CSE 484 / CSE M 584: Computer Security and Privacy

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

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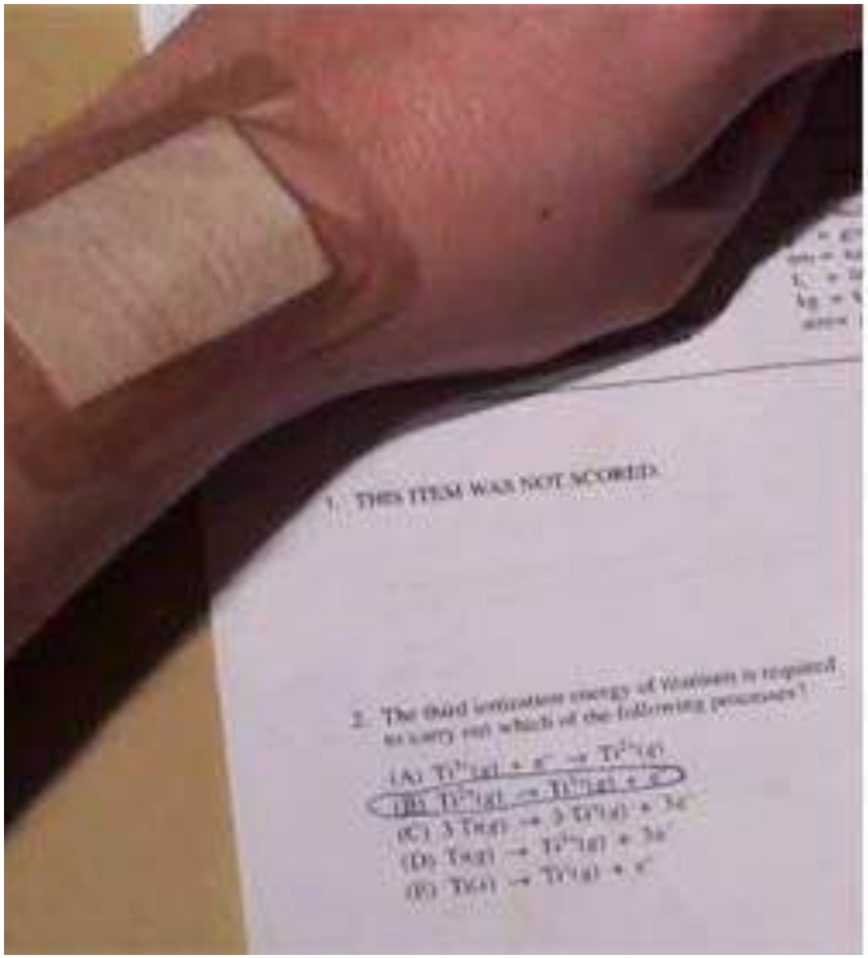
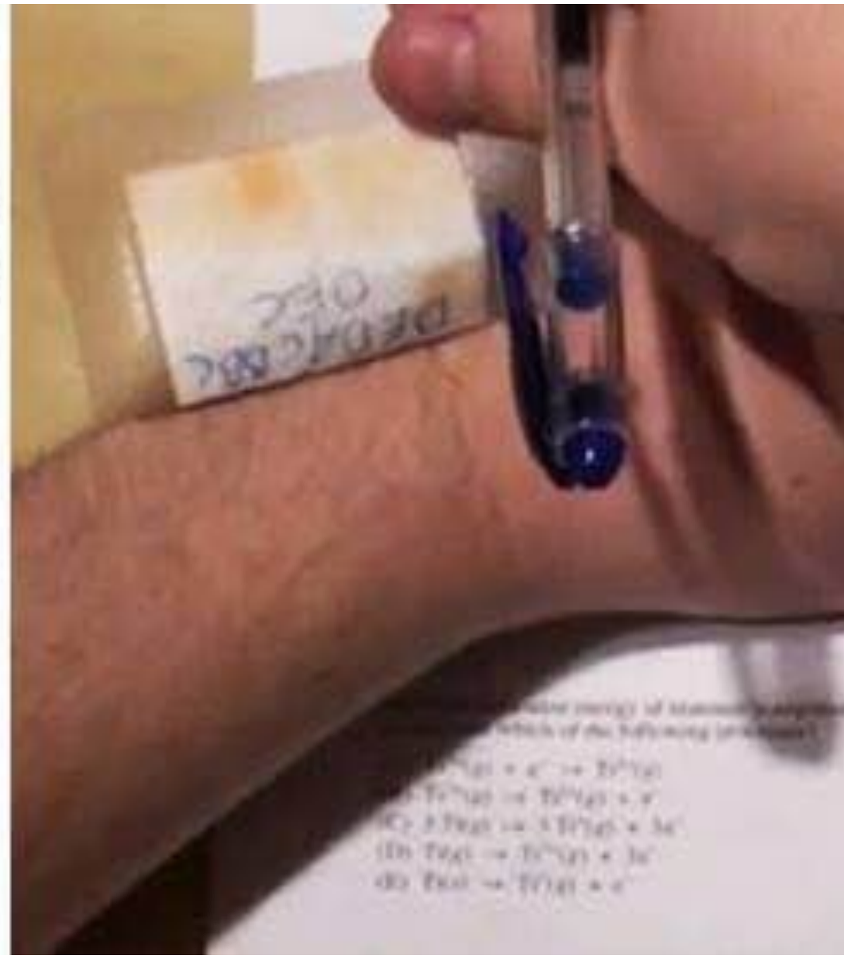
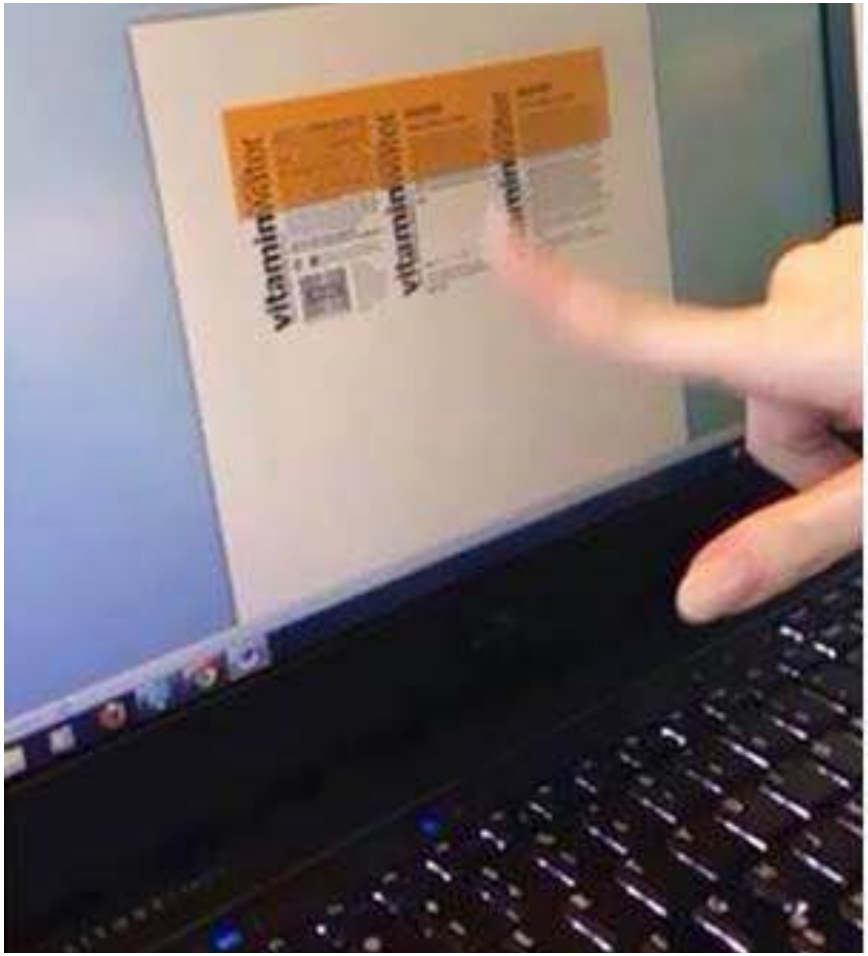
Thanks to Franzi Roesner, Dan Boneh, Dieter Gollmann, Dan Halperin, Yoshi Kohno, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

More Cheating





More Cheating



Dirty COW Vulnerability

- Race condition involving memory mapped files which allows user processes to write to root-owned files

Dirty COW Fixed

commit 19be0eaffa3ac7d8eb6784ad9bdbc7d67ed8e619
Author: Linus Torvalds torvalds@linux-foundation.org
Date: Thu Oct 13 20:07:36 2016 GMT

This is an ancient bug that was actually attempted to be fixed once (badly) by me eleven years ago in commit 4ceb5db9757a ("Fix get_user_pages() race for write access") but that was then undone due to problems on s390 by commit f33ea7f404e5 ("fix get_user_pages bug").

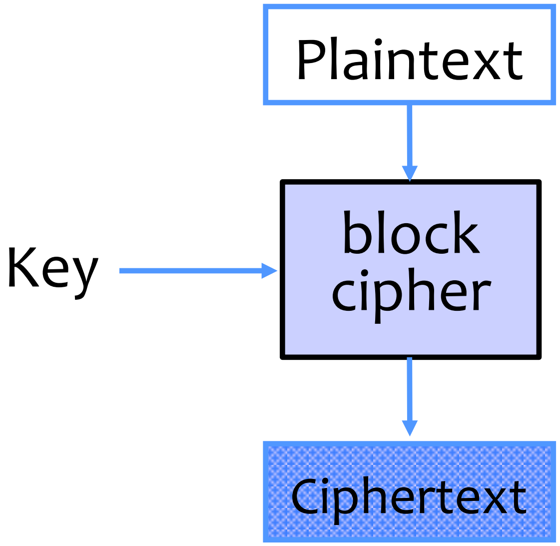
Dirty COW Vulnerability

- `madvise(map,100,MADV_DONTNEED)`
- `write("/proc/self/mem")`

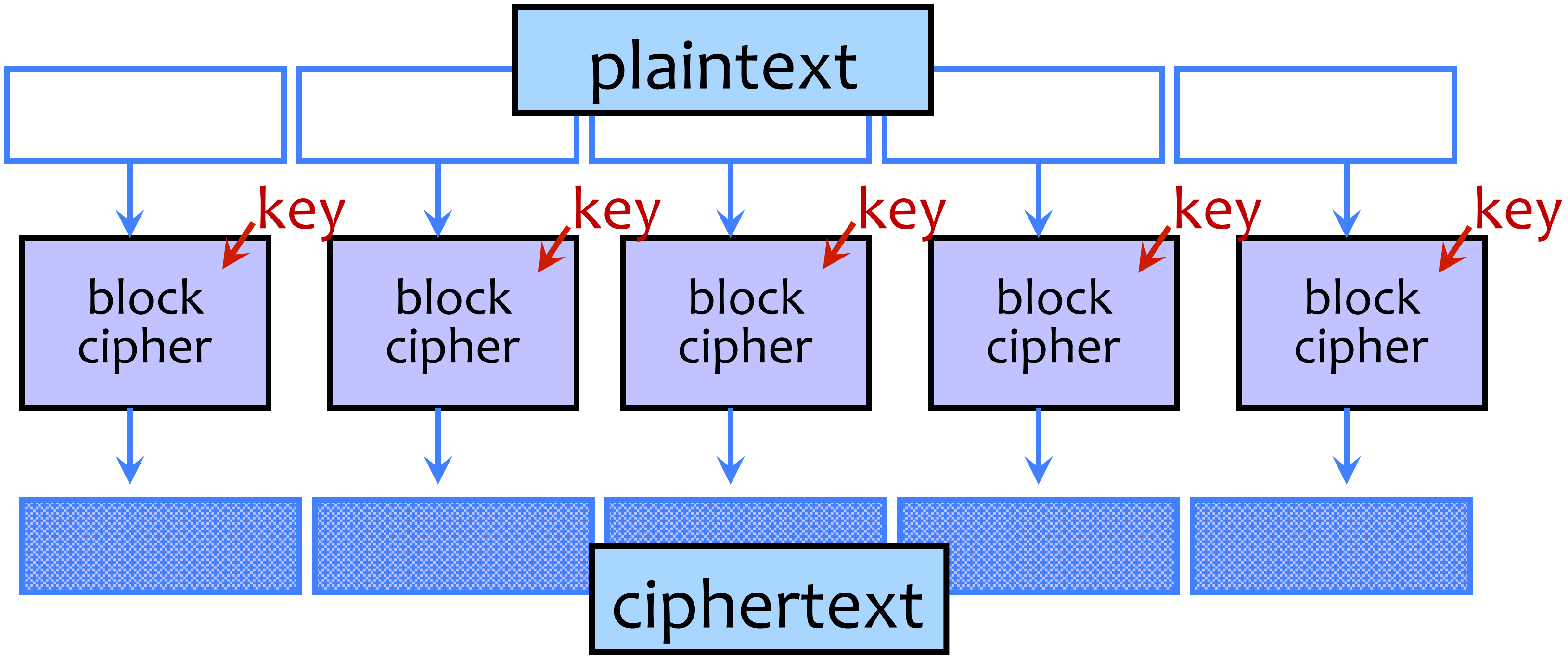
- Eventually writes to a file in the middle of page table updates, causing inappropriate file overwriting.

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)

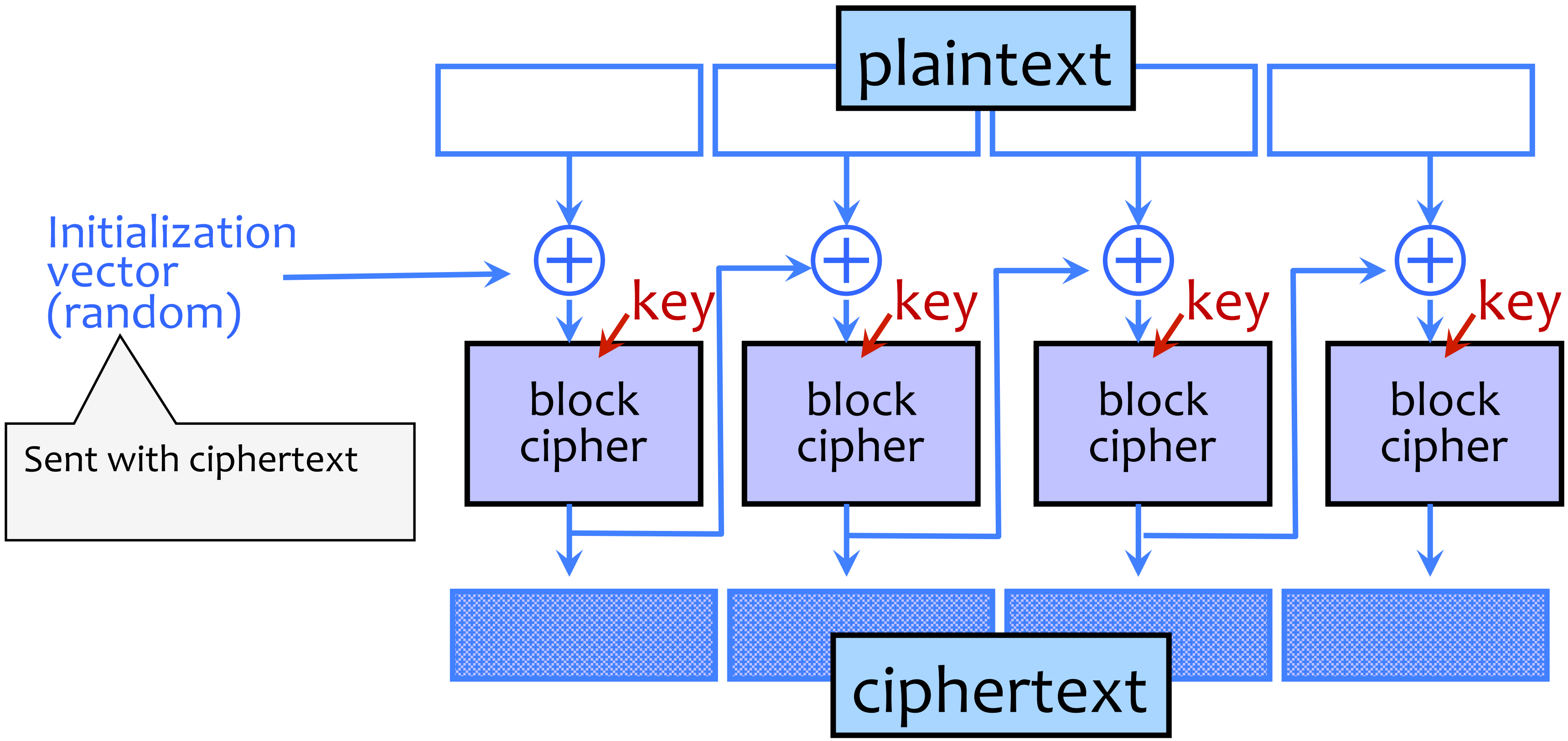


Electronic Code Book (ECB) Mode

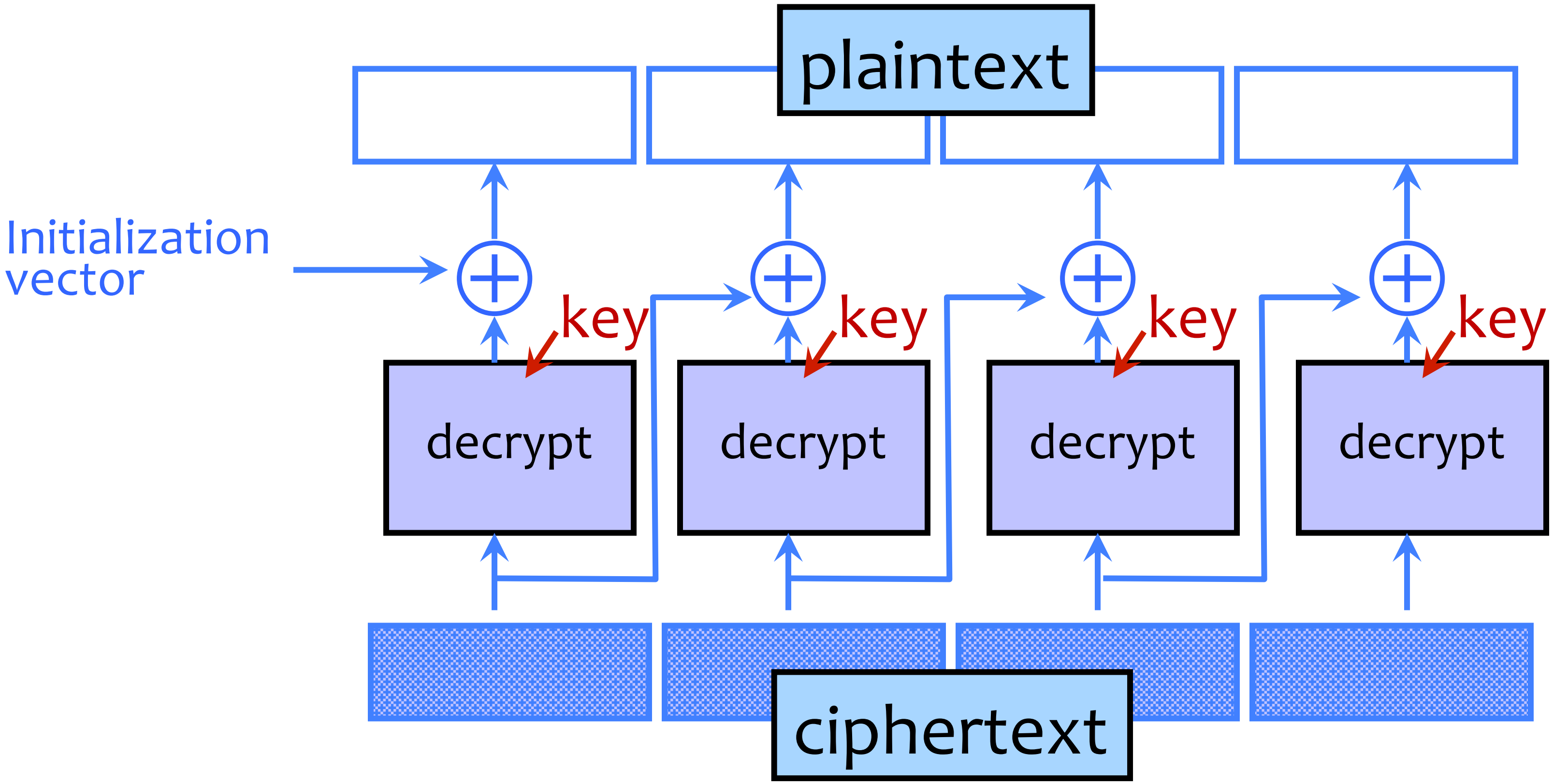


- Don't use ECB mode

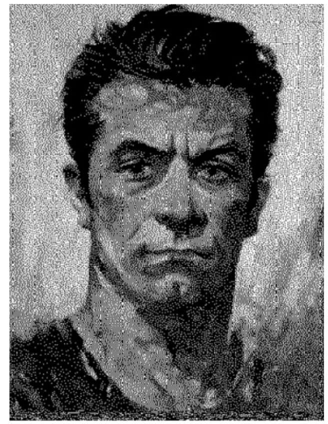
Cipher Block Chaining (CBC) Mode: Encryption



CBC Mode: Decryption

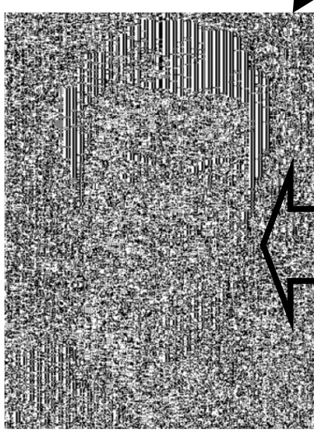


ECB vs. CBC

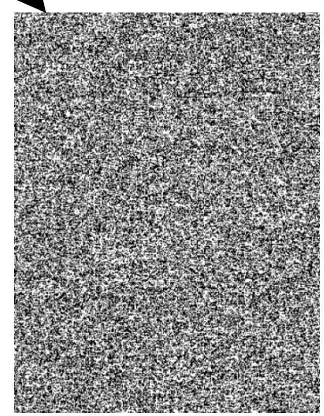


AES in ECB mode

AES in CBC mode

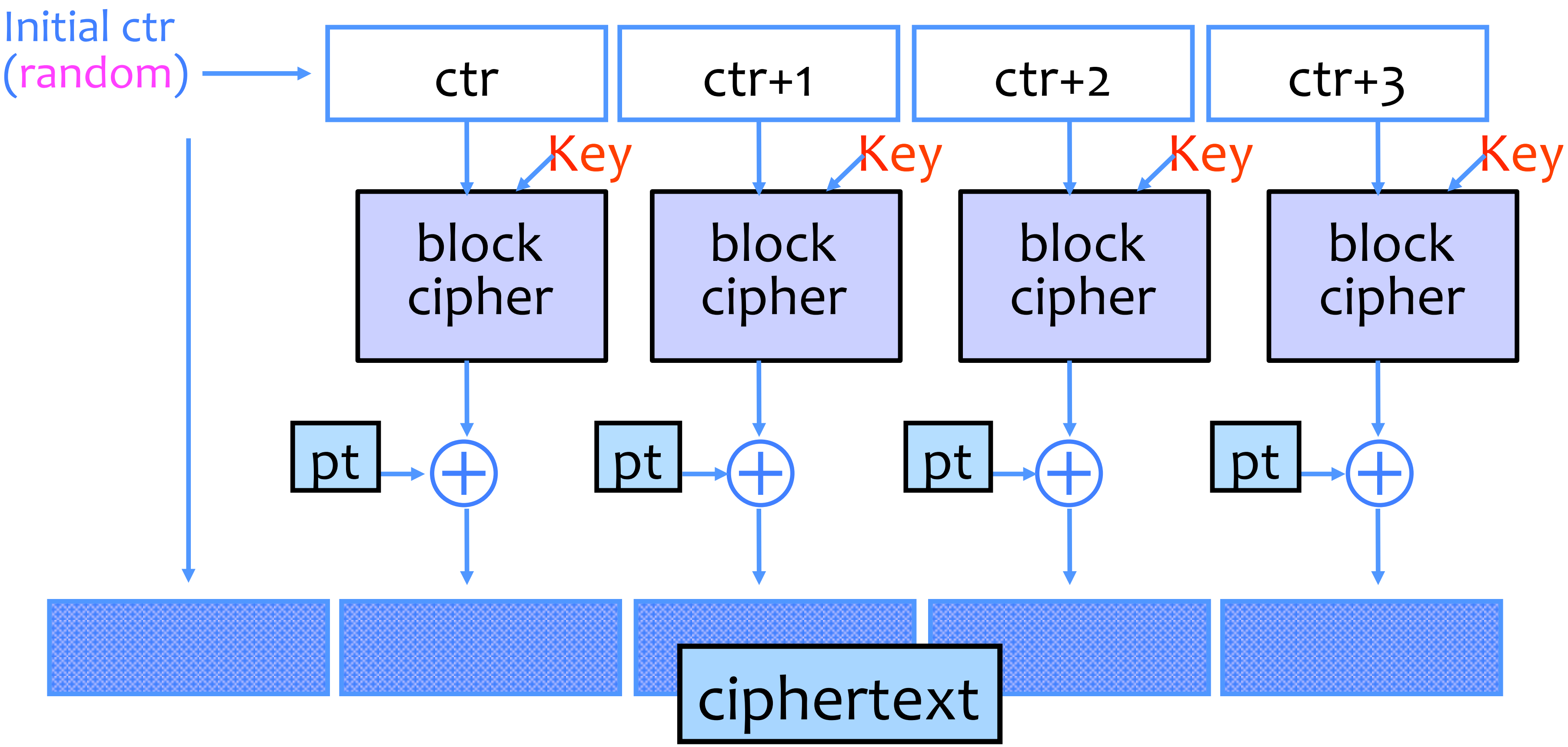


Similar plaintext
blocks produce
similar ciphertext
blocks (not good!)

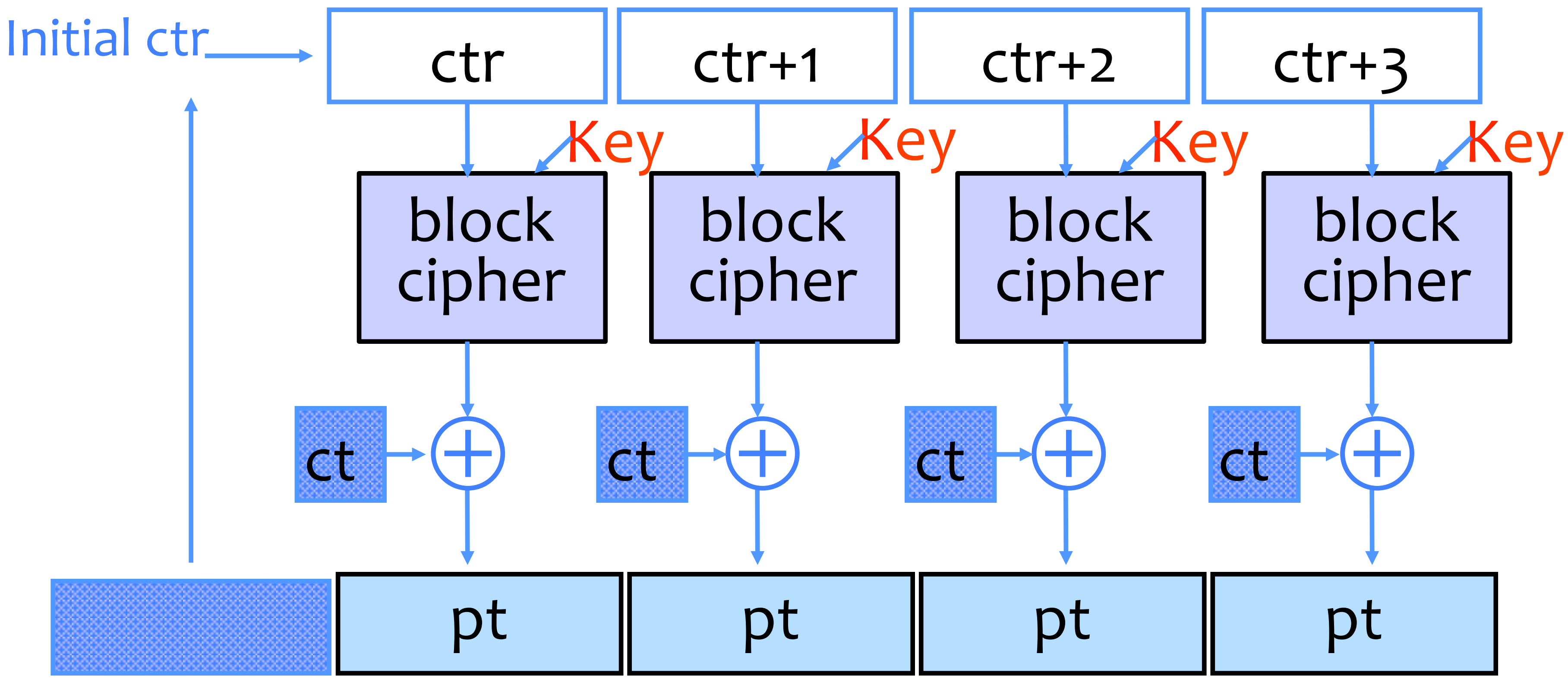


[Picture due to Bart Preneel]

Counter Mode (CTR): Encryption



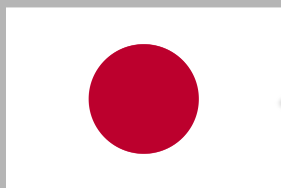
Counter Mode (CTR): Decryption

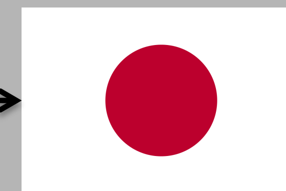


How Can a Cipher Be Attacked?

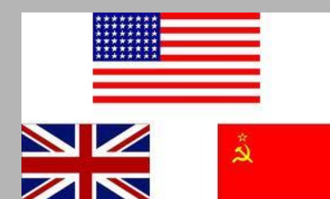
- Attackers knows ciphertext and encryption algthm
  - What else does the attacker know? Depends on the application in which the cipher is used!
- Ciphertext-only attack
- KPA: Known-plaintext attack (stronger)
  - Knows some plaintext-ciphertext pairs
- CPA: Chosen-plaintext attack (even stronger)
  - Can obtain ciphertext for any plaintext of his choice
- CCA: Chosen-ciphertext attack (very strong)
  - Can decrypt any ciphertext <u>except</u> the target

Ex: Chosen Plaintext Attacks





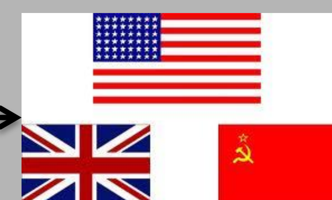
"Let's plan an attack on AF"



[wikipedia]

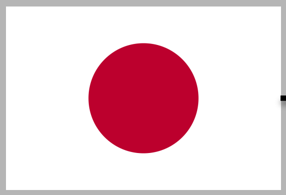
Ex: Chosen Plaintext Attacks

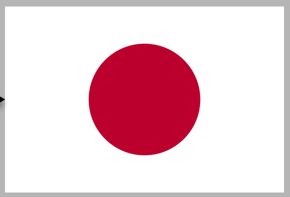
“This is Midway Island, we’re low on supplies”



[wikipedia]

Ex: Chosen Plaintext Attacks





"AF is low on supplies"

[wikipedia]

Ex: Chosen Plaintext Attack

- When the allies planted mines in the ocean, the German Navy would send messages about those locations to warn their ships.

[wikipedia]

Examples of Chosen Ciphertext Attacks

- Some serious attacks against SSH have been based on Chosen Ciphertext Attacks

- Example: send chosen ciphertext to SSH server, see whether it responds with an error or not.

Examples of Chosen Ciphertext Attacks

- Imagine a system with very few commands, e.g., a military system which responds to the commands (“FIRE”) and (“DON’T FIRE”). Try sending ciphertexts and observe in real life whether the weapon fires or not.
- The side effects of the command serve as a “decryption” of your ciphertext.

<u>Very</u> Informal Intuition

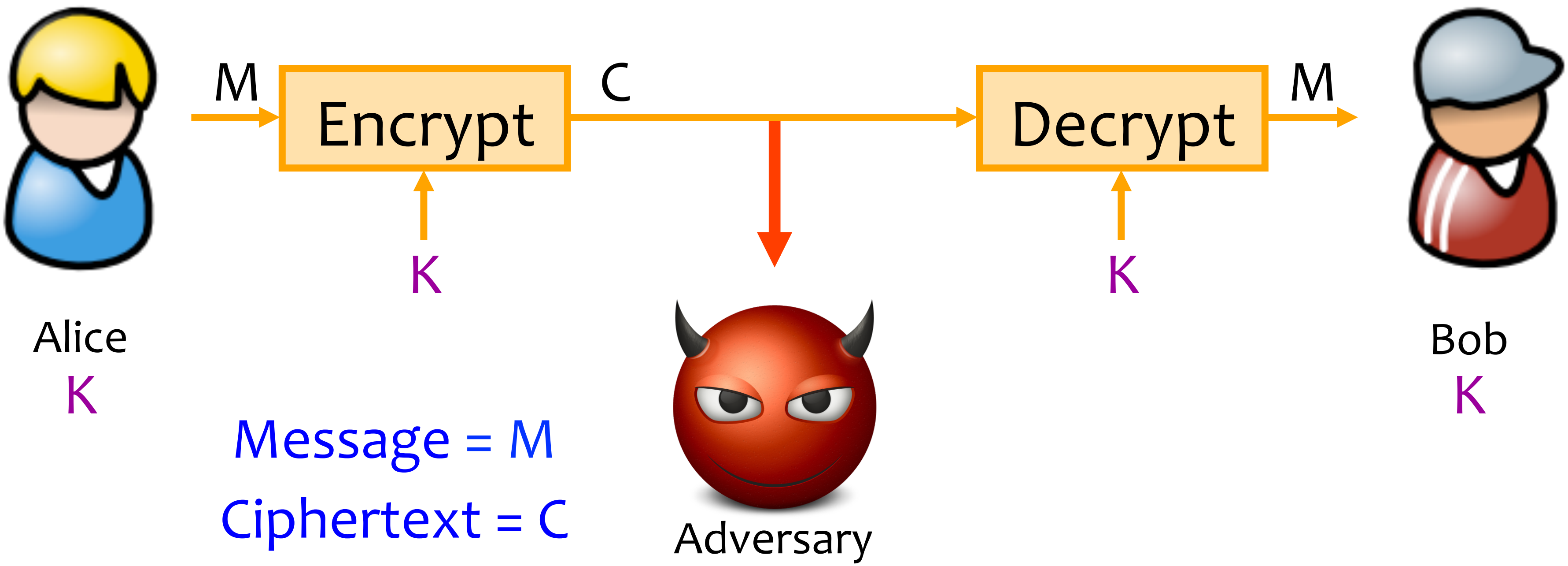
Minimum security requirement for a modern encryption scheme

- 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

Message Authentication Codes

So Far: Achieving Privacy

Encryption schemes: A tool for protecting privacy.

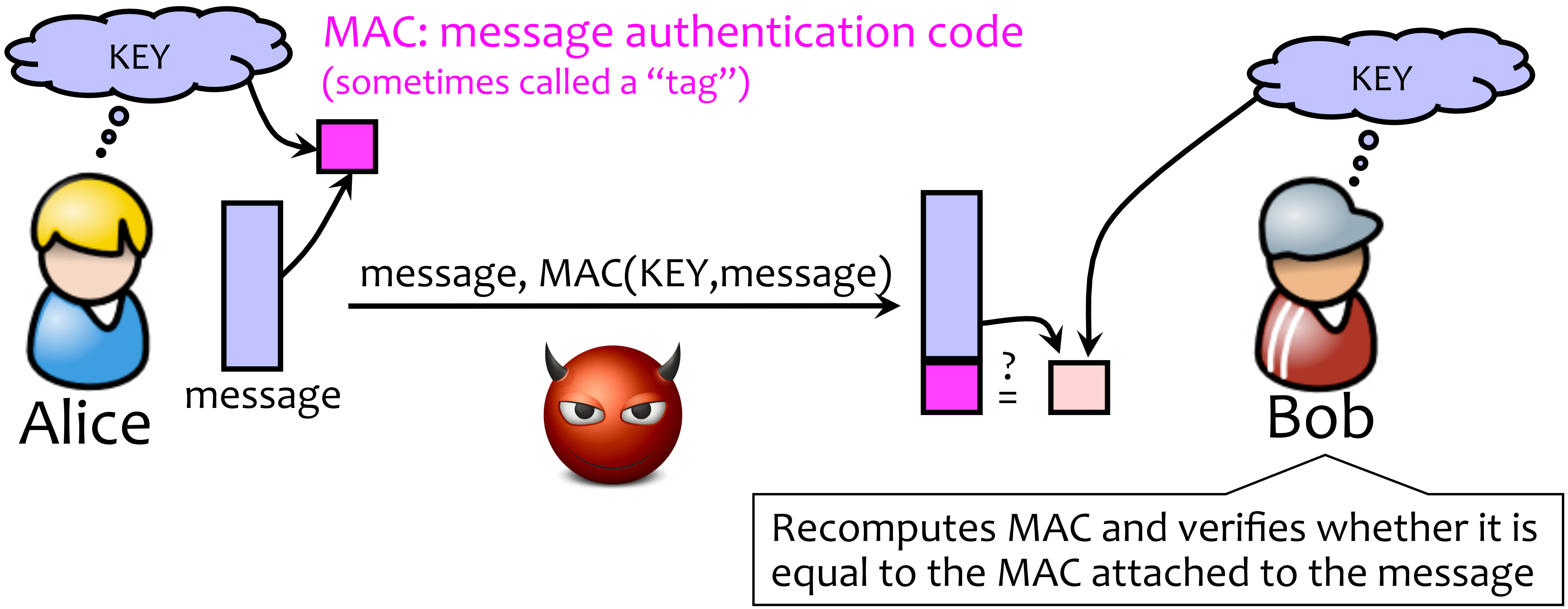


Message = M

Ciphertext = C

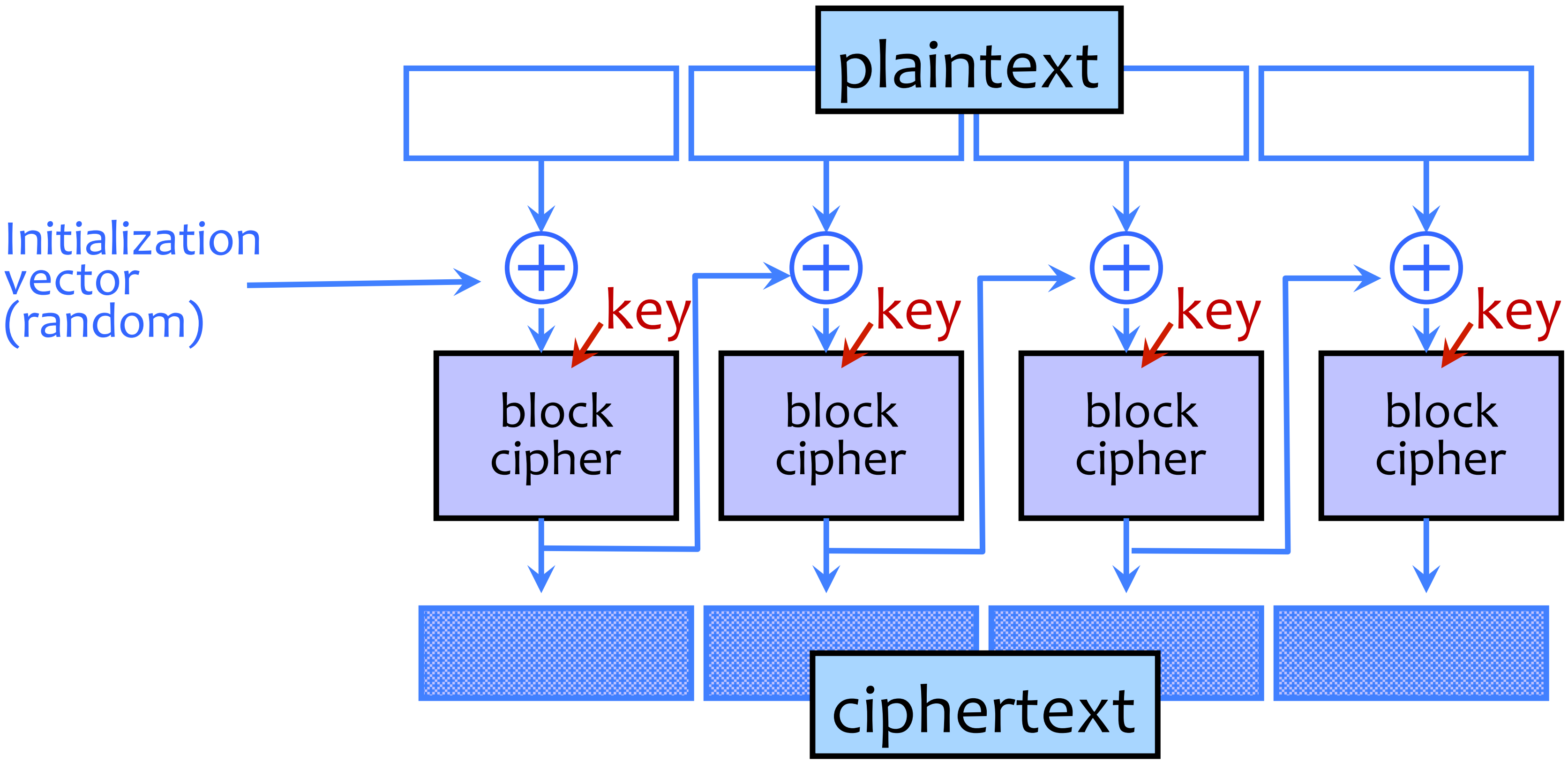
Now: Achieving Integrity

Message authentication schemes: A tool for protecting integrity.

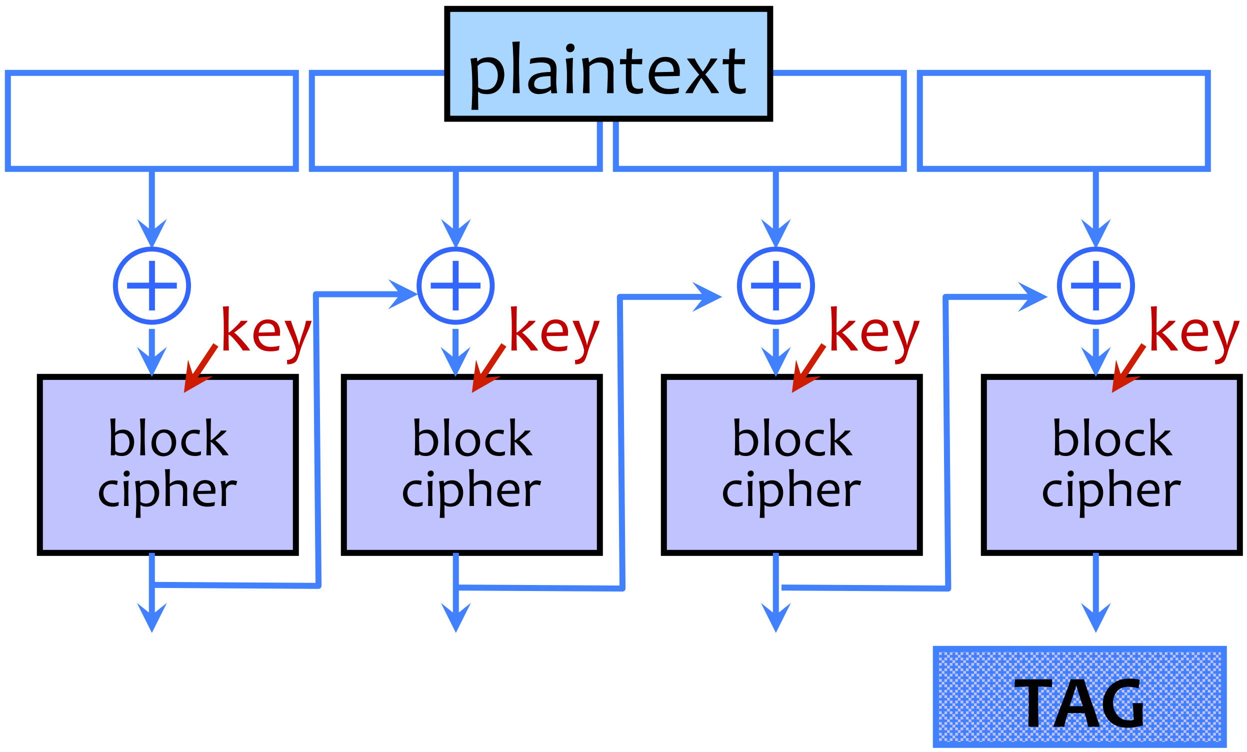


Integrity and authentication: only someone who knows KEY can compute correct MAC for a given message.

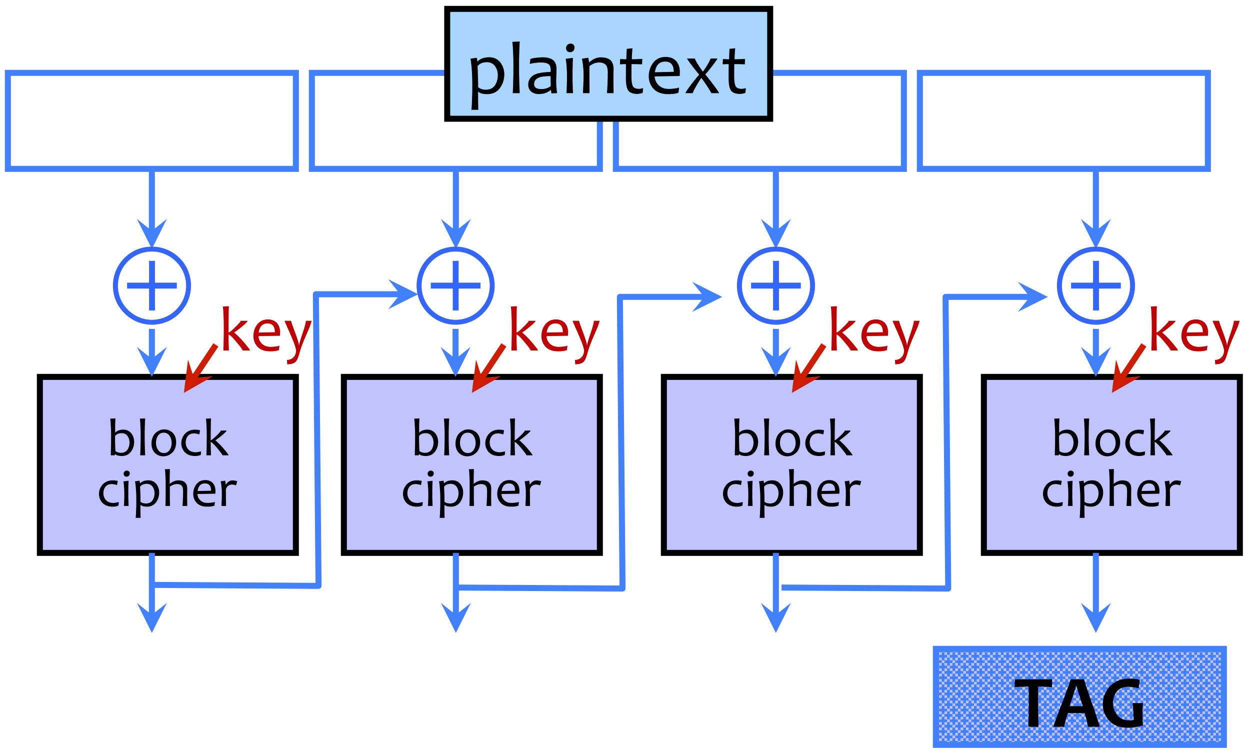
Reminder: CBC Mode Encryption



CBC-MAC


plaintext
key
key
key
key
block cipher
block cipher
block cipher
block cipher
TAG

CBC-MAC



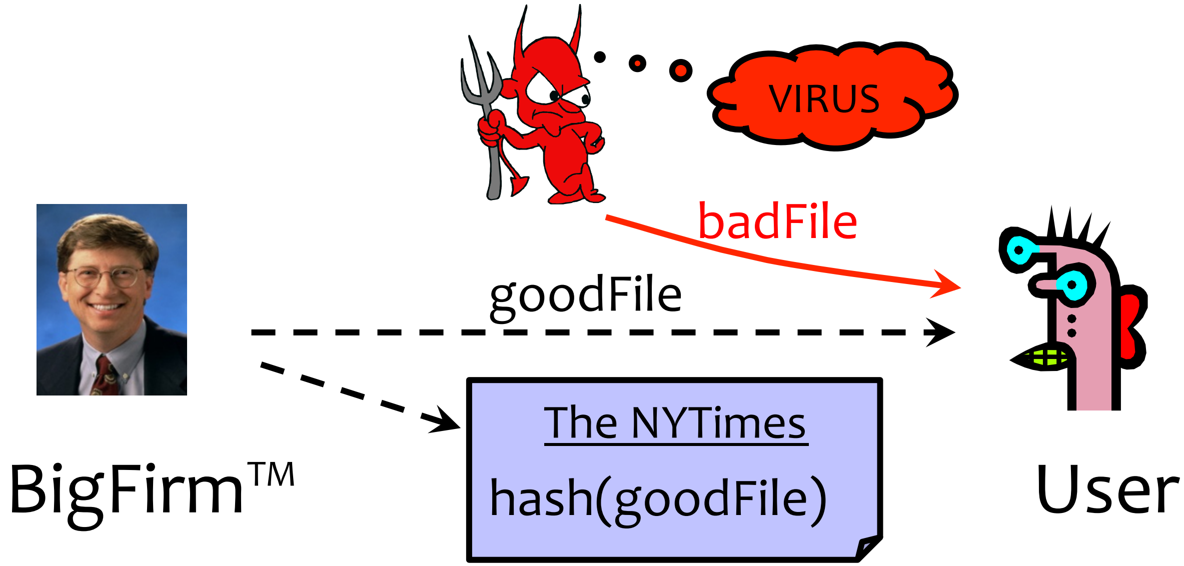
- Not secure when system may MAC messages of different lengths.

Hash Functions

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
  - System does not store actual passwords!
  - Cannot go from hash to password!
- Why is hashing better than encryption here?
- Does hashing protect weak, easily guessable passwords?

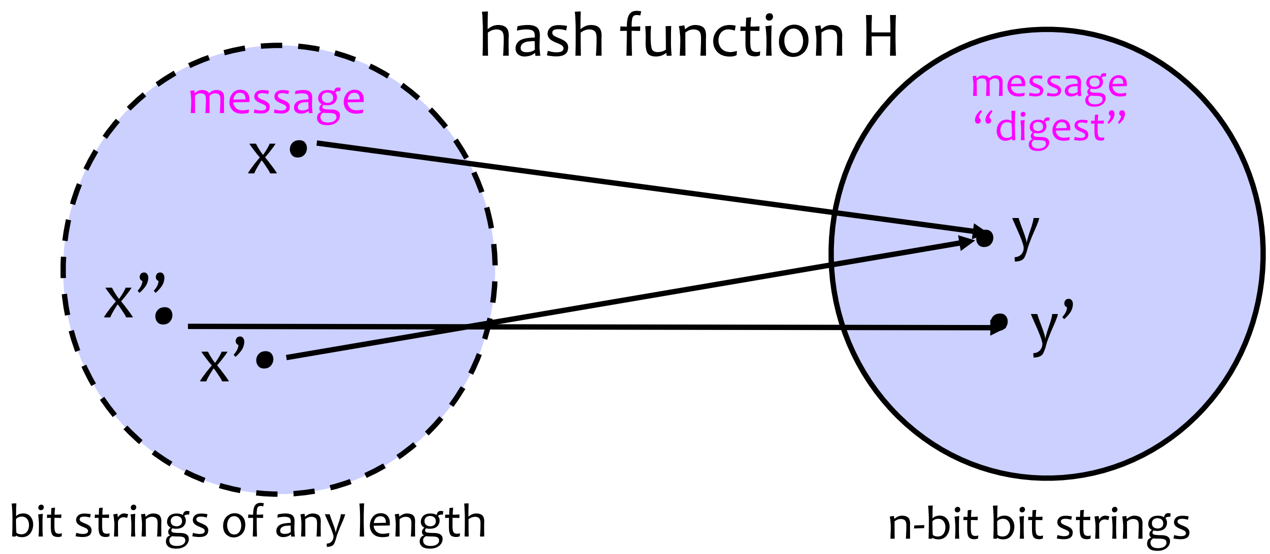
Application: Software Integrity



<u>Goal:</u> Software manufacturer wants to ensure file is received by users without modification.

<u>Idea:</u> given goodFile and hash(goodFile), very hard to find badFile such that hash(goodFile)=hash(badFile)

Hash Functions: Main Idea



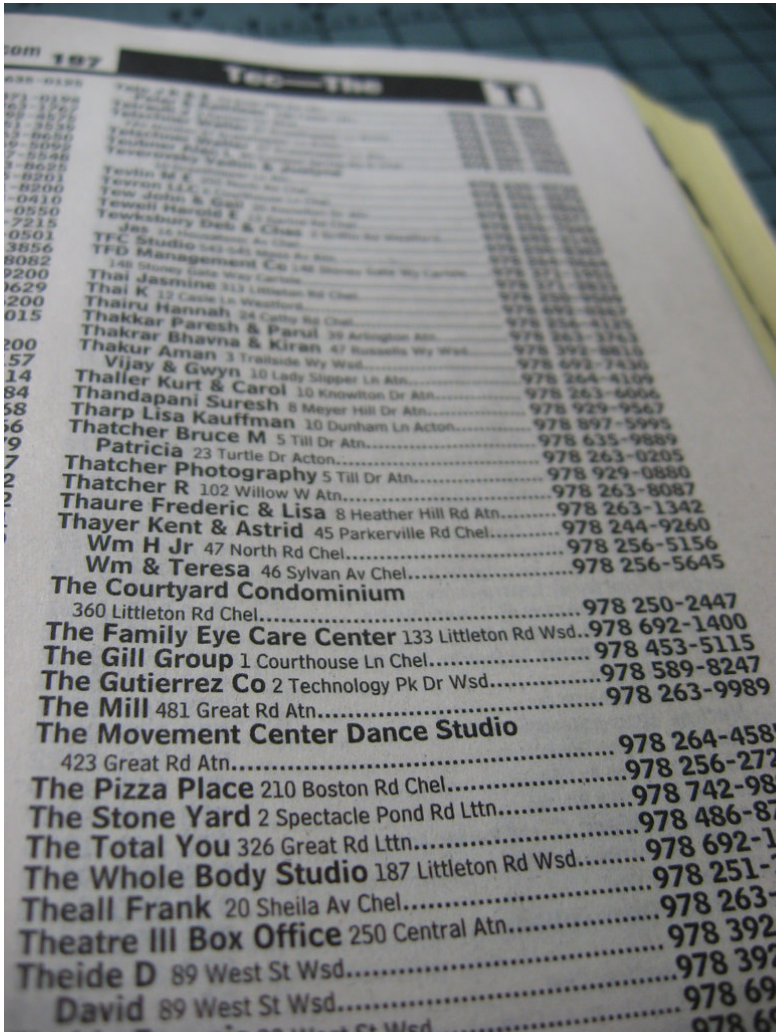
- Hash function H is a lossy compression function
  - Collision: h(x)=h(x') for distinct inputs x, x'
- H(x) should look "random"
  - Every bit equally likely to be 0 or 1
- <u>Cryptographic</u> hash function needs a few properties…

Property 1: One-Way

- The hash should be hard to invert
  - "Preimage resistance"
  - Let $h(x') = y \in \{0,1\}^n$ for random x'
  - Given y, it should be hard to find any x such that $h(x)=y$

Security Mindset Anecdote

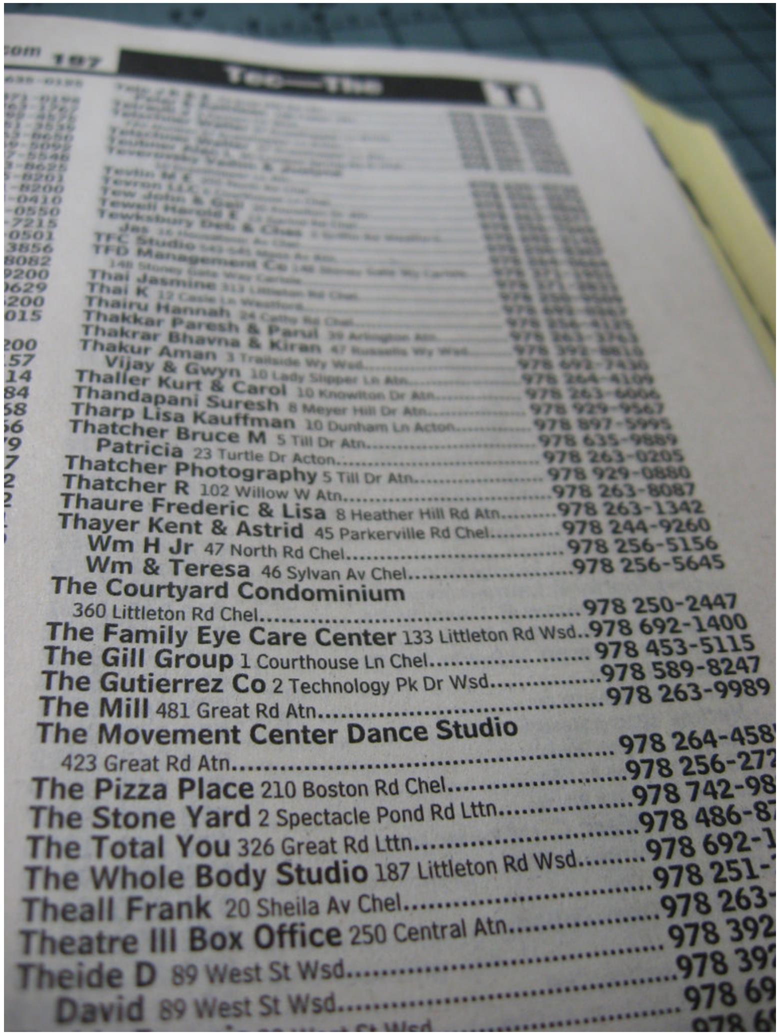
- A clever example of a one-way function: phone books.



Security Mindset Anecdote

- A clever example of a one-way function: phone books.

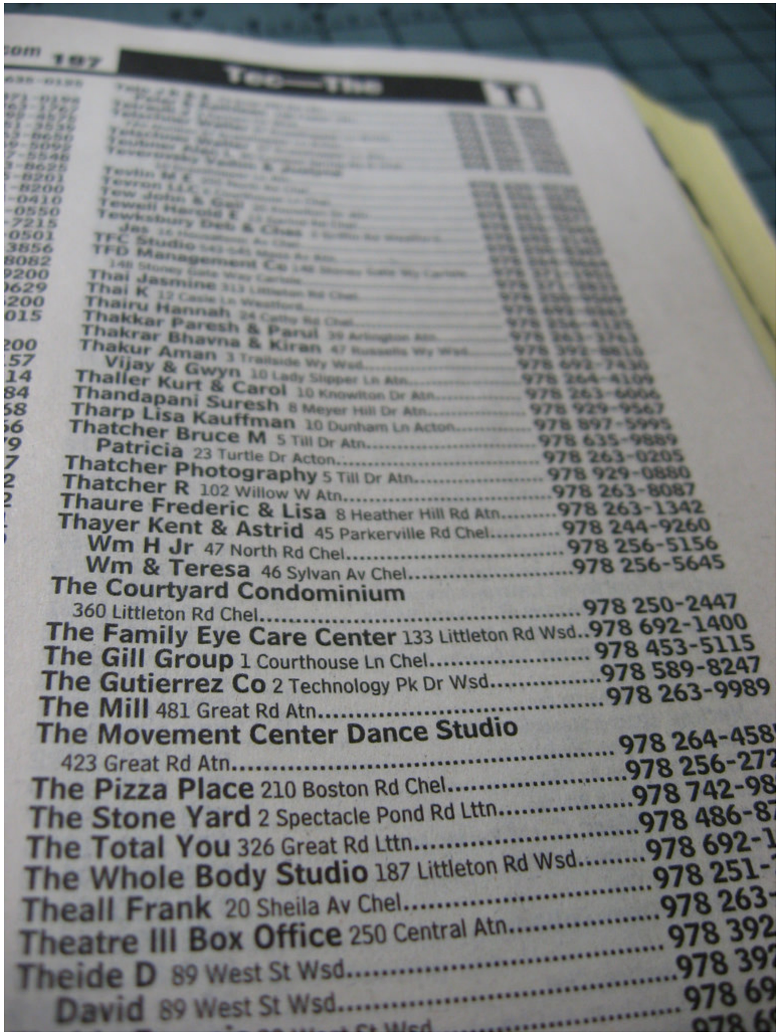
- `Hash(name)` = Phone number of person with that name



Security Mindset Anecdote

- Easy to compute forward (phonebook is alphabetical)

- Hard to invert backward (must search n/2 pages on average to find person by phone number)



S ... ote

Property 2: Collision Resistance

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

Birthday Paradox

- Expect birthday "collision" half the time with a room of only 23 people.
    - Approximate: 50% probability = 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? $\text{Choose}(t,2)=t(t-1)/2 \sim O(t^2)$
  - 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. $O(2^{160})$

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.

Properties of a Cryptographic Hash Function

- One-wayness
  - Given h(x)…
- Collision resistance
  - Hard to find…
- Weak collision resistance
  - Hard to find…

Properties of a Cryptographic Hash Function

- One-wayness
  - Given h(x): hard to find x
- Collision resistance
  - Hard to find x ≠ x’ s.t. h(x) == h(x’)
- Weak collision resistance
  - Hard to find x ≠ x’ s.t. h(x) == h(x’) **for specific, random x**