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CSCI 445:
Mobile Application Security

Lecture 3

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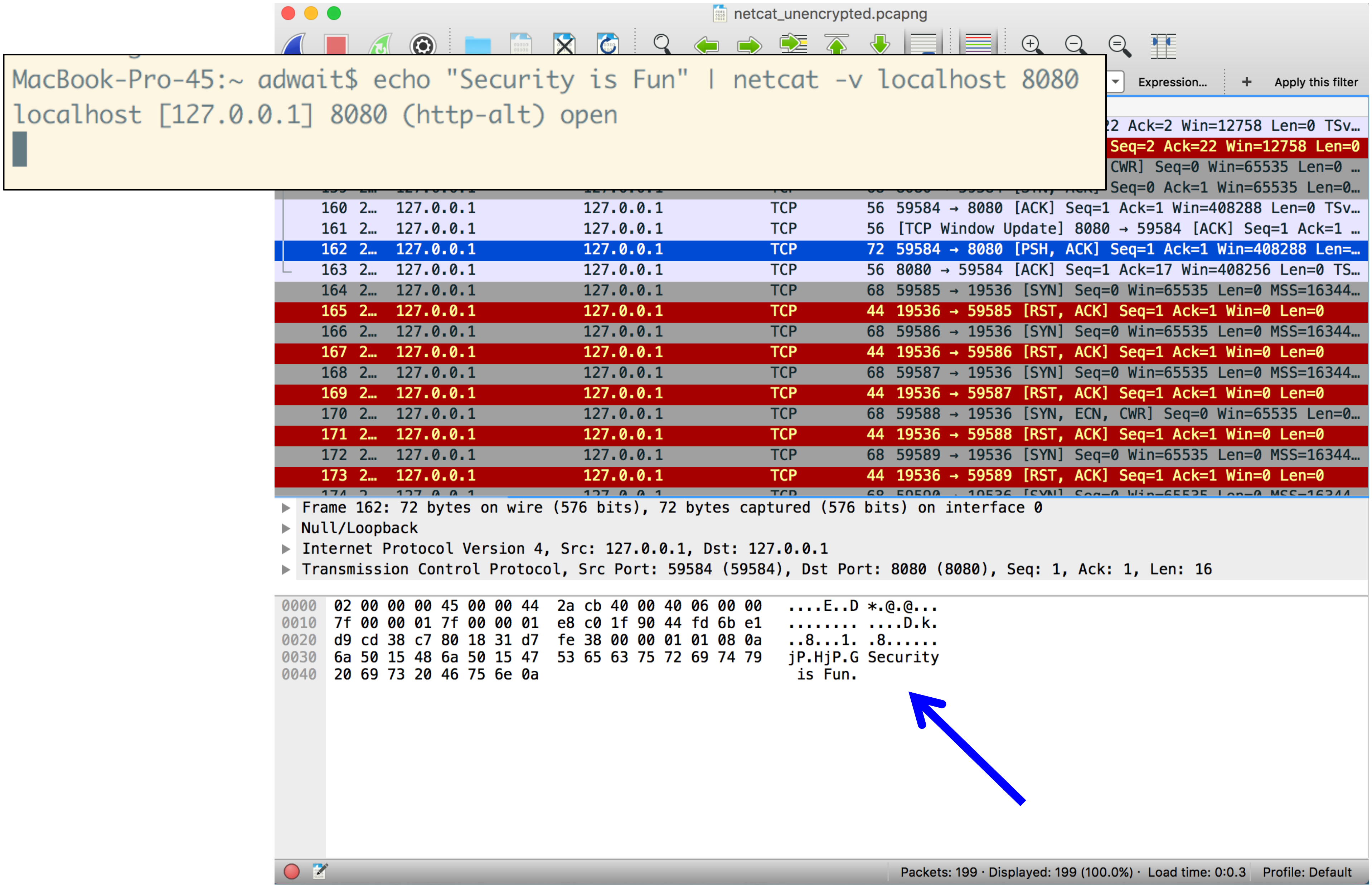
Derived from slides by William Enck, Micah Sherr and Patrick McDaniel

Cryptography

Crypto in Apps

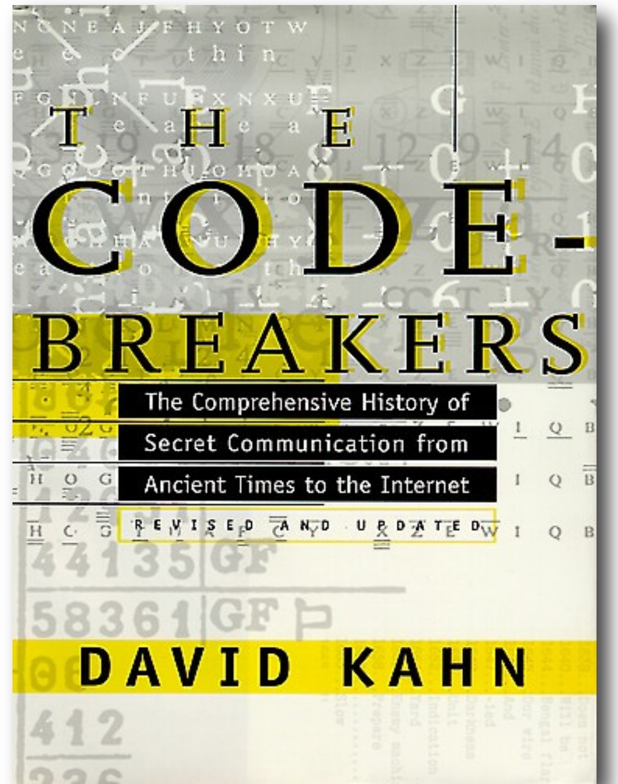
- Networks designed for data transport, *not for data confidentiality or privacy*
  - Internet eavesdropping is (relatively) easy
- Sensitive data is often stored locally on the device.
  - Other apps/root can get to it.
- Crypto enables:
  - e-commerce and e-banking
  - confidential messaging
  - digital identities
  - protection of personal data
  - ...

Why is crypto useful?



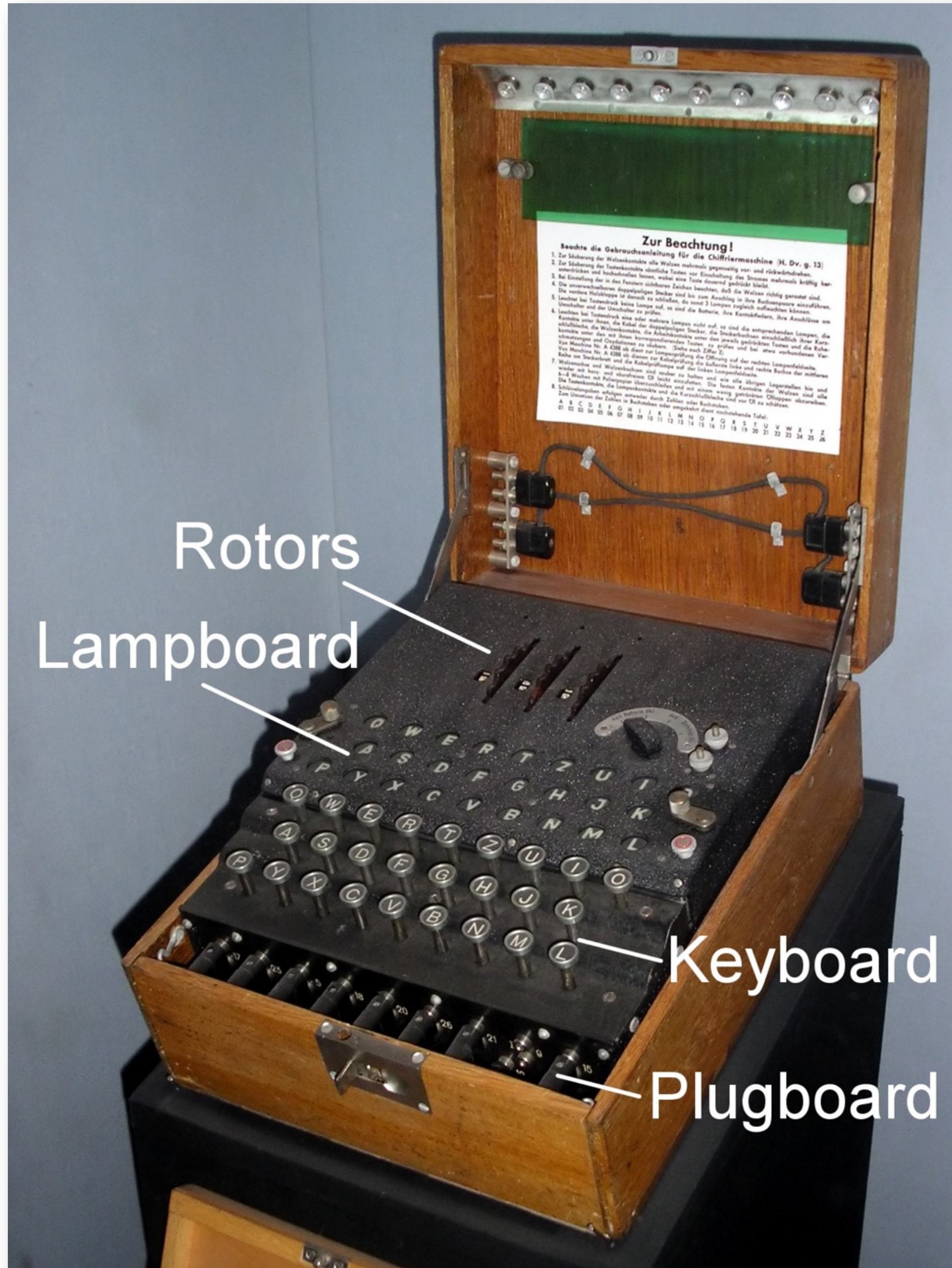
Cryptographic History

- hide secrets from your enemy
- ~4000 year old discipline
  - Egyptians' use of non-standard hieroglyphics
  - Spartans used *scytale* to perform transposition cipher
  - Italian Leon Battista Alberti ("father of western cryptography") invents polyalphabetic ciphers in 1466



Enigma

- German WWII encryption device
- Used polyalphabetic substitution cipher
- Broken by Allied forces
- Intelligence called Ultra
- Codebreaking at Bletchley Park
- See original at the International Spy Museum (bring your wallet)



Some terminology

- **cryptosystem**: method of disguising (encrypting) plaintext messages so that only select parties can decipher (decrypt) the ciphertext
- **cryptography**: the art/science of developing and using cryptosystems
- **cryptanalysis**: the art/science of breaking cryptosystems
- **cryptology**: the combined study of cryptography and cryptanalysis

What can crypto do?

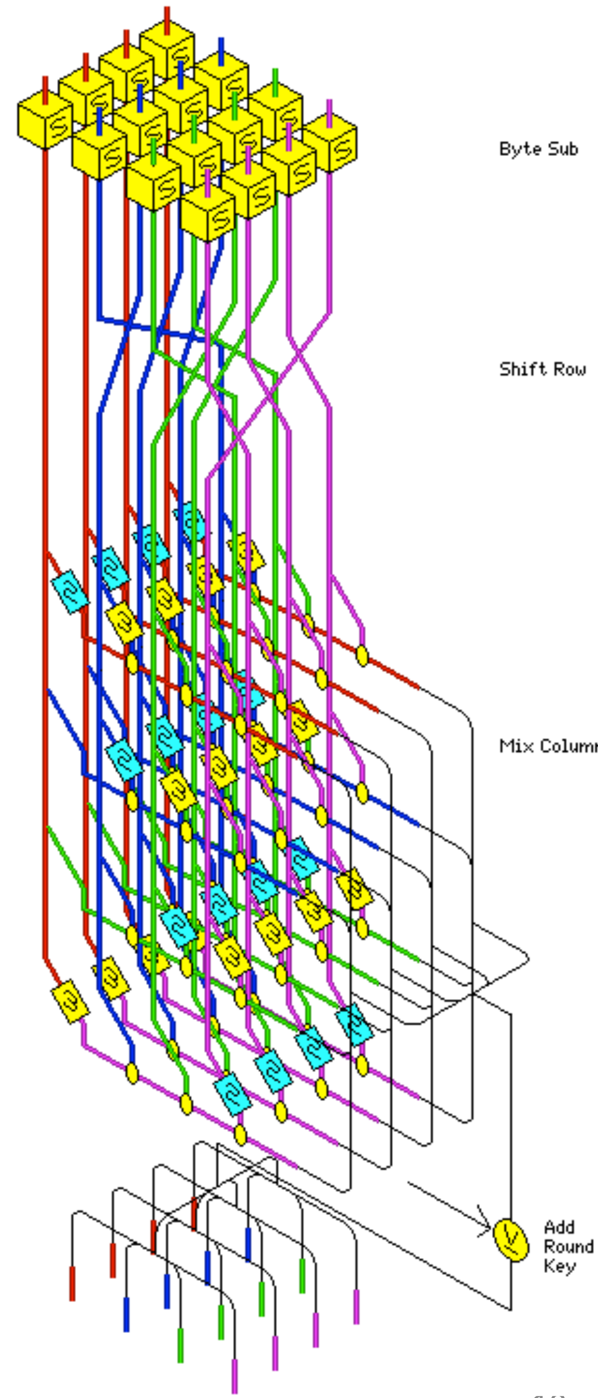
- **Confidentiality**
  - Keep data and communication secret
  - Encryption / decryption
- **Integrity**
  - Protect reliability of data against tampering
  - "Was this the original message that was sent?"
- **Authenticity**
  - Provide evidence that data/messages are from their purported originators
  - "Did Alice really send this message?"

cryptography < security

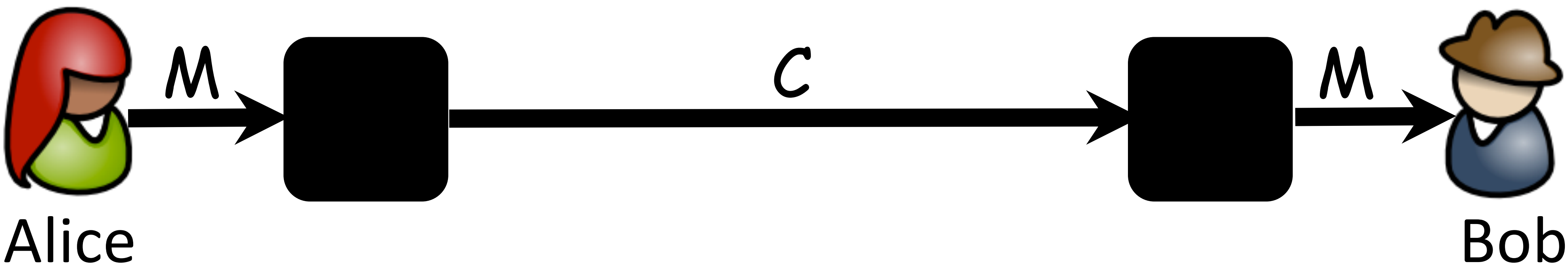
- Cryptography isn't the solution to security
  - Buffer overflows, worms, viruses, trojan horses, SQL injection attacks, cross-site scripting, bad programming practices, etc.
- It's a tool, not a solution
- **It is difficult to get right: Lost of choices**
  - Choice of encryption algorithms (many tradeoffs)
  - Choice of parameters (key size, IV, ...)
  - Implementation (std. libraries work in most cases)
  - Hard to detect errors
    - Even when crypto fails, the program may still work
    - May not learn about crypto problems until after they've been exploited

Crypto is really, really, really, really, hard

- Task: develop a cryptosystem that is secure against all conceivable (and inconceivable) attacks, and will be for the foreseeable future
- If you are inventing your own crypto, you're doing it wrong
- Common security idiom: "no one ever got fired for using AES"



Encryption and Decryption



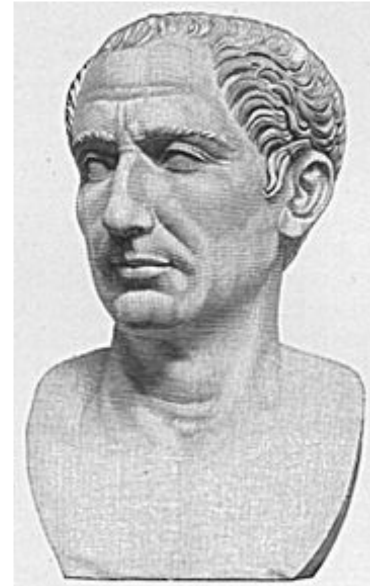
C=E(M)
M=D(C)
i.e.,
M=D(E(M))

where

M = plaintext
C = ciphertext
E(x) = encryption function
D(y) = decryption function

Let’s look at some old crypto algos (don’t use these)

Caesar Cipher



- A.K.A. Shift Cipher or ROT-x cipher (e.g., ROT-13)
- Used by Julius to communicate with his generals
- x is the key:
- Encryption: Right-shift every character by x: c = E(x, p) = (p + x) mod 26
- Decryption: Left-shift every character by x: p = D(x, c) = (c – x) mod 26

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C

S E C U R I T Y A N D P R I V A C Y

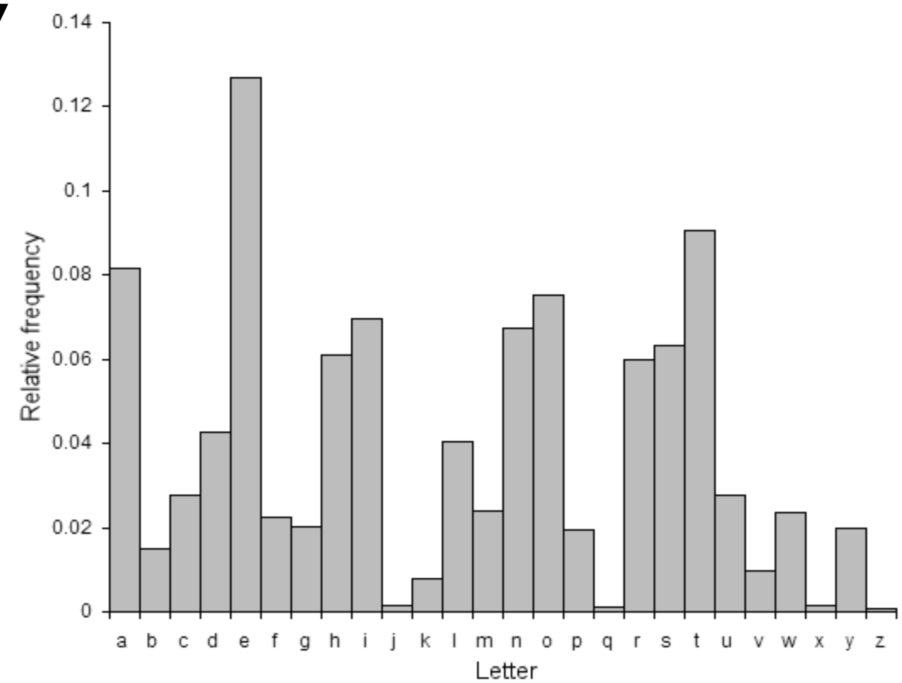
V H F X U L W B D Q G S U L Y D F B

Cryptanalyze this …

"GUVF VF N TERNG PYNFF"

Cryptanalyzing the Caesar Cipher

- Cryptanalysis:
  - **Brute-force attack:** try all 26 possible shifts (i.e., values of x)
  - **Frequency analysis:** look for frequencies of characters
  - Also, same plaintext (repetitions) *always* leads to same ciphertext, since *monoalphabetic*



Polyaphebetic Cipher

- Improves on the simple monoalphabetic ciphers by using multiple monoalphabetic subsitutions
- Example: Vigenère Cipher
  - A set of Caesar Ciphers where each cipher is denoted by a key letter that designates the shift
  - The key repeats for the length of the message

key: deceptivedeceptivedeceptive
plaintext: wearediscoveredsaveyourself
ciphertext: ZICVTWQNGRZGVTWAVZHCQYGLMGJ

One-time Pads

- To produce ciphertext, XOR the plaintext with the **one-time pad** (secret key)
  - $E(M) = M \oplus Pad$
  - $D(E(M)) = E(M) \oplus Pad$
- Requires sizeof(pad) == sizeof(plaintext)

- Offers **perfect secrecy**:
  - *a posteriori* probability of guessing plaintext given ciphertext equals the *a priori* probability
  - given a ciphertext without the pad, any plaintext of same length is possible input (there exists a corresponding pad)
  - $Pr[M=m|C=c] = Pr[M=m]$ (you learn nothing from the ciphertext)

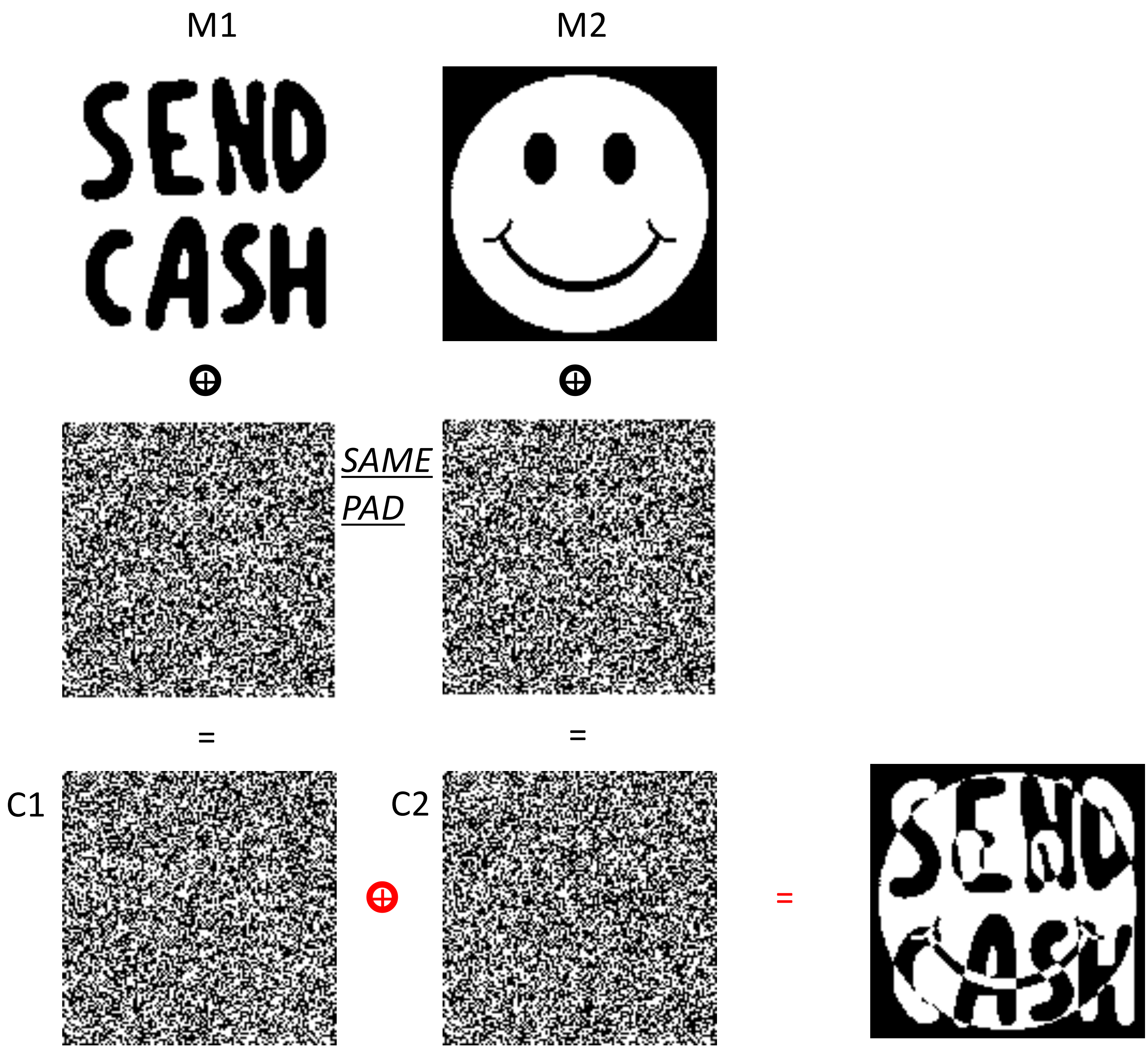
- **Never reuse the pad (hence "one-time")!** Why not?

XOR properties

- $A \oplus A = ?$
  - 0
- $A \oplus 0 = ?$
  - A

- $C1 = M1 \oplus Pad$, $C2 = M2 \oplus Pad$
- $C1 \oplus C2 = ?$

$M1 \oplus M2$!



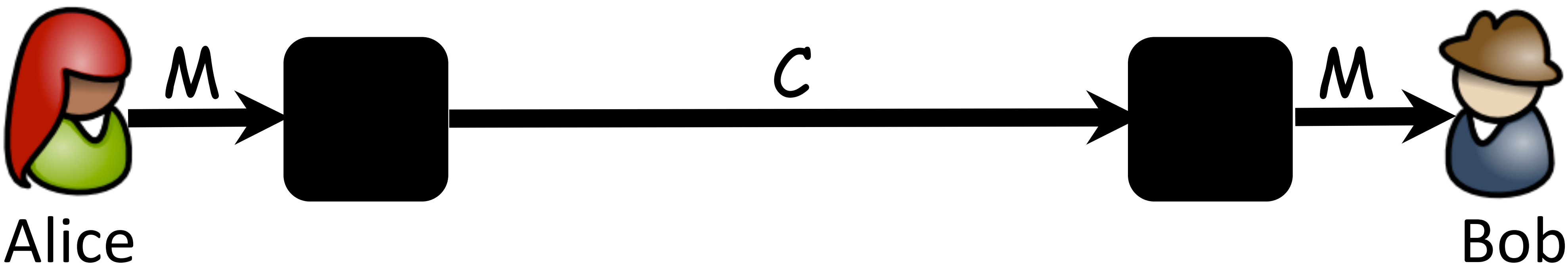
https://cryptosmith.com/2008/05/31/stream-reuse/

Modern Cryptography

Two flavors of confidentiality

- **Unconditional** or **probabilistic security**: cryptosystem offers provable guarantees, irrespective of computational abilities of an attacker
  - given ciphertext, the probabilities that bit i of the plaintext is 0 is p and the probability that it is 1 is (1-p)
  - e.g., one-time pad
  - often requires key sizes that are equal to size of plaintext
- **Conditional** or **computational security**: cryptosystem is secure assuming a computationally bounded adversary, or under certain hardness assumptions (e.g., P<>NP)
  - e.g., DES, 3DES, AES, RSA, DSA, ECC, DH, MD5, SHA
  - Key sizes are much smaller (~128 bits)
- Almost all deployed modern cryptosystems are conditionally secure

Recall: Encryption and Decryption



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Kerckhoffs' Principles

- Modern cryptosystems use a key to control encryption and decryption
- Ciphertext should be undecipherable without the correct key
- Encryption key may be different from decryption key.
- **Kerckhoffs' principles** [1883]:
  - Assume Eve knows cipher algorithm
  - Security should rely on choice of key
  - If Eve discovers the key, a new key can be chosen

Kerckhoffs' Principles

- Kerckhoffs' Principles are contrary to the principle of "**security by obscurity**", which relies only upon the secrecy of the algorithm/cryptosystem
  - If security of a keyless algorithm compromised, cryptosystem becomes permanently useless (and unfixable)
  - Algorithms relatively easy to reverse engineer

Key Sizes

- Original DES used 56-bit keys
- 3DES uses 168-bit keys
- AES uses 128-, 192- or 256-bit keys
- Are these numbers big enough?
  - DES has 2^{56} = 72,057,594,037,927,936 possible keys
    - In Feb 1998, distributed.net cracked DES in 41 days
    - In July 1998, the Electronic Frontier Foundation (EFF) and distributed.net cracked DES in 56 hours using a $250K machine
    - In Jan 1999, the team did in less than 24 hours
  - **Each additional bit adds 2X brute-force work factor (exponential security for linear keysize increase)**
  - There are approximately 2^{250} atoms in the universe, so don't expect 256-bit keys to be brute forced anytime in the next trillion years.
- Takeaway: 128-keys are reasonably secure

$$2^{256} =$$

115,792,089,237,316,195,
423,570,985,008,687,907,
853,269,984,665,640,564,
039,457,584,007,913,129,
639,936

Cryptanalysis

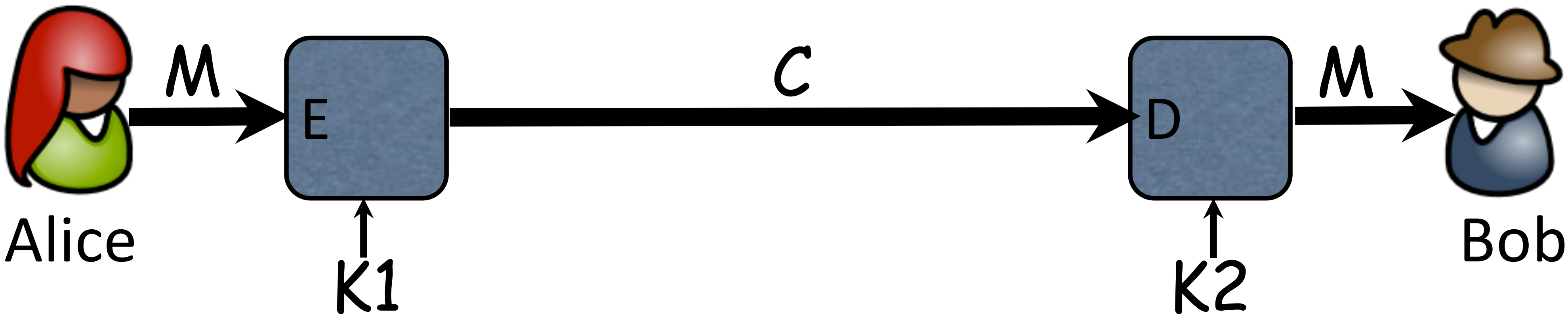
- Goal: learn the key
- Classifications:
  - **ciphertext-only** attack: Eve has access only to ciphertext
  - **known-plaintext** attack: Eve has access to plaintext and corresponding ciphertext
  - **chosen-plaintext** attack: Eve can choose plaintext and learn ciphertext
  - **chosen-ciphertext** attack: Eve can choose ciphertext and learn plaintext

Which of these are passive/active attacks?

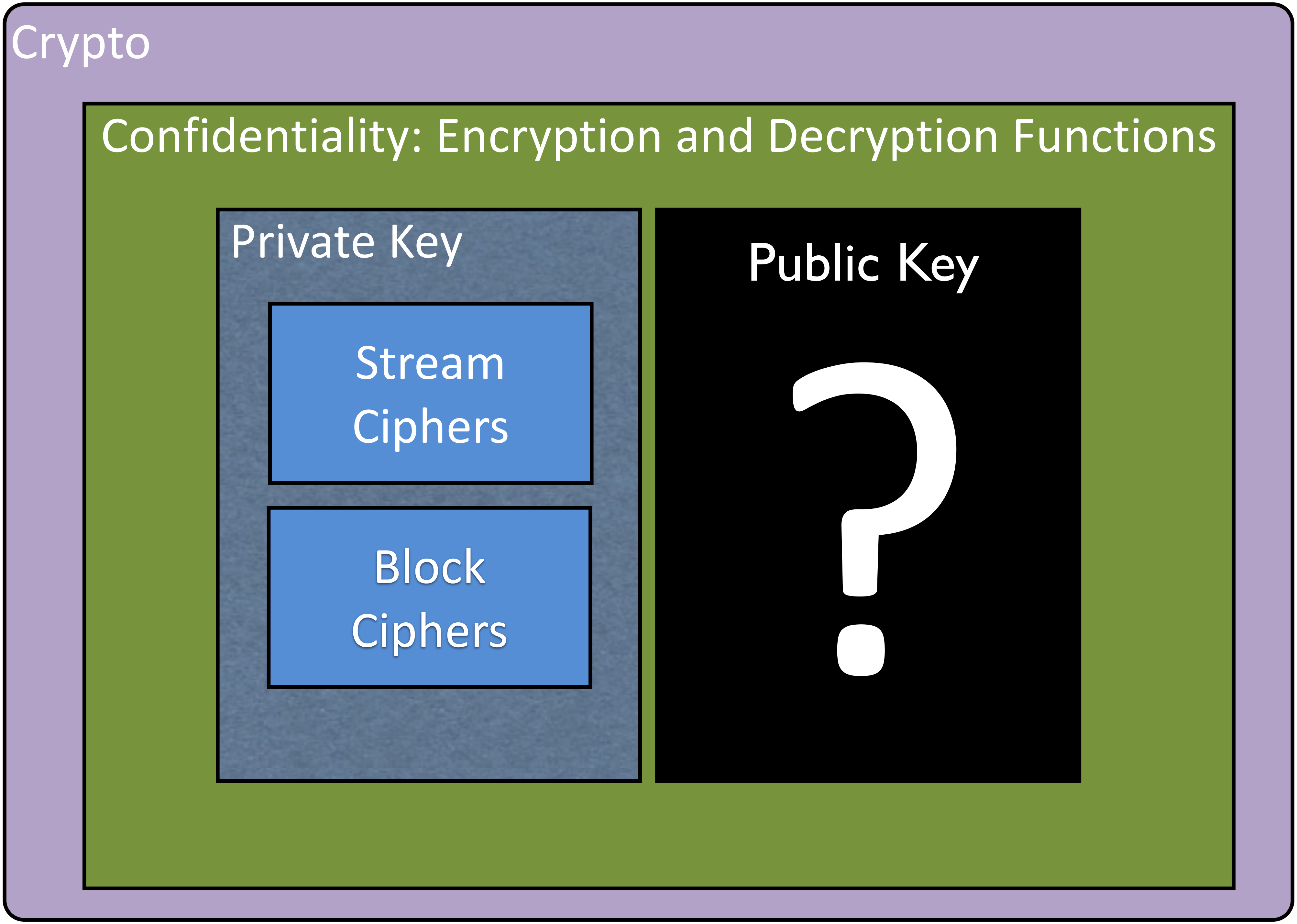
Other cryptanalysis ...

- Brute force cryptanalysis
  - Just keep trying different keys and check result
- Not covered in this class:
  - Linear cryptanalysis
    - Construct linear equations relating plaintext, ciphertext and key bits that have a high bias
    - Use these linear equations in conjunction with known plaintext-ciphertext pairs to derive key bits
  - Differential cryptanalysis
    - Study how differences in an input can affect the resultant difference at the output
    - Use chosen plaintext to uncover key bits

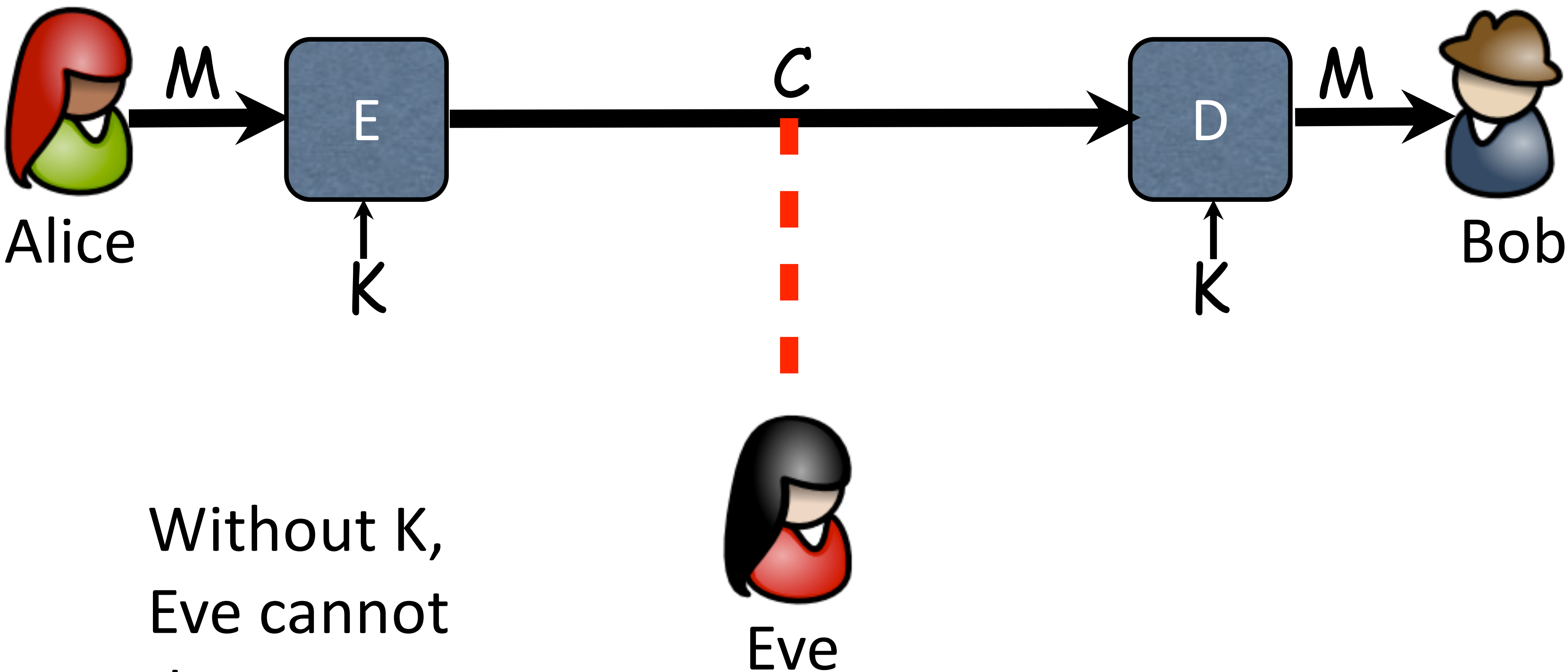
Symmetric and Asymmetric Crypto



- **Symmetric crypto:** (also called **private key crypto**)
  - Alice and Bob share the same key (K=K1=K2)
  - K used for both encrypting and decrypting
  - Doesn't imply that encrypting and decrypting are the same algorithm
  - Also called **private key** or **secret key** cryptography, since knowledge of the key reveals the plaintext
- **Asymmetric crypto:** (also called **public key crypto**)
  - Alice and Bob have different keys
  - Alice encrypts with K1 and Bob decrypts with K2
  - Also called **public key** cryptography, since Alice and Bob can publicly post their *public* keys


Crypto
Confidentiality: Encryption and Decryption Functions
Private Key
Stream Ciphers
Block Ciphers
Public Key
?

Secret Key Crypto



Without K,
Eve cannot
decrypt C

Block ciphers vs. Stream ciphers

- **Stream Ciphers**
  - Combine (e.g., XOR) plaintext with pseudorandom stream of bits
  - Pseudorandom stream generated based on key
  - XOR with same bit stream to recover plaintext
  - E.g., RC4, FISH
- **Block Ciphers**
  - Fixed block size
  - Encrypt block-sized portions of plaintext
  - Combine encrypted blocks (more on this later)
  - E.g., DES, 3DES, AES

Stream Ciphers

- $E(M1) = M1 \oplus C(K)$
  - [C(K) = pseudorandom stream produced using key K]
- Useful when plaintext arrives as a stream (e.g., 802.11's WEP)
- Vulnerable if used incorrectly

Stream Ciphers

- **Key reuse:** [C(K) = pseudorandom stream produced using key K]
  - $E(M1) = M1 \oplus C(K)$
  - $E(M2) = M2 \oplus C(K)$
  - Suppose Eve knows ciphertexts E(M1) and E(M2)
  - $E(M1) \oplus E(M2) = M1 \oplus C(K) \oplus M2 \oplus C(K) = M1 \oplus M2$
  - M1 and M2 can be derived from $M1 \oplus M2$ using frequency analysis
- Countermeasure is to use IV (**initialization vector**)
  - IV sent in clear and is combined with K to produce pseudorandom sequence
  - E.g., replace C(K) with $C(K \oplus IV)$
  - IVs should never be reused and should be sufficiently large
  - WEP broken partly because IVs were insufficiently large
  - modern stream ciphers take IVs, but it's up to the programmer to generate them

Stream Ciphers

- **Substitution Attack:**
  - M = "Pay me $100.00"
  - E(M) = M $\oplus$ C(K)
  - Suppose Eve knows M and E(M) but doesn't know K
  - She can substitute M for M' by replacing E(M) with:
    - E'(M) = E(M) $\oplus$ M $\oplus$ M' = M $\oplus$ C(K) $\oplus$ M $\oplus$ M' = C(K) $\oplus$ M'
    - Eve can then replace E(M) with E'(M), which Bob will decrypt message as M' ("Pay me $900.00")
  - *Encryption alone does not provide integrity:* Countermeasure is to include message authentication code (more on this later) that helps detect manipulation (i.e., provides integrity and authenticity)