CSE 484 (Winter 2010)

Symmetric Cryptography

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Thanks to Dan Boneh, Dieter Gollmann, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

Goals for Today

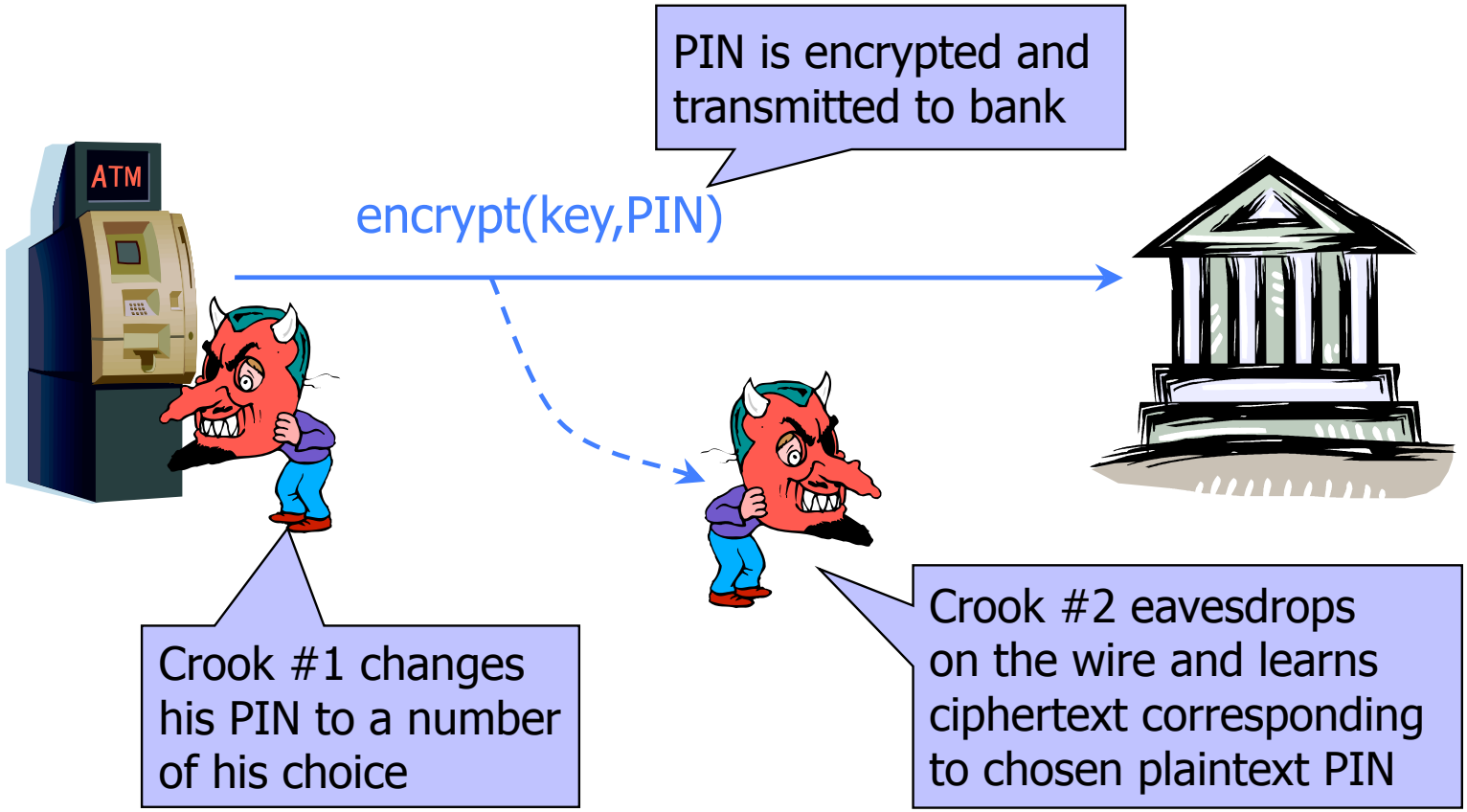
- Under the hood: Symmetric encryption

Attack Scenarios for Encryption

- Ciphertext-Only
- Known Plaintext
- Chosen Plaintext
- Chosen Ciphertext (and Chosen Plaintext)

- (General advice: Target strongest level of privacy possible -- even if not clear why -- for extra "safety")

Chosen-Plaintext Attack

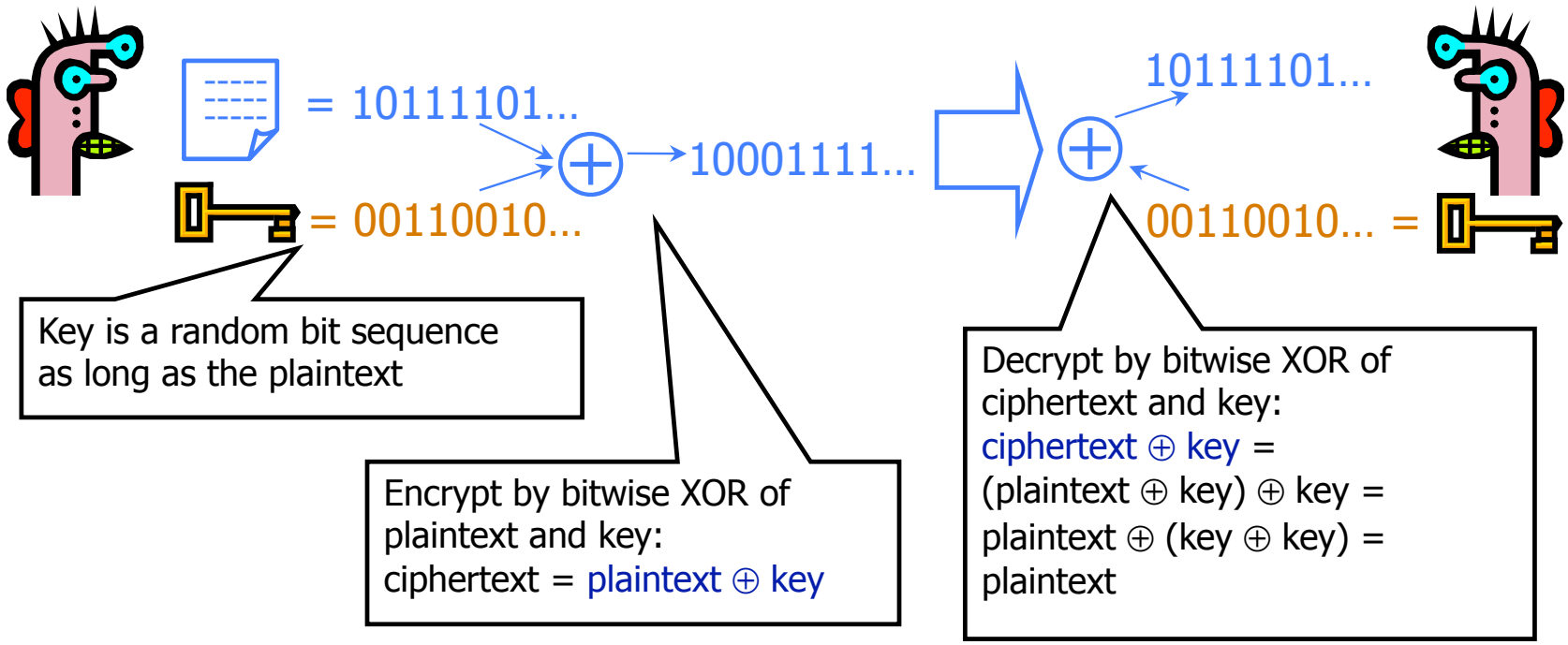


… repeat for any PIN value

Attack Scenarios for Integrity

- What do you think these scenarios should be?

One-Time Pad

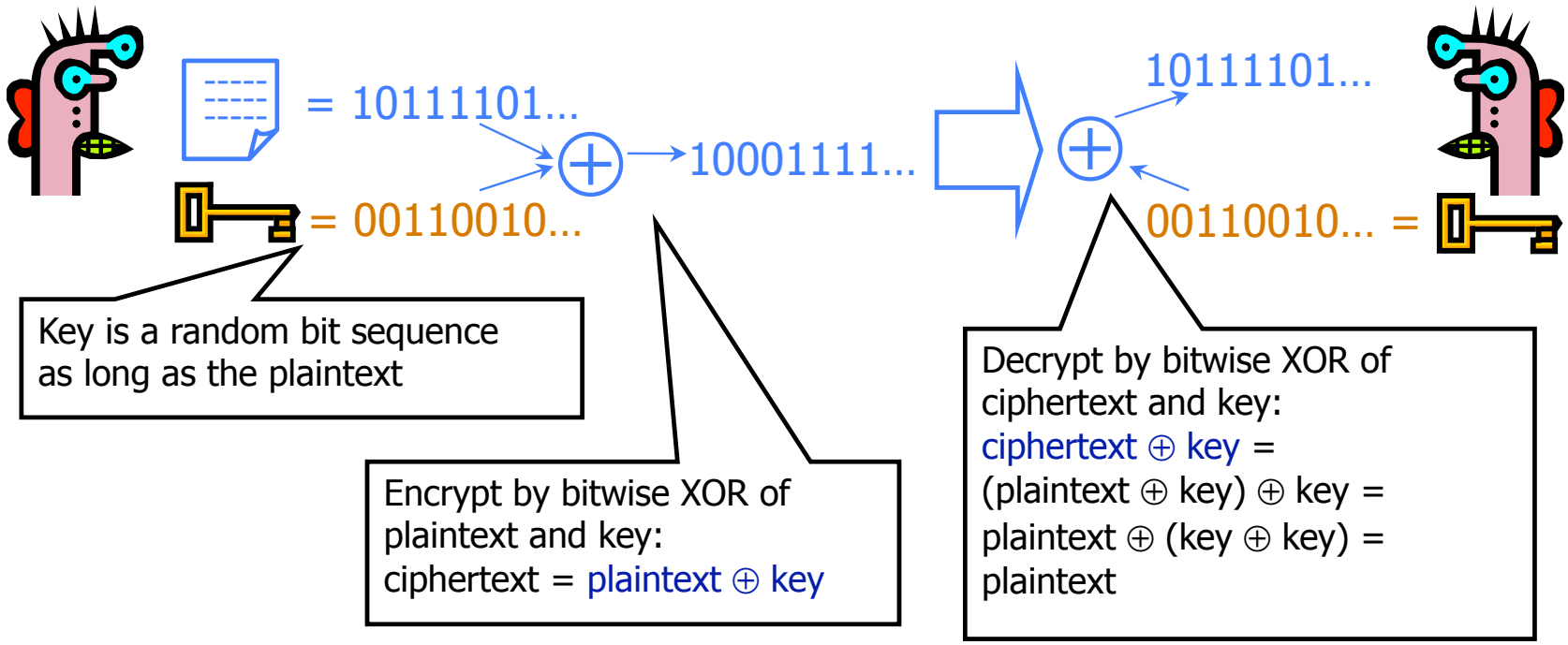


Cipher achieves perfect secrecy if and only if there are as many possible keys as possible plaintexts, and every key is equally likely (Claude Shannon)

Advantages of One-Time Pad

- Easy to compute
  - Encryption and decryption are the same operation
  - Bitwise XOR is very cheap to compute
- As secure as theoretically possible
  - 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 the sender communicate the key to receiver?

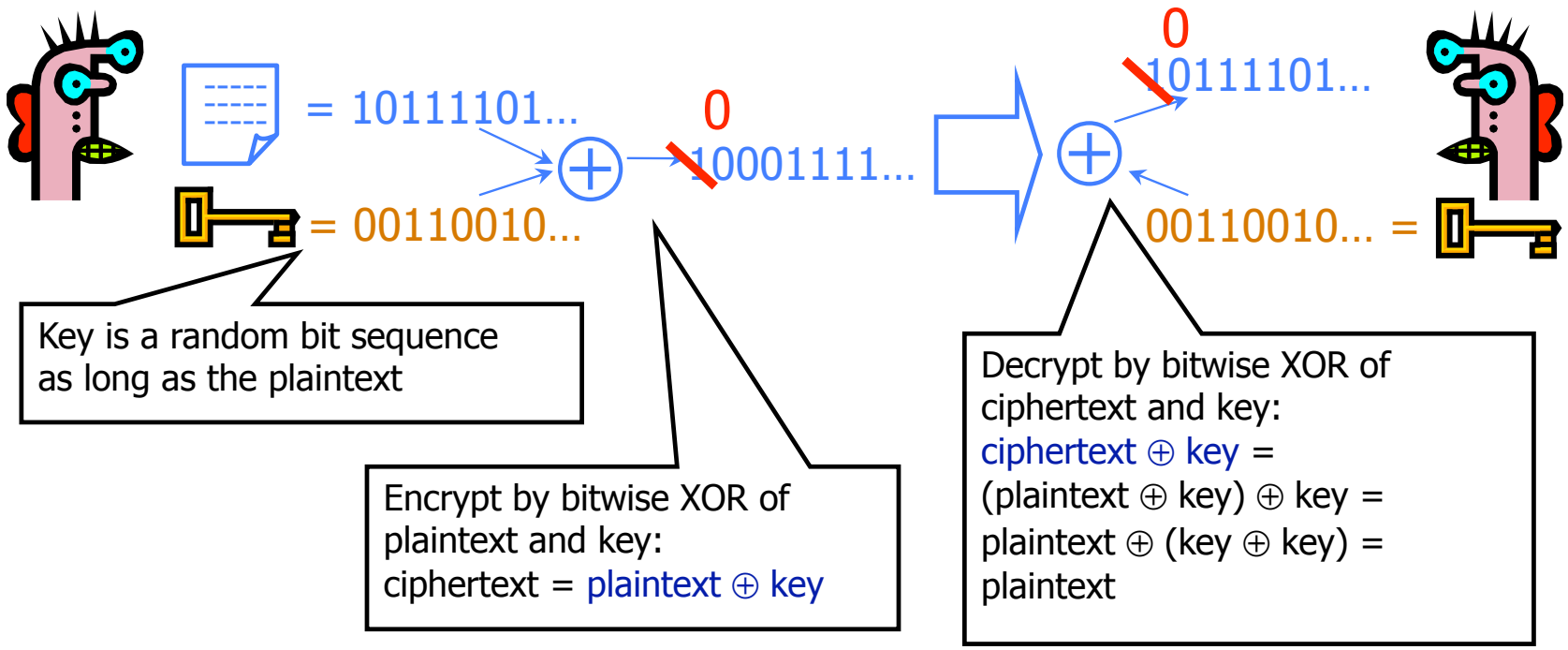
Disadvantages



Disadvantage #1: Keys as long as messages.

- Impractical in most scenarios
- Still used by intelligence communities

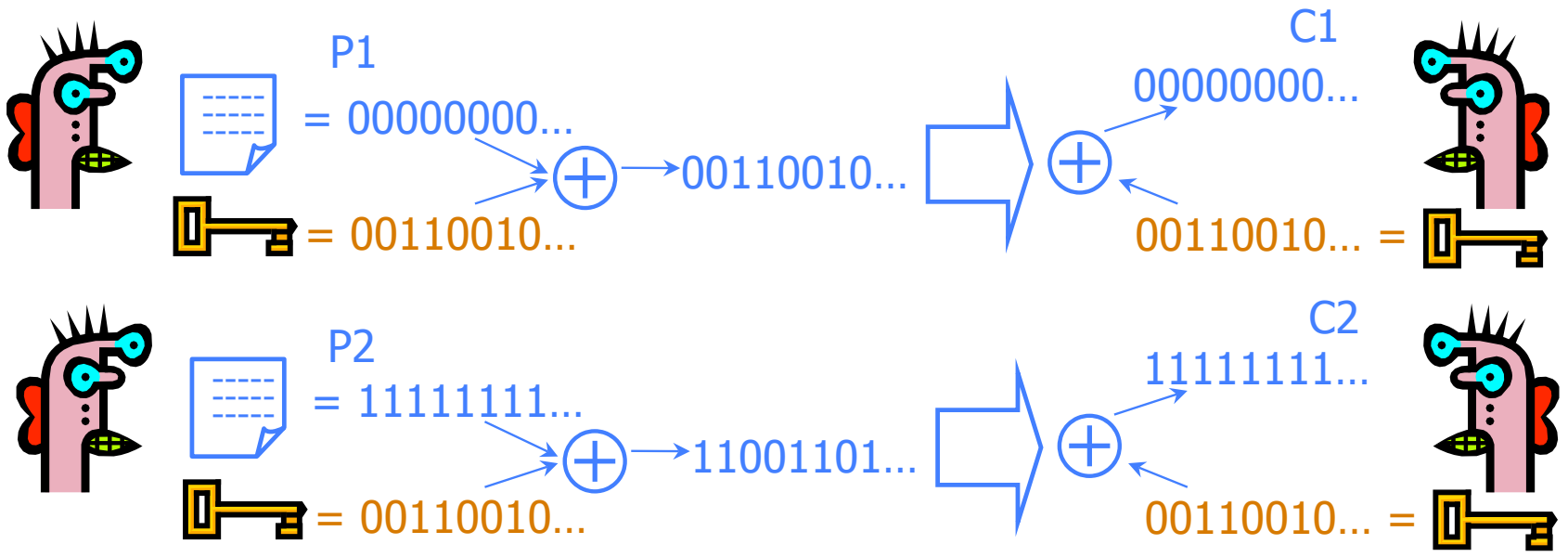
Disadvantages



Disadvantage #2: No integrity protection

Disadvantages

Disadvantage #3: Keys cannot be reused



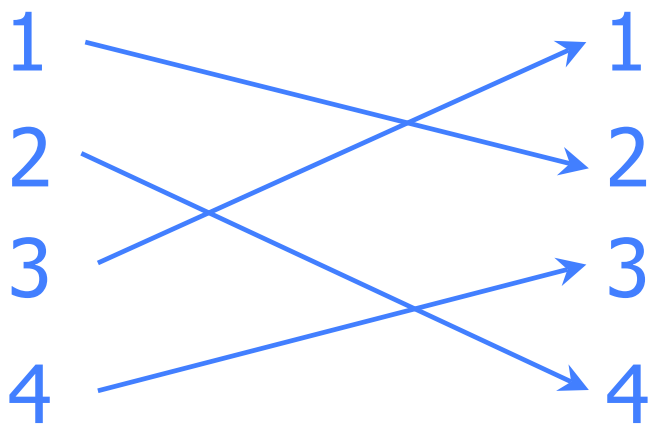
Learn relationship between plaintexts:

$C1 \oplus C2 = (P1 \oplus K) \oplus (P2 \oplus K) = (P1 \oplus P2) \oplus (K \oplus K) = P1 \oplus P2$

Reducing Keysize

- What do we do when we can't pre-share huge keys?
  - When OTP is unrealistic
- We use special cryptographic primitives
  - Single key can be reused (with some restrictions)
  - But no longer provable secure (in the sense of the OTP)
- Examples: Block ciphers, stream ciphers

Background: Permutation

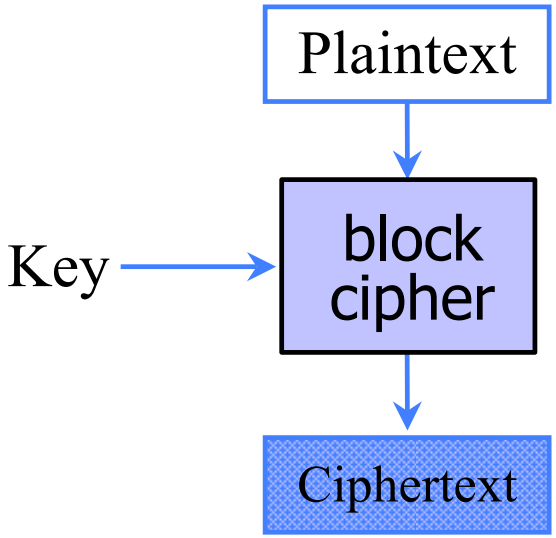


CODE becomes DCEO

- For N-bit input, N! possible permutations
- Idea: split plaintext into blocks; for each block use secret key to pick a permutation
  - Without the key, permutation should "look random"

Block Ciphers

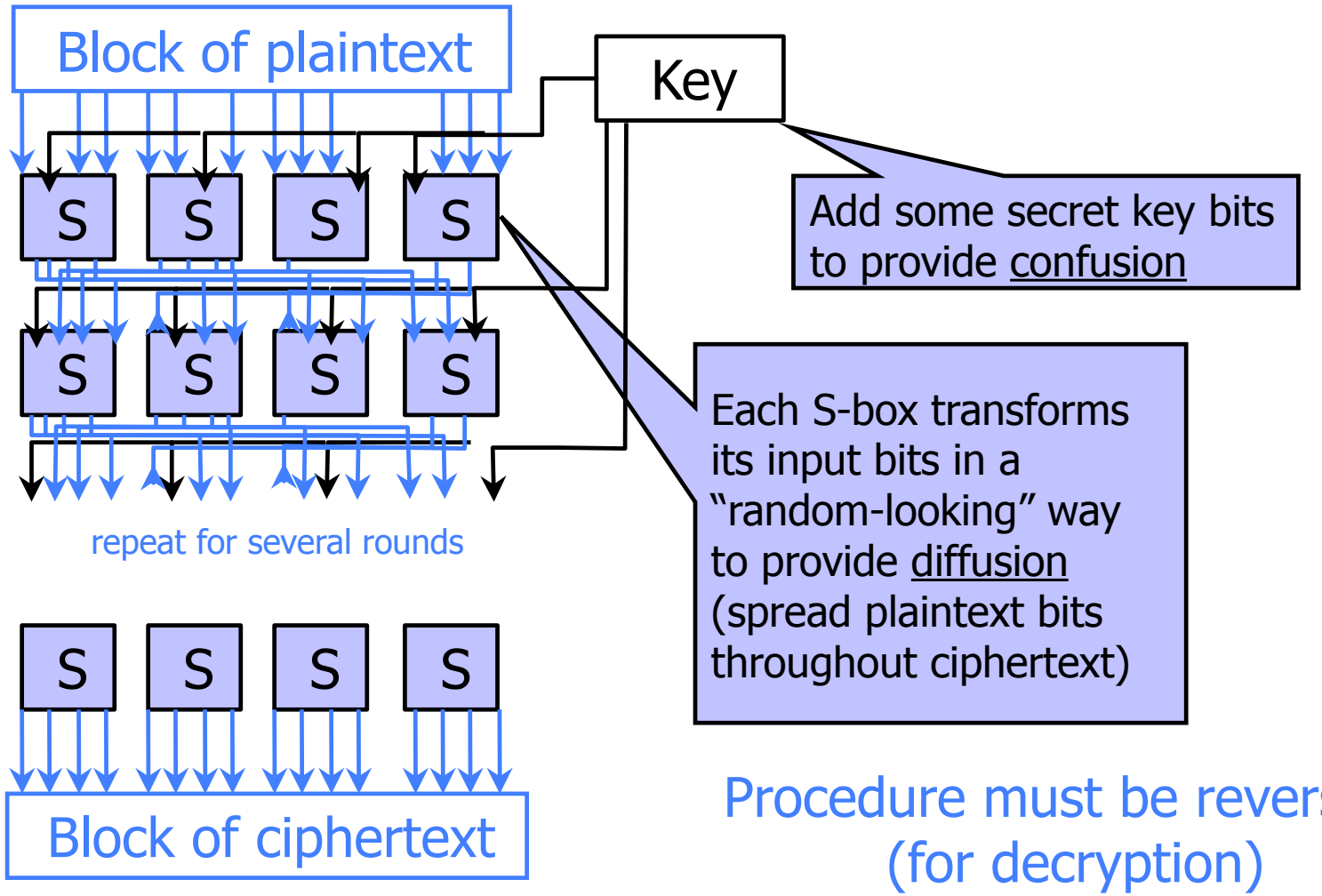
- Operates on a single chunk ("block") of plaintext
  - For example, 64 bits for DES, 128 bits for AES
  - Same key is reused for each block (can use short keys)



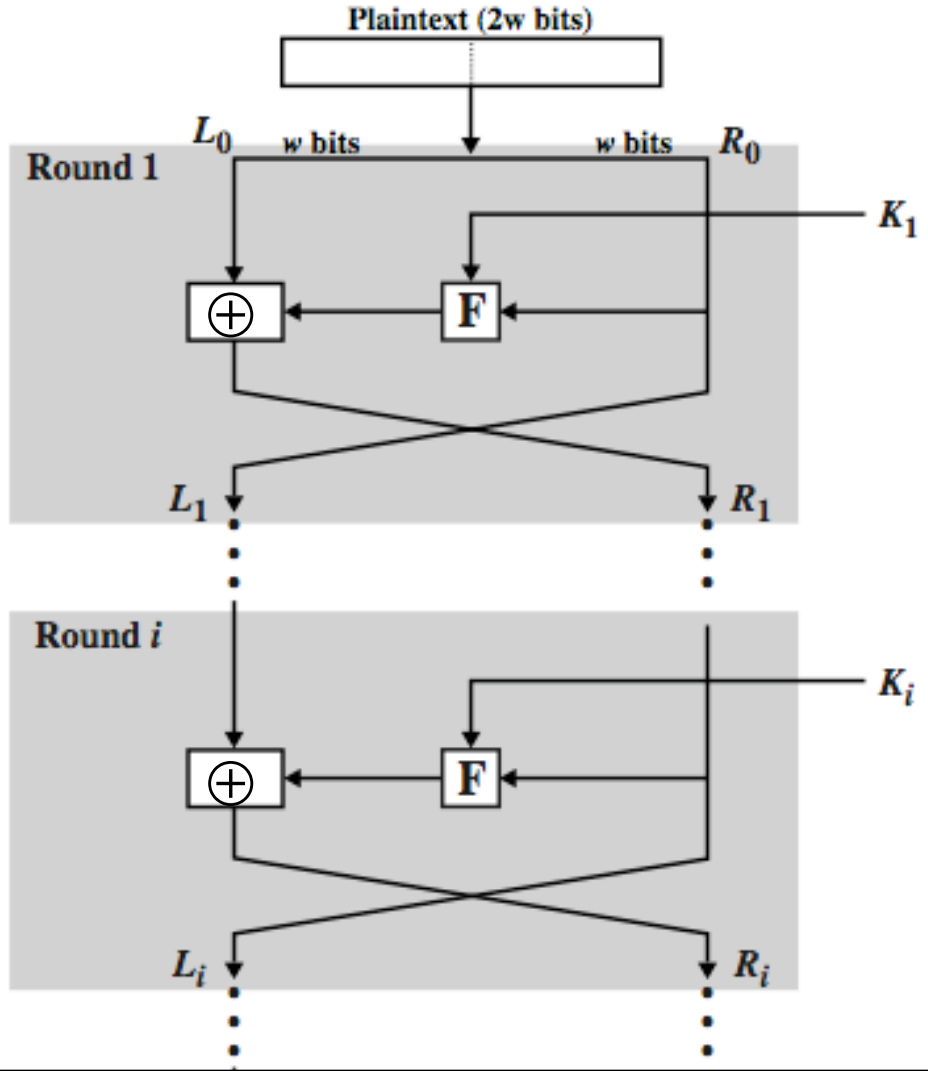
Block Cipher Security

- Result should look like a random permutation
  - "As if" plaintext bits were randomly shuffled
- Only computational guarantee of secrecy
  - Not impossible to break, just very expensive
    - If there is no efficient algorithm (unproven assumption!), then can only break by brute-force, try-every-possible-key search
  - Time and cost of breaking the cipher exceed the value and/or useful lifetime of protected information

Block Cipher Operation (Simplified)



Feistel Structure (Stallings Fig 2.2)



DES

- Feistel structure
  - "Ladder" structure: split input in half, put one half through the round and XOR with the other half
  - After 3 random rounds, ciphertext indistinguishable from a random permutation if internal F function is a pseudorandom function (Luby & Rackoff)
- DES: Data Encryption Standard
  - Feistel structure
  - Invented by IBM, issued as federal standard in 1977
  - 64-bit blocks, 56-bit key + 8 bits for parity

DES and 56 bit keys (Stallings Tab 2.2)

- 56 bit keys are quite short

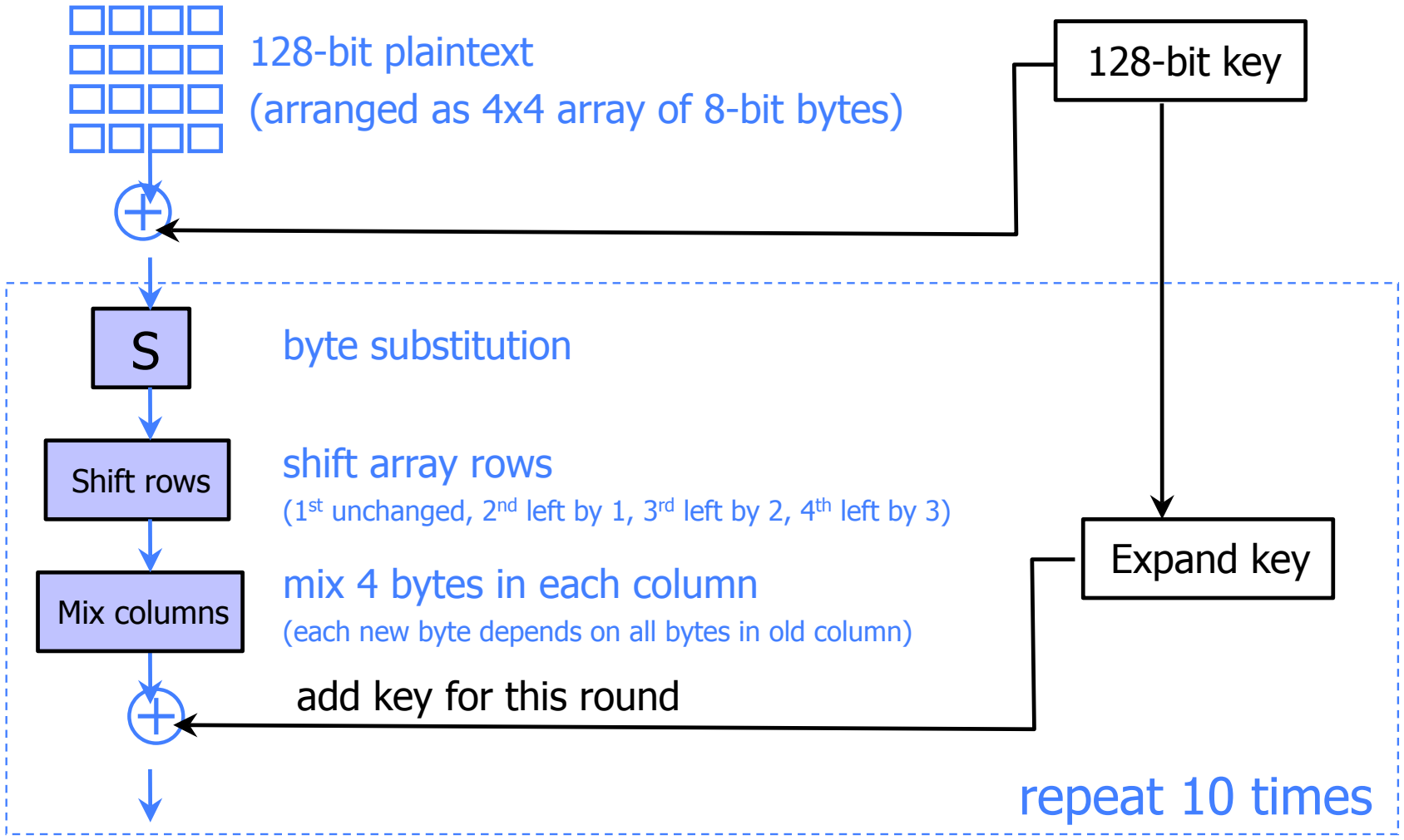
Key Size (bits)	Number of Alternative Keys	Time required at 1 encryption/μs	Time required at 10^6 encryptions/μs
32	$2^{32} = 4.3 \times 10^9$	$2^{31}\ \mu s = 35.8$ minutes	2.15 milliseconds
56	$2^{56} = 7.2 \times 10^{16}$	$2^{55}\ \mu s = 1142$ years	10.01 hours
128	$2^{128} = 3.4 \times 10^{38}$	$2^{127}\ \mu s = 5.4 \times 10^{24}$ 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 + distibuted machines
  - < 24 hours to find DES key
- DES ---> 3DES
  - 3DES: DES + inverse DES + DES (with 2 or 3 diff keys)

Advanced Encryption Standard (AES)

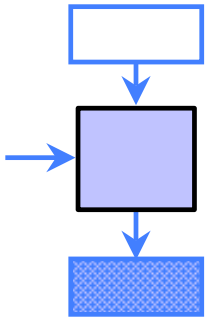
- New federal standard as of 2001
- Based on the Rijndael algorithm
- 128-bit blocks, keys can be 128, 192 or 256 bits
- Unlike DES, does not use Feistel structure
  - The entire block is processed during each round
- Design uses some very nice mathematics

Basic Structure of Rijndael



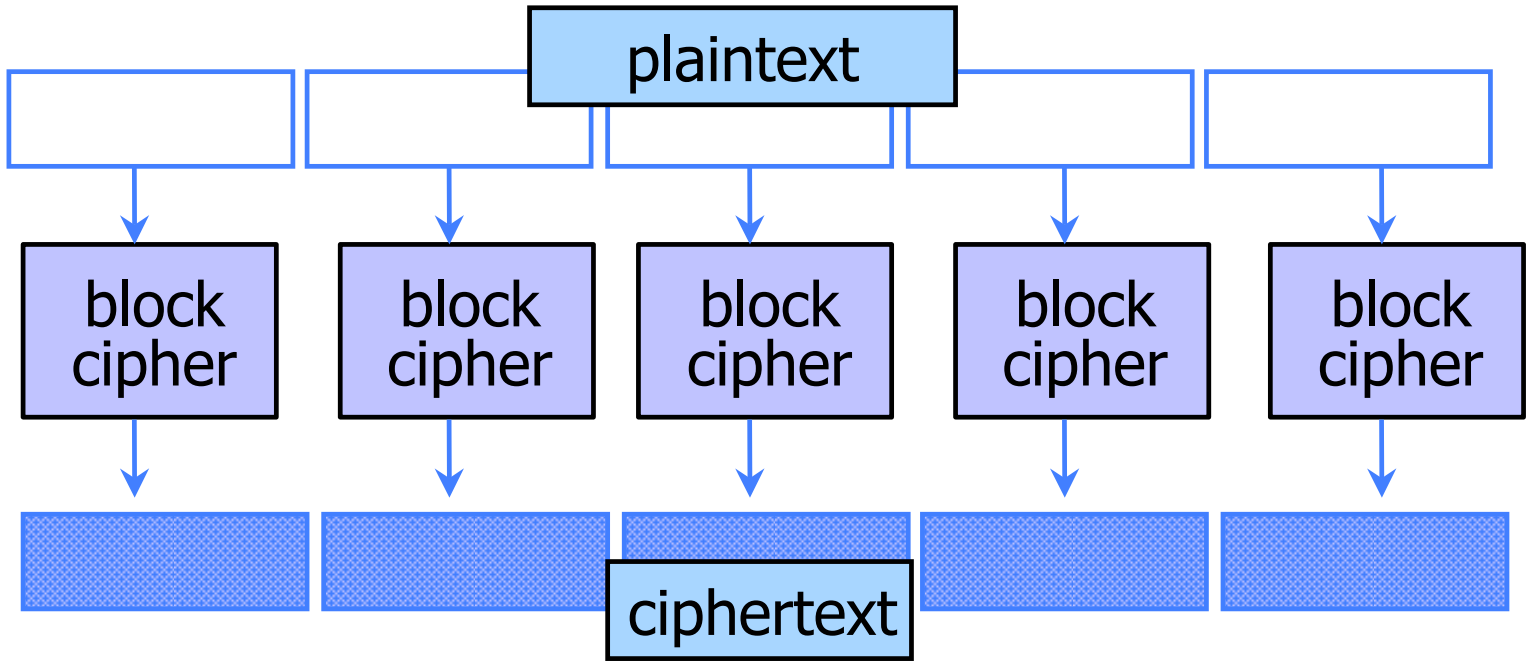
Encrypting a Large Message

- So, we've got a good block cipher, but our plaintext is larger than 128-bit block size
- Electronic Code Book (ECB) mode
  - Split plaintext into blocks, encrypt each one separately using the block cipher



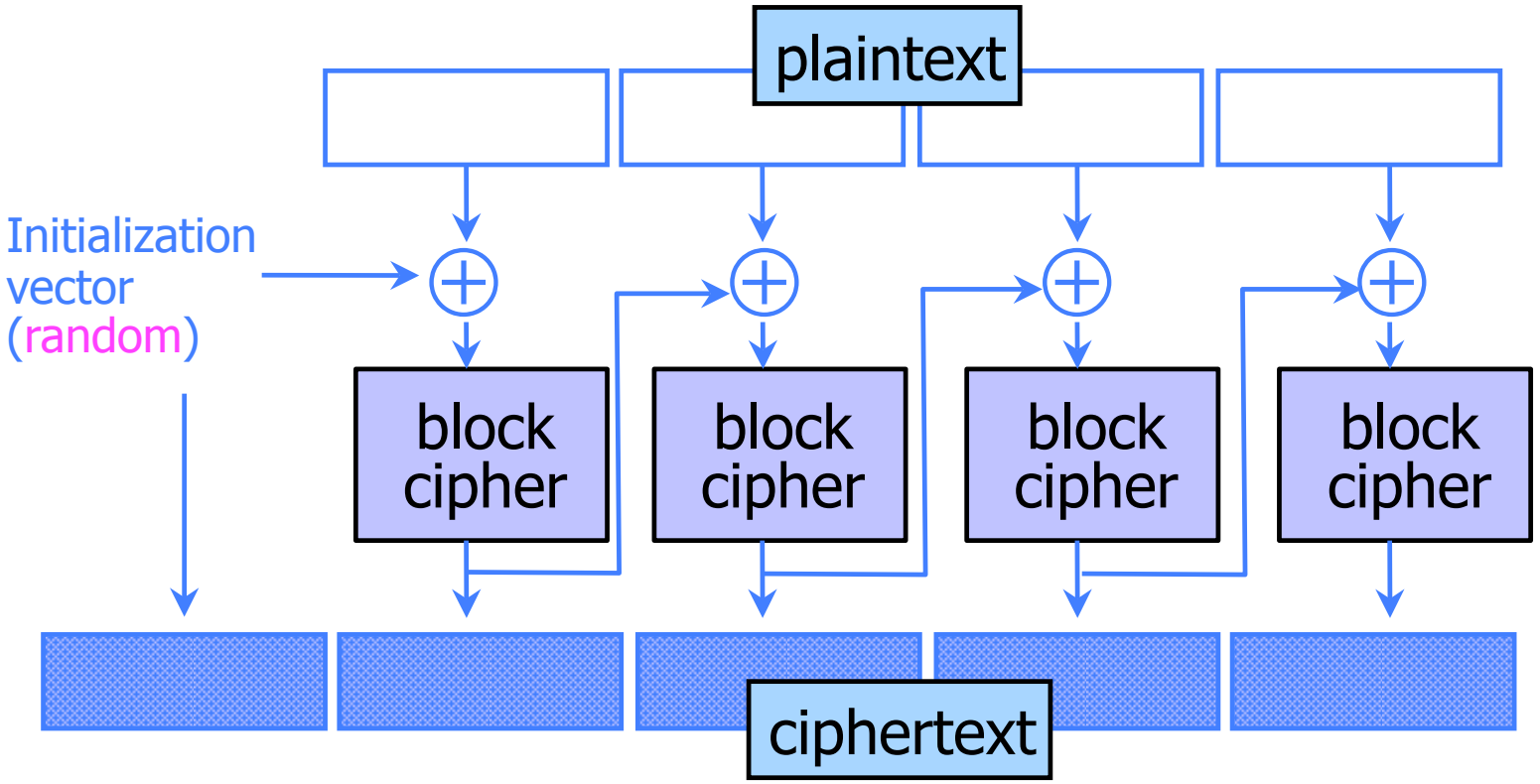
- Cipher Block Chaining (CBC) mode
  - Split plaintext into blocks, XOR each block with the result of encrypting previous blocks
- Counter (CTR) mode
  - Use block cipher to generate keystream, like a stream cipher
- ...

ECB Mode



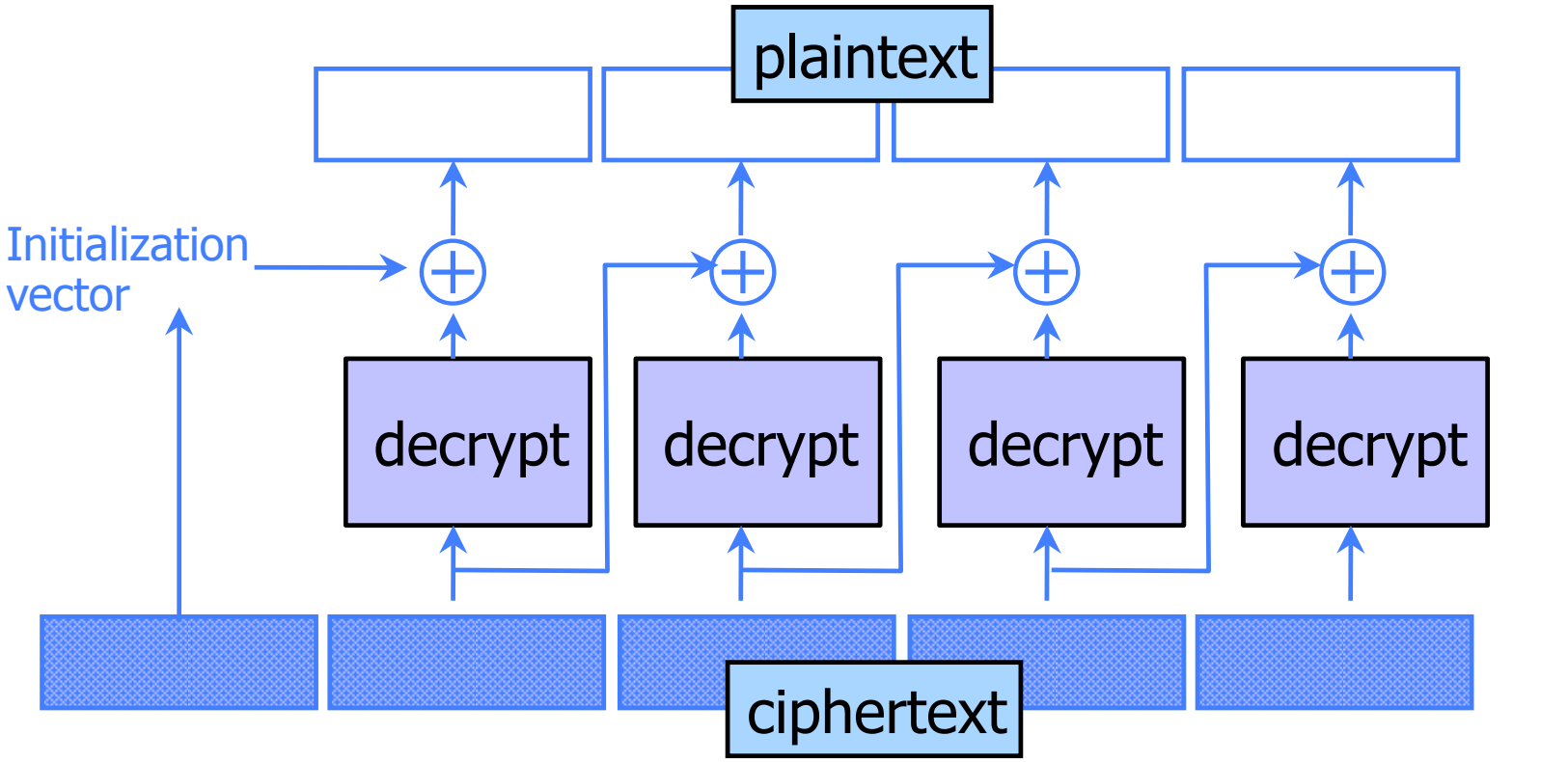
- Identical blocks of plaintext produce identical blocks of ciphertext
- No integrity checks: can mix and match blocks

CBC Mode: Encryption



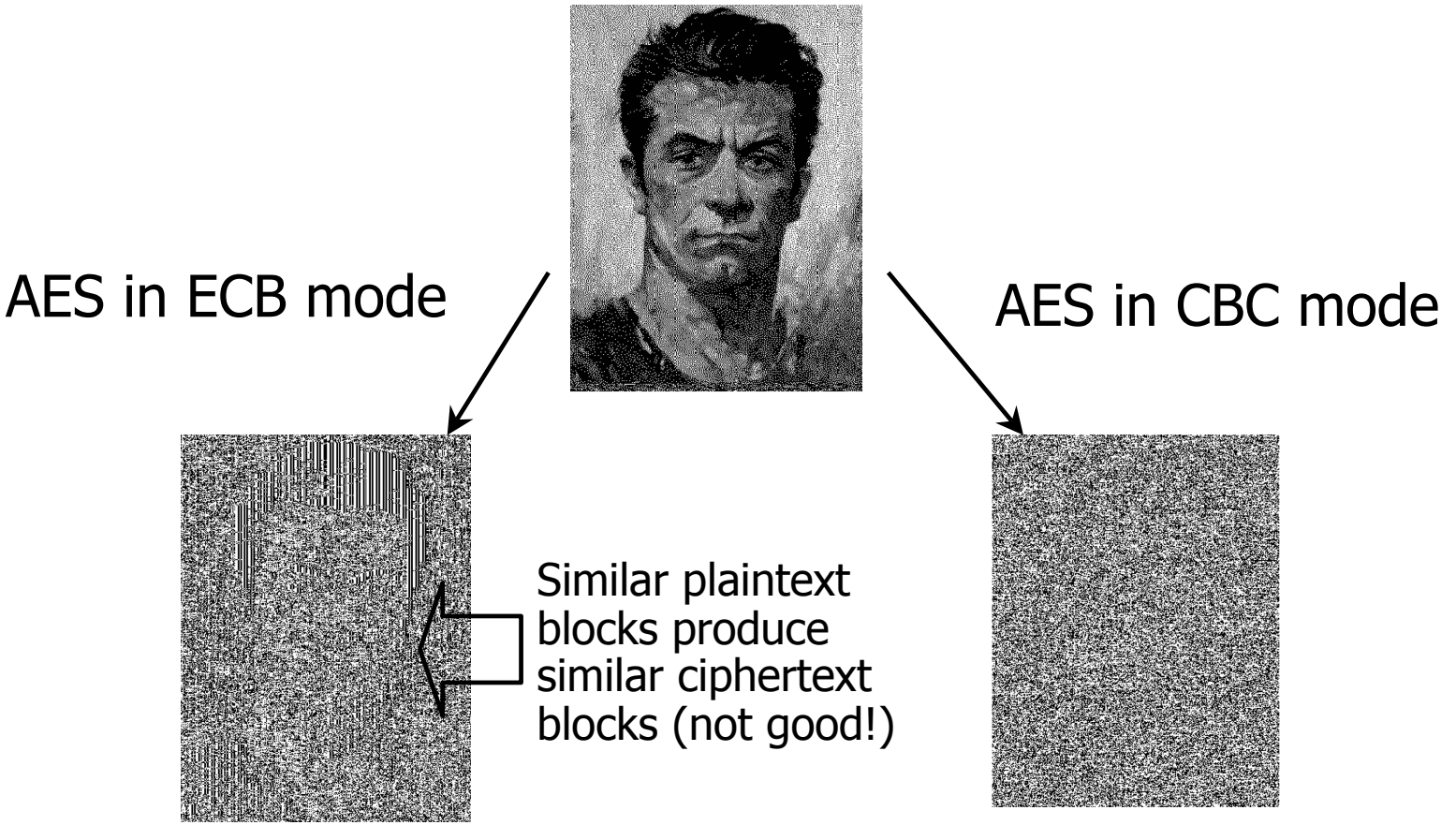
- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext
  - Still does not guarantee integrity

CBC Mode: Decryption



ECB vs. CBC

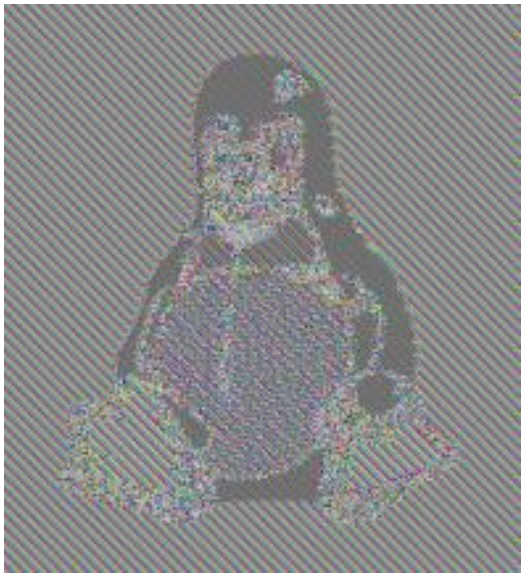
[Picture due to Bart Preneel]



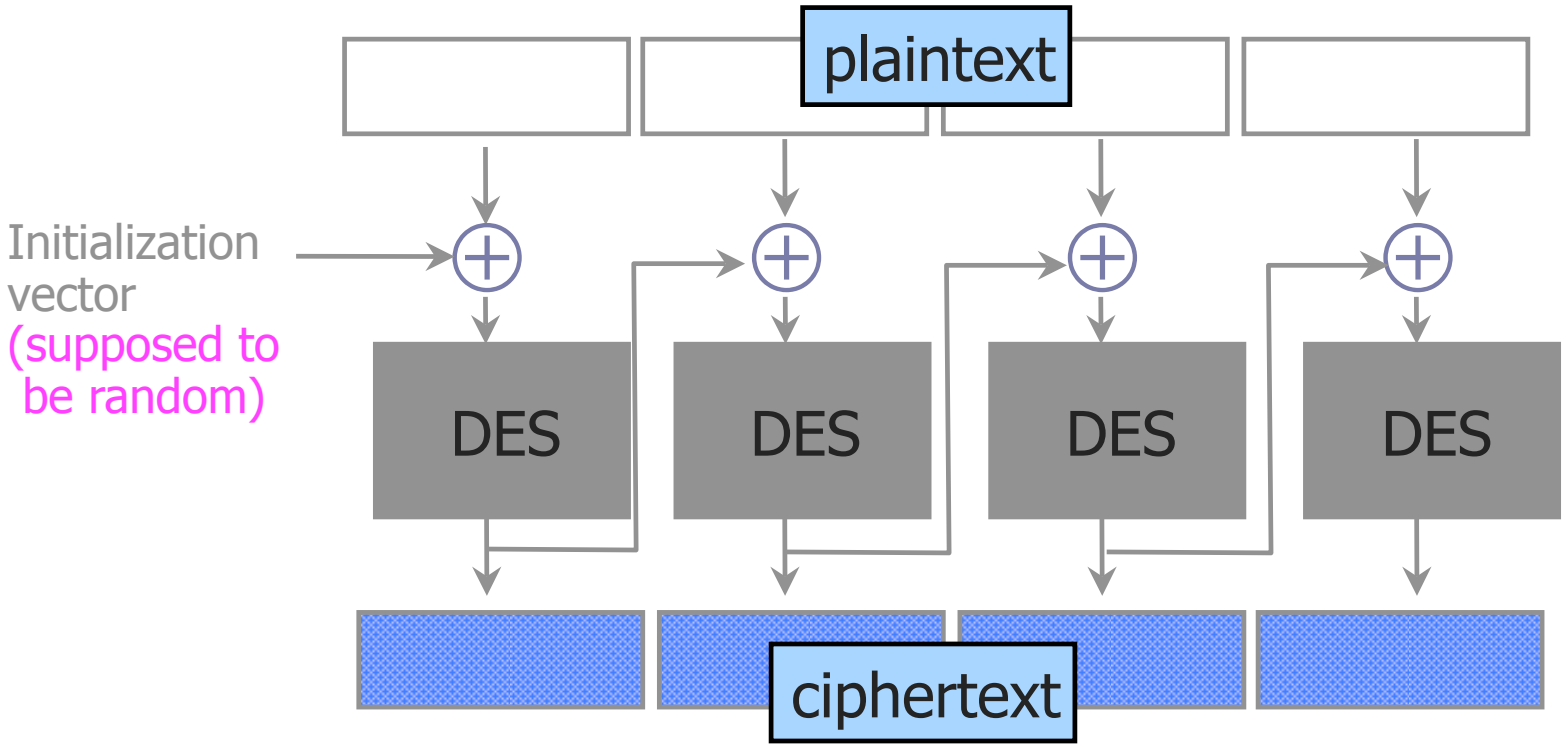
Information Leakage in ECB Mode

[Wikipedia]

Encrypt in ECB mode



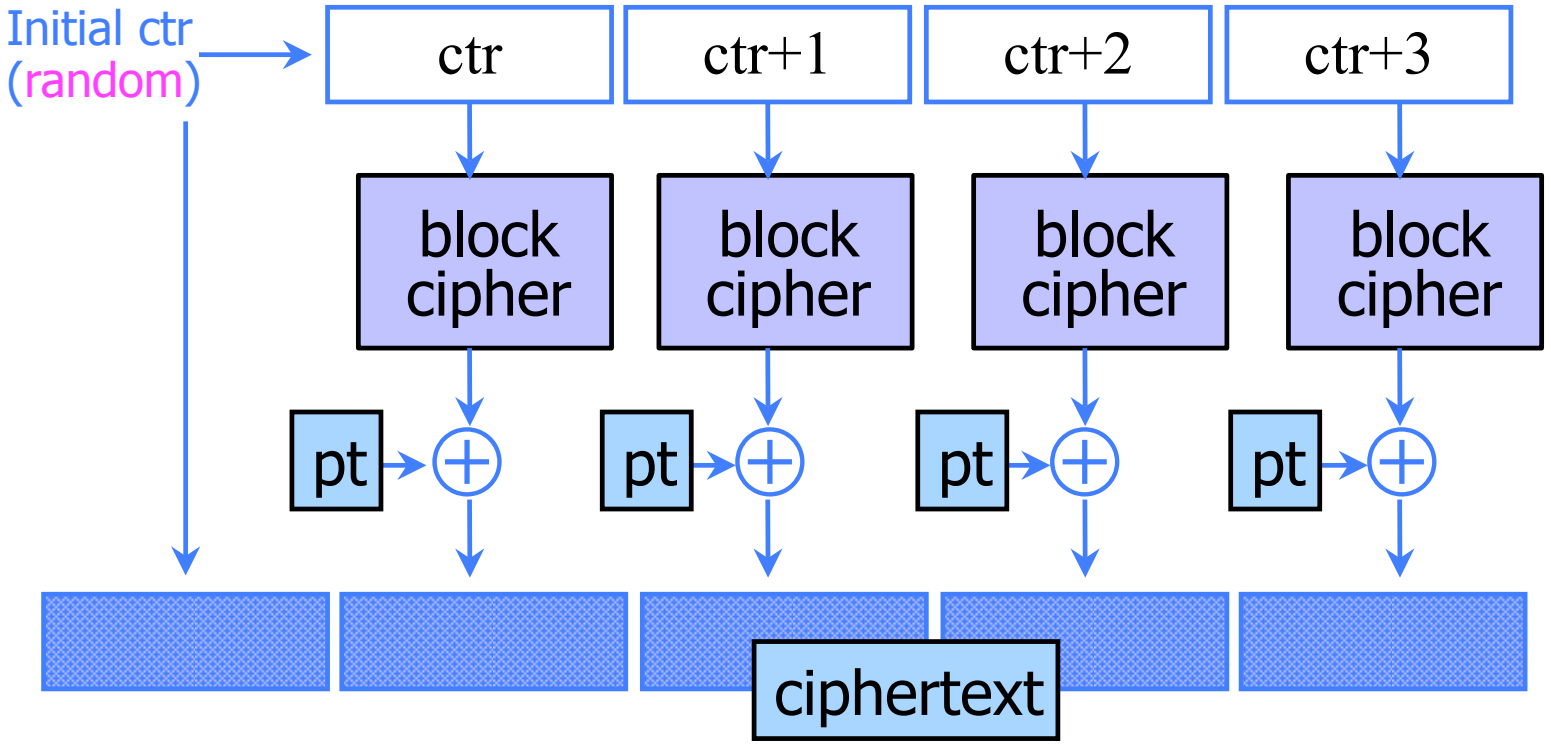
CBC and Electronic Voting



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)
```

CTR Mode: Encryption



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

CTR Mode: Decryption