CSE 484: Computer Security and Privacy

Symmetric Cryptography

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David Kohlbrenner

dkohlbre@cs

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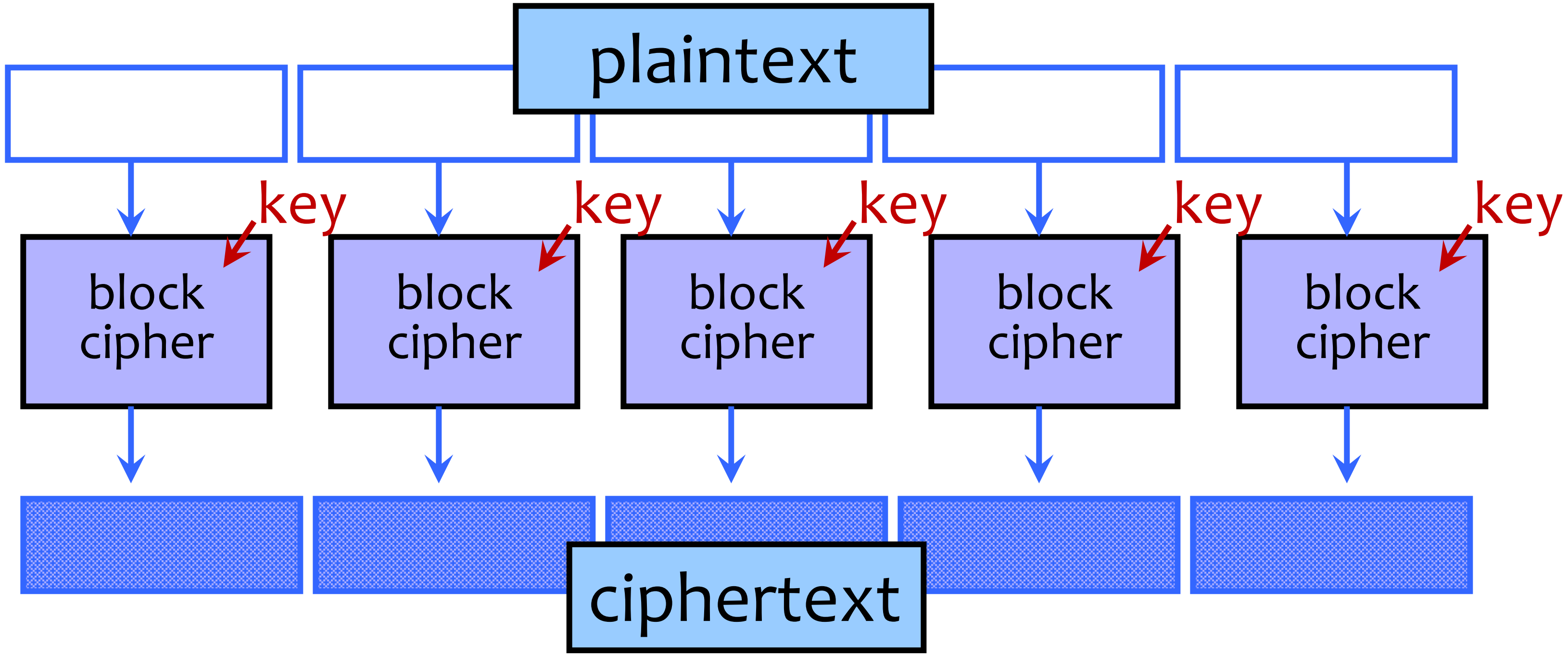
Admin

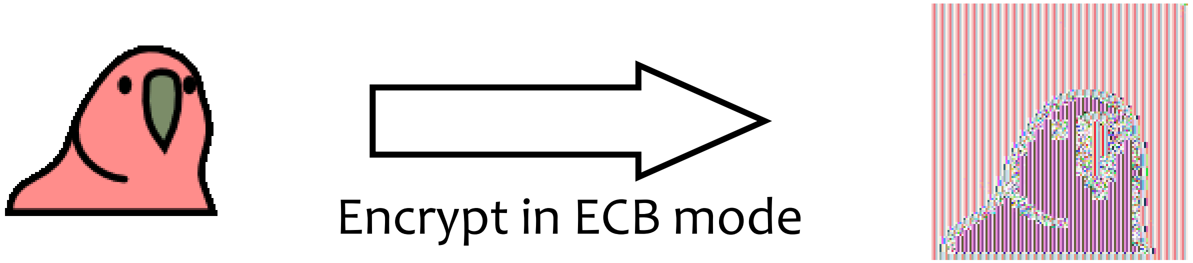
- Homework 2: Out!

Electronic Code Book (ECB) Mode



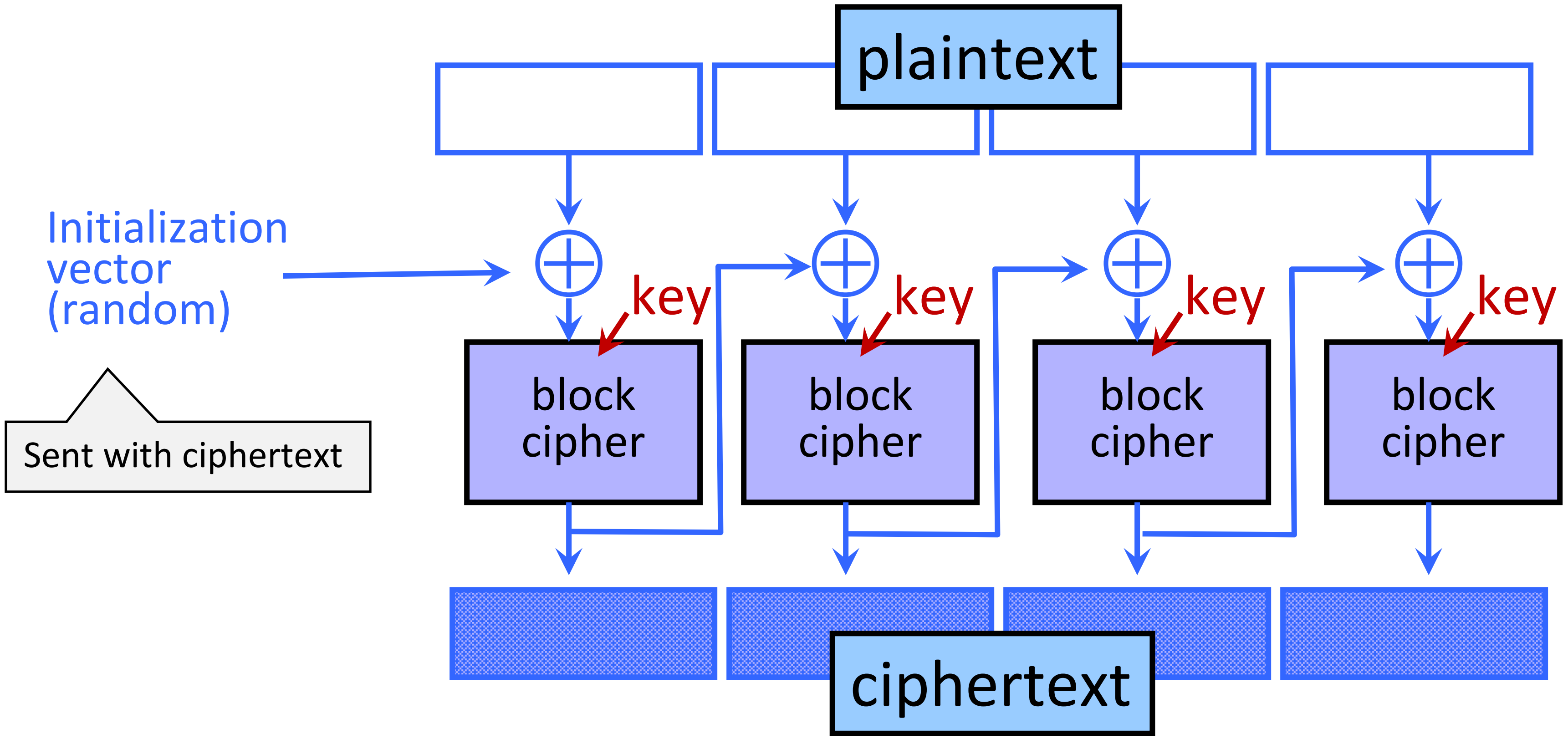
- Identical blocks of plaintext produce identical blocks of ciphertext
- No integrity checks: can mix and match blocks

Information Leakage in ECB Mode



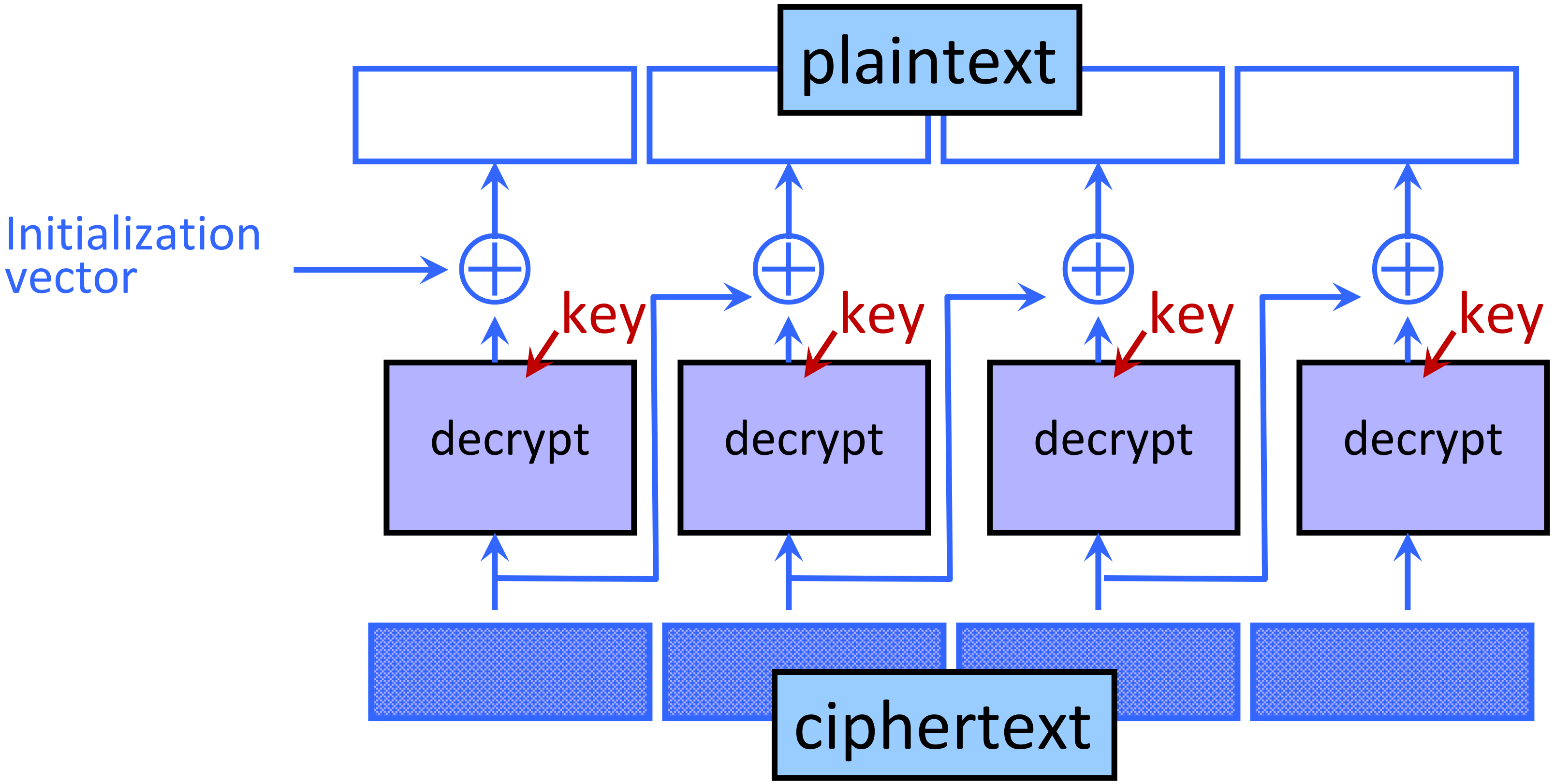
[Wikipedia]

Cipher Block Chaining (CBC) Mode: Encryption

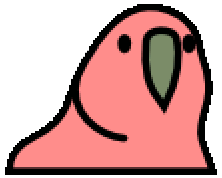


- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext
  - Still does not guarantee integrity

CBC Mode: Decryption

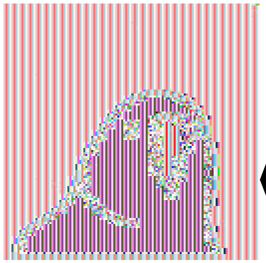


ECB vs. CBC

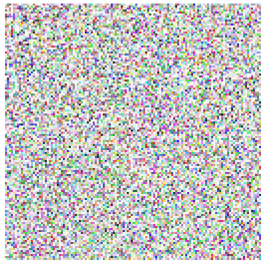


AES in ECB mode

AES in CBC mode

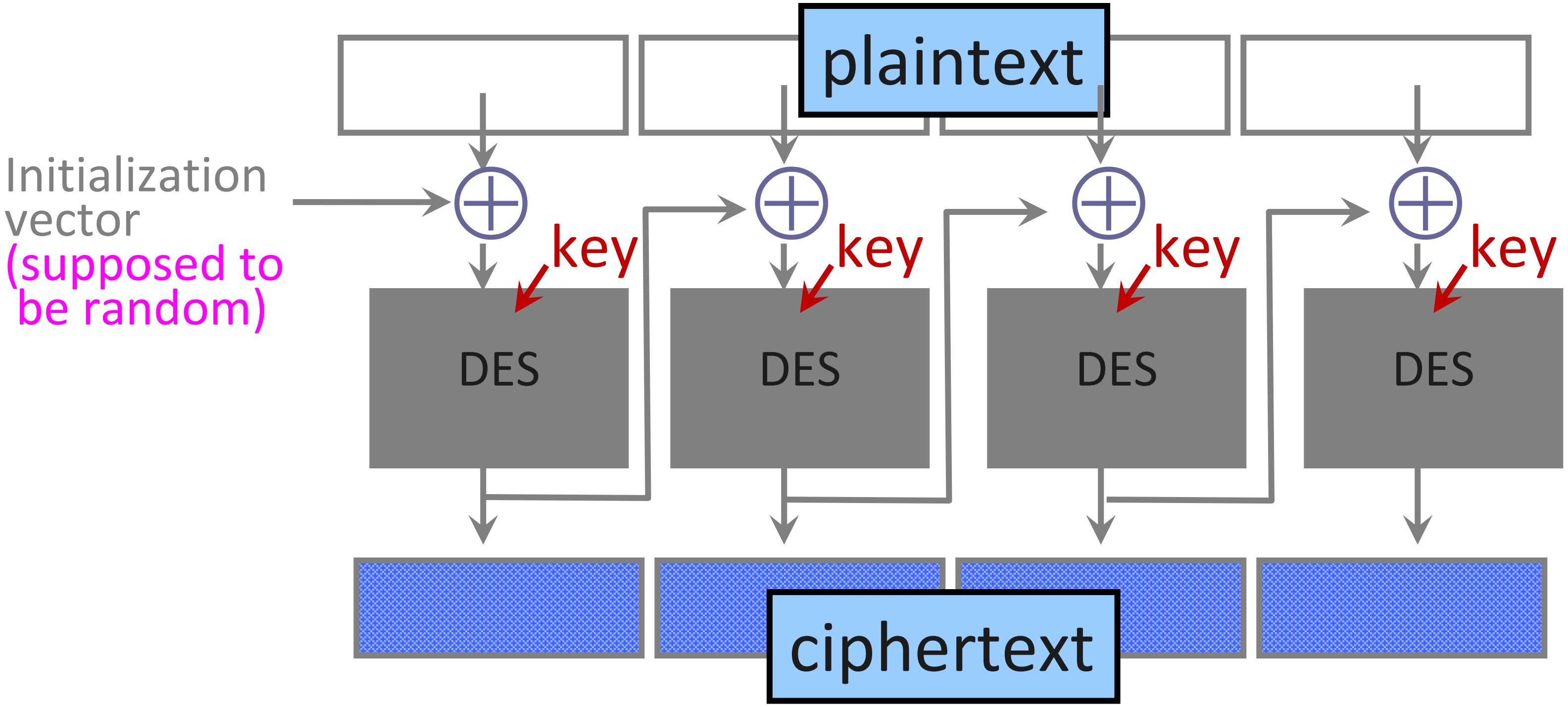


Similar plaintext blocks produce similar ciphertext blocks (not good!)



[Picture due to Bart Preneel]

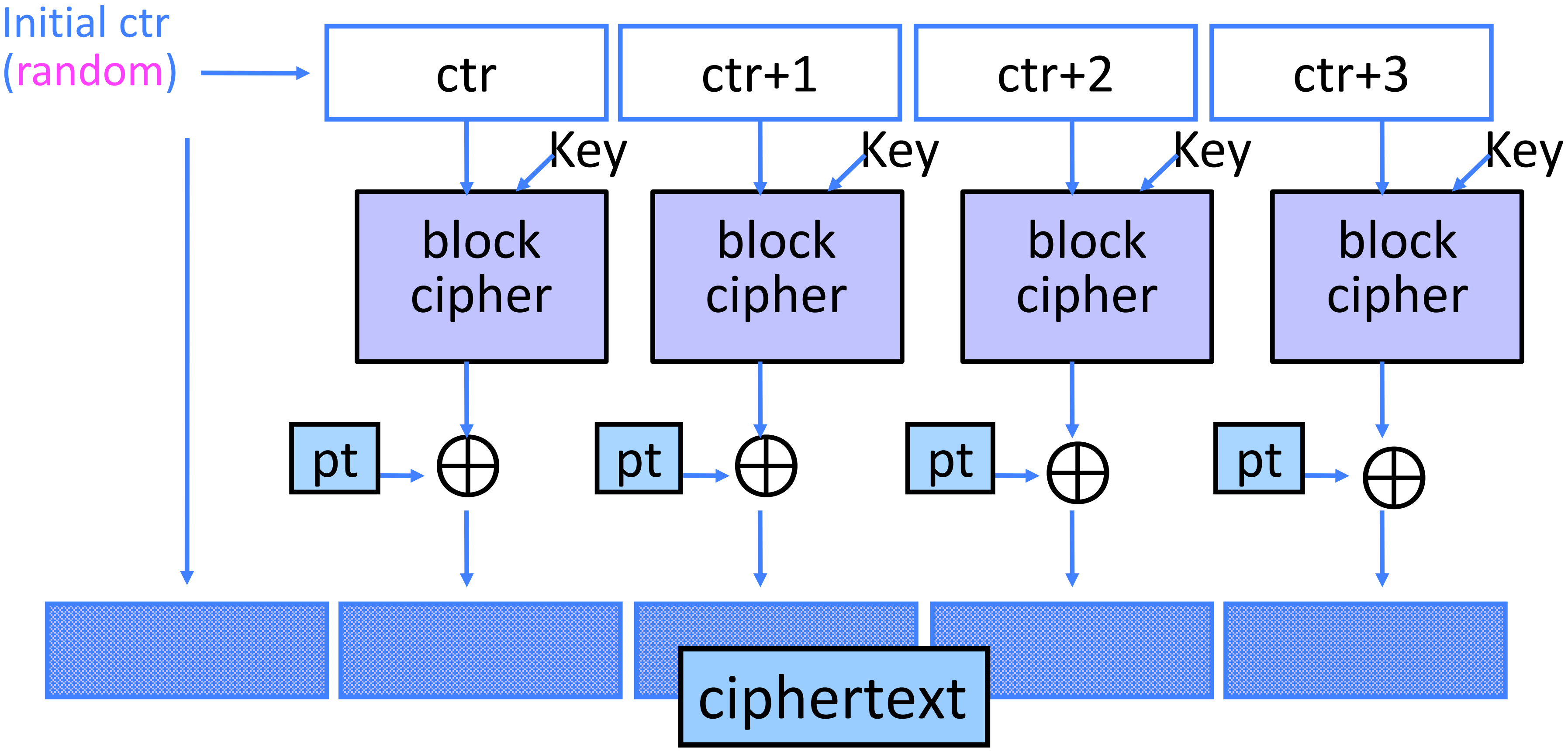
Initialization Vector Dangers



Found in the source code for Diebold voting machines:

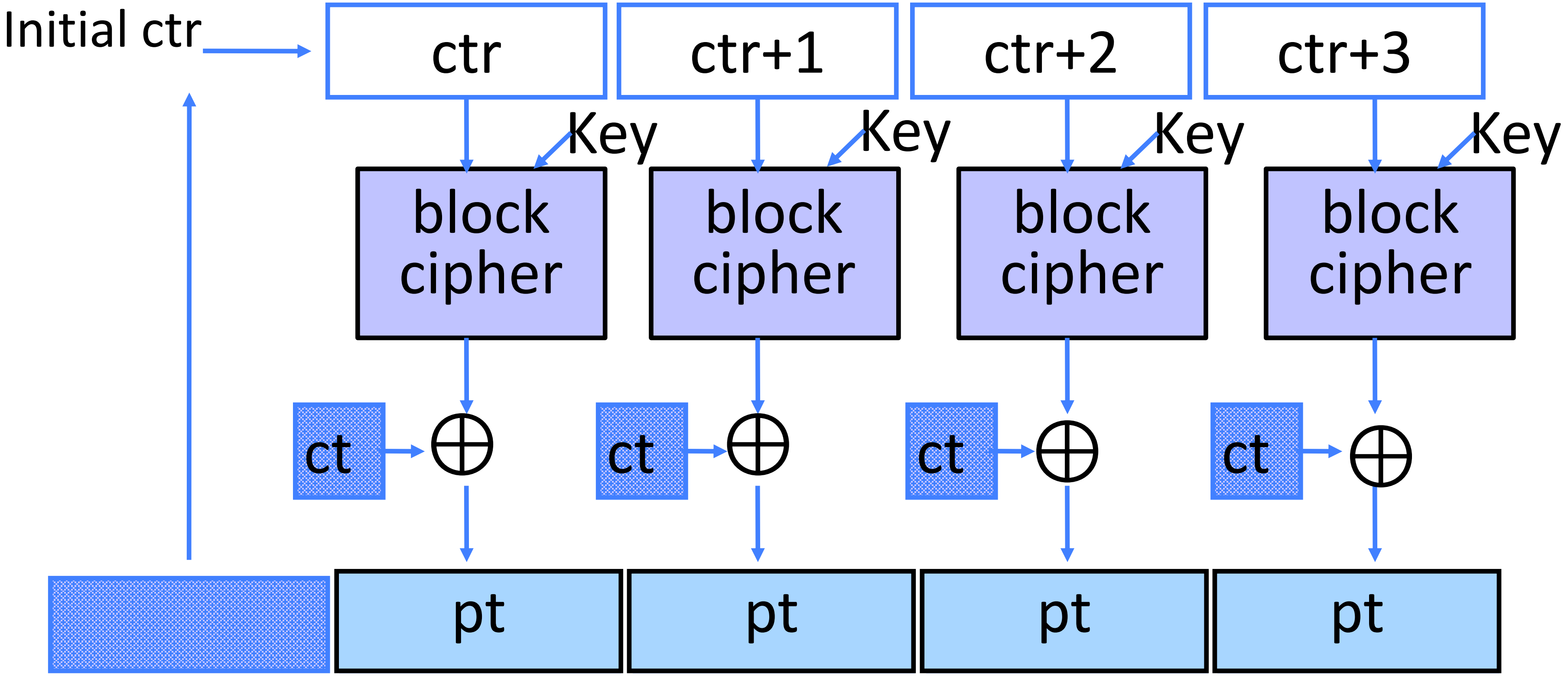
```
DesCBCEncrypt((des_c_block*)tmp, (des_c_block*)record.m_Data,
        totalSize, DESKEY, NULL, DES_ENCRYPT)
```

Counter Mode (CTR): Encryption



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

Counter Mode (CTR): Decryption



Bonus: I can still do this wrong!

What happens if we reuse the same ctr for each message?

Ok, so what mode do I use?

- Don't choose a mode, use established libraries ☺

- Good modes:
  - GCM - Galois/Counter Mode
  - CTR (sometimes)
  - Even ECB is fine in 'the right circumstance'

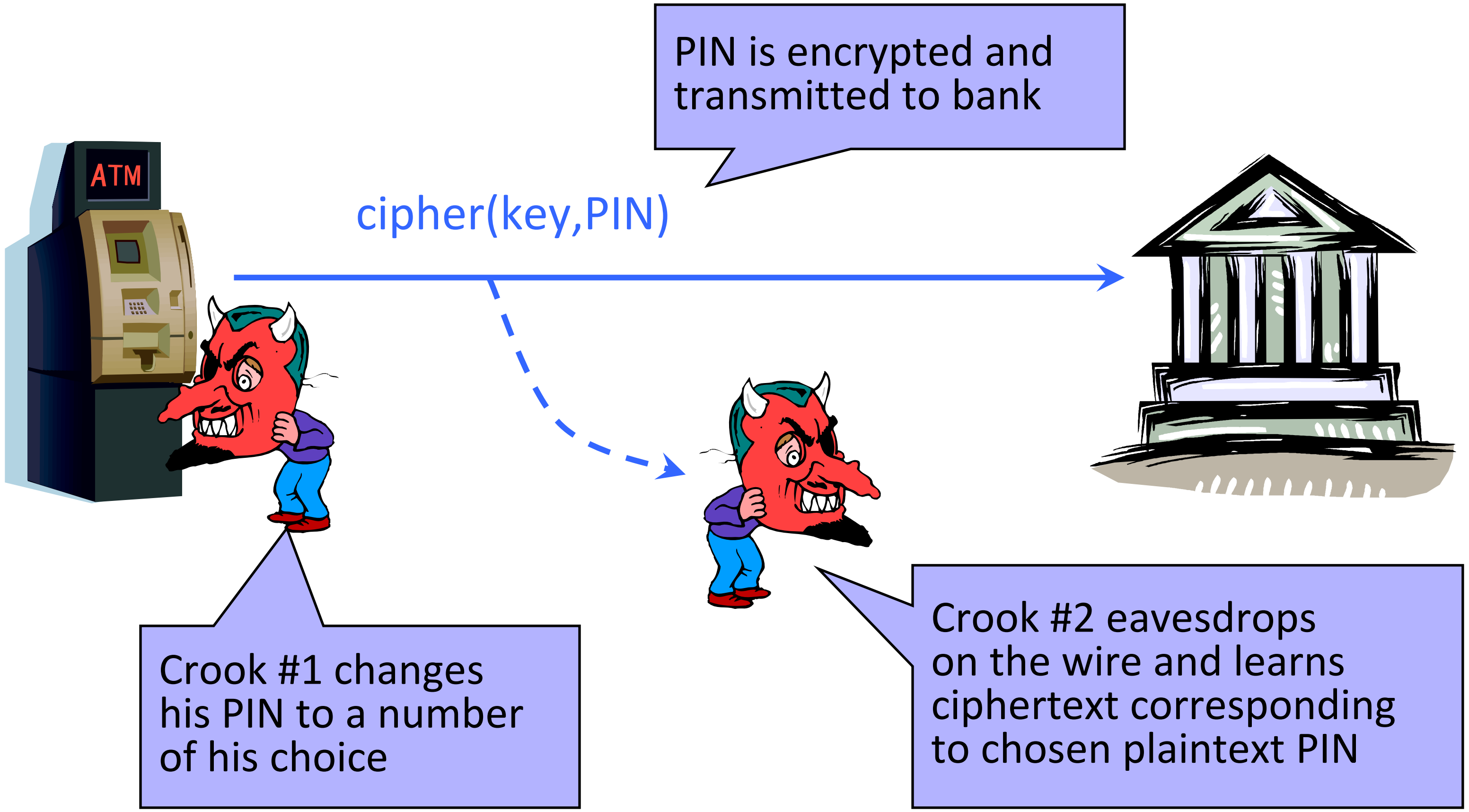
When is an Encryption Scheme “Secure”?

- 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 algorithm
  - 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 <u>except</u> 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

The shape of the formal approach

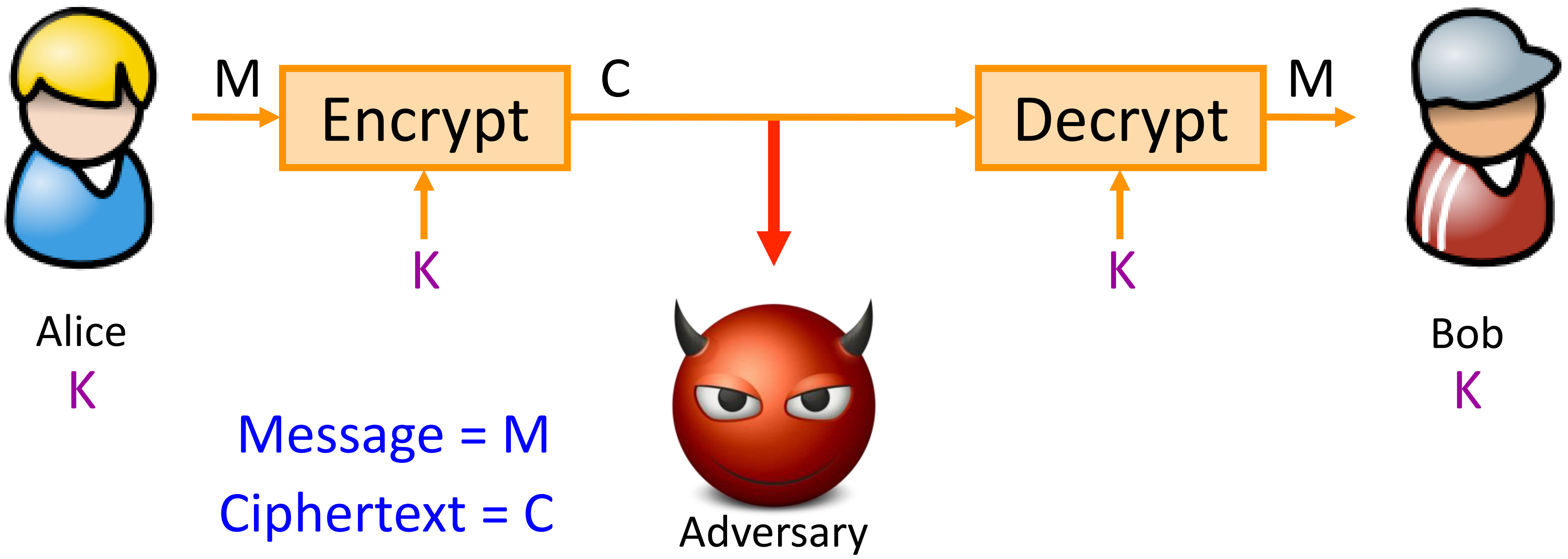
- INDistinguishability under Chosen Plaintext Attack
  - IND-CPA
- Formalized *cryptographic game*

- Adversary submits pairs of *plaintexts* (M_a, M_b)
  - Gets back ONE of the *ciphertexts* (C_x)

- Adversary must guess which ciphertext this is (C_a or C_b)
  - If they can do better than 50/50, they win

So Far: Achieving Privacy

Encryption schemes: A tool for protecting privacy.

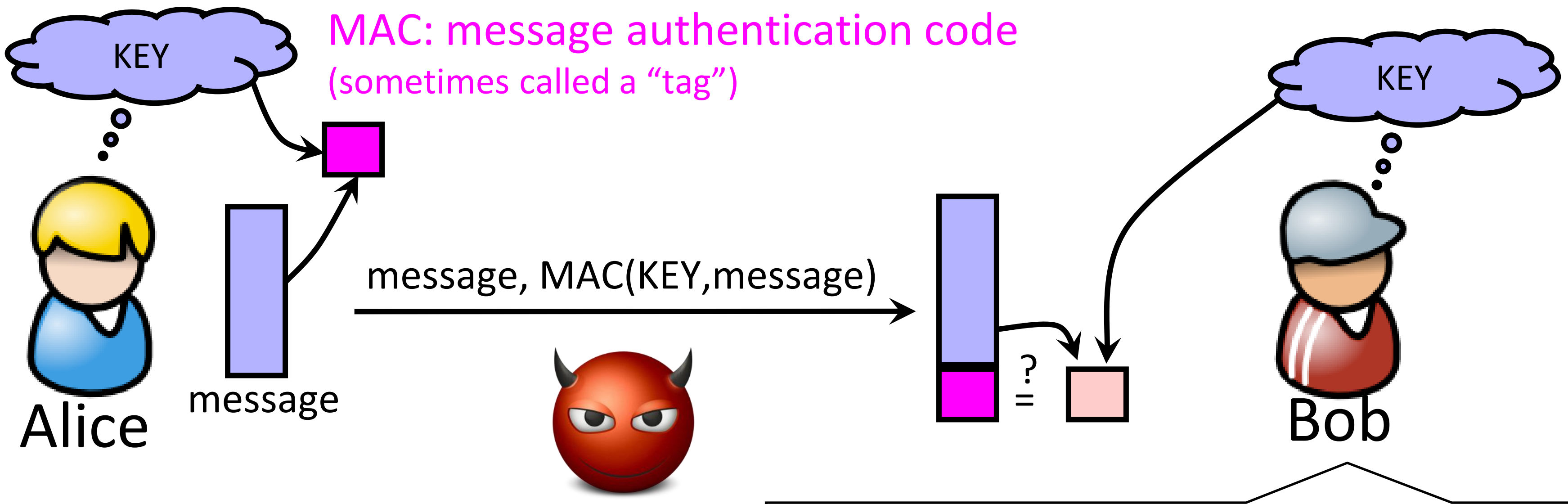


Message = M

Ciphertext = C

Now: Achieving Integrity

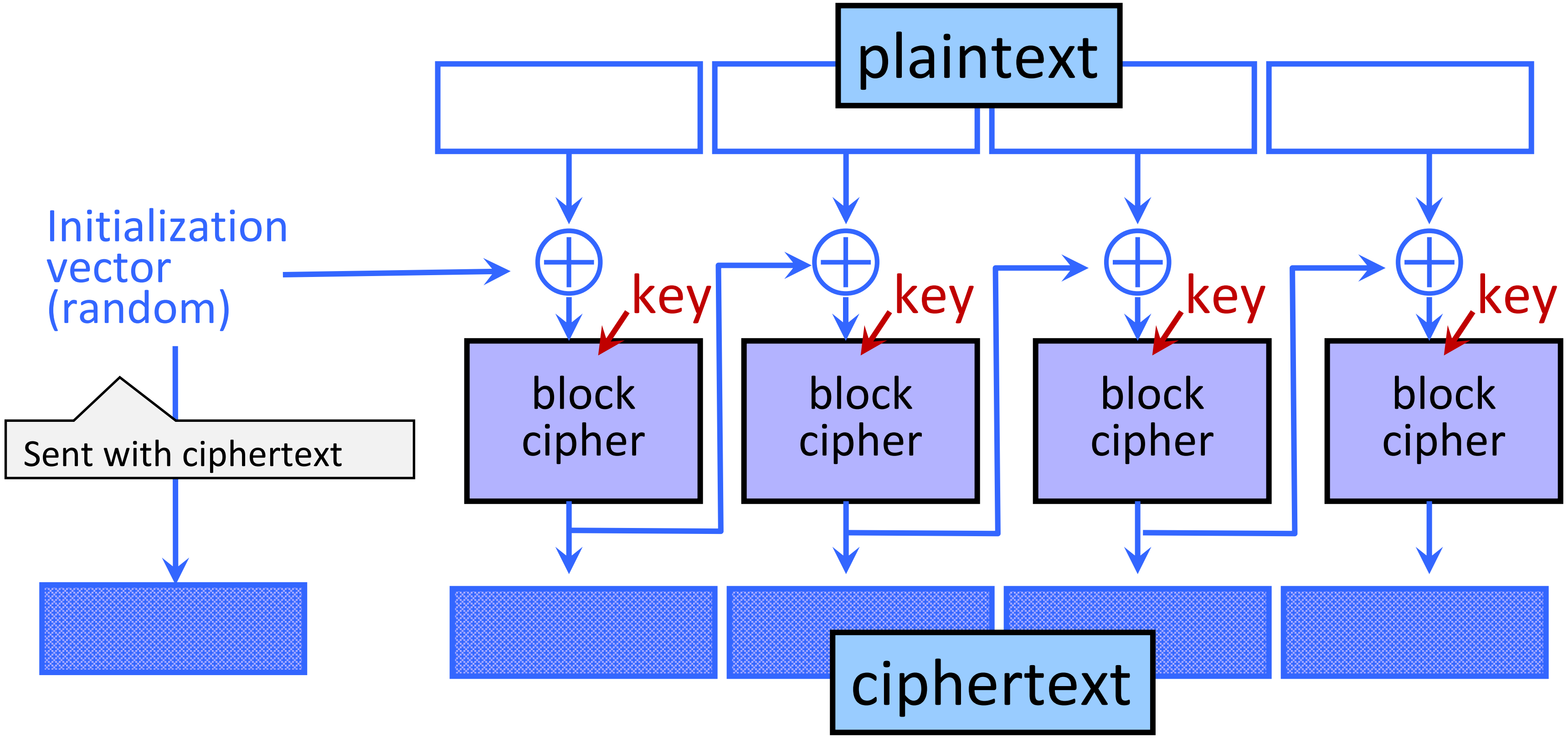
Message authentication schemes: A tool for protecting integrity.



Recomputes MAC and verifies whether it is equal to the MAC attached to the message

Integrity and authentication: only someone who knows KEY can compute correct MAC for a given message.

Reminder: CBC Mode Encryption



- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext
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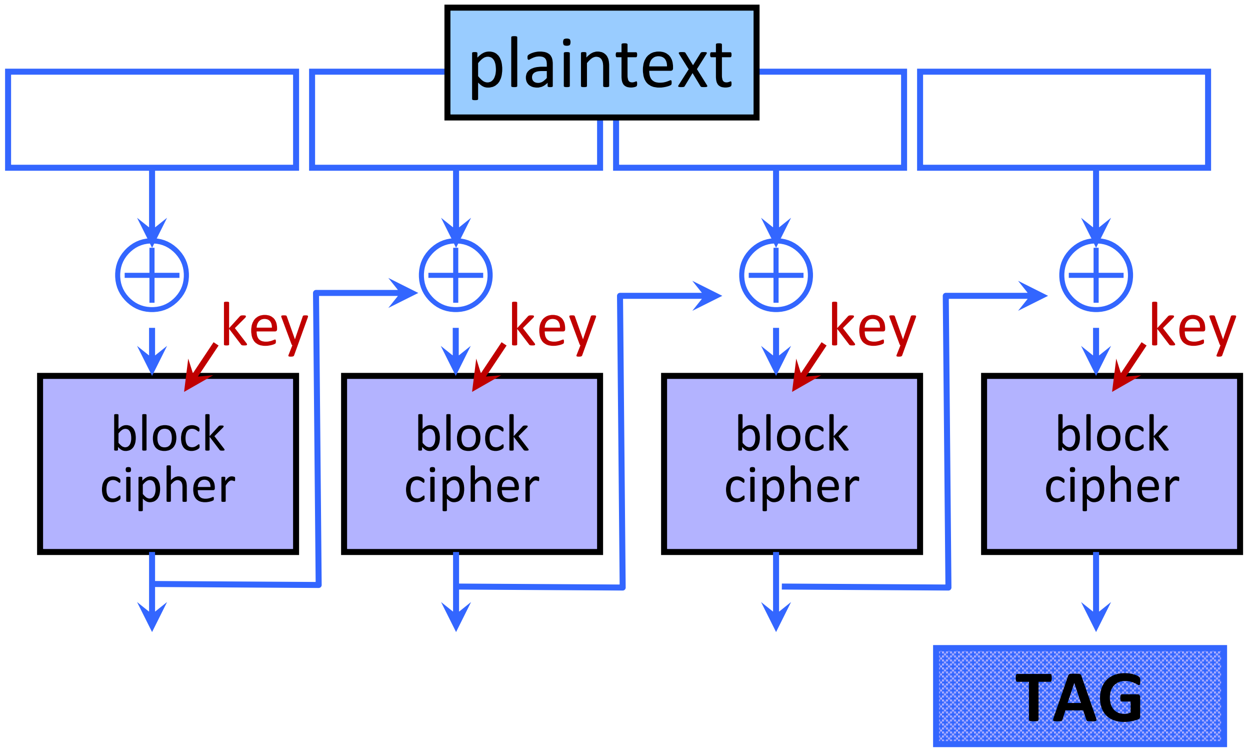
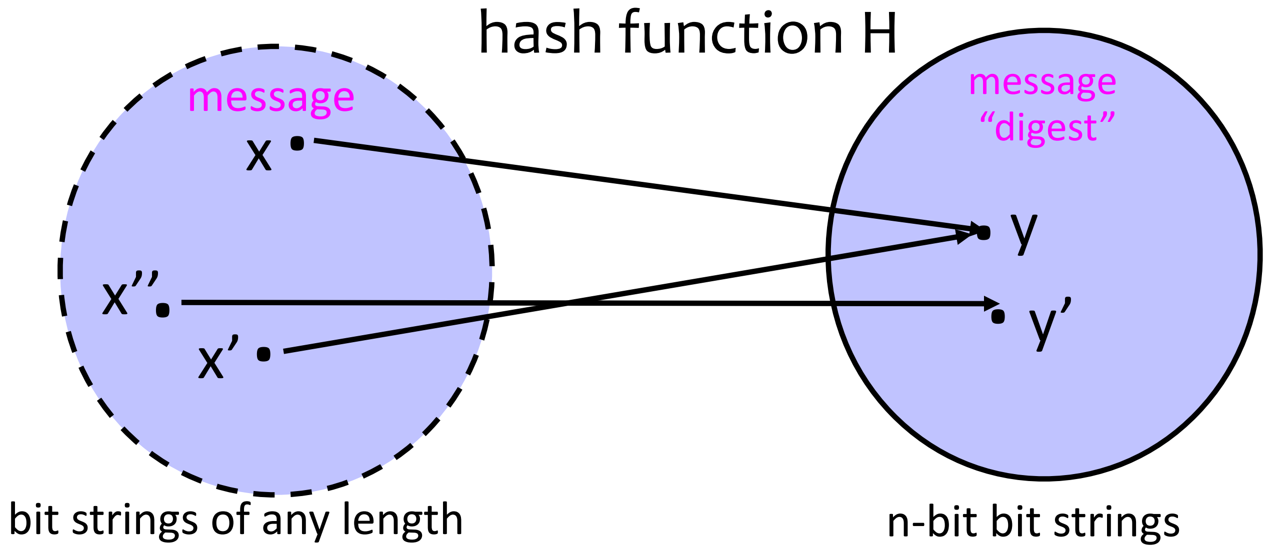
CBC-MAC



- Not secure when system may MAC messages of different lengths *(more in section!).*
- Use a different key – not encryption key
- NIST recommends a derivative called CMAC [FYI only]

Another Tool: Hash Functions

Hash Functions: Main Idea



- Hash function H is a lossy compression function
  - Collision: h(x)=h(x') for distinct inputs x, x'
- H(x) should look "random"
  - Every bit (almost) equally likely to be 0 or 1
- Cryptographic hash function needs a few properties…

Property 1: One-Way

- Intuition: hash should be hard to invert
  - "Preimage resistance"
  - Let h(x') = y in $\{0,1\}^n$ for a random x'
  - Given y, it should be hard to find any x such that h(x)=y
- How hard?
  - Brute-force: try every possible x, see if h(x)=y
  - SHA-1 (common hash function) has 160-bit output
    - Expect to try 2^{159} inputs before finding one that hashes to y.

Property 2: Collision Resistance

- Should be hard to find $x \neq x'$ such that $h(x)=h(x')$

Birthday Paradox

- Are there two people in the ~first page of people on Zoom (depending on the size of your window) that have the same birthday?
  - 365 days in a year (366 some years)
    - Pick one person. To find another person with same birthday would take on the order of 365/2 = 182.5 people
    - **Expect birthday "collision" with a room of only 23 people.**
    - For simplicity, approximate when we expect a collision as **sqrt(365)**.
- Why is this important for cryptography?
  - 2^{128} different 128-bit values
    - Pick one value at random. To exhaustively search for this value requires trying on average 2^{127} values.
    - **Expect "collision" after selecting approximately 2^{64} random values.**
    - **64 bits** of security against collision attacks, not 128 bits.

Property 2: Collision Resistance

- Should be hard to find x≠x' such that h(x)=h(x')
- Birthday paradox means that brute-force collision search is only $O(2^{n/2})$, *not* $O(2^n)$
  - For SHA-1, this means $O(2^{80})$ vs. $O(2^{160})$

One-Way vs. Collision Resistance

One-wayness does **not** imply collision resistance.

Collision resistance does **not** imply one-wayness.

You can prove this by constructing a function that has one property but not the other.

One-Way vs. Collision Resistance
(Details here mainly FYI)

- One-wayness does <u>not</u> imply collision resistance
  - Suppose g is one-way
  - Define h(x) as g(x') where x' is x except the last bit
    - h is one-way (to invert h, must invert g)
    - Collisions for h are easy to find: for any x, h(x0)=h(x1)
- Collision resistance does <u>not</u> imply one-wayness
  - Suppose g is collision-resistant
  - Define y=h(x) to be 0x if x is n-bit long, 1g(x) otherwise
    - Collisions for h are hard to find: if y starts with 0, then there are no collisions, if y starts with 1, then must find collisions in g
    - h is not one way: half of all y's (those whose first bit is 0) are easy to invert (how?); random y is invertible with probab. ½

Property 3: Weak Collision Resistance

- Given randomly chosen x, hard to find x' such that h(x)=h(x')
  - Attacker must find collision for a specific x. By contrast, to break collision resistance it is enough to find any collision.
  - Brute-force attack requires $O(2^n)$ time
- Weak collision resistance does not imply collision resistance.

Hashing vs. Encryption

- Hashing is one-way. There is no "un-hashing"
  - A ciphertext can be decrypted with a decryption key… hashes have no equivalent of "decryption"
- Hash(x) looks "random" but can be compared for equality with Hash(x')
  - Hash the same input twice → same hash value
  - Encrypt the same input twice → different ciphertexts
- Crytographic hashes are also known as "cryptographic checksums" or "message digests"

Application: Password Hashing

- Instead of user password, store hash(password)
- When user enters a password, compute its hash and compare with the entry in the password file

- Why is hashing better than encryption here?
  - Breakout