CSE 127: Computer Security

Symmetric Cryptography

Deian Stefan

Some slides adopted from Nadia Heninger, Kirill Levchenko and Dan Boneh

Cryptography

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- Is:
  - A tremendous tool
  - The basis for many security mechanisms
- Is not:
  - The solution to all security problems
  - Reliable unless implemented and used properly

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  - Something you should try to invent yourself
  - Blockchain

How Does It Work?

- Goal: learn how to use cryptographic primitives correctly
  - We will treat them as a black box that mostly does what it says
- To learn what's inside black box take CSE 107
- Do not roll your own crypto*

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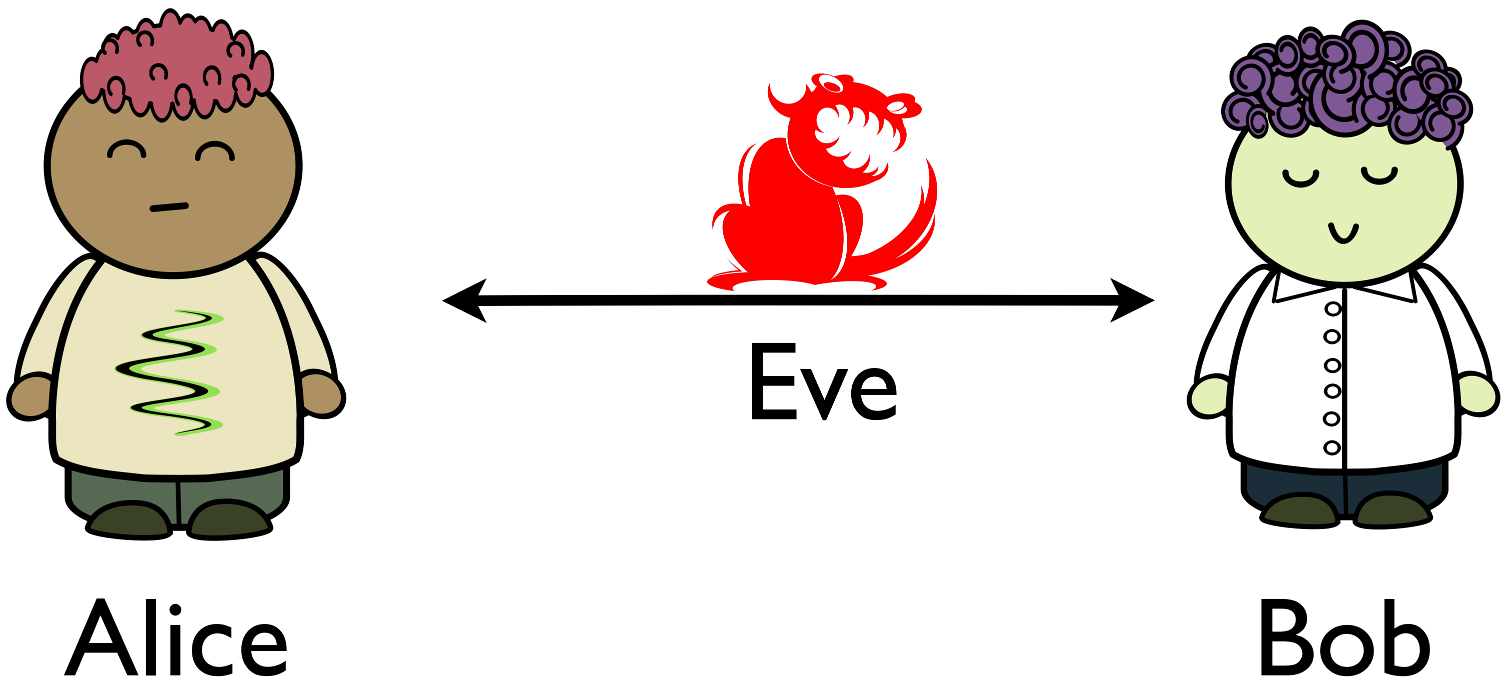
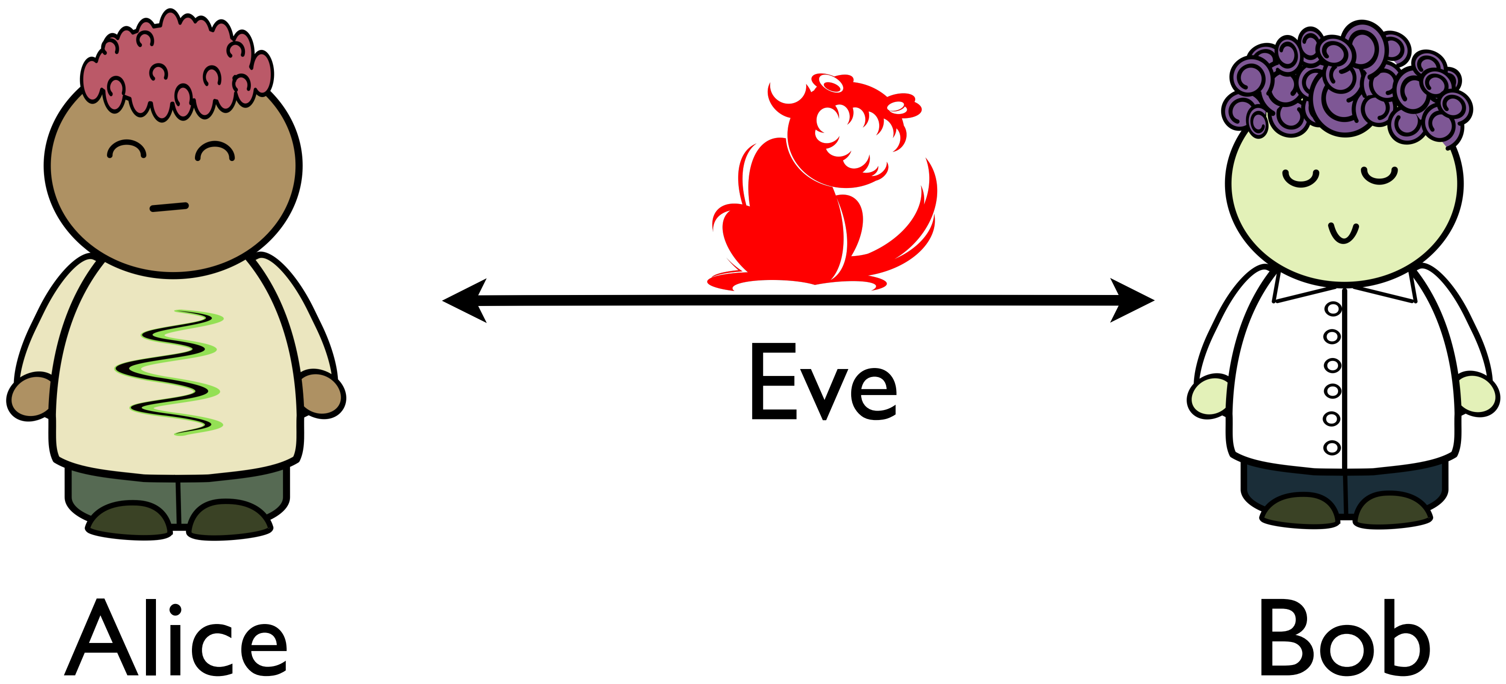
* Exceptions: You are Daniel J. Bernstein, Joan Daemen, Neal Koblitz, Dan Boneh, or similar, or you have finished your PhD in cryptography under an advisor of that caliber, and your work has been accepted at Crypto, Eurocrypt, Asiacrypt, FSE, or PKC and/or NIST is running another competition, and then wait several years for full standardization and community vetting.

This class: secure communication



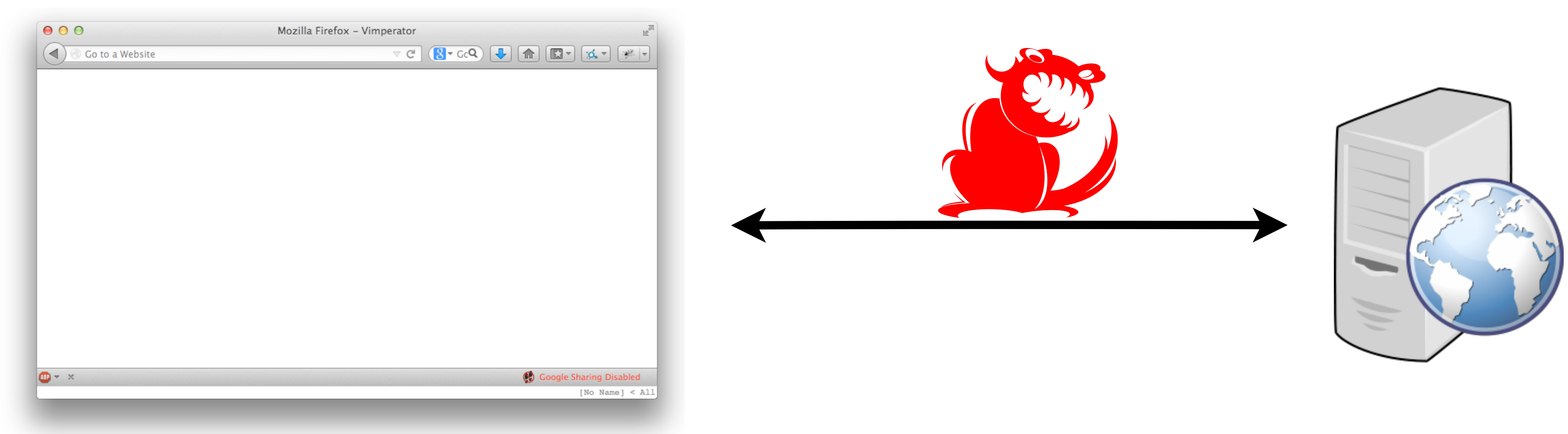
- Authenticity: Parties cannot be impersonated
- Secrecy: No one else can read messages
- Integrity: Messages cannot be modified

Attacker models



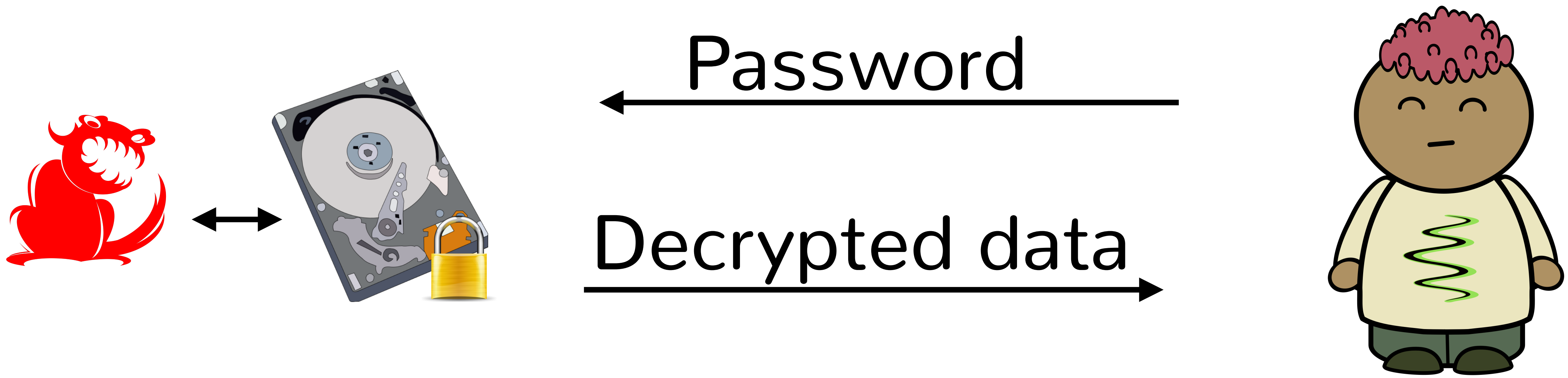
- Passive attacker: Eve only snoops on channel
- Active attacker: Eve can snoop, inject, block, tamper, etc.

Real-world crypto: SSL/TLS



1. **Browser and web server run "handshake protocol":**
   - Establishes shared secret key using public-key cryptography (next lecture)
2. **Browser and web server use negotiated key to symmetrically encrypt** data ("Record layer")

Real-world crypto: File encryption



- Files are symmetrically encrypted with a secret key
- The symmetric key is stored encrypted or in tamperproof hardware.
- The password is used to unlock the key so the data can be decrypted.

Outline

- Symmetric-key crypto
  - Symmetric encryption
  - Hash functions
  - Message authentication codes
- Next time: asymmetric (public-key) crypto
  - Key exchange
  - Digital signatures

Symmetric-key encryption

- **Encryption:** (key, plaintext) → ciphertext
  - $E_k(m) = c$
- **Decryption:** (key, ciphertext) → plaintext
  - $D_k(c) = m$
- Encryption and decryption are inverse operations
  - $D_k(E_k(m)) = m$

Symmetric-key encryption

- **One-time key:** used to encrypt one message
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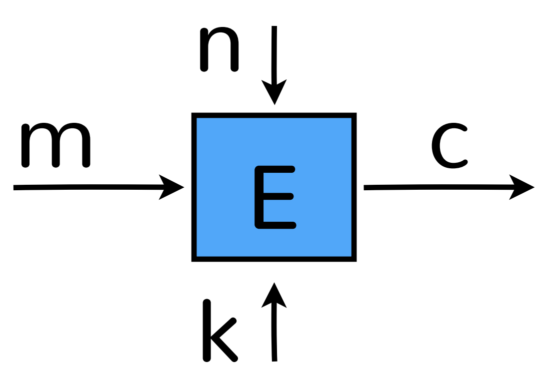
Symmetric-key encryption



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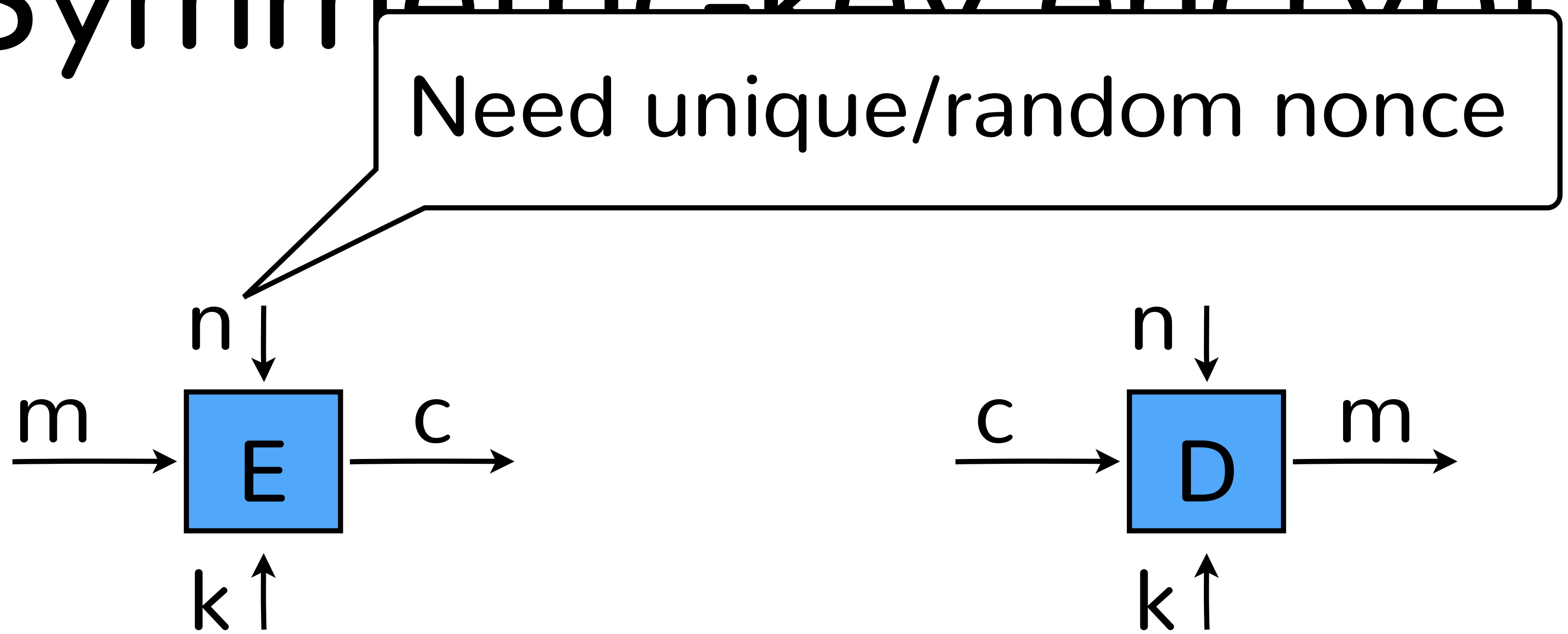

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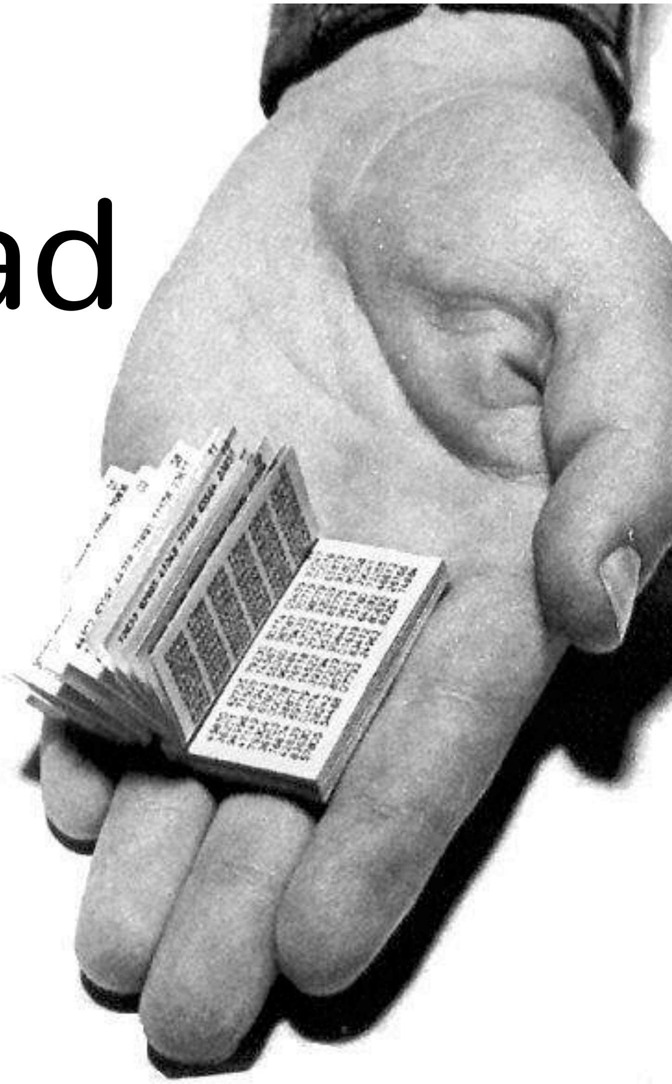
Security definition: Passive eavesdropper

- Simplest security definition
- Secrecy against a passive eavesdropper:
  - Ciphertext reveals nothing about plaintext
  - Informal formal definition: Given $E_k(m_1)$ and $E_k(m_2)$, can't distinguish which plaintext was encrypted without key

Example: One Time Pad



Vernam (1917)

Key:	0	1	0	1	1	1	0	0	1	0	$\oplus$
Plaintext:	1	1	0	0	0	1	1	0	0	0	
Ciphertext:	1	0	0	1	1	0	1	0	1	0	

- **Encryption:** $c = E_k(m) = m \oplus k$
- **Decryption:** $D_k(c) = \qquad =$

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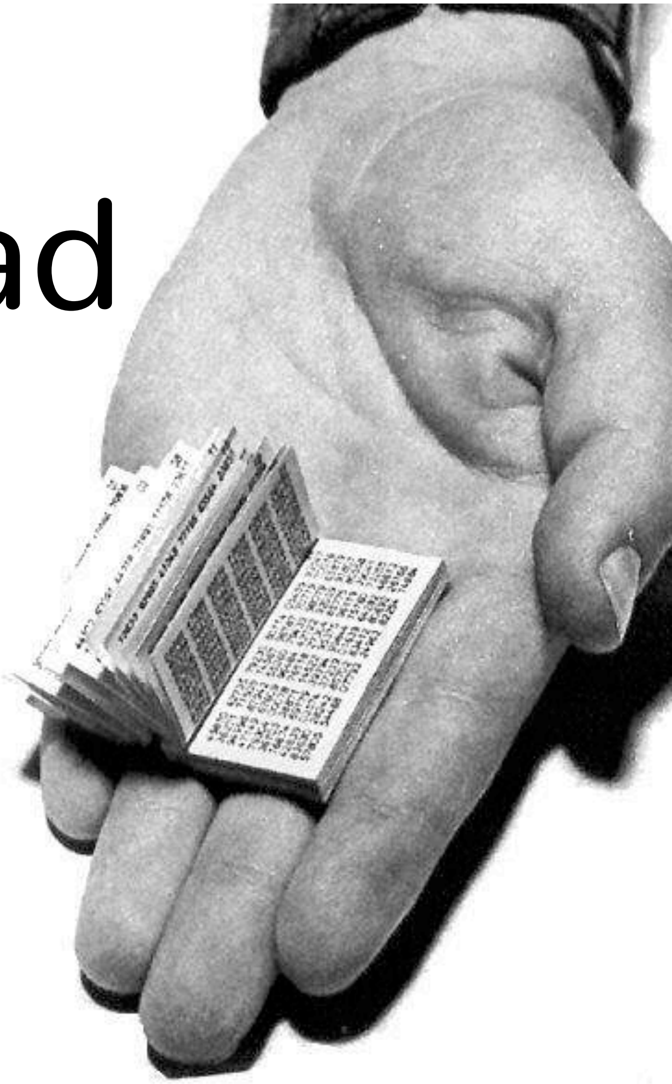

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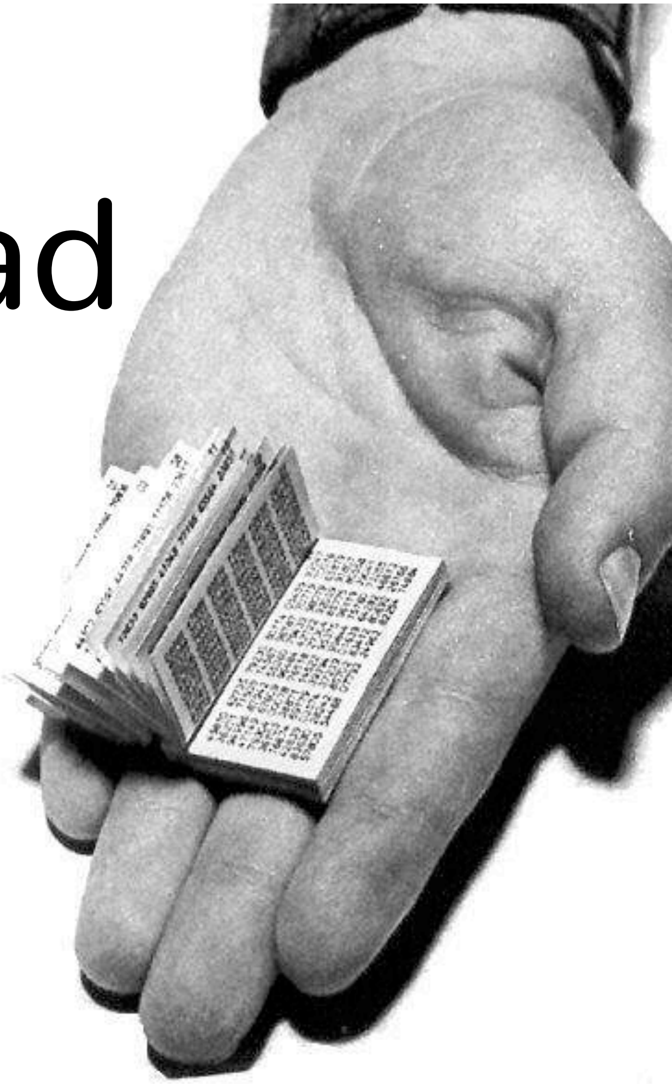

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- **Encryption:** $c = E_k(m) = m \oplus k$
- **Decryption:** $D_k(c) = c \oplus k = (m \oplus k) \oplus k = m$

OTP security

- Shannon (1949)
  - Information-theoretic security: without key, ciphertext reveals no "information" about plaintext
- Problems with OTP

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  - Information-theoretic security: without key, ciphertext reveals no “information” about plaintext
- Problems with OTP
  - Can only use key once
  - Key is as long as the message

Computational cryptography

- Want the size of the secret to be small
  - Theorem: If size of keyspace smaller than size of message space, information-theoretic security is impossible.
- Solution: Weaken security requirement
  - It should be infeasible for a computationally bounded attacker to violate security

Stream ciphers

- Problem: OTP key is as long as message
- Solution: Pseudo random key

key

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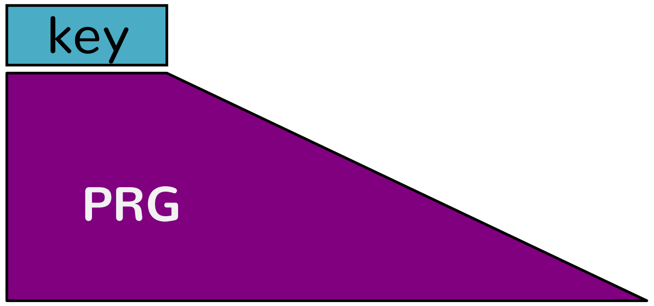
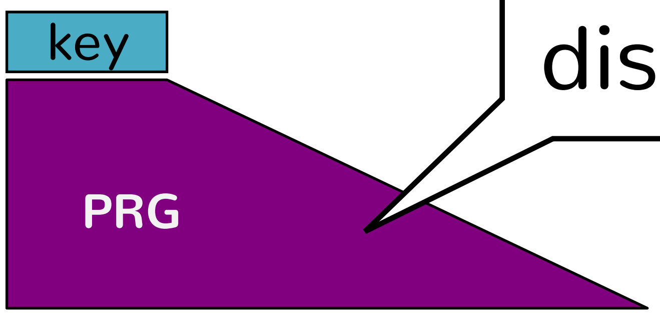


Stream ciphers

- Problem: OTP key is as long as message
- Solution: Pseudo random key

Computationally hard to distinguish from random



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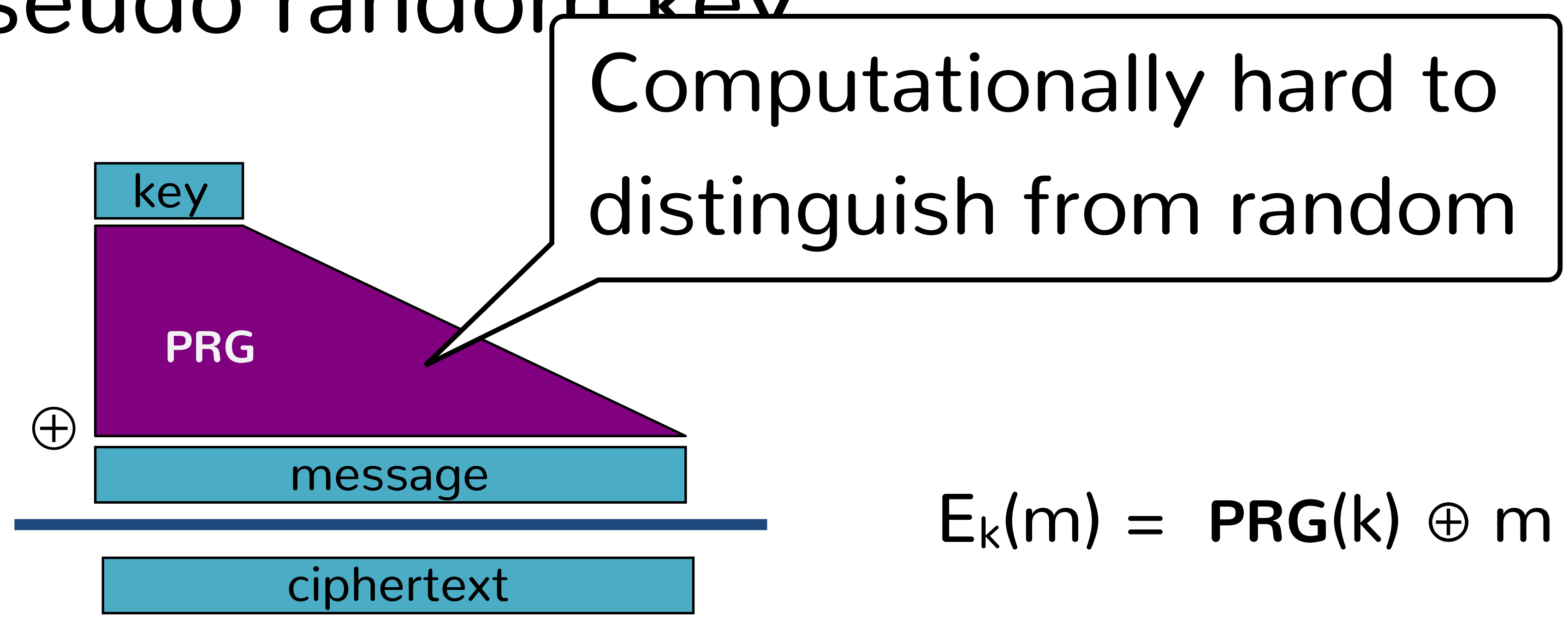

$E_k(m) = \textbf{PRG}(k) \oplus m$

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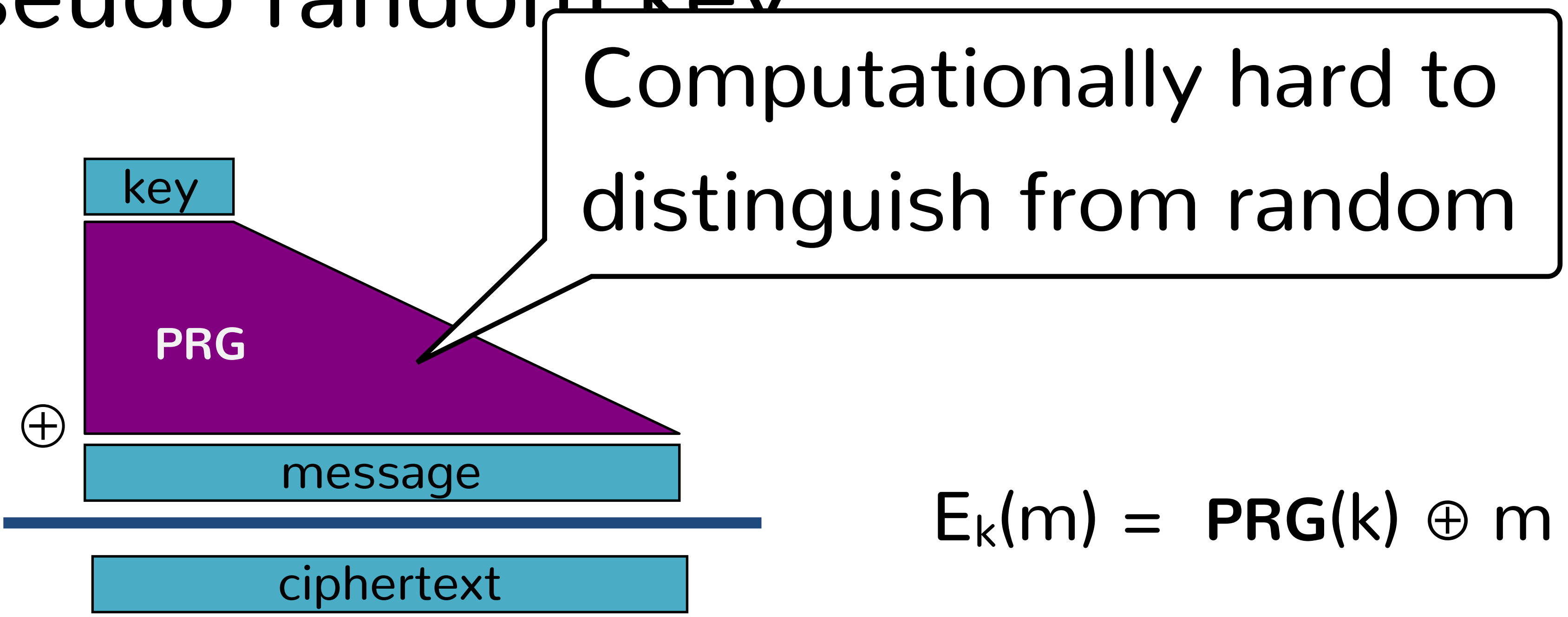

$E_k(m) = \mathbf{PRG}(k) \oplus m$

➤ Examples: ChaCha, Salsa, etc.

Dangers in using stream ciphers

- Can we use a key more than once?
  - E.g., $c_1 \leftarrow m_1 \oplus PRG(k)$

    $c_2 \leftarrow m_2 \oplus PRG(k)$
  - Yes? No?

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    $c_2 \leftarrow m_2 \oplus \mathrm{PRG}(k)$
  - Yes? No?
  - Eavesdropper does: $c_1 \oplus c_2 \rightarrow m_1 \oplus m_2$
  - Enough redundant information in English that:
    $m_1 \oplus m_2 \rightarrow m_1 , m_2$

Security definition: Chosen plaintext attacks

- **Threat model:** Attacker can learn encryptions for arbitrary plaintexts.
- Historical example:
  - During WWII the US Navy sent messages about Midway Island and watched Japanese ciphertexts to learn codename.
- Modern example:
  - WEP WiFi encryption has poor randomization and can result in the same stream cipher used multiple times: This is how Aircrack works.

Block ciphers: crypto work horses

- Block ciphers operate on fixed-size blocks
  - E.g., 3DES: |m| = |c| = 64 bits, |k| = 168 bits
  - E.g., AES: |m| = |c| = 128 bits, |k| = 128, 192, 256
- A block cipher = permutation of fixed-size inputs
  - Each input mapped to exactly one output

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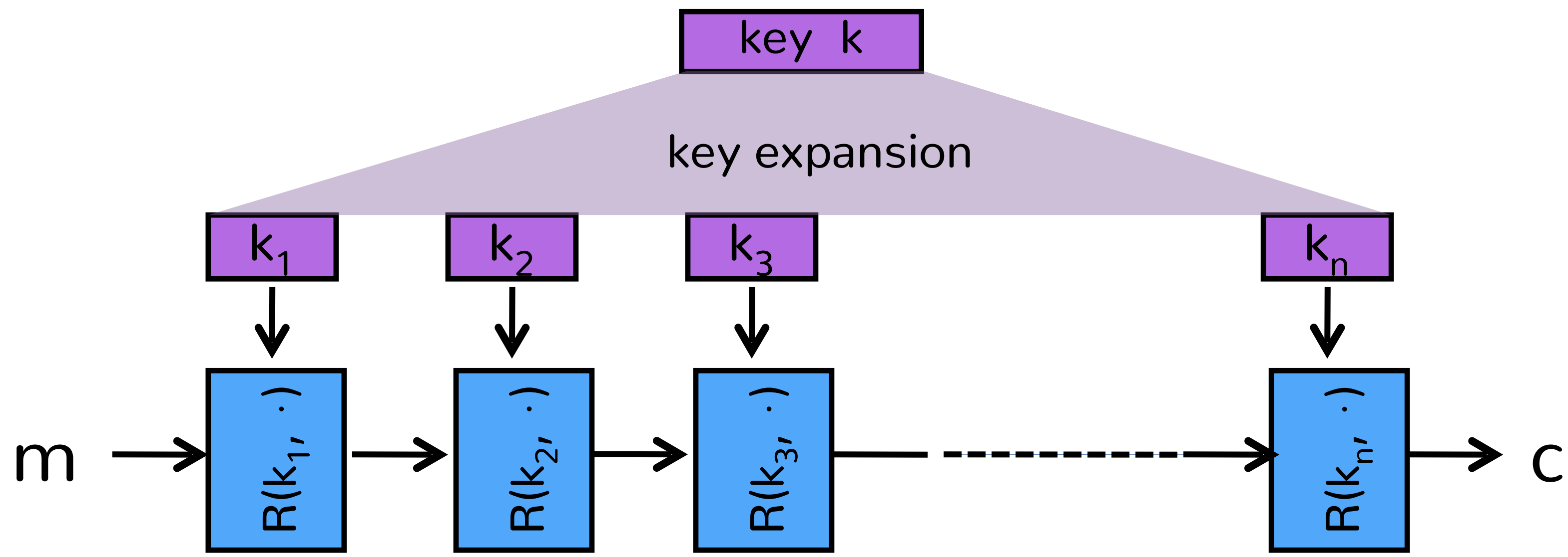
Correct block cipher choice: AES

What's inside the box?



R(k,m): round function
for AES-128 (n=10)

What’s inside the box?

Challenges with block ciphers

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- Block ciphers operate on single fixed-size block
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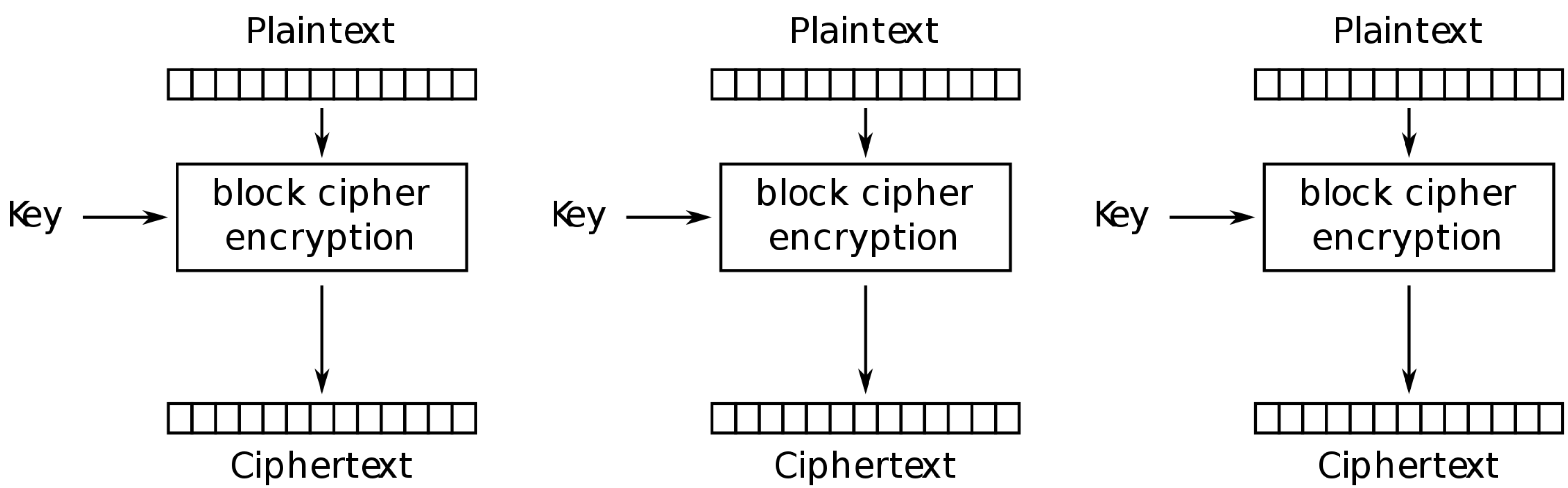
- Block ciphers operate on single fixed-size block
- How do we encrypt longer messages?
  - Several modes of operation for longer messages
- How do we deal with messages that are not block-aligned?
  - Must pad messages in a distinguishable way

Insecure block cipher usage: ECB mode



Electronic Codebook (ECB) mode encryption

Source: wikipedia

Why is ECB so bad?

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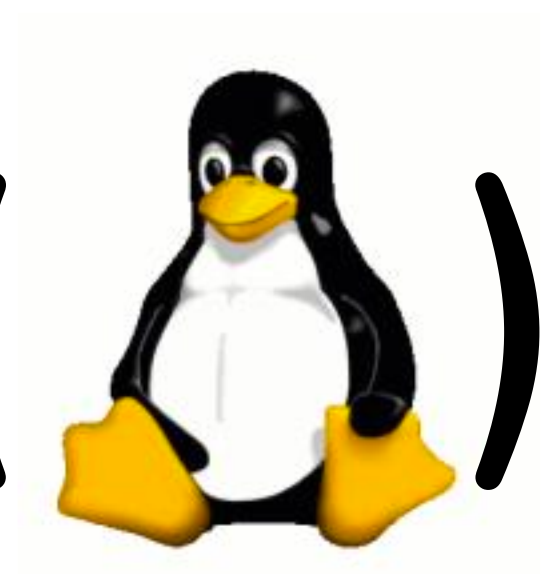
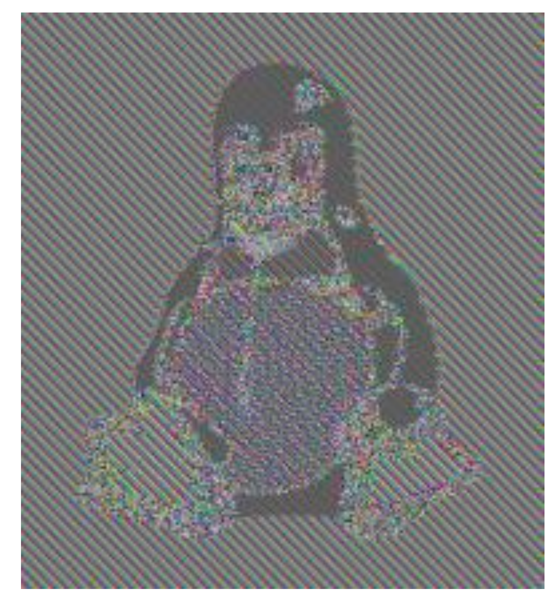
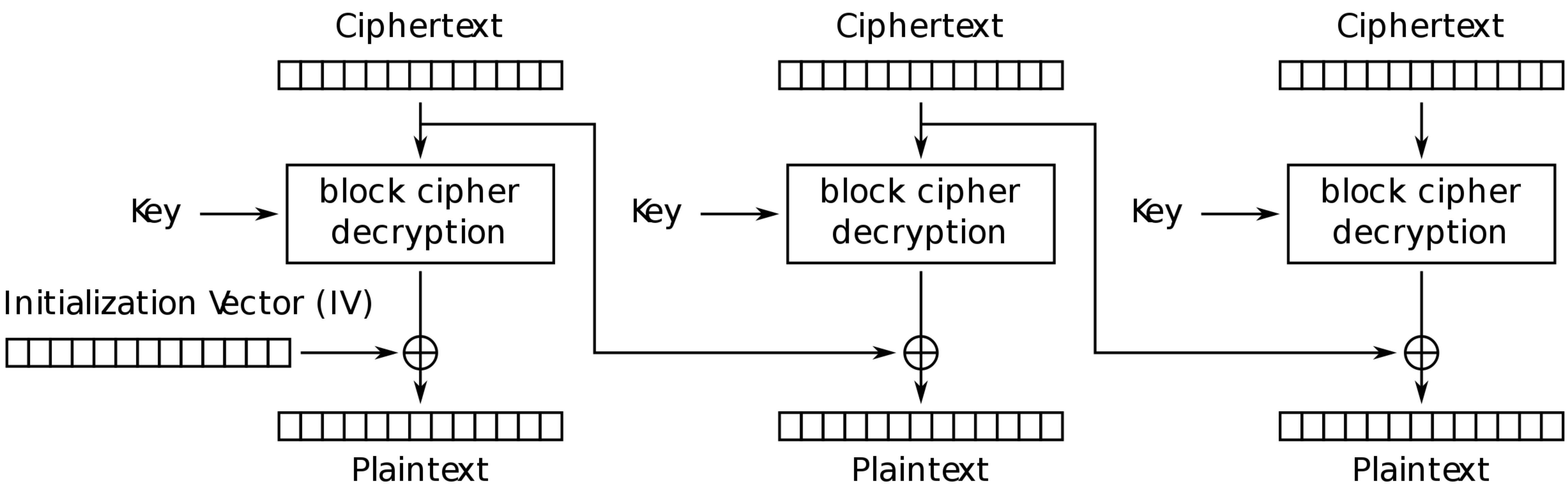
Why is ECB so bad?

$E_k($  $) =$ 

Source: wikipedia

Moderately secure usage:

CBC mode with random IV



Cipher Block Chaining (CBC) mode decryption

Source: wikipedia

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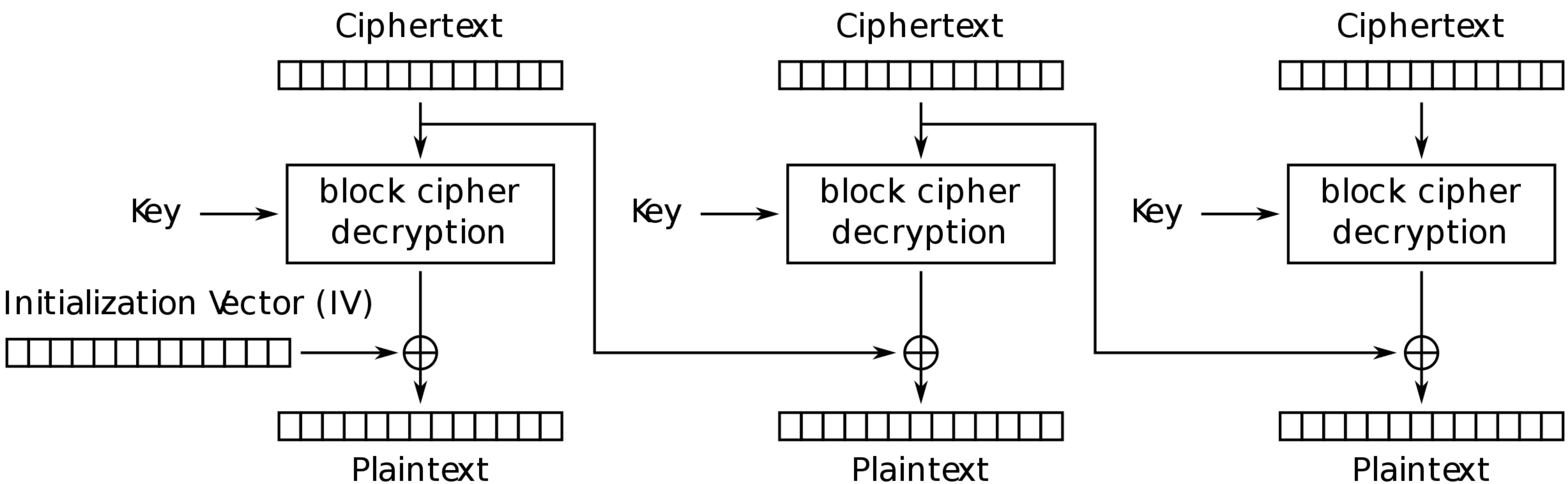
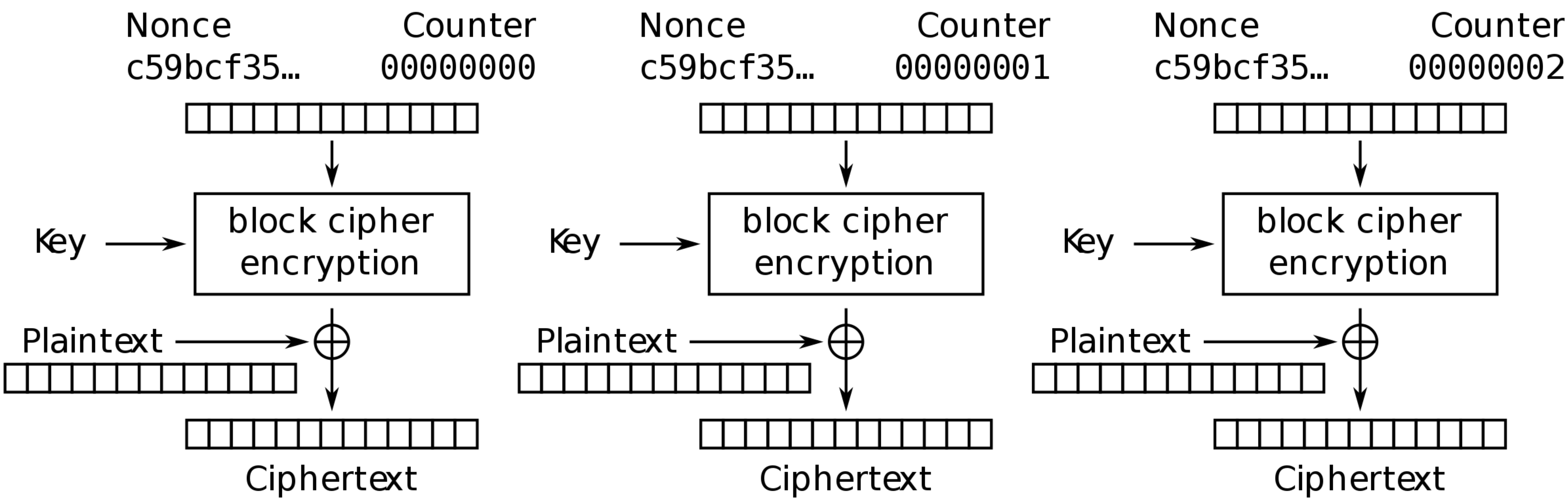


Cipher Block Chaining (CBC) mode decryption

Subtle attacks that abuse padding possible!

Source: wikipedia

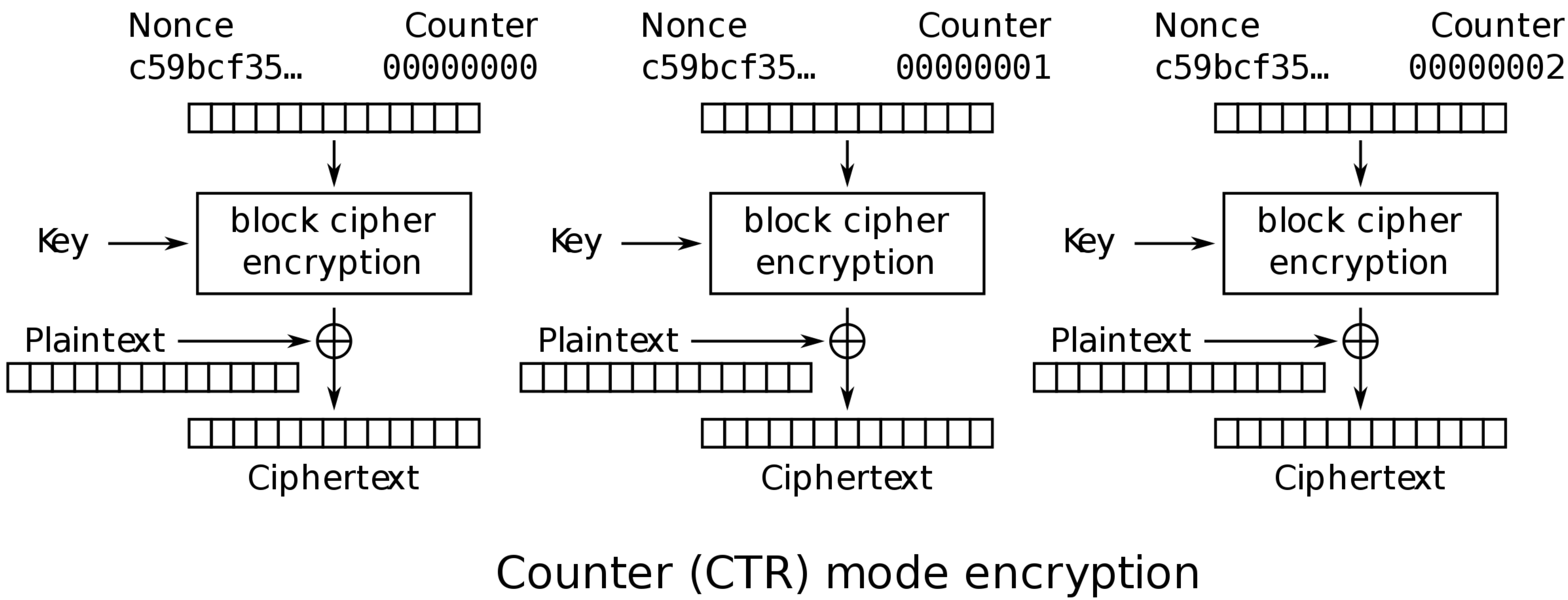
Better block cipher usage: CTR mode with random IV



Counter (CTR) mode encryption

Source: wikipedia

Better block cipher usage:
CTR mode with random IV



Essentially use block cipher as stream cipher!

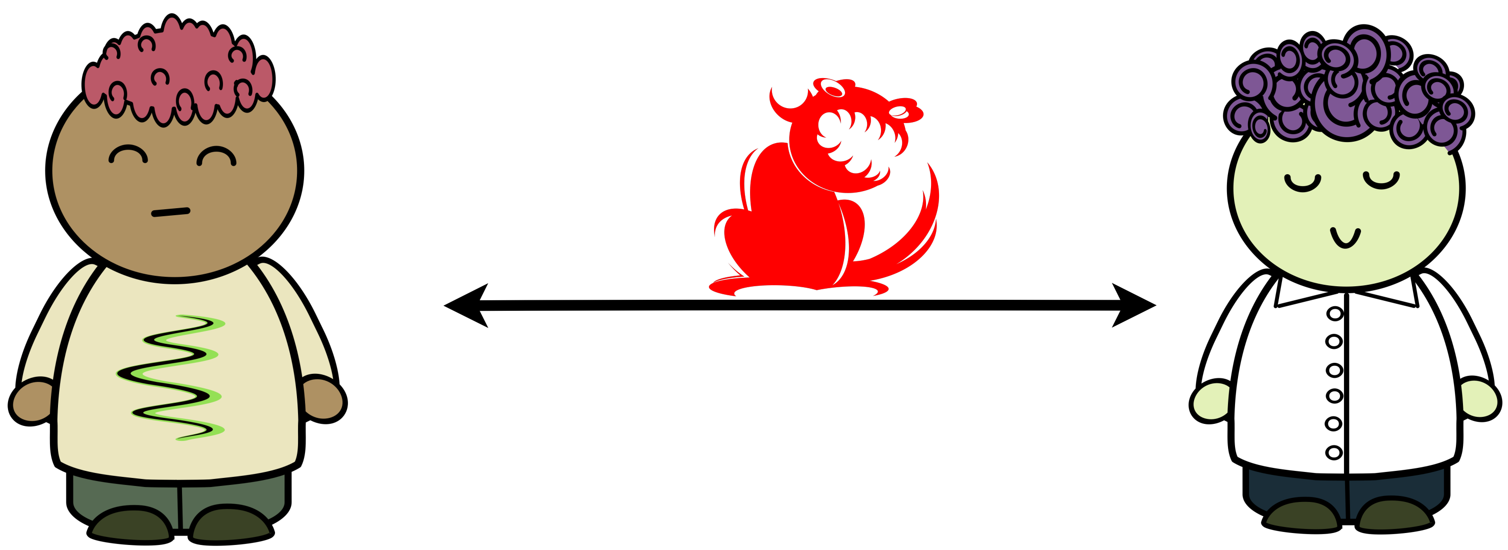
Source: wikipedia

What security do we actually get?

- All encryption breakable by brute force given enough knowledge about plaintext
  - Try to decrypt ciphertext with every possible key until a valid plaintext is found
- Attack complexity proportional to size of key space
  - 128-bit key requires 2^{128} decryption attempts

Security definition: Chosen ciphertext attacks

- What if Eve can alter the ciphertexts sent between Alice and Bob?



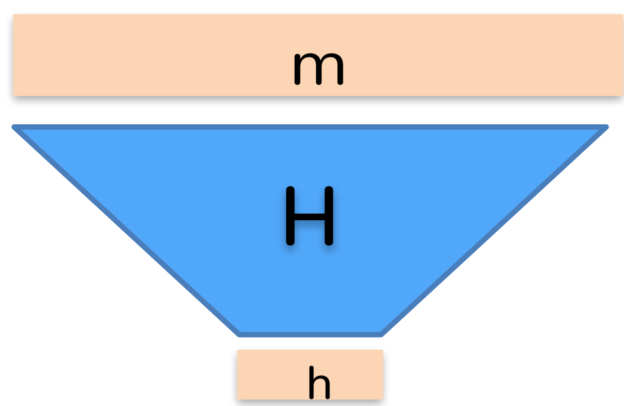
- Symmetric encryption alone is not enough to ensure security.
  - Need to protect integrity of ciphertexts (and thus underlying encrypted messages)

Outline

- Symmetric-key crypto
  - ➢ Encryption
  - ➢ Hash functions
  - ➢ Message authentication codes
- Asymmetric (public-key) crypto
  - ➢ Key exchange
  - ➢ Digital signatures

Hash Functions

- A (cryptographic) hash function maps arbitrary length input into a fixed-size string



$h=H(m)$

  - $|m|$ is arbitrarily large
  - $|h|$ is fixed, usually 128-512 bits

Hash Function Properties

- Finding a preimage is hard
  - Given h, find m such that H(m)=h
- Finding a collision is hard
  - Find m_1 and m_2 such that $H(m_1)=H(m_2)$

Hash function bit security

- A 128-bit output hash function only has 64 bits of security

Hash function bit security

- A 128-bit output hash function only has 64 bits of security
  - It takes 2^{64} time to find a collision
  - Why? Birthday bound

Real-world crypto: Hash functions

- Versioning systems (e.g., git)
  - Better than _1, _final, _really_final
- Sub-resource integrity
  - Integrity of files you include from CDN
- File download integrity
  - Make sure the thing you download is the thing you thought you were downloading

blob: 41732ca416bc88034636778b4a76fa0ea03c4ebc (plain)

```
# Maintainer: Deian Stefan

pkgname=xwrits
pkgver=2.26
pkgrel=1
pkgdesc="reminds you to take wrist breaks "
arch=('any')
url="http://www.lcdf.org/xwrits/"
license=('GPLv2')
depends=()
makedepends=()
conflicts=()
source=("http://www.lcdf.org/xwrits/$pkgname-$pkgver.tar.gz")
sha256sums=('aaca4809b4cd62a627335ca14a231d4ab556fc872458bdb6fdbf6e76b103fed8')
sha512sums=('c8beeca957e41468d85819a7d6d4475c83a99735ff17d13d724658a421d1d3b9a15191ee8ab903104ab19b869a4832103dbe7d3ec2a9bf89ae95a7899e92f927')

build() {
  cd "$pkgname-$pkgver"
  ./configure --prefix=/usr
  make
}

check() {
  cd "$pkgname-$pkgver"
  make -k check
}

package() {
  cd "$pkgname-$pkgver"
  make DESTDIR="$pkgdir/" install
}
```

Hash Functions

- MD5: Message Digest
  - Designed by Ron Rivest
  - Very popular hash function
  - Output: 128 bits
  - Broken — **do not use!**

Hash Functions

- SHA-1: Secure Hash Algorithm 1
  - Designed by NSA
  - Output: 160 bits
  - Broken — **do not use!**
- SHA-2: Secure Hash Algorithm 2
  - Designed by NSA
  - Output: 224, 256, 384, or 512 bits
  - Recommended for use today

Hash Functions

- SHA-3: Secure Hash Algorithm 3
  - Result of NIST SHA-3 contest
  - Output: arbitrary size
  - Replacement once SHA-2 broken

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  - Symmetric Encryption
  - Hash functions
  - Message authentication code
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  - Key exchange
  - Digital signatures

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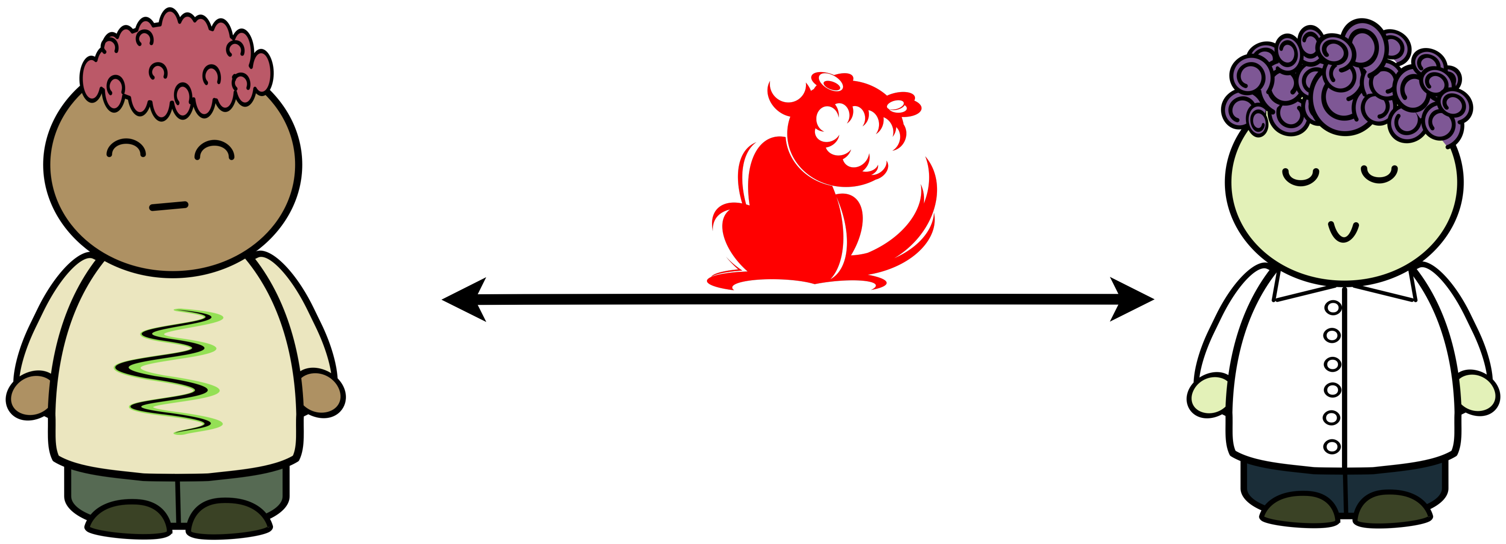

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MACs

- Validate message integrity based on shared secret
- MAC: Message Authentication Code
  - Keyed function using shared secret
  - Hard to compute function without knowing key

$$a = MAC_k(m)$$

MAC constructions

- HMAC: MAC based on hash function

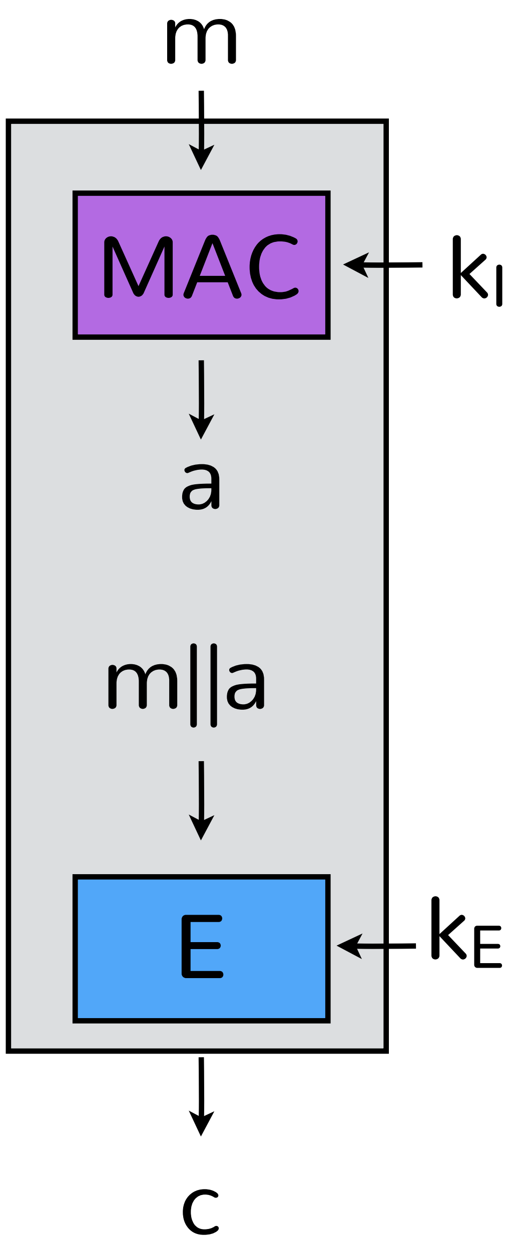
  $MAC_k(m) = H(\ k \oplus opad \ \| \ H(\ k \oplus ipad \ \| \ m\ )\ )$

  - HMAC-SHA256: HMAC construction using SHA-256
  - A perfectly fine modern choice.

Combining MAC with encryption

MAC then Encrypt (SSL)

- Integrity for plaintext not ciphertext
- Issue: need to decrypt before you can verify integrity
- Hard to get right!



Combining MAC with encryption

Encrypt and MAC (SSH)

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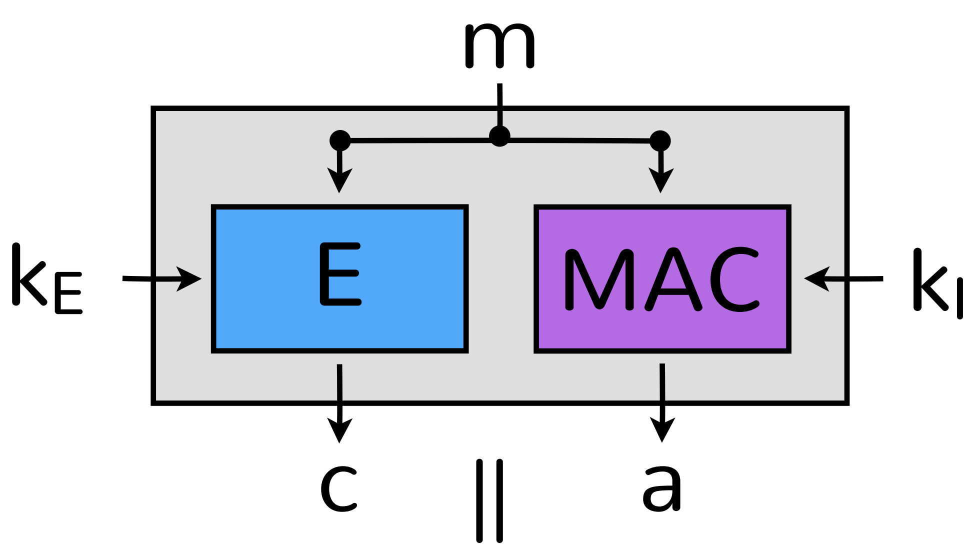
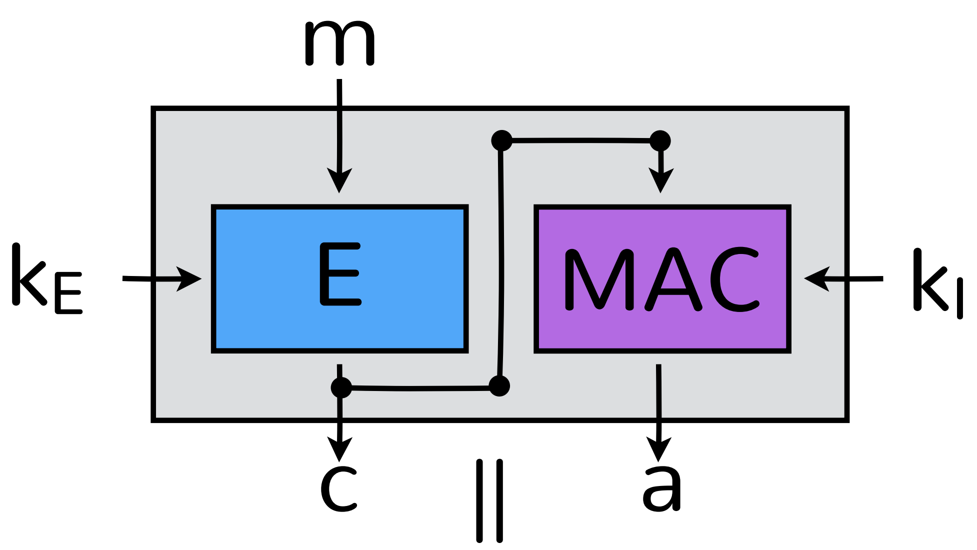


Combining MAC with encryption

Encrypt then MAC (IPSec)

- Integrity for plaintext and ciphertext
- Almost always right!



Correct encryption solution: Use AEAD construction

- Authenticated Encryption with Associated Data
    - AES-GCM, AES-GCM-SIV
- Always use an authenticated encryption mode
    - Combines mode of operation with integrity protection/MAC in the right way

This is default in good libraries

Libsodium documentation | GitHub repository | Download | Quickstart | Libhydrogen | Search...

Authenticated encryption

Example

```
#define MESSAGE ((const unsigned char *) "test")
#define MESSAGE_LEN 4
#define CIPHERTEXT_LEN (crypto_secretbox_MACBYTES + MESSAGE_LEN)

unsigned char key[crypto_secretbox_KEYBYTES];
unsigned char nonce[crypto_secretbox_NONCEBYTES];
unsigned char ciphertext[CIPHERTEXT_LEN];

crypto_secretbox_keygen(key);
randombytes_buf(nonce, sizeof nonce);
crypto_secretbox_easy(ciphertext, MESSAGE, MESSAGE_LEN, nonce, key);

unsigned char decrypted[MESSAGE_LEN];
if (crypto_secretbox_open_easy(decrypted, ciphertext, CIPHERTEXT_LEN, nonce, key) != 0)
    /* message forged! */
}
```