CSE 484 / CSE M 584: Computer Security and Privacy

# Cryptography
## [Symmetric Encryption]

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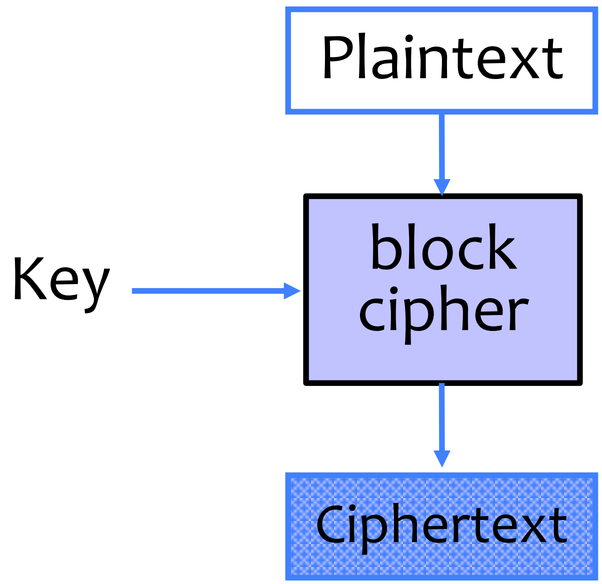
# Recap: Block Ciphers

- Operates on a single chunk ("block") of plaintext
  - For example, 64 bits for DES, 128 bits for AES
  - Each key defines a different permutation
  - Same key is reused for each block (can use short keys)



# 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/$\mu s$ | Time required at $10^6$ encryptions/$\mu s$ |
|---|---|---|---|
| 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 | $5.4 \times 10^{18}$ years |
| 168 | $2^{168} = 3.7 \times 10^{50}$ | $2^{167}\ \mu s = 5.9 \times 10^{36}$ years | $5.9 \times 10^{30}$ years |
| 26 characters (permutation) | $26! = 4 \times 10^{26}$ | $2 \times 10^{26}\ \mu s = 6.4 \times 10^{12}$ years | $6.4 \times 10^6$ 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)

# Standard Block Ciphers

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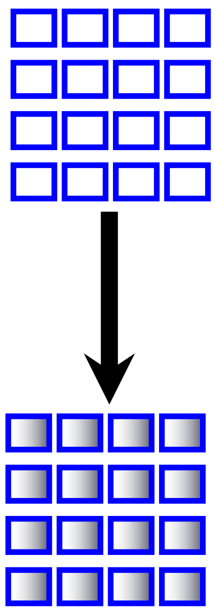
- **AES: Advanced Encryption Standard**
  - New federal standard as of 2001
    - NIST: National Institute of Standards & Technology
  - Based on the Rijndael algorithm
    - Selected via an open process
  - 128-bit blocks, keys can be 128, 192 or 256 bits

# Encrypting a Large Message

- So, we've got a good block cipher, but our plaintext is larger than 128-bit block size



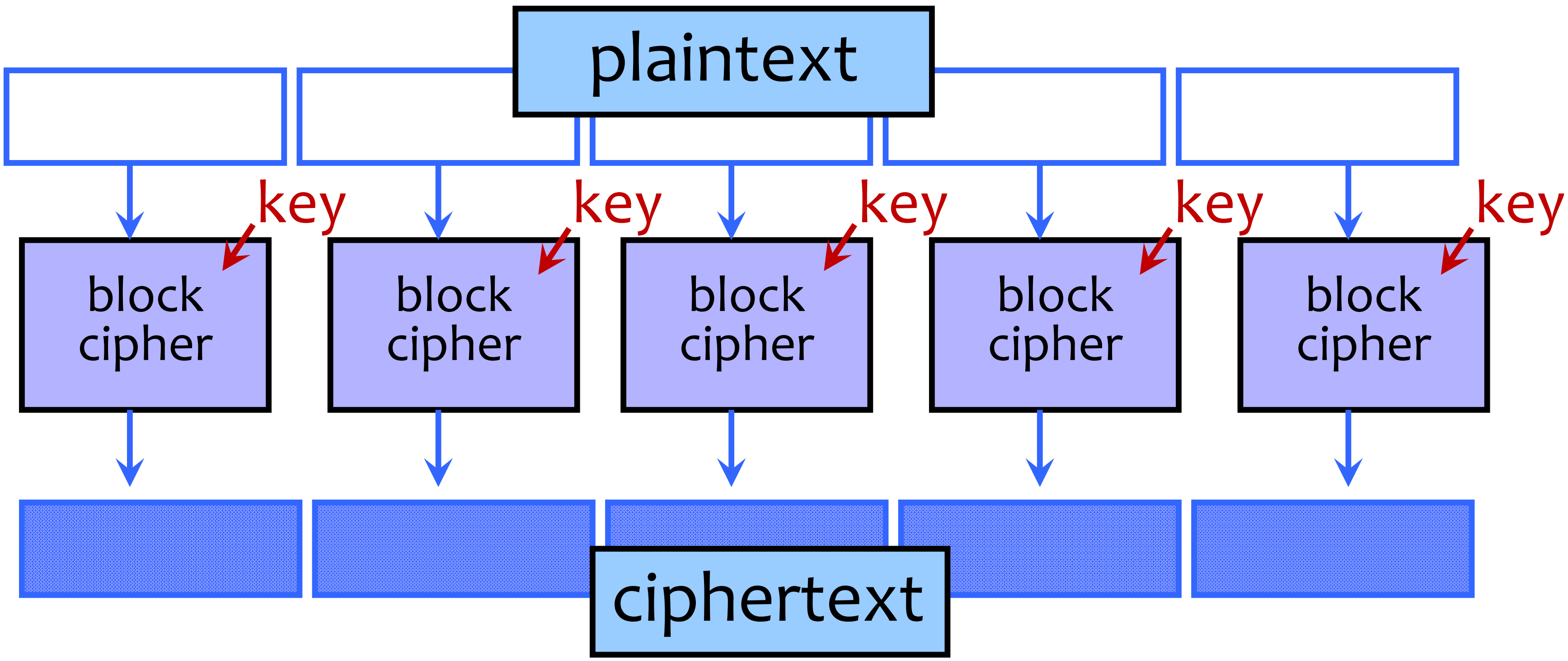
**128-bit plaintext**

(arranged as 4x4 array of 8-bit bytes)

128-bit ciphertext

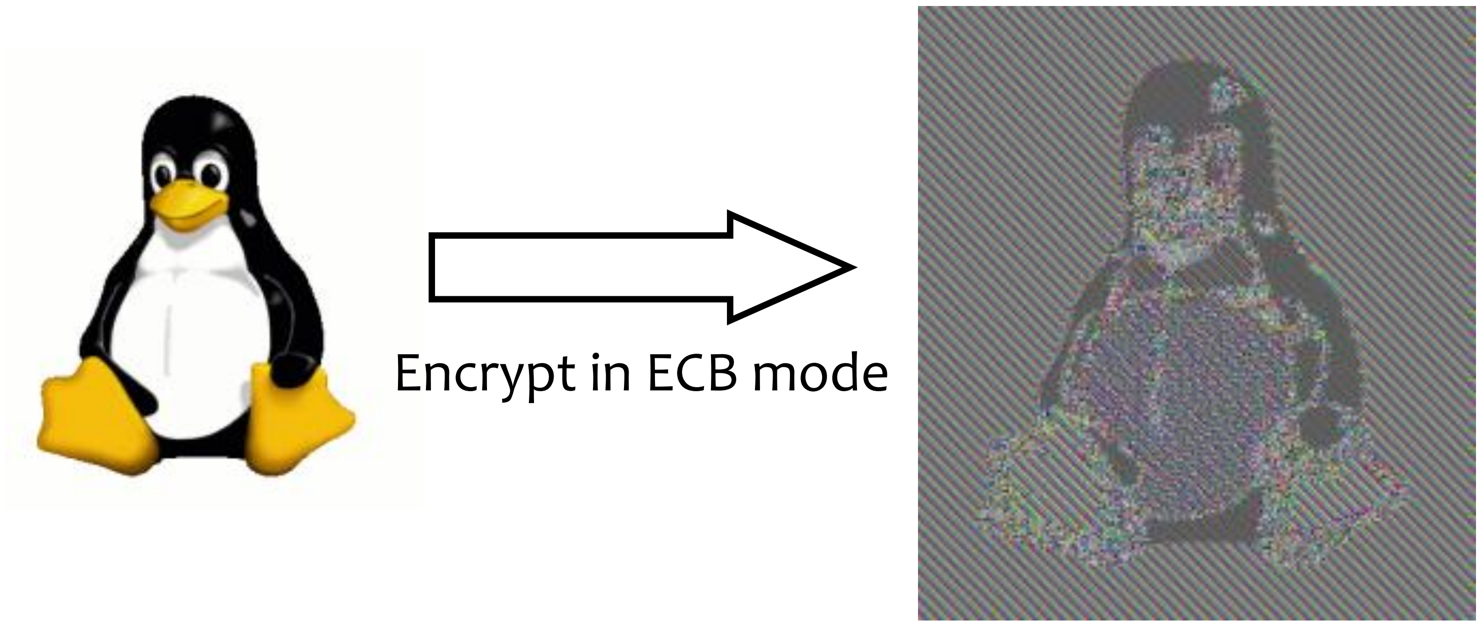
- What should we do?

# Electronic Code Book (ECB) Mode



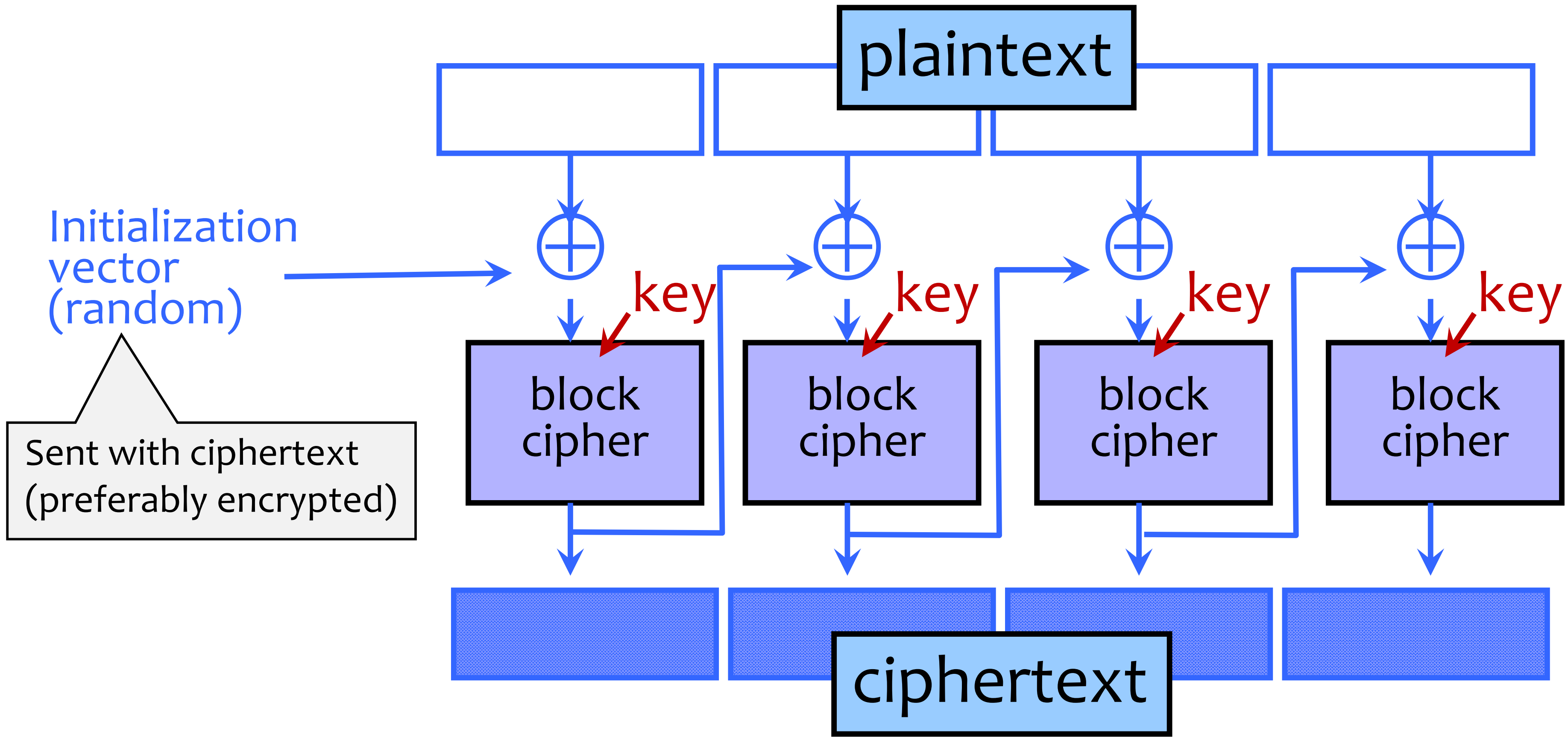

- Identical blocks of plaintext produce identical blocks of ciphertext
- No integrity checks: can mix and match blocks

# Information Leakage in ECB Mode



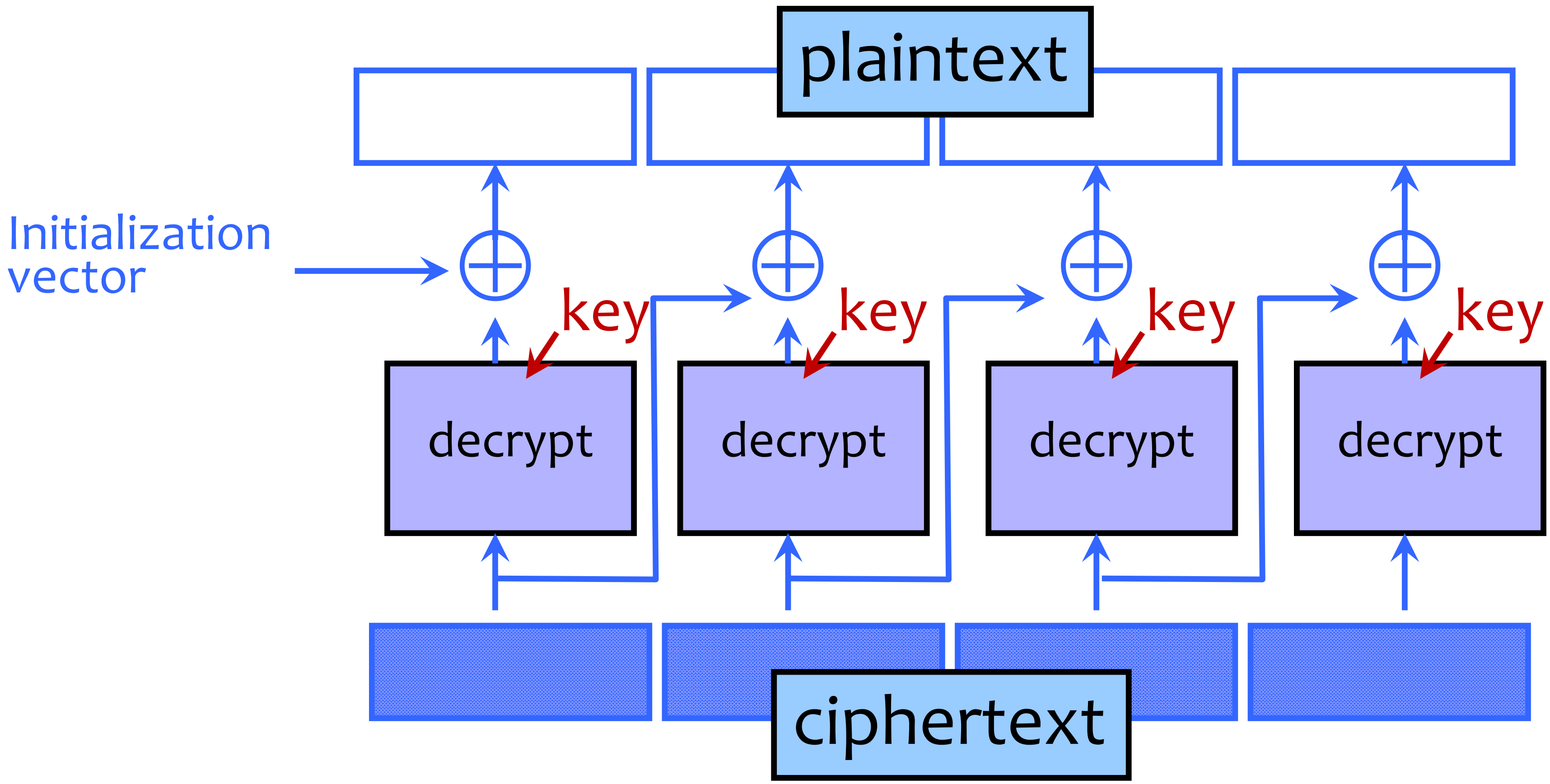

[Wikipedia]

# Cipher Block Chaining (CBC) Mode: Encryption

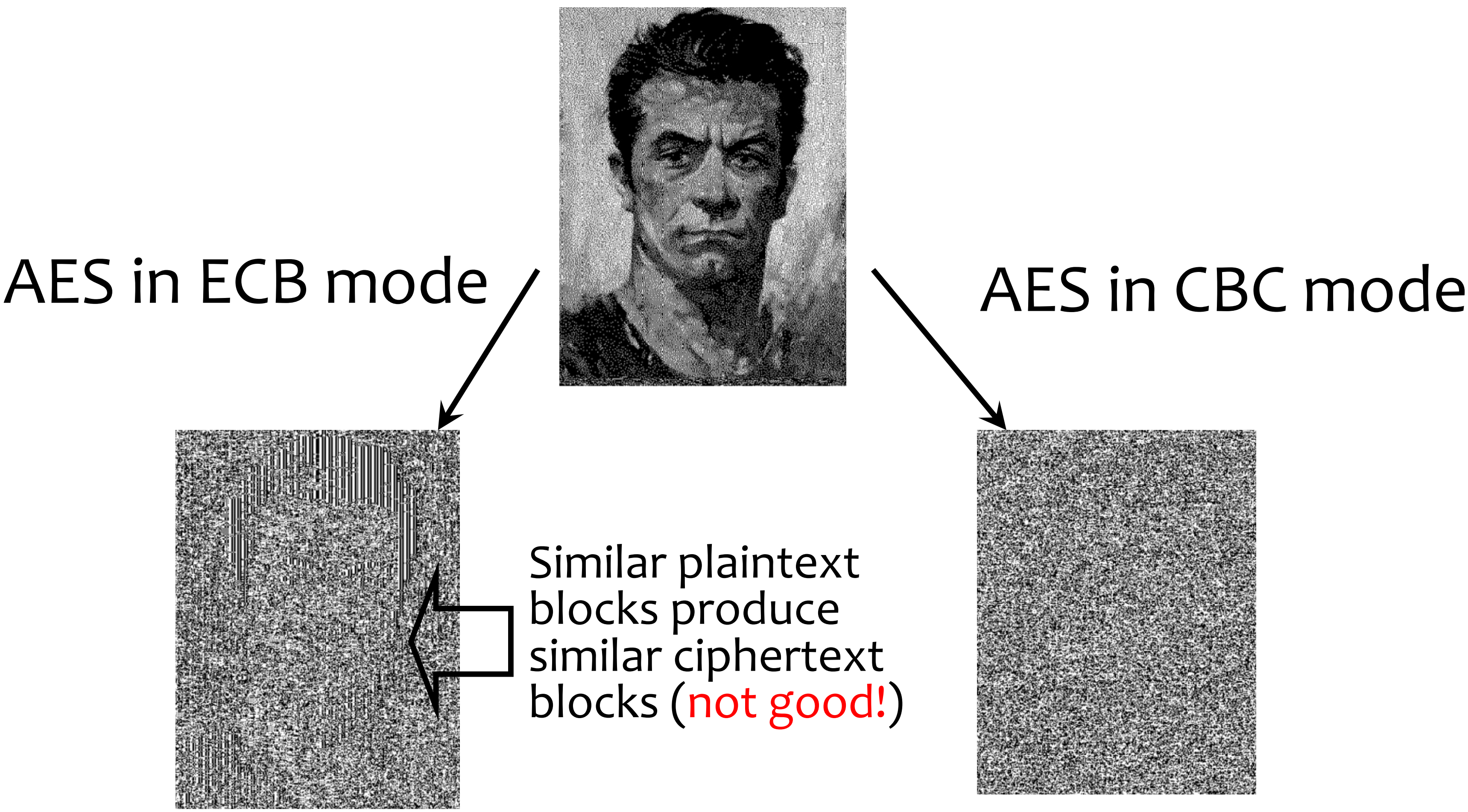



- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext
  - Still does not guarantee integrity

# CBC Mode: Decryption

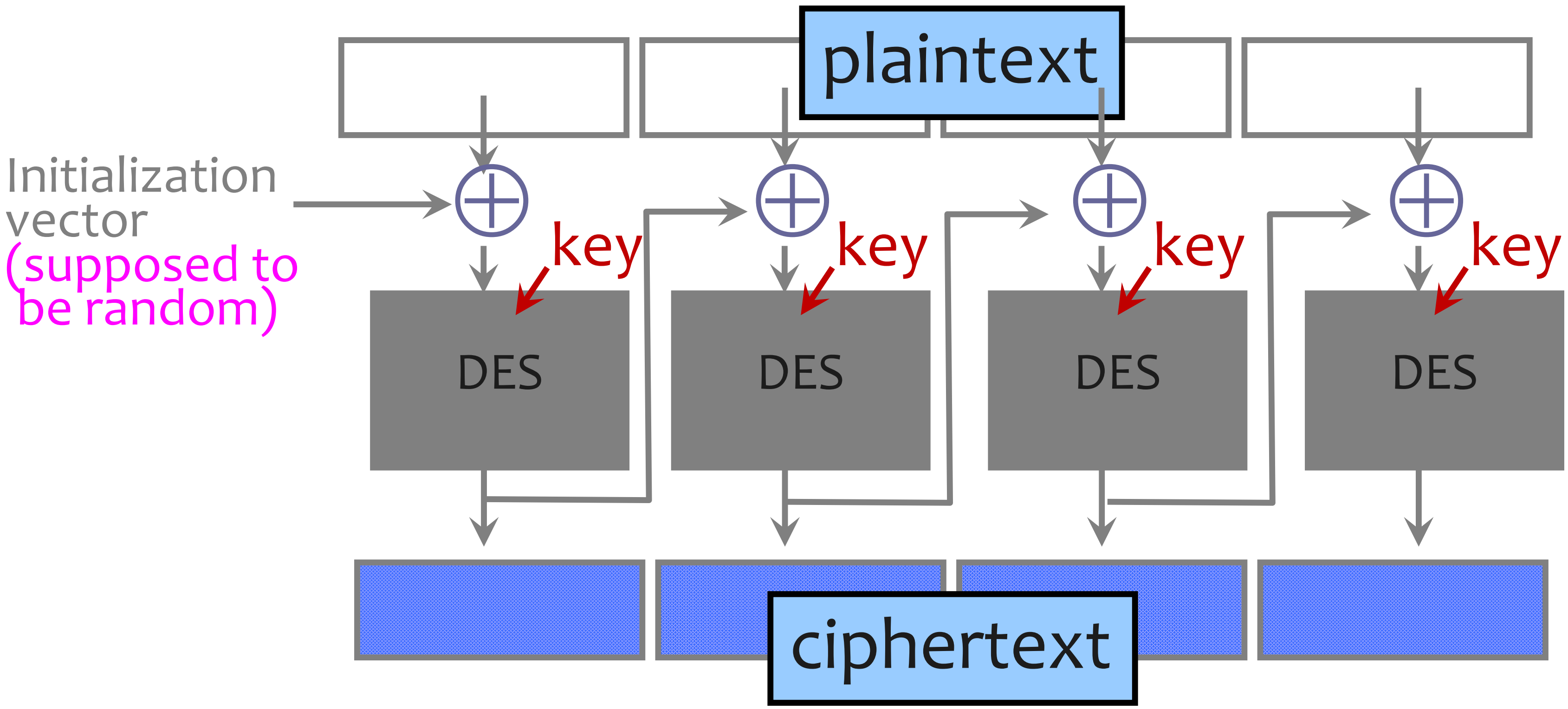


# ECB vs. CBC




[Picture due to Bart Preneel]

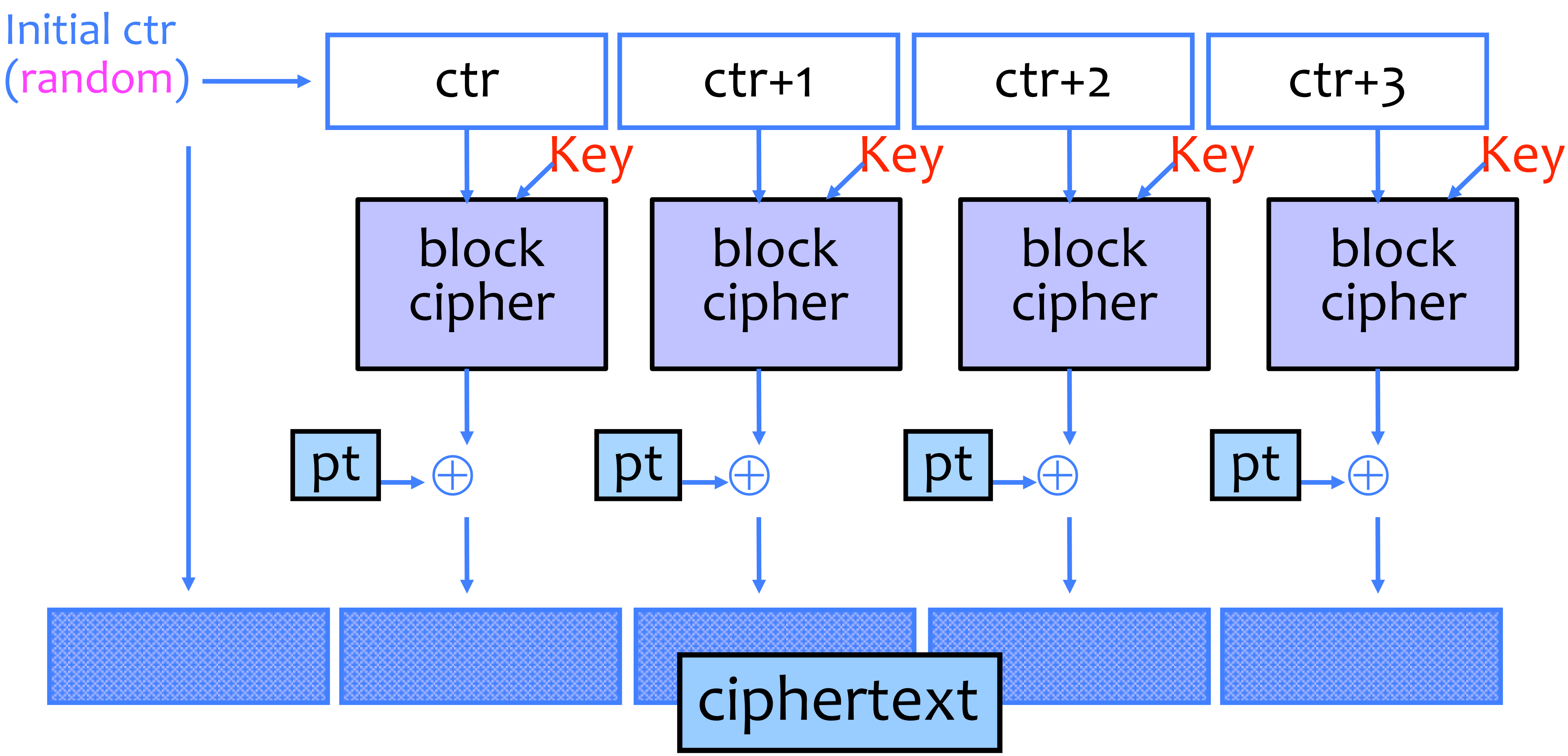
# CBC and Electronic Voting




Found in the source code for Diebold voting machines:

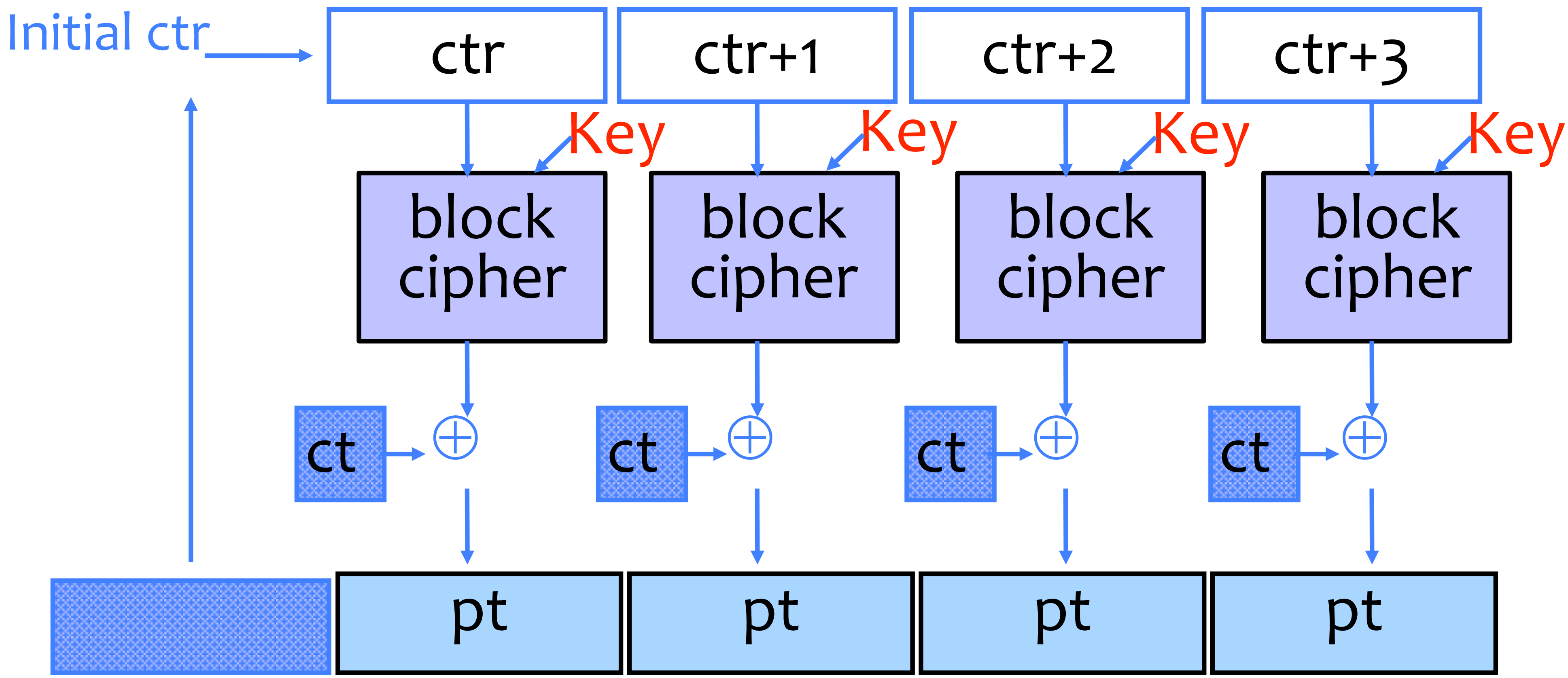
```
DesCBCEncrypt((des_c_block*)tmp, (des_c_block*)record.m_Data,
              totalSize, DESKEY, NULL, DES_ENCRYPT)
```

# Counter Mode (CTR): Encryption




- Identical blocks of plaintext encrypted differently
- Still does not guarantee integrity; Fragile if ctr repeats

# Counter Mode (CTR): Decryption



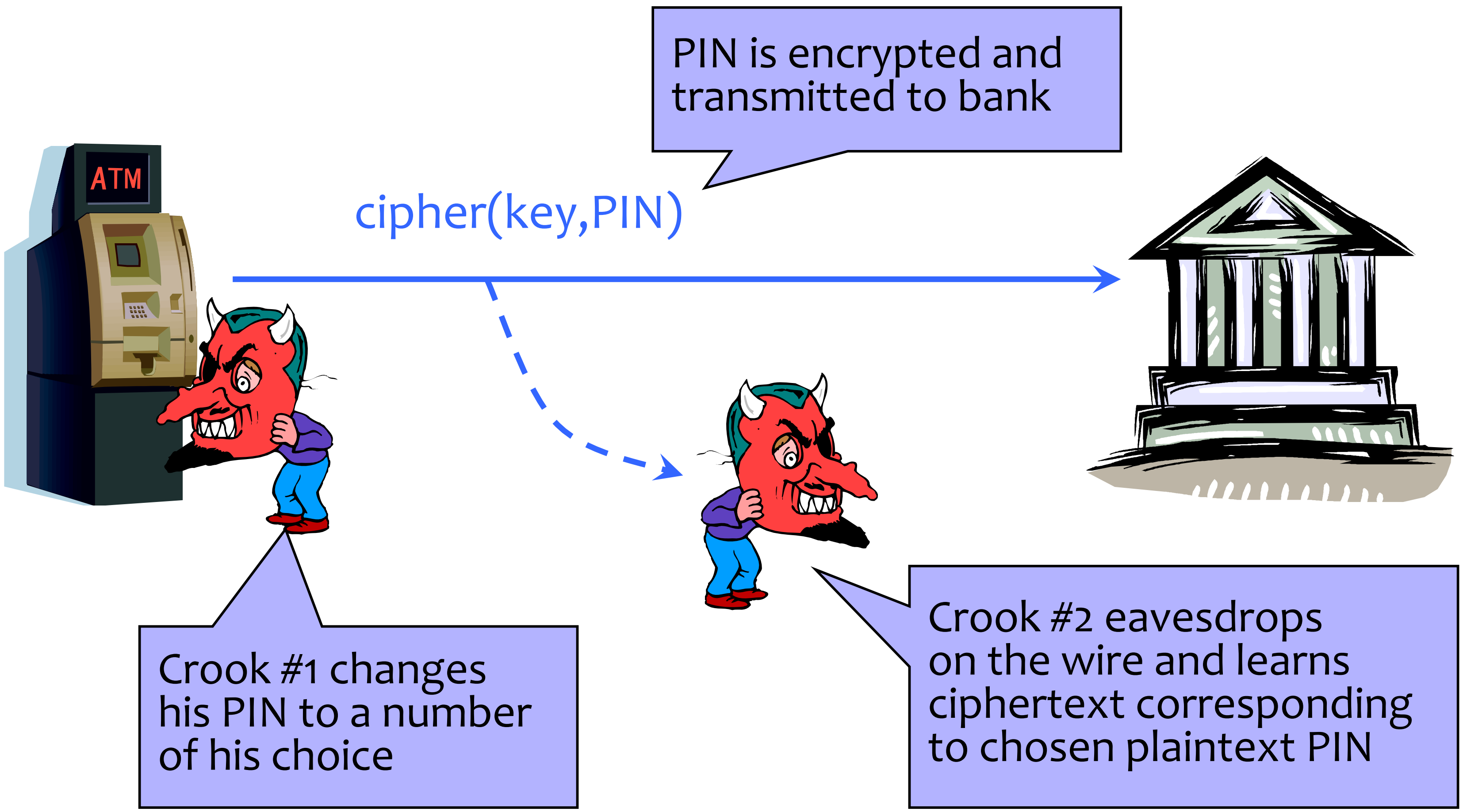
# When is an Encryption Scheme "Secure"?

- 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?

# How Can a Cipher Be Attacked?

- Attackers knows ciphertext and encryption algthm
  - 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
- CCA: Chosen-ciphertext attack (very strong)
  - Can decrypt any ciphertext except the target

# Chosen Plaintext Attack




… repeat for any PIN value

# 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, he cannot verify his guess
  - Every ciphertext is unique, encrypting same message twice produces completely different ciphertexts
    - Implication: encryption must be randomized or stateful
- Security against chosen-ciphertext attack (CCA)
  - Integrity protection – it is not possible to change the plaintext by modifying the ciphertext