CSE 484: Computer Security and Privacy

# Cryptography
## [Symmetric Encryption]

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Thanks to Franzi Roesner, Dan Boneh, Dieter Gollmann, Dan Halperin, Yoshi Kohno, Ada Lerner, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

# Admin

- Lab 1 ongoing
- Homework 2 (crypto) will be out soon
  - Due on 2/10 (designed to give you hands-on experience with crypto concepts, not be tricky – not intended to take you a full 2 weeks)

- Watching the recording? Please fill out: https://forms.gle/5qoJSfxap3mmBsJk6

# Reducing Key Size

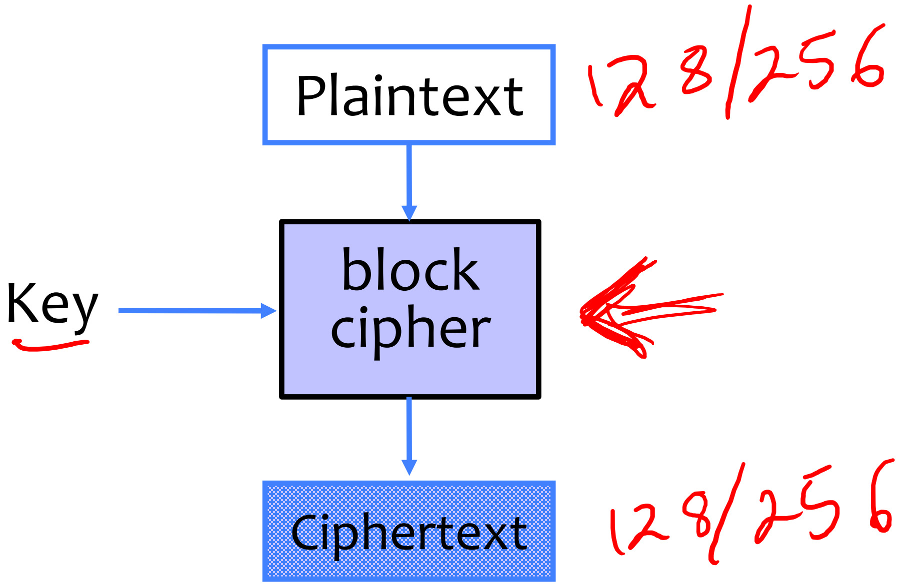
- What to do when it is infeasible to pre-share huge random keys?
  - When one-time pad is unrealistic…
- Use special cryptographic primitives: block ciphers, stream ciphers
  - Single key can be re-used (with some restrictions)
  - Not as theoretically secure as one-time pad

56 / 128/256

bits

# 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)



# Keyed Permutation

| input | possible output | possible output | etc. |
|---|---|---|---|
| 000 | 010 | 111 | … |
| 001 | 111 | 110 | … |
| 010 | 101 | 000 | … |
| 011 | 110 | 101 | … |
| … | … | | … |
| 111 | 000 | 110 | … |

Key = 00

Key = 01

00 / 01

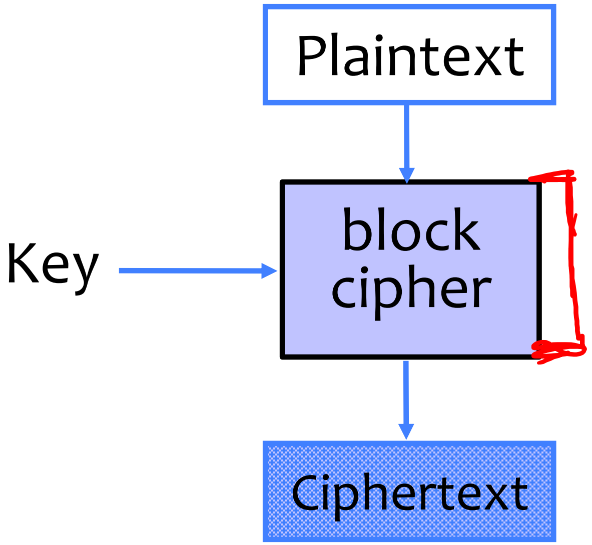
Out$_1$ / Out$_2$

For N-bit input, $2^N$! possible permutations

For K-bit key, $2^K$ possible keys

# Keyed Permutation

- Not just shuffling of input bits!
  - Suppose plaintext = “111”.
  - Then “111” is not the only possible ciphertext!
- Instead:
  - **Permutation of possible outputs**
  - Use secret key to pick a permutation



# Block Cipher Security

128 bit

block $2^{128}$

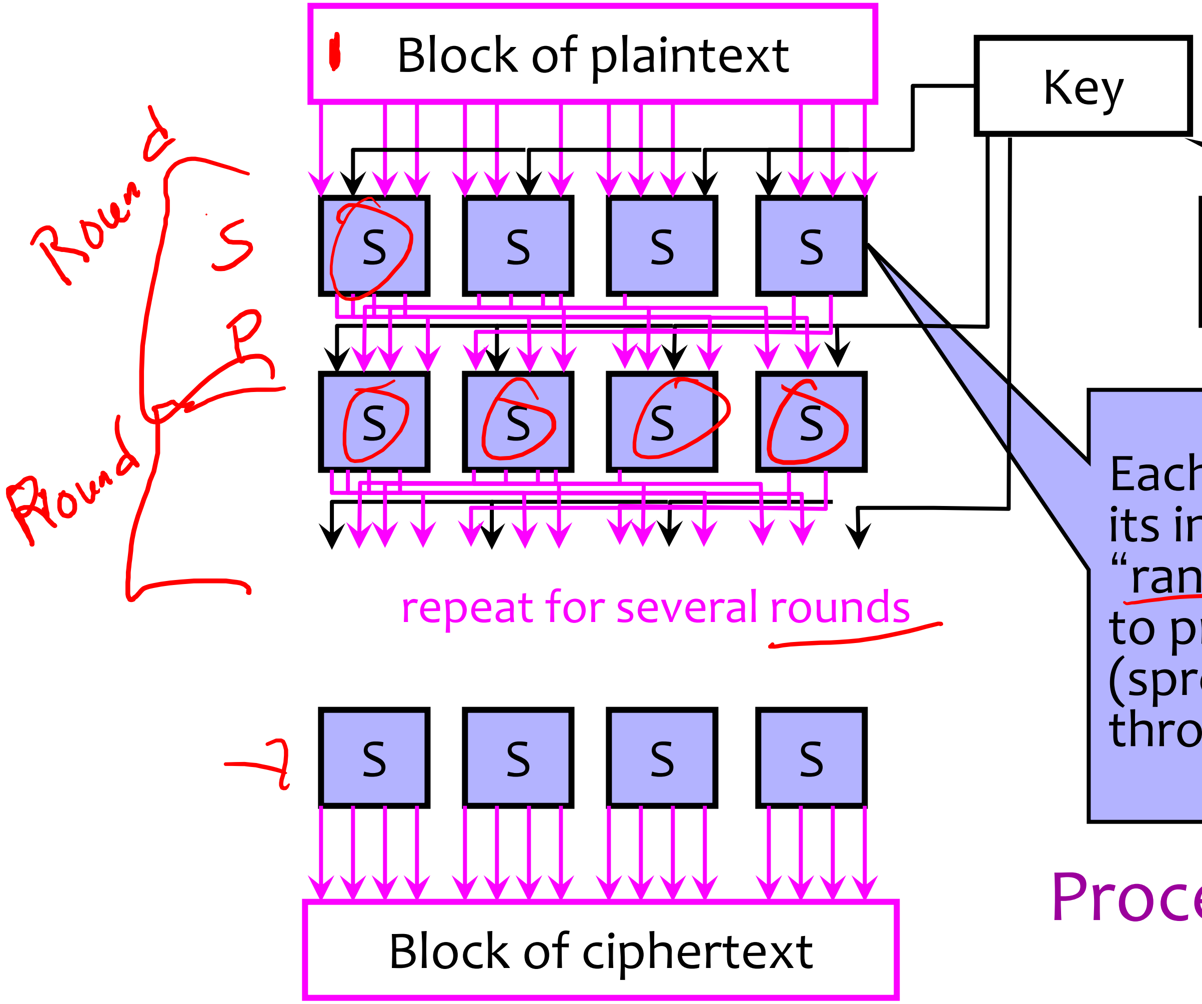
1024 OTP

$2^{1024}$

$2^{\text{min bits}}$

- Result should look like a random permutation on the inputs
  - Recall: not just shuffling bits. N-bit block cipher permutes over $2^N$ inputs.
- 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

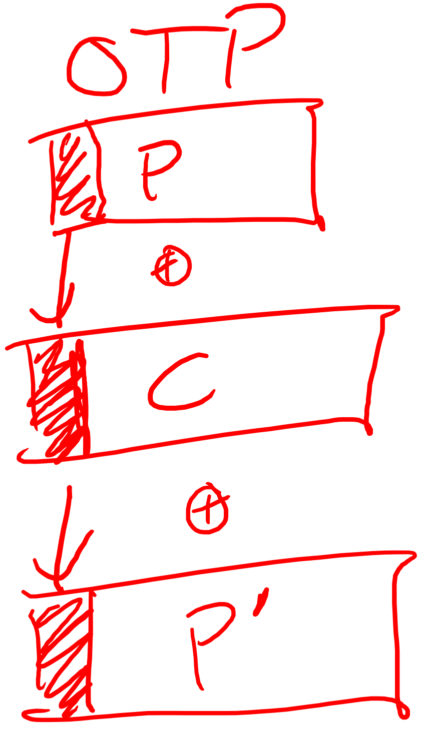
# Block Cipher Operation (Simplified)




Add some secret key bits to provide confusion

Each S-box transforms its input bits in a “random-looking” way to provide diffusion (spread plaintext bits throughout ciphertext)

Procedure must be reversible
(for decryption)



# Standard Block Ciphers

differential cryptanalysis

- **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

$2^{56}$

- 56 bit keys are quite short

P
DES $K_0$
$C_0$
DES $K_1$
$C_1$
DES $K_2$
$C_2$

| 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 |

P / C

?

- 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)

K K K

# But wait… what about *2DES*?

- Meet-in-the-middle attack

$P \xrightarrow[DES_{K_1}]{} X \xrightarrow[DES_{K_2}]{} C$

$56 \quad 56$

$\overline{112}$

$2^{112}$

adv: P/C pair

| P | |
|---|---|
| $2^{56}$ 0 | $Y_0$ |
| 1 | $Y_1$ |
| 2 | $Y_2$ |
| 3 | $Y_3$ |
| ⋮ | |

encrypt

| C | |
|---|---|
| $2^{56}$ 0 | $Z_0$ |
| 1 | $Z_1$ |
| 2 | $Z_2$ |
| 3 | $Z_3$ |
| 4 | ⋮ |
| 5 | ⋮ |

decrypt

$Y_n == Z_m == X$

$K_1 = K_n \quad K_2 = K_m$

# Defining the strength of a scheme

work = # encrypts

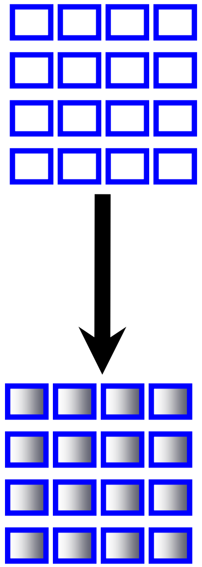
- *Effective Key Strength*
  - Amount of 'work' the adversary needs to do
- DES: 56-bits
  - 2^56 encryptions to try 'all keys'
- 2DES: 57-bits
  - 2*(2^56) encryptions = 2^57
- 3DES: 112-bits (or sometimes 80-bits)
  - Meet-in-the-middle + more work = 2^112 (for 3 keys, e.g. K1, K2, K3)
  - Various attacks = 2^80 (for 2 keys, e.g. K1, K2, K1)

# Standard Block Ciphers

- **DES: Data Encryption Standard** deprecated
  - 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** 12 reduced AES 8 rounds
  - 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**

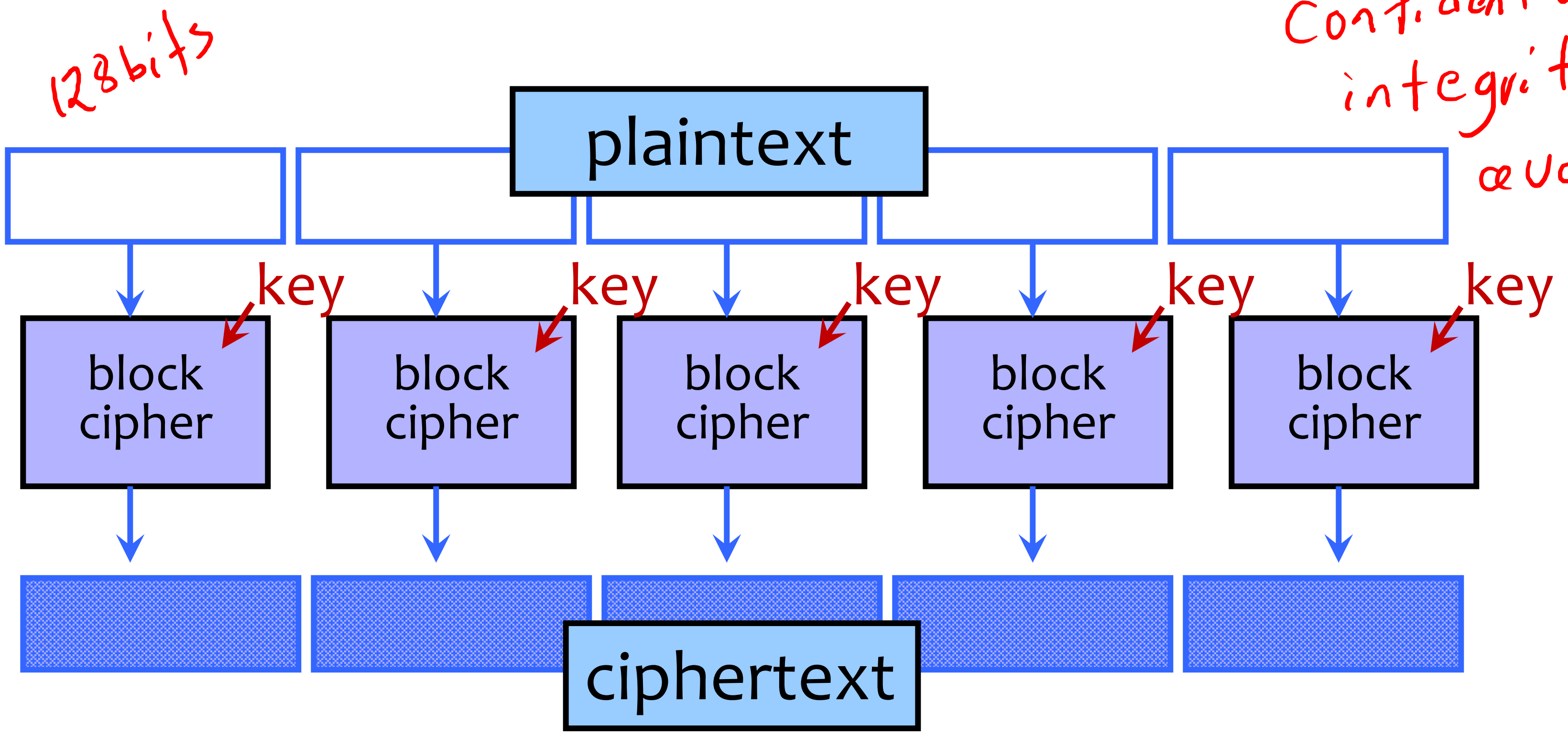
(arranged as 4x4 array of 8-bit bytes)

128-bit ciphertext

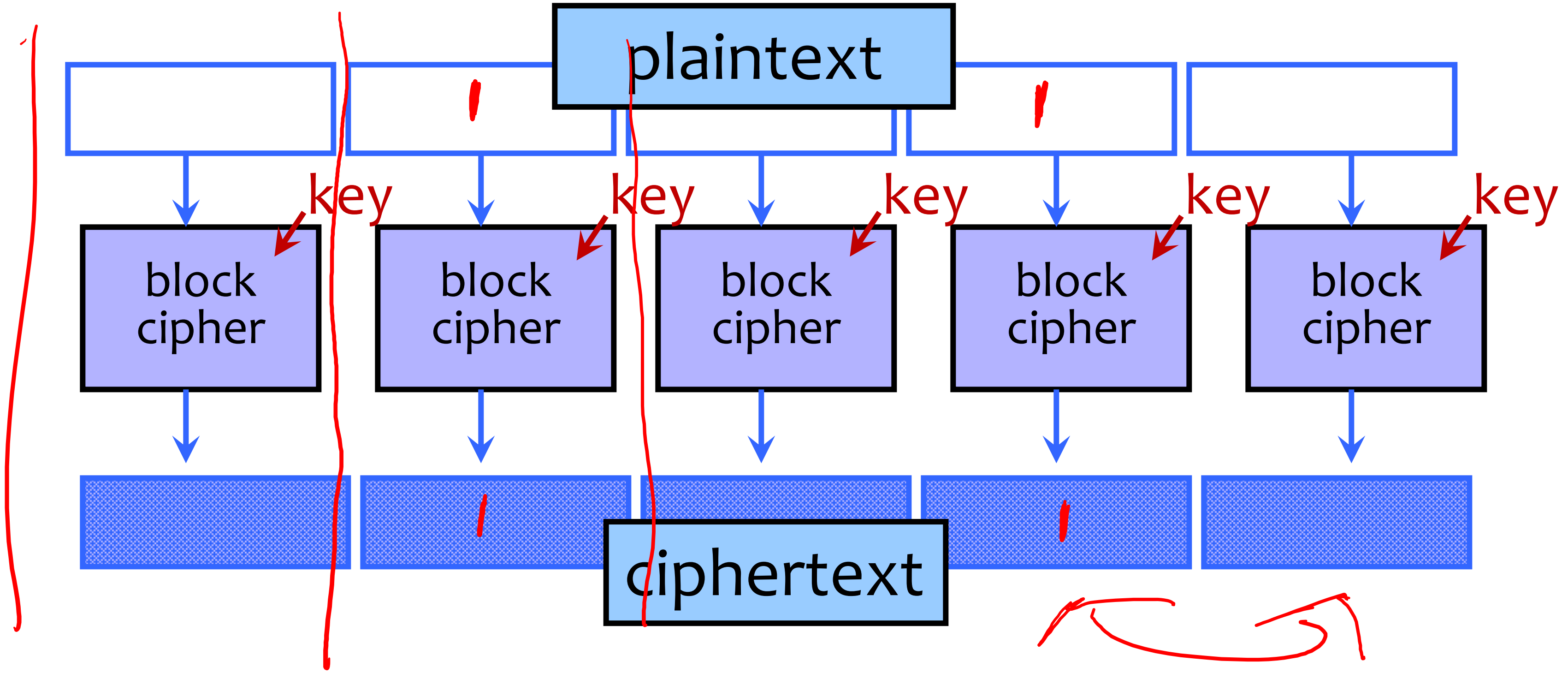
- What should we do?

# Electronic Code Book (ECB) Mode

CIA
Confidentiality
integrity
availability
authenticity

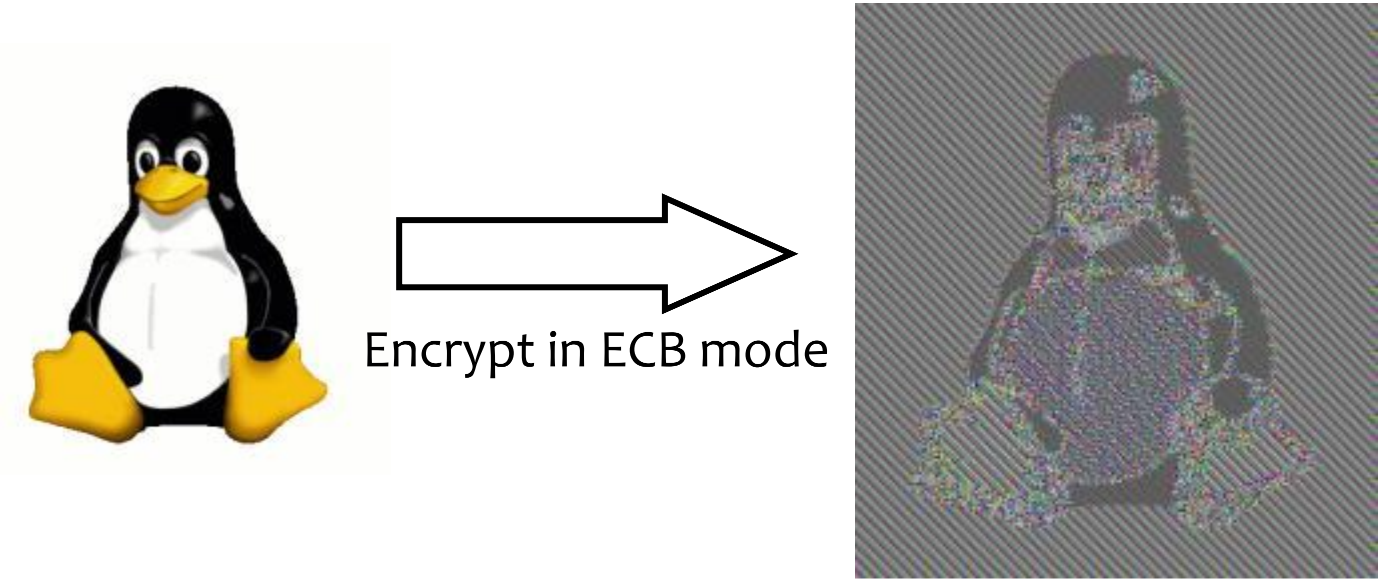


# Electronic Code Book (ECB) Mode




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

# Information Leakage in ECB Mode




[Wikipedia]

# Oops

## Move Fast and Roll Your Own Crypto

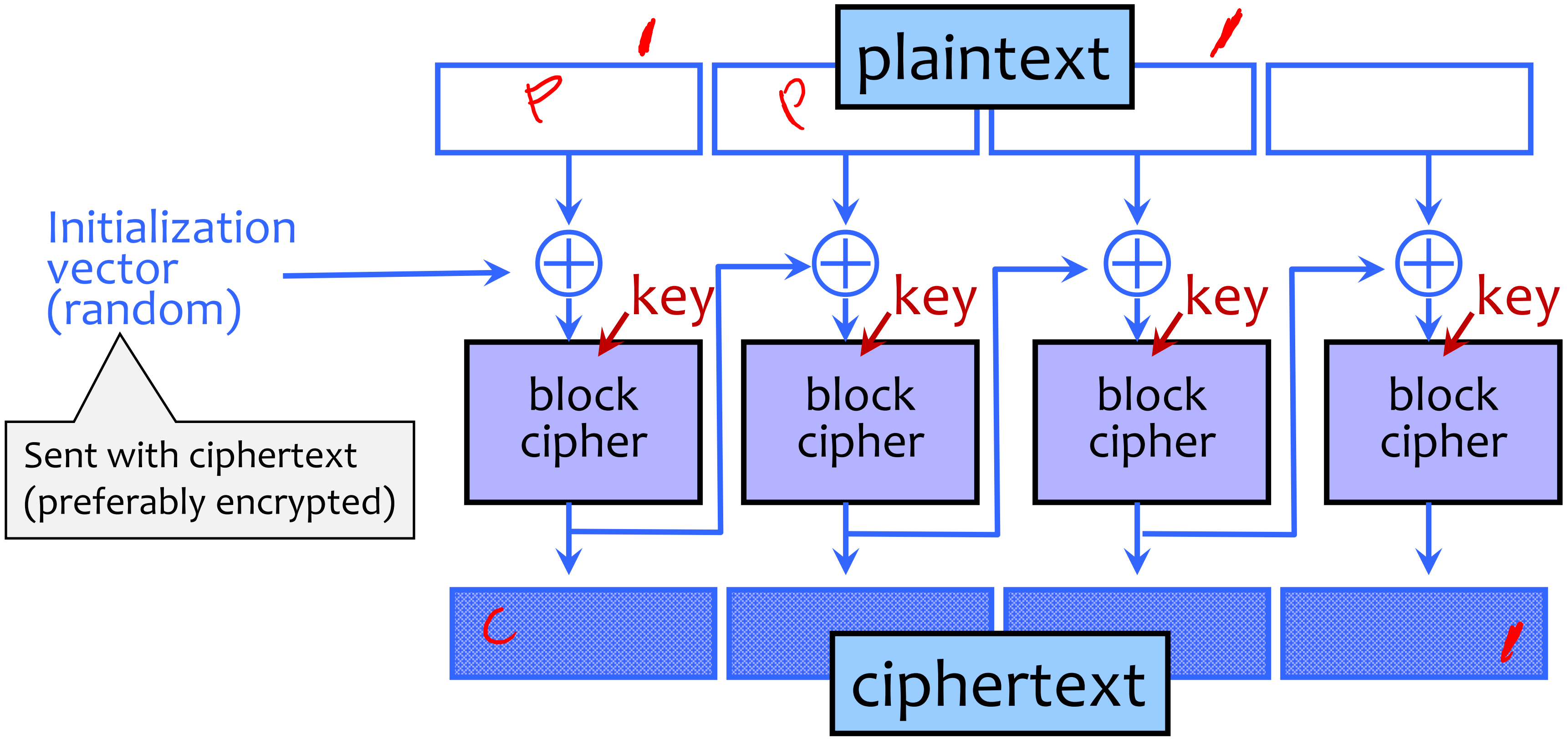
### A Quick Look at the Confidentiality of Zoom Meetings

**By Bill Marczak and John Scott-Railton** April 3, 2020

- Zoom documentation claims that the app uses "AES-256" encryption for meetings where possible. However, we find that in each Zoom meeting, a single AES-128 key is used in ECB mode by all participants to encrypt and decrypt audio and video. The use of ECB mode is not recommended because patterns present in the plaintext are preserved during encryption.

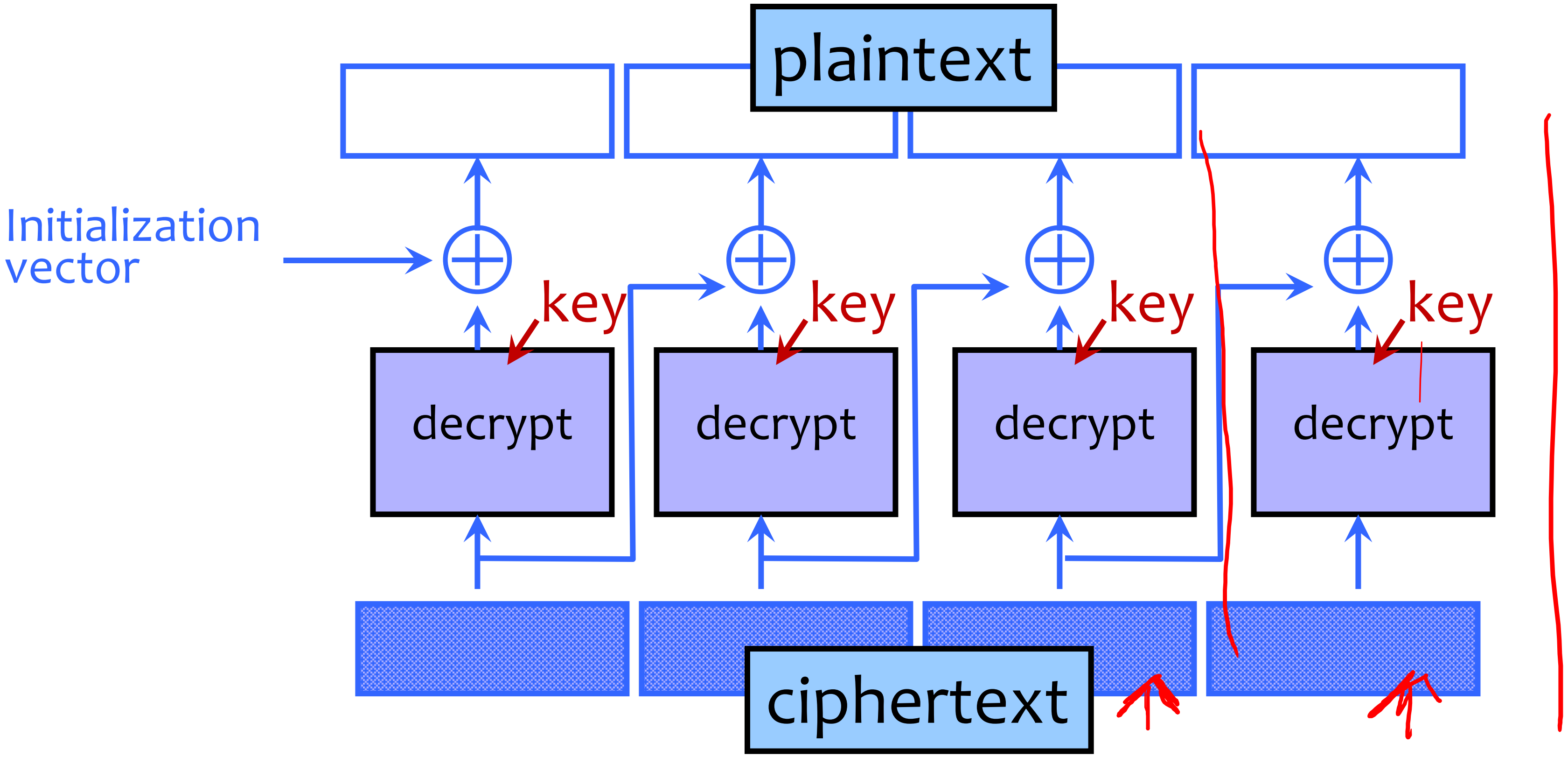
https://citizenlab.ca/2020/04/move-fast-roll-your-own-crypto-a-quick-look-at-the-confidentiality-of-zoom-meetings/

# Cipher Block Chaining (CBC) Mode: Encryption

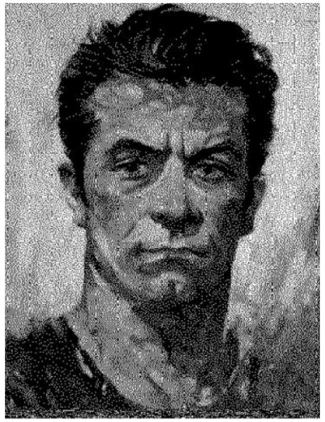



- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext
  - Still does not guarantee integrity

# CBC Mode: Decryption

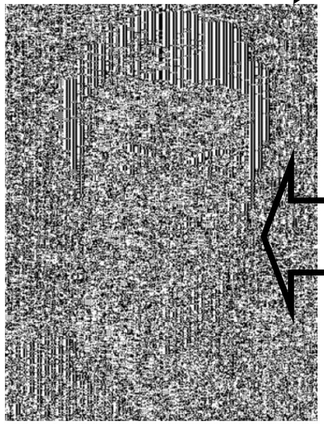


# ECB vs. CBC

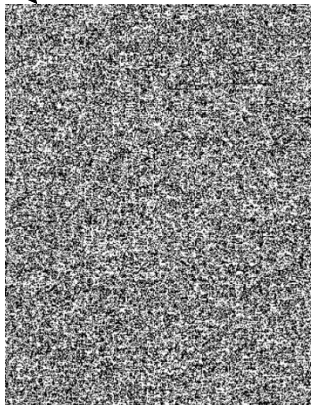


AES in ECB mode

AES in CBC mode

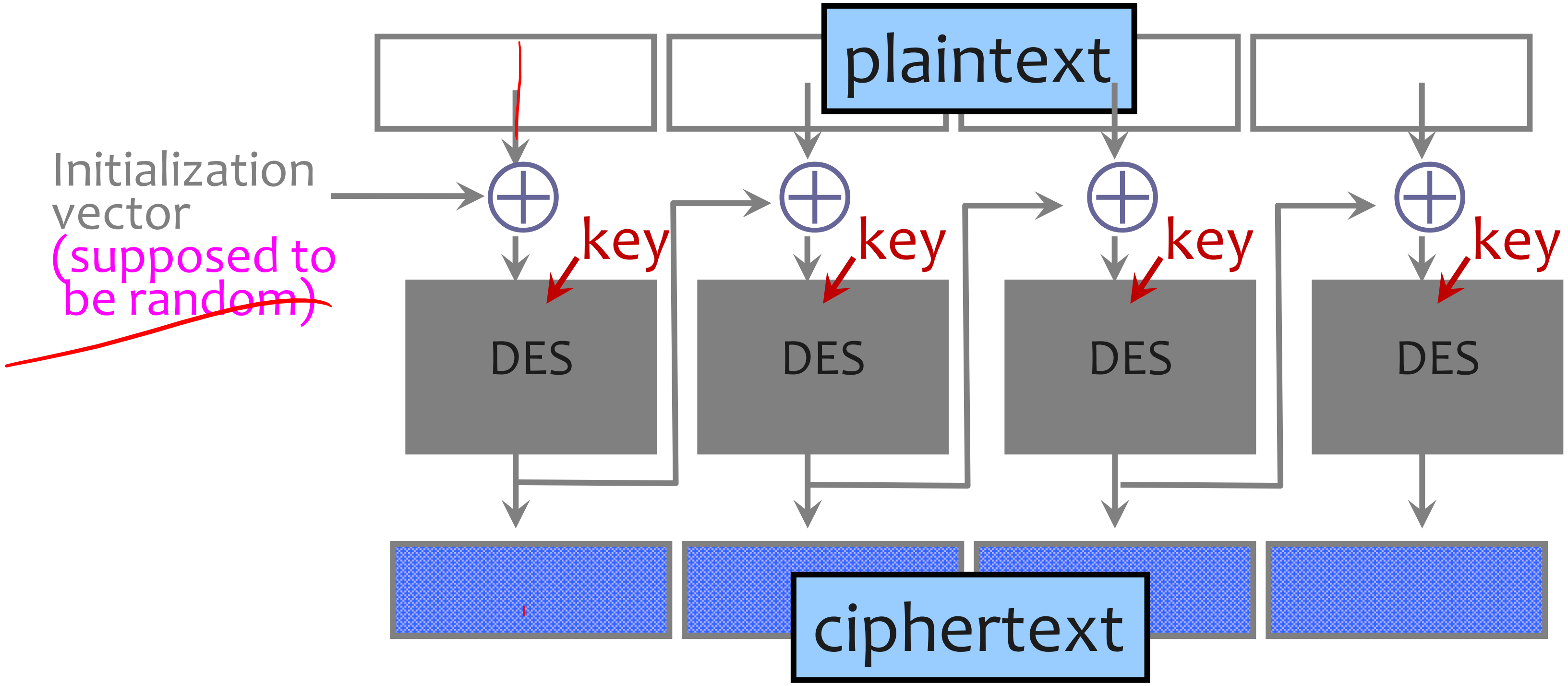


Similar plaintext blocks produce similar ciphertext blocks (not good!)



[Picture due to Bart Preneel]

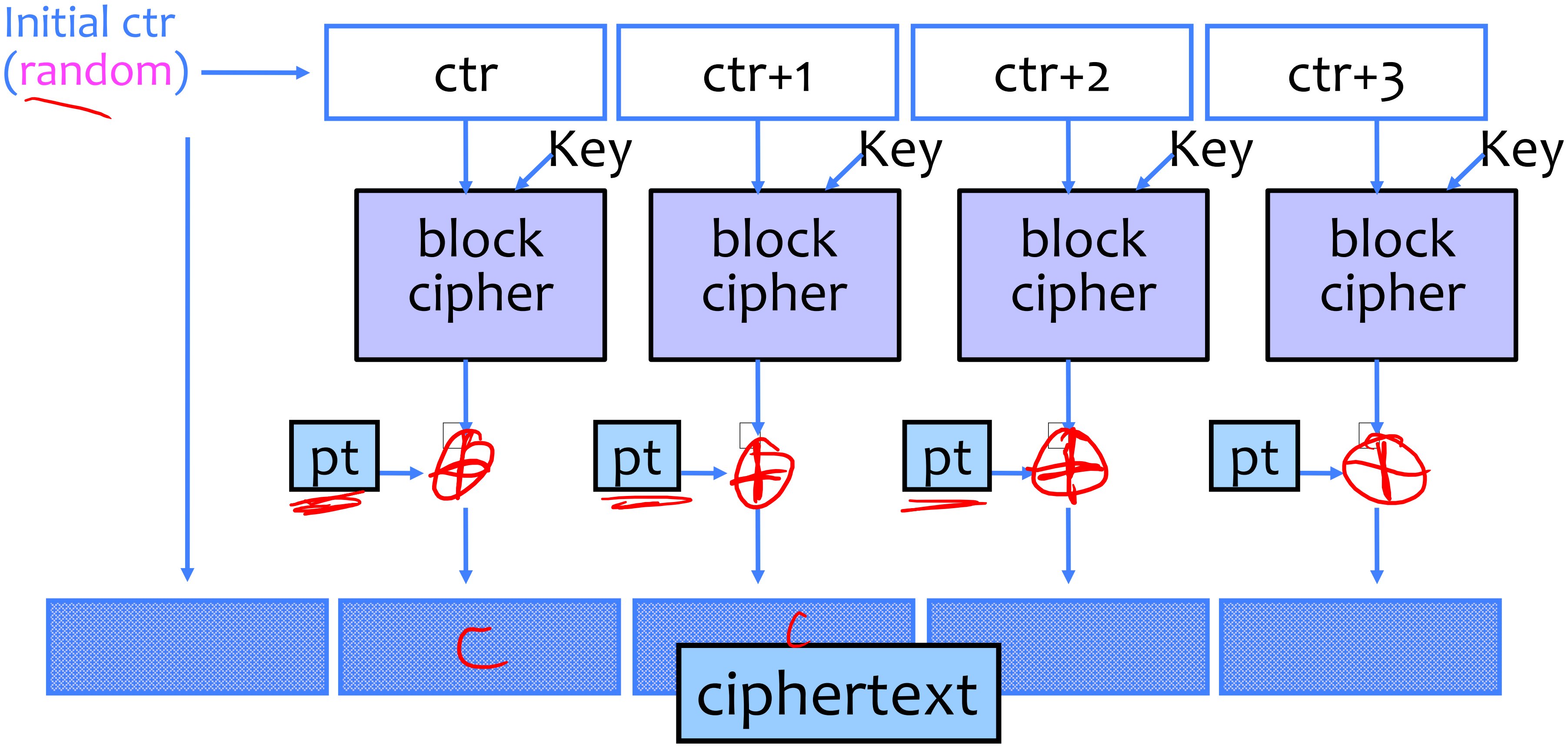
# Initialization Vector Dangers




Found in the source code for Diebold voting machines:

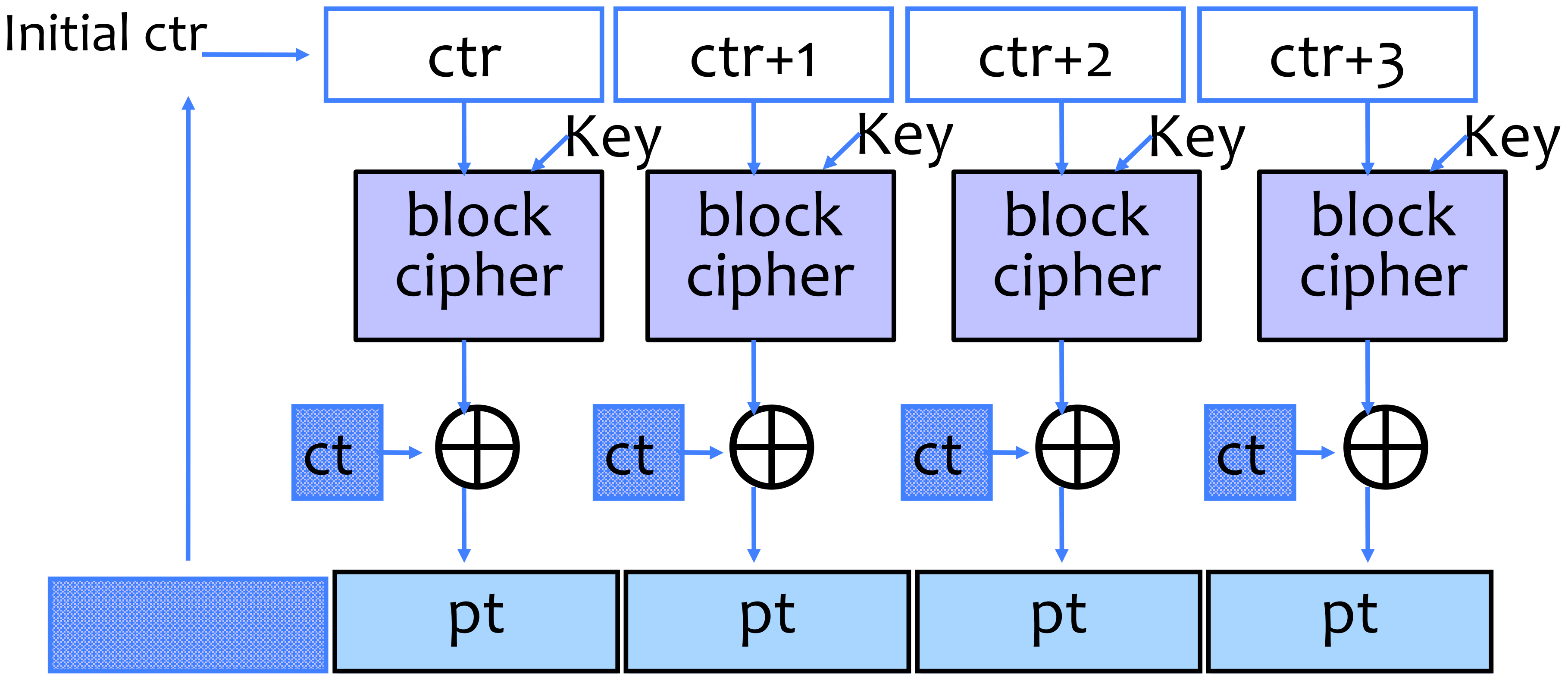
```
DesCBCEncrypt((des_c_block*)tmp, (des_c_block*)record.m_Data,
        totalSize, DESKEY, NULL, DES_ENCRYPT)
```

# Counter Mode (CTR): Encryption




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

# Counter Mode (CTR): Decryption



# Ok, so what mode do I use?

- Don't choose a mode, use established libraries ☺
- Good modes:
  - GCM - Galois/Counter Mode CTR + auth
  - CTR (sometimes)
  - Even ECB is fine in 'the right circumstance'

CBC is fine ...

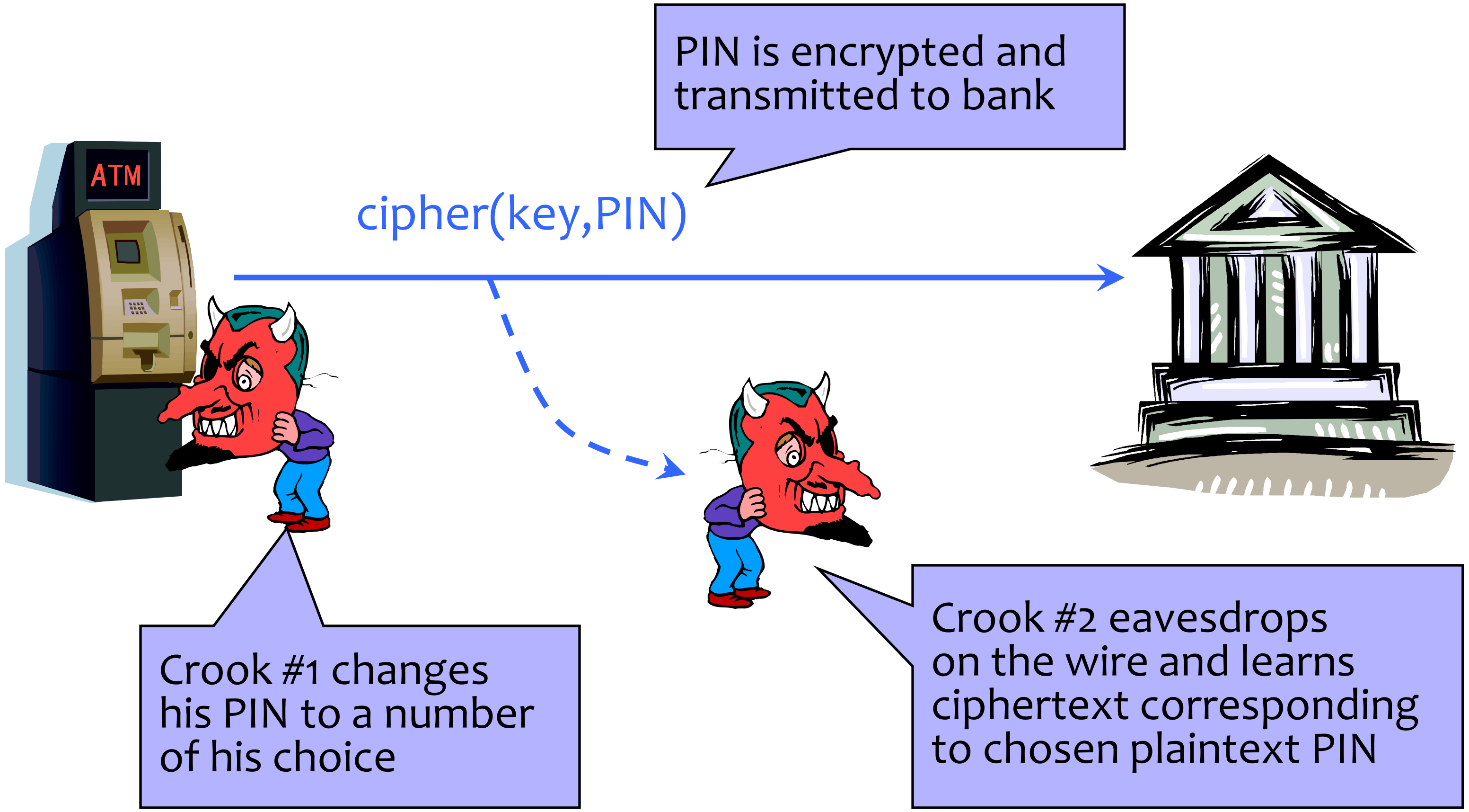
# When is an Encryption Scheme "Secure"?

- 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 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