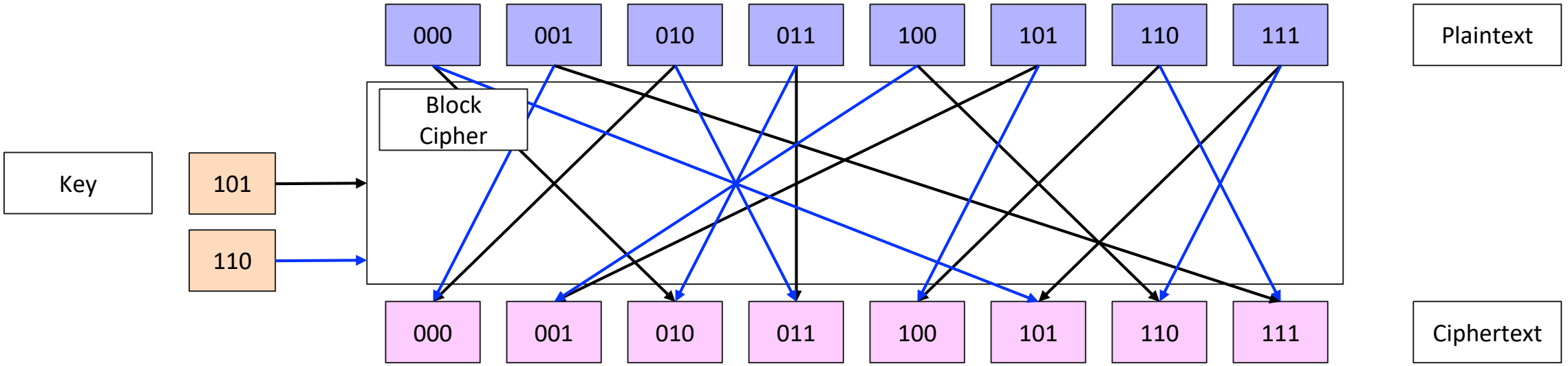


- Each key defines a permutation from the plaintext space to the ciphertext space
- Ideal: Permutation looks "random" if you don't know the key
  - Is that possible?
  - How many permutations exist?
- Next best: Computationally indistinguishable from random!

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

- 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

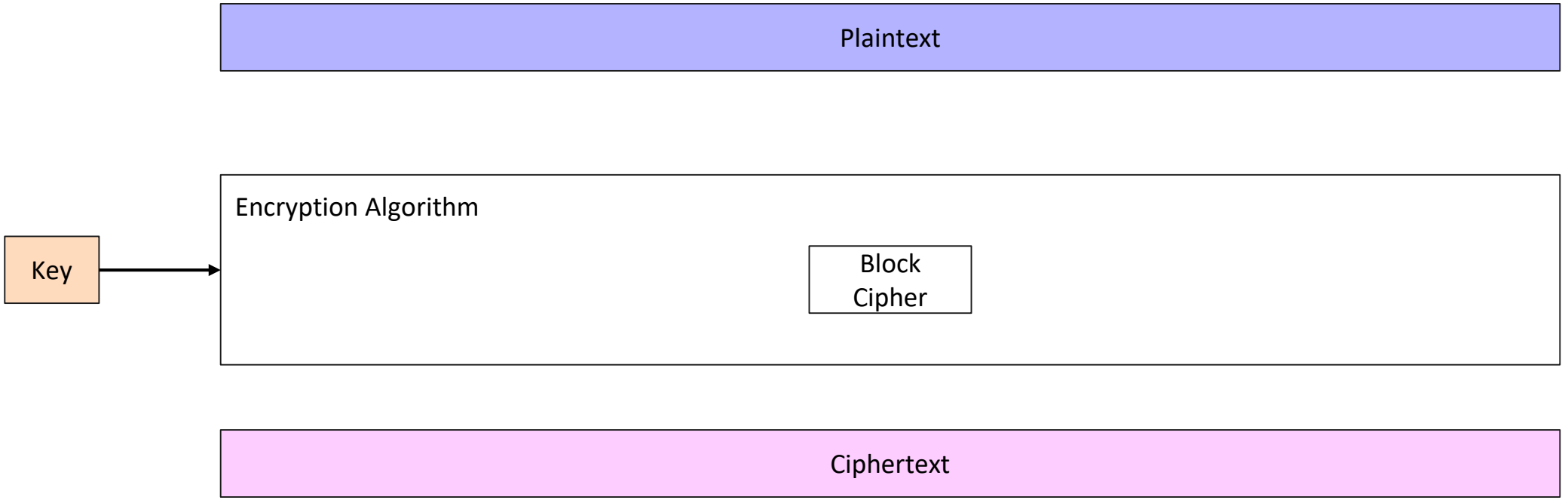
Standard Block Ciphers

- **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

- **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

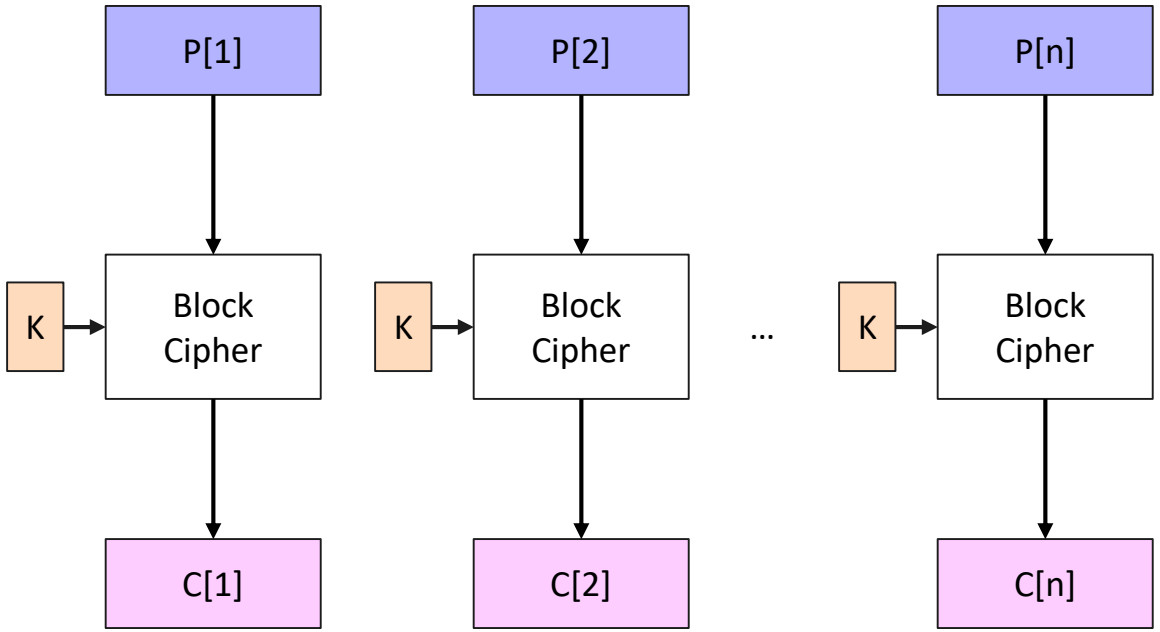
Encrypting a Large Message

- 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!



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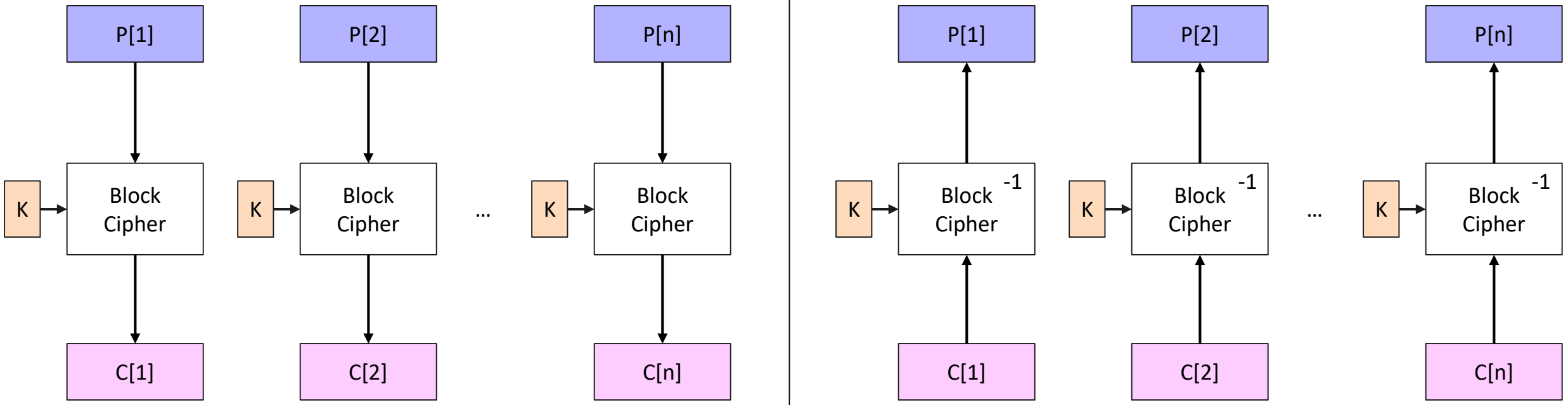

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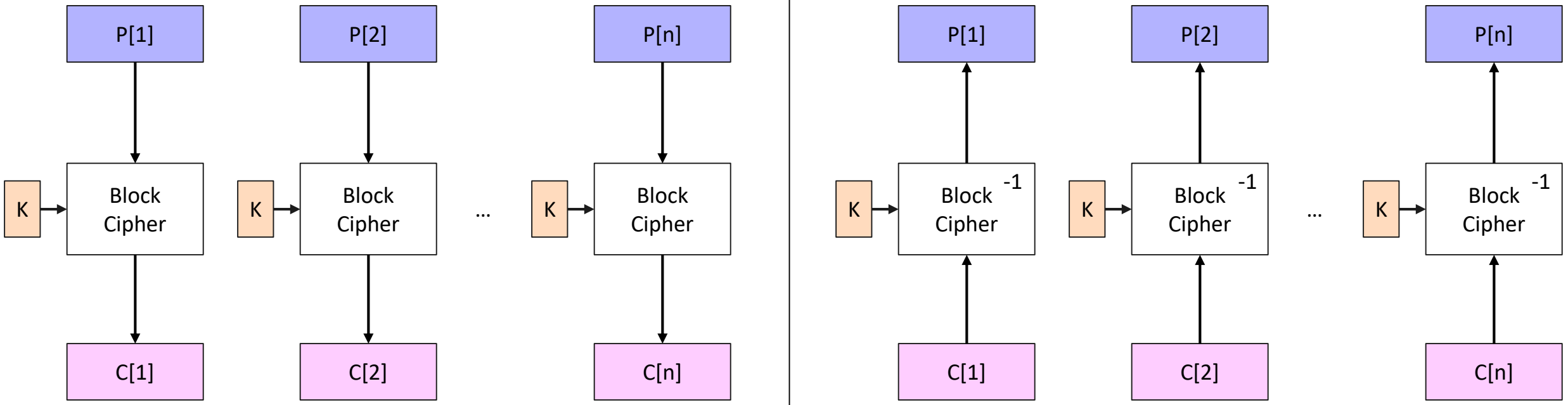

In-class Activity 1/29: Good idea?

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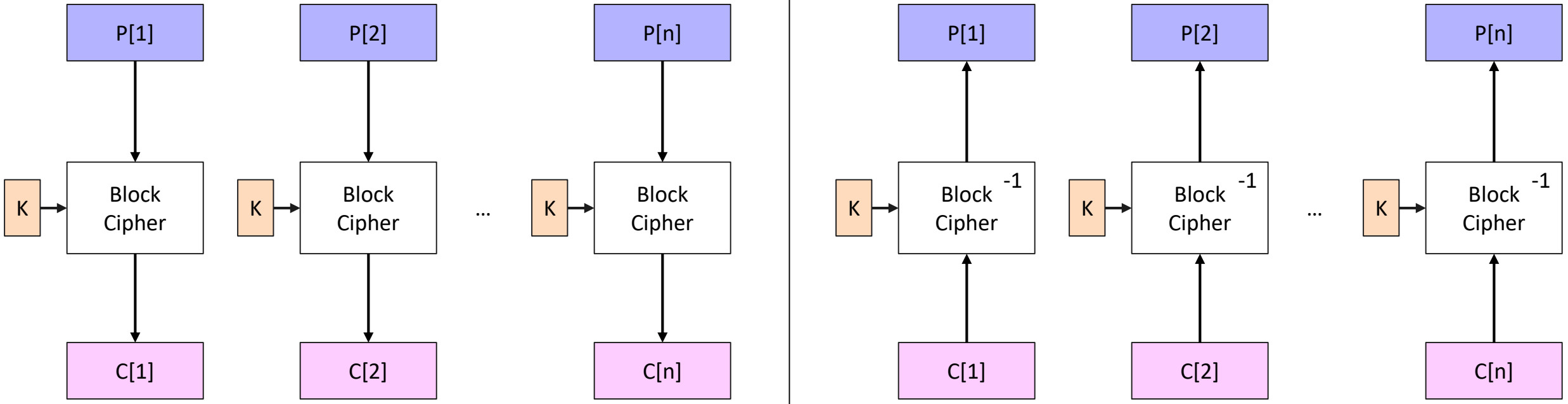
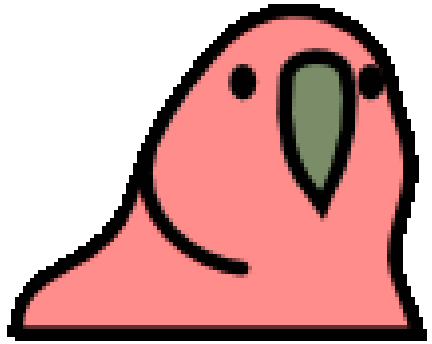


- Identical blocks of plaintext produce identical blocks of ciphertext
- No integrity checks: can mix and match blocks

Information Leakage in ECB Mode



Encrypt in ECB mode