CSE 484 / CSE M 584: Computer Security and Privacy

Cryptography:

Symmetric Encryption (finish), Hash Functions, Message Authentication Codes

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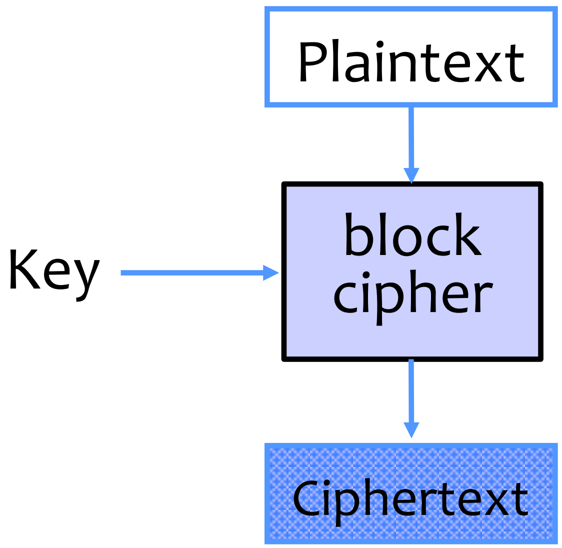
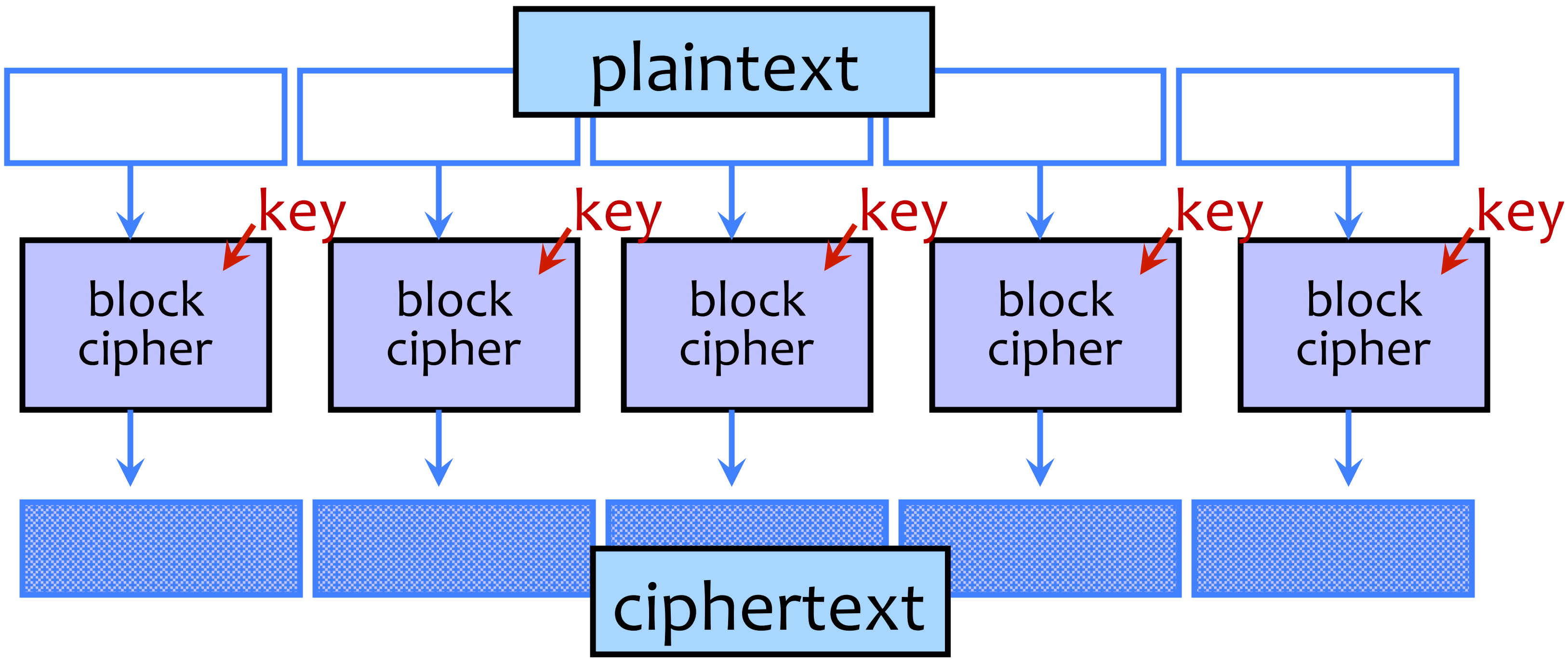
Recap: Block Ciphers

- 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)

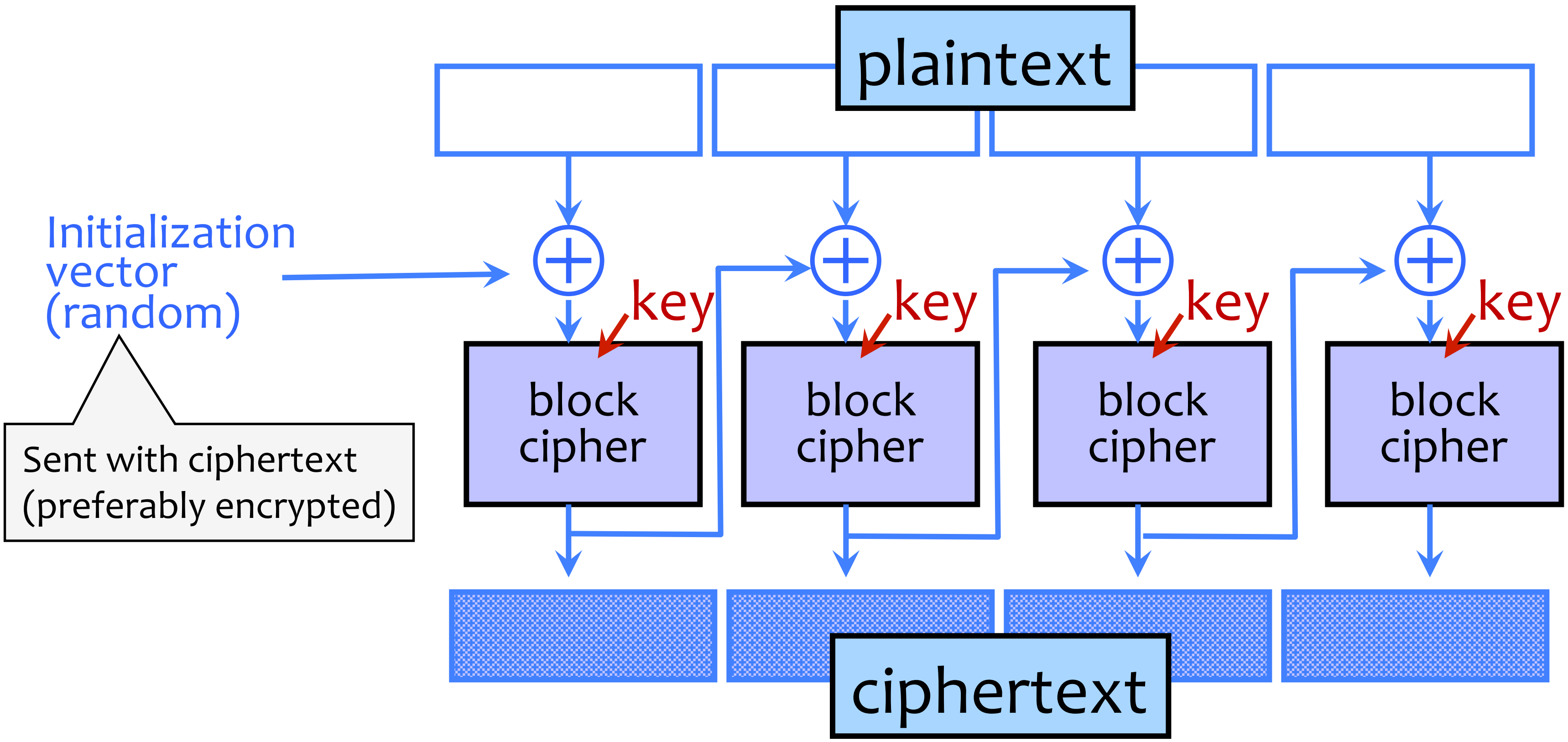


Electronic Code Book (ECB) Mode



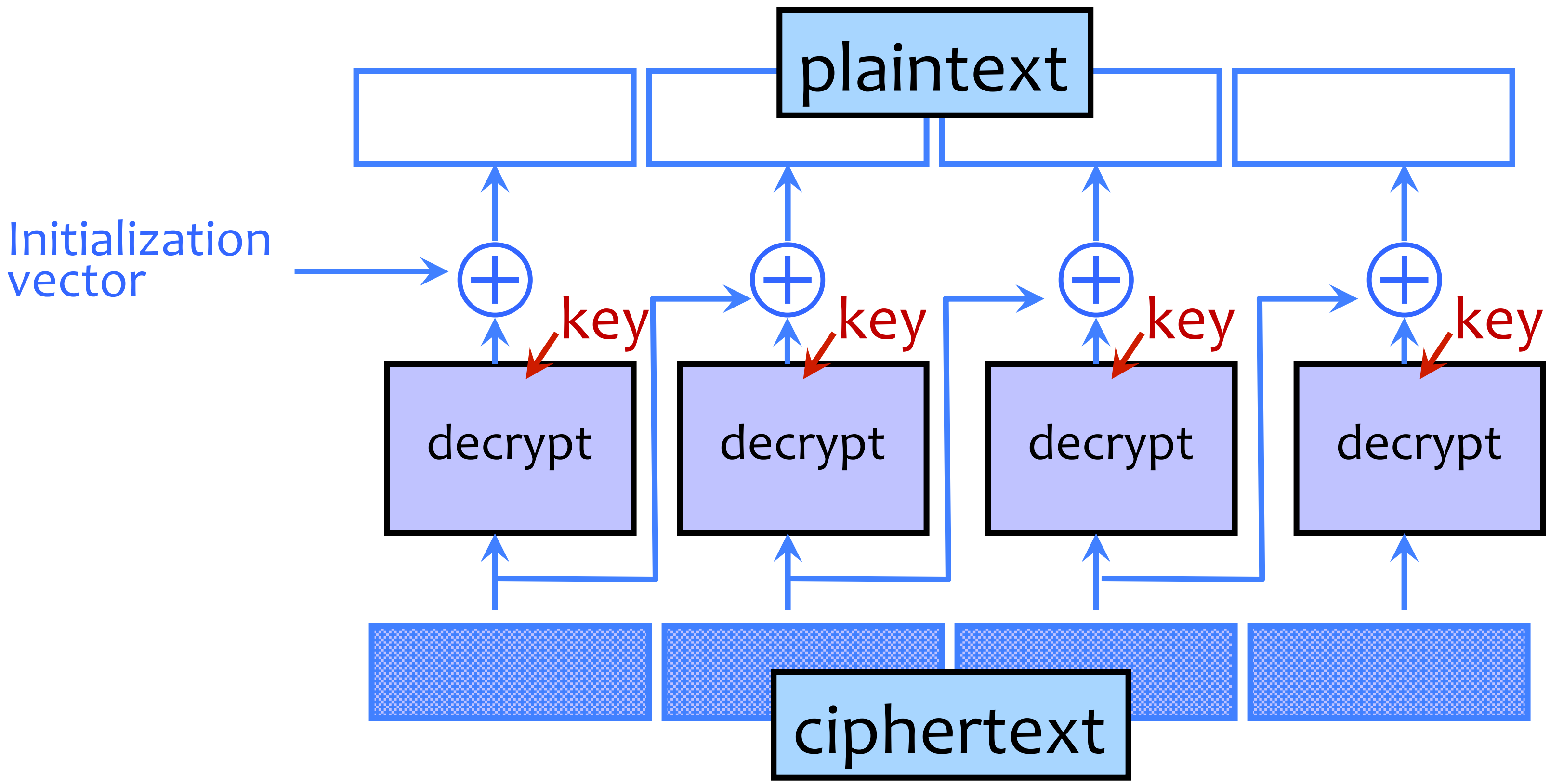
- Identical blocks of plaintext produce identical blocks of ciphertext
- No integrity checks: can mix and match blocks

Cipher Block Chaining (CBC) Mode: Encryption

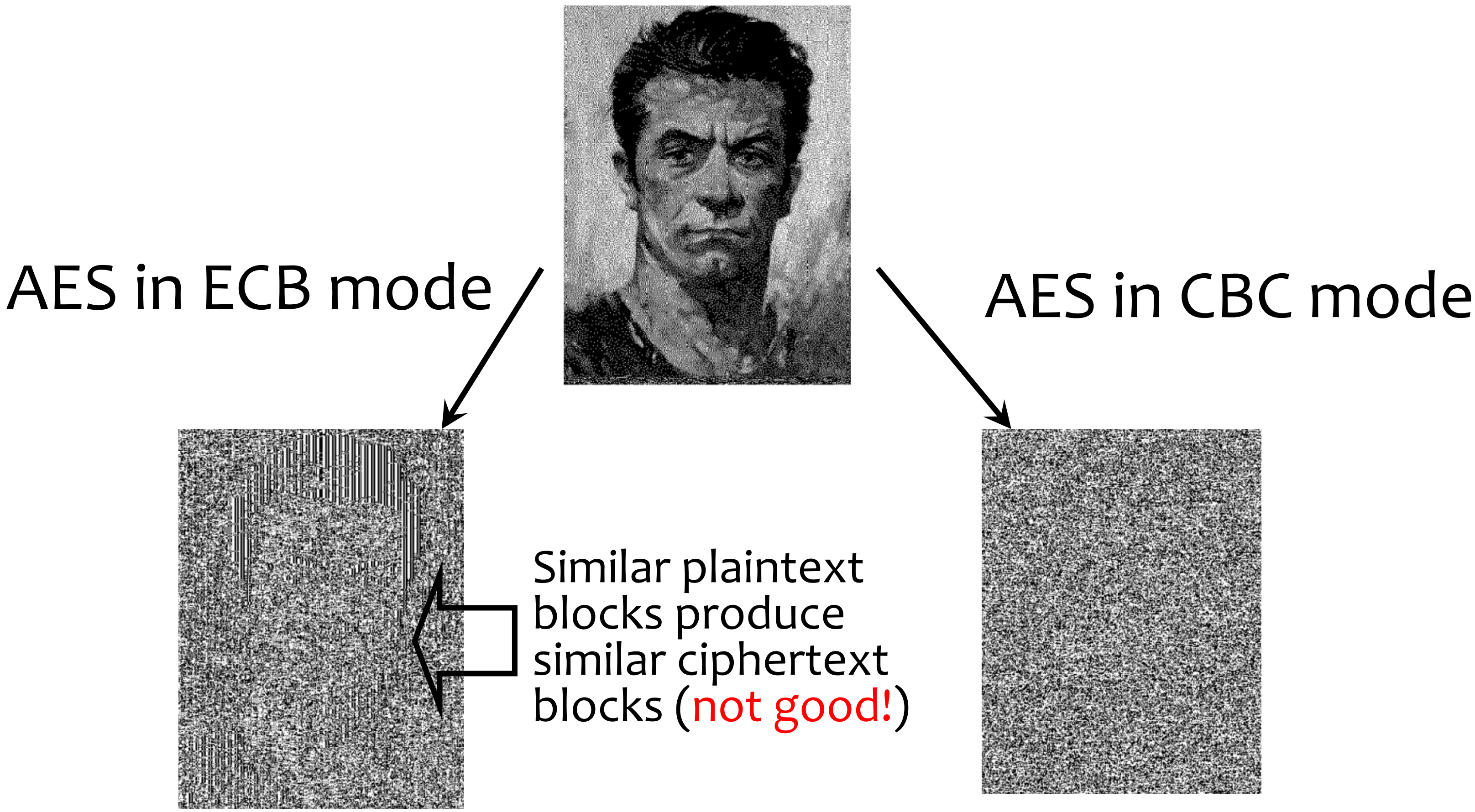


- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext
  - Still does not guarantee integrity

CBC Mode: Decryption

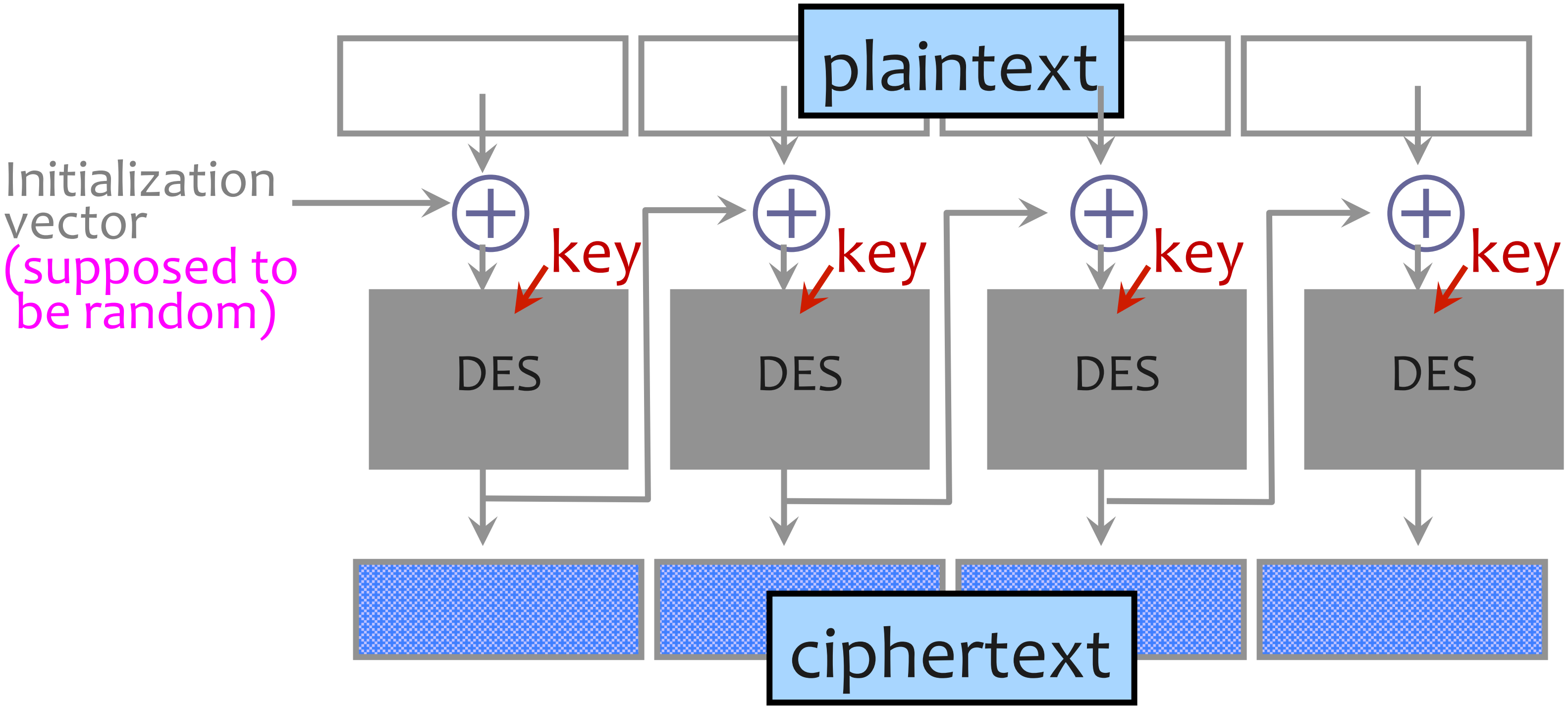


ECB vs. CBC



[Picture due to Bart Preneel]

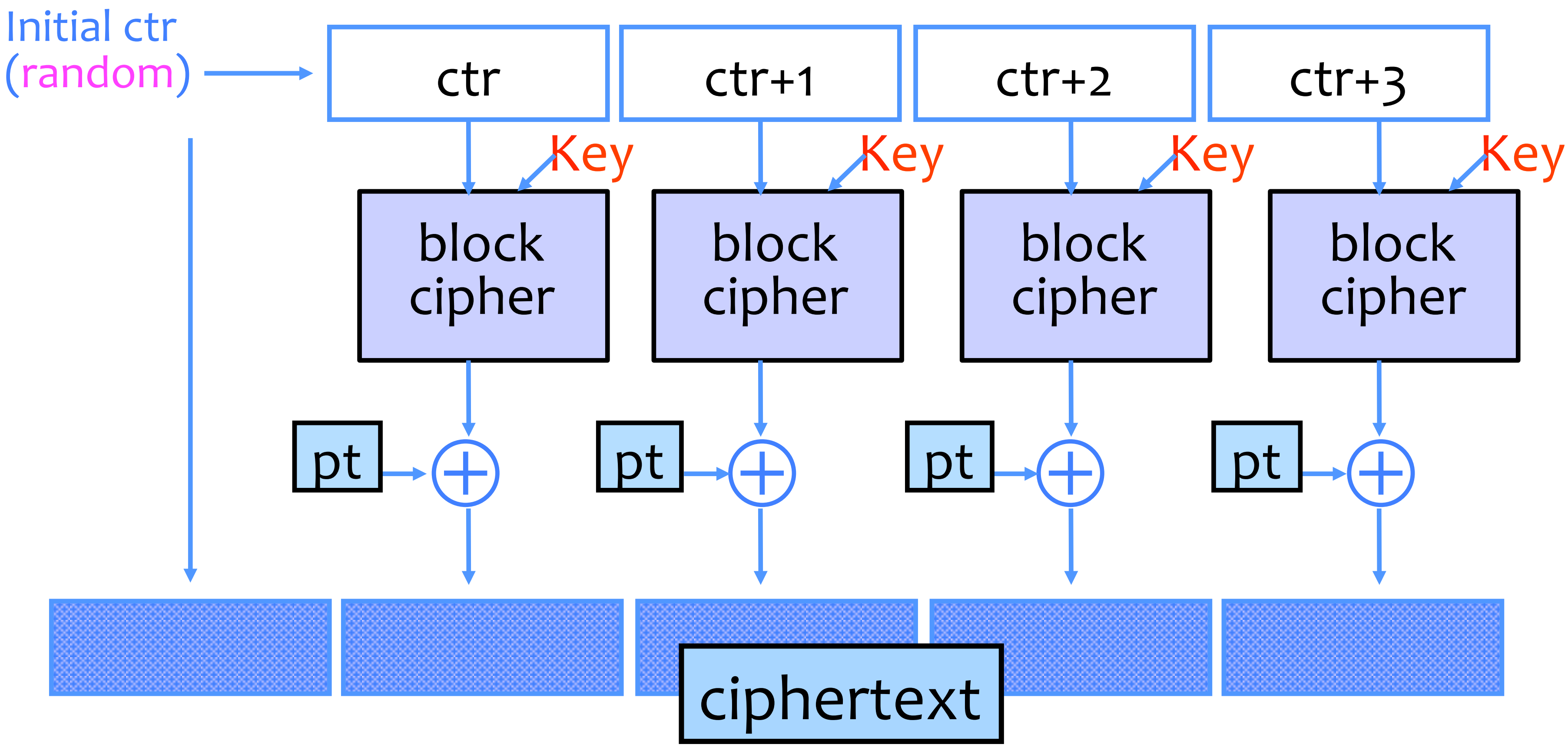
CBC and Electronic Voting



Found in the source code for Diebold voting machines:

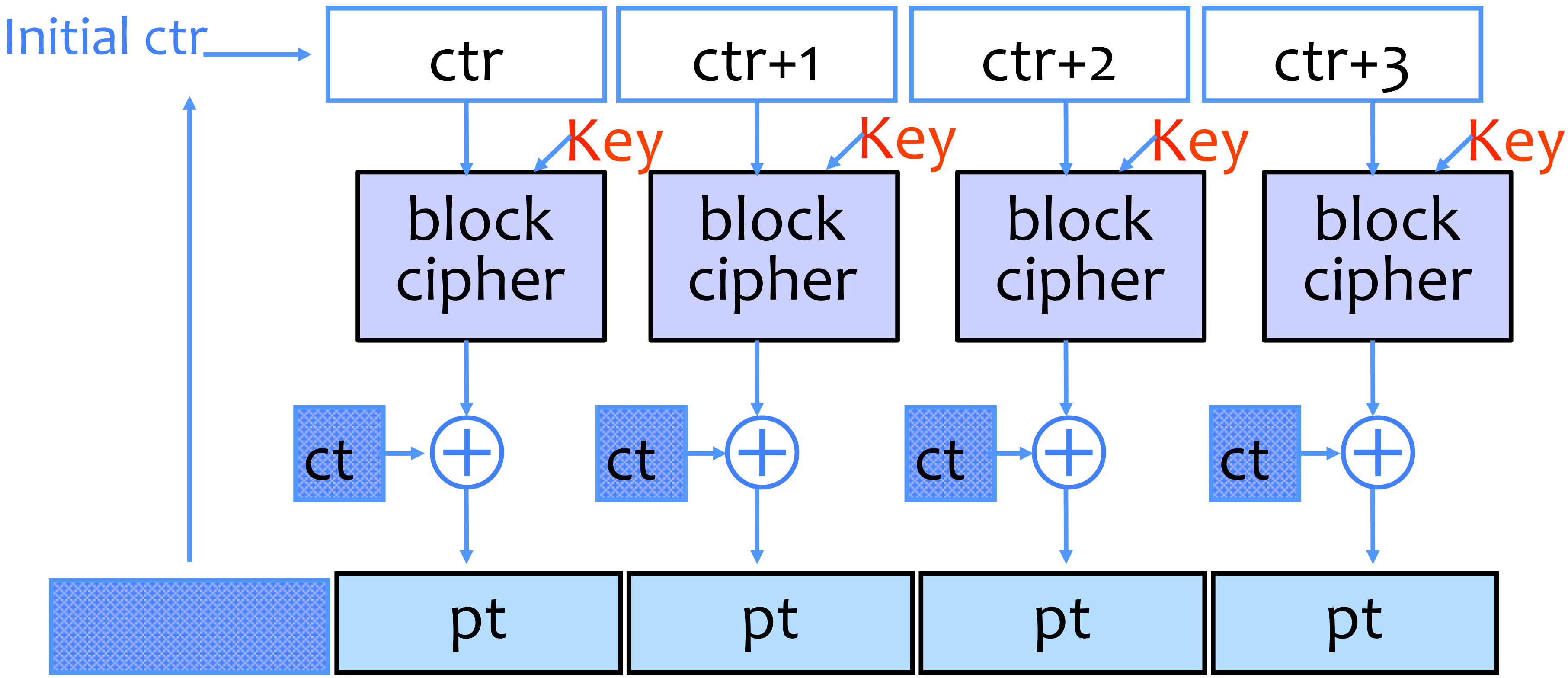
```
DesCBCEncrypt((des_c_block*)tmp, (des_c_block*)record.m_Data,
        totalSize, DESKEY, NULL, DES_ENCRYPT)
```

Counter Mode (CTR): Encryption



- Identical blocks of plaintext encrypted differently
- Can compute in parallel (unlike CBC)
- Still does not guarantee integrity; Fragile if ctr repeats

Counter Mode (CTR): Decryption



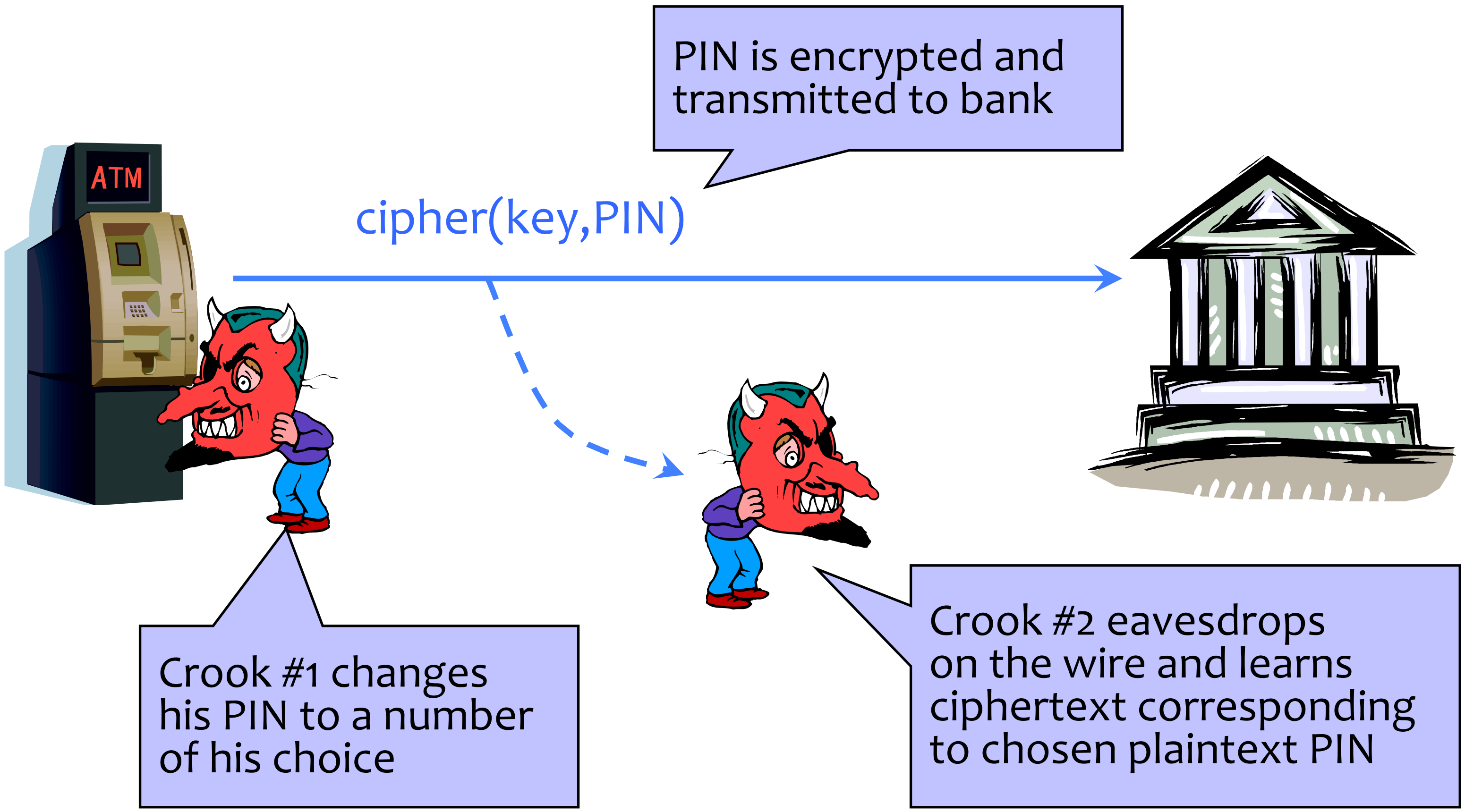
When is an Encryption Scheme "Secure"?

- 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?
- Fixed mapping from plaintexts to ciphertexts?
  - What if attacker sees two identical ciphertexts and infers that the corresponding plaintexts are identical?
  - Implication: encryption must be randomized or stateful

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
- Security against chosen-ciphertext attack (CCA)
  - Integrity protection – it is not possible to change the plaintext by modifying the ciphertext

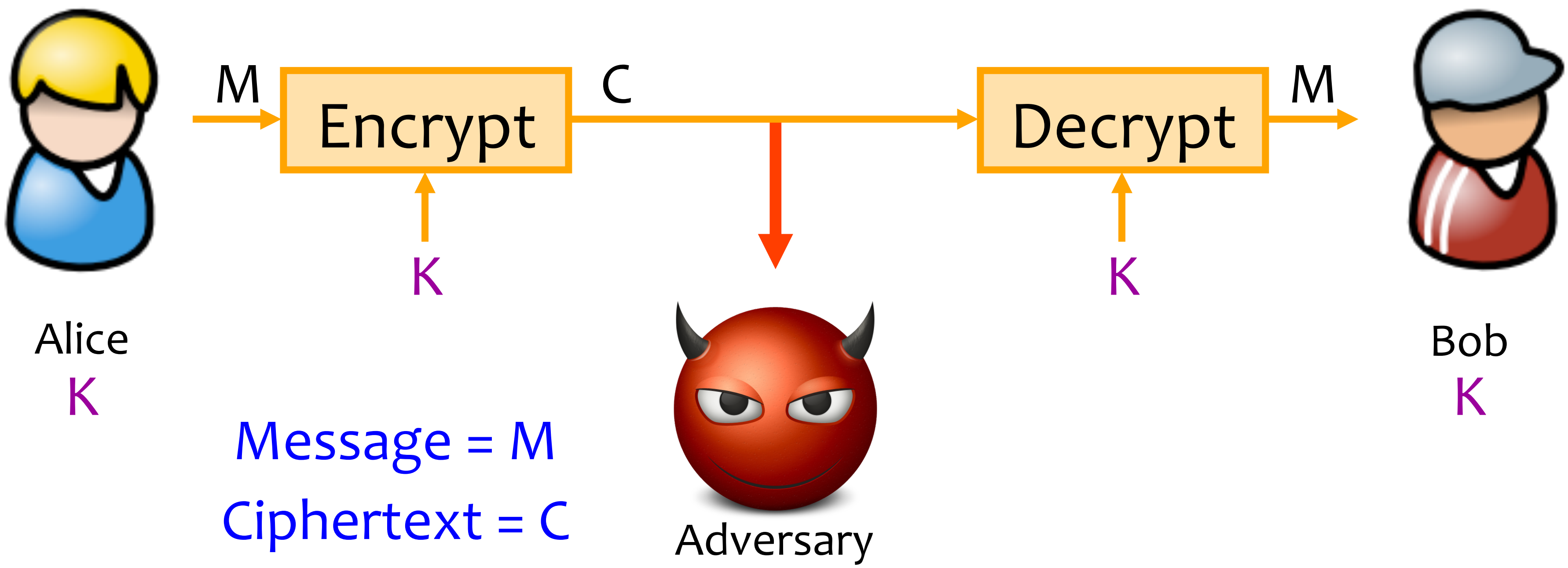
Why Hide Everything?

- Leaking even a little bit of information about the plaintext can be disastrous
- Electronic voting
  - 2 candidates on the ballot (1 bit to encode the vote)
  - If ciphertext leaks the parity bit of the encrypted plaintext, eavesdropper learns the entire vote
- Also, want a strong definition, that implies other definitions (like not being able to obtain key)

Message Authentication Codes

So Far: Achieving Privacy

Encryption schemes: A tool for protecting privacy.

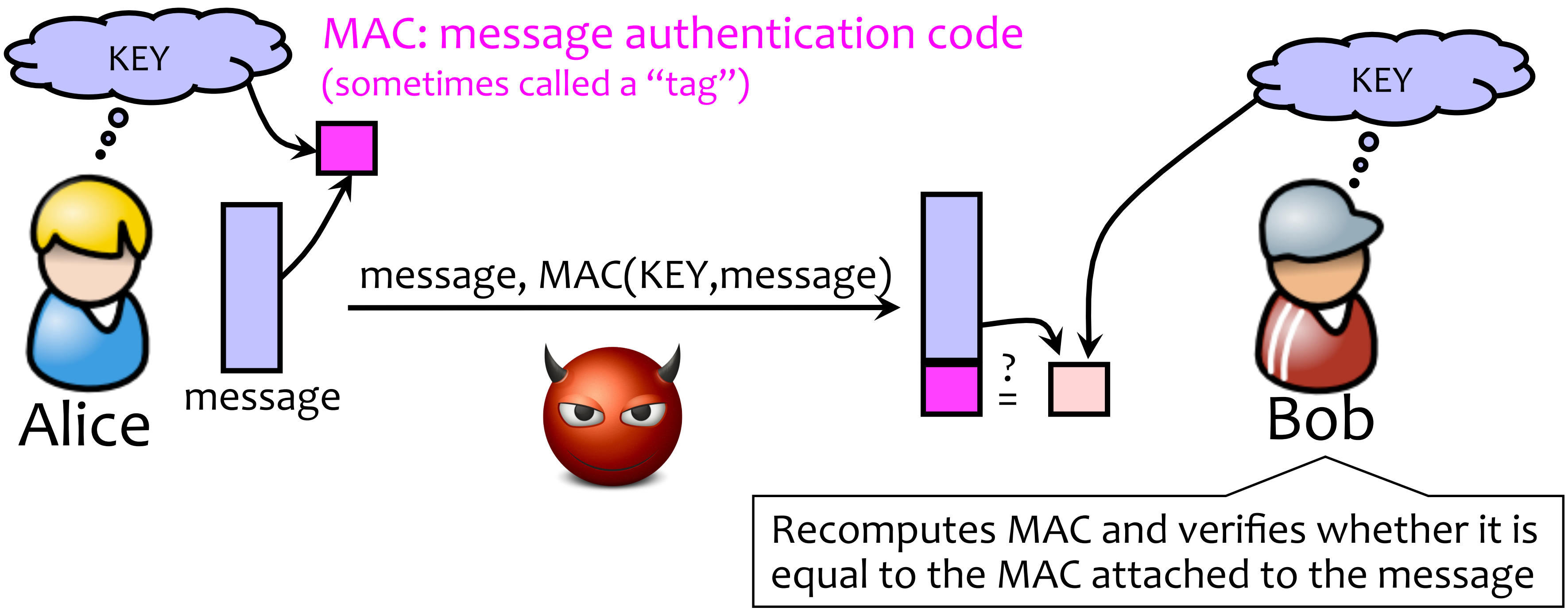


Message = M

Ciphertext = C

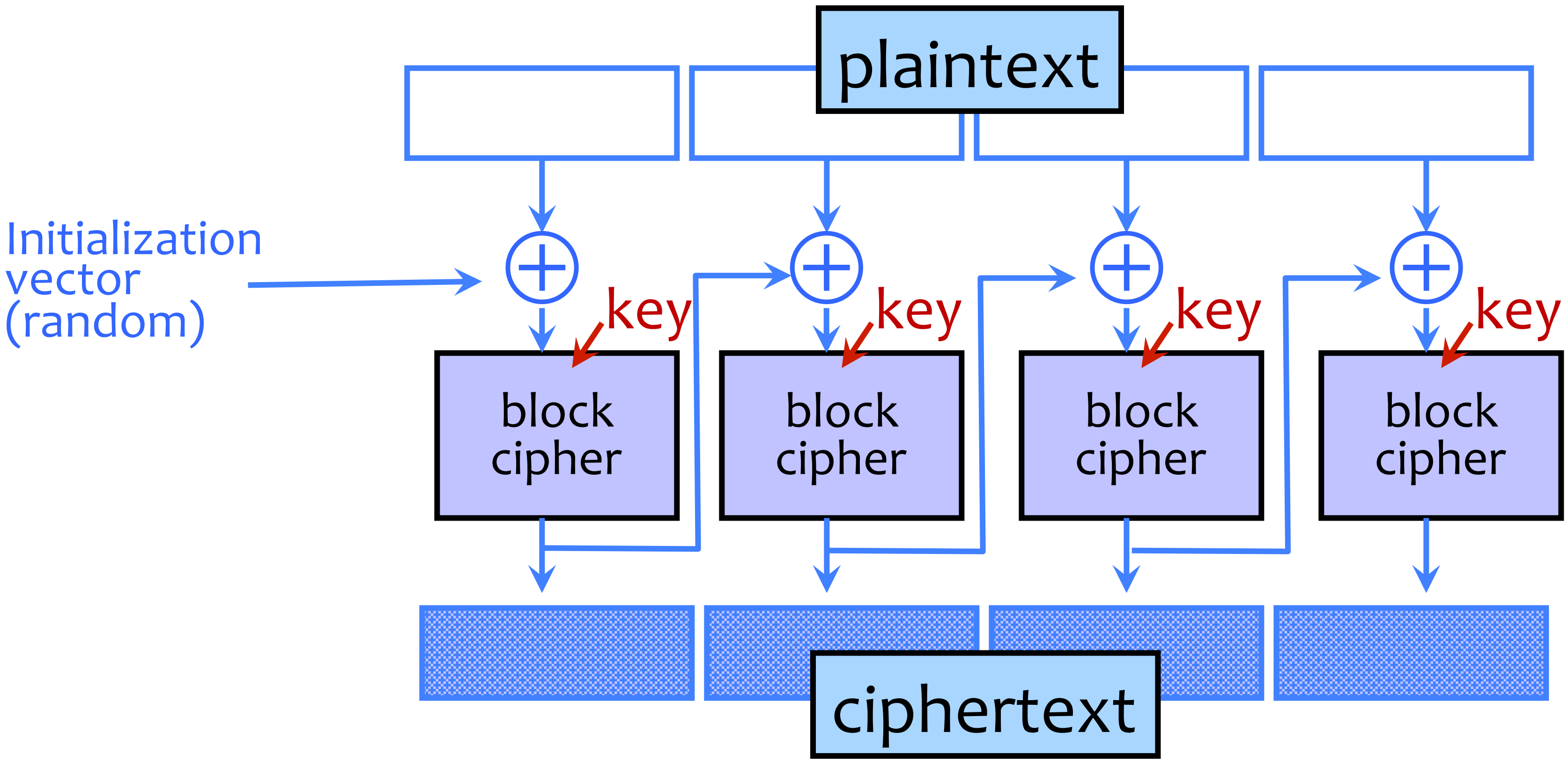
Now: Achieving Integrity

Message authentication schemes: A tool for protecting integrity.



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

Reminder: CBC Mode Encryption



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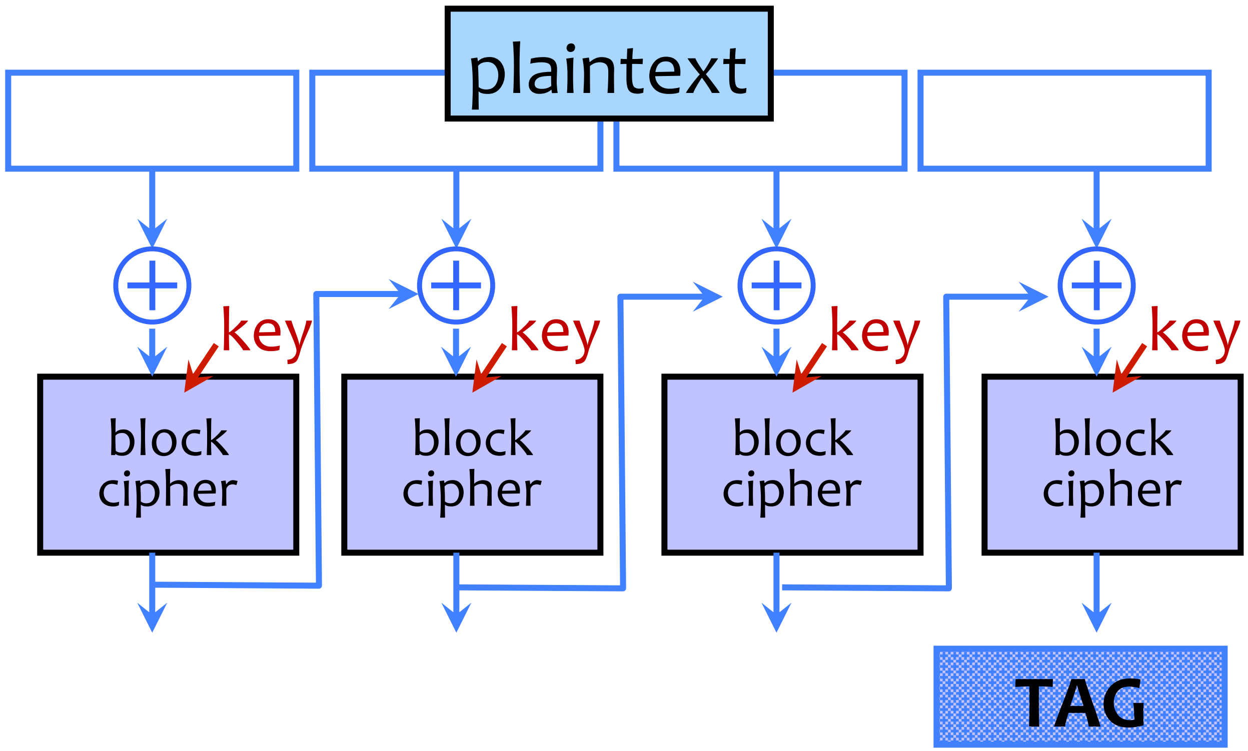
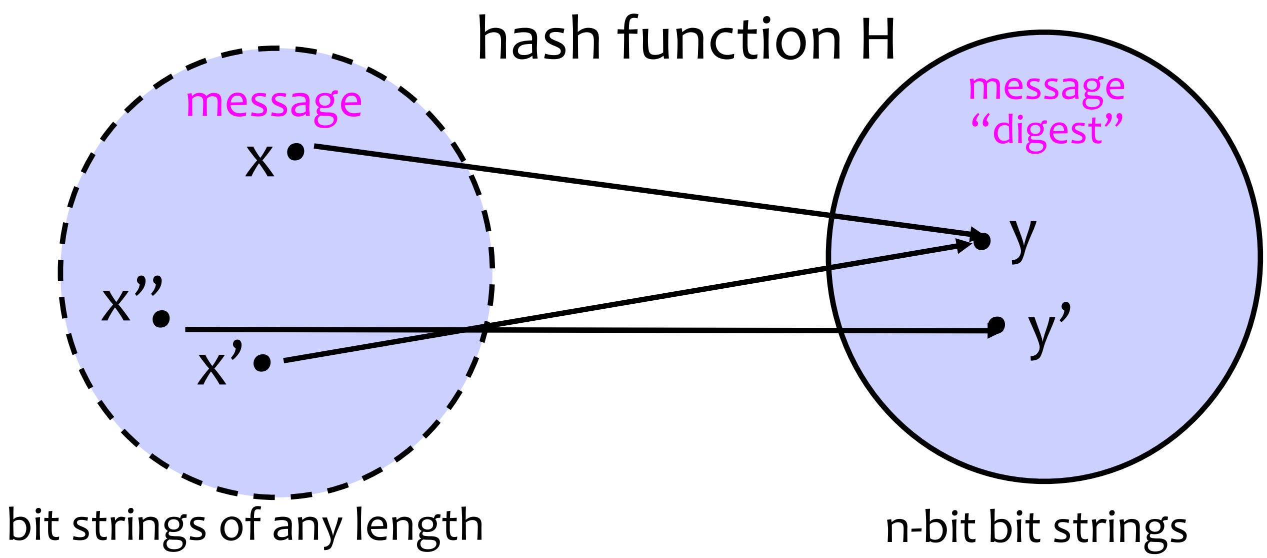
CBC-MAC



- Not secure when system may MAC messages of different lengths.
- NIST recommends a derivative called CMAC [FYI only]

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≠x' such that h(x)=h(x')

Birthday Paradox

- Are there two people in the first 1/3 of this classroom 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 $x \neq x'$ such that $h(x)=h(x')$
- Birthday paradox (informal)
  - Let t be the **number** of values x,x',x''… we need to look at before finding the first pair x,x' s.t. $h(x)=h(x')$
  - What is probability of collision for each **pair** x,x'? $1/2^n$
  - How many **pairs** would we need to look at before finding the first collision? $O(2^n)$
  - How many **pairs** x,x' total? $Choose(t,2)=t(t-1)/2 \sim O(t^2)$
  - What is t, the **number** of values we need to look at? $2^{n/2}$
- Brute-force collision search is only $O(2^{n/2})$, *not* $O(2^n)$
  - For SHA-1, this means $O(2^{80})$ vs. $O(2^{160})$

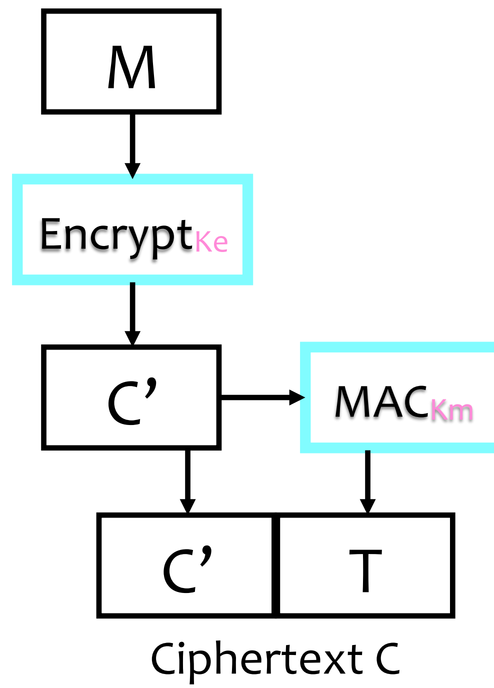
Property 2: Collision Resistance

- Should be hard to find $x \neq x'$ 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. $O(2^{160})$

Authenticated Encryption

- Instead:
  Encrypt *then* MAC.

- (Not as good:
  MAC-then-Encrypt)



Encrypt-then-MAC