CSE 484: Computer Security and Privacy

Cryptography
[Symmetric Encryption]

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...

How Cryptosystems Work Today

- **Layered approach:** Cryptographic protocols (like “CBC mode encryption”) built on top of cryptographic primitives (like “block ciphers”)
- **Flavors of cryptography:** Symmetric (private key) and asymmetric (public key)
- Public algorithms (Kerckhoff’s Principle)
- Security proofs based on assumptions *(not this course)*

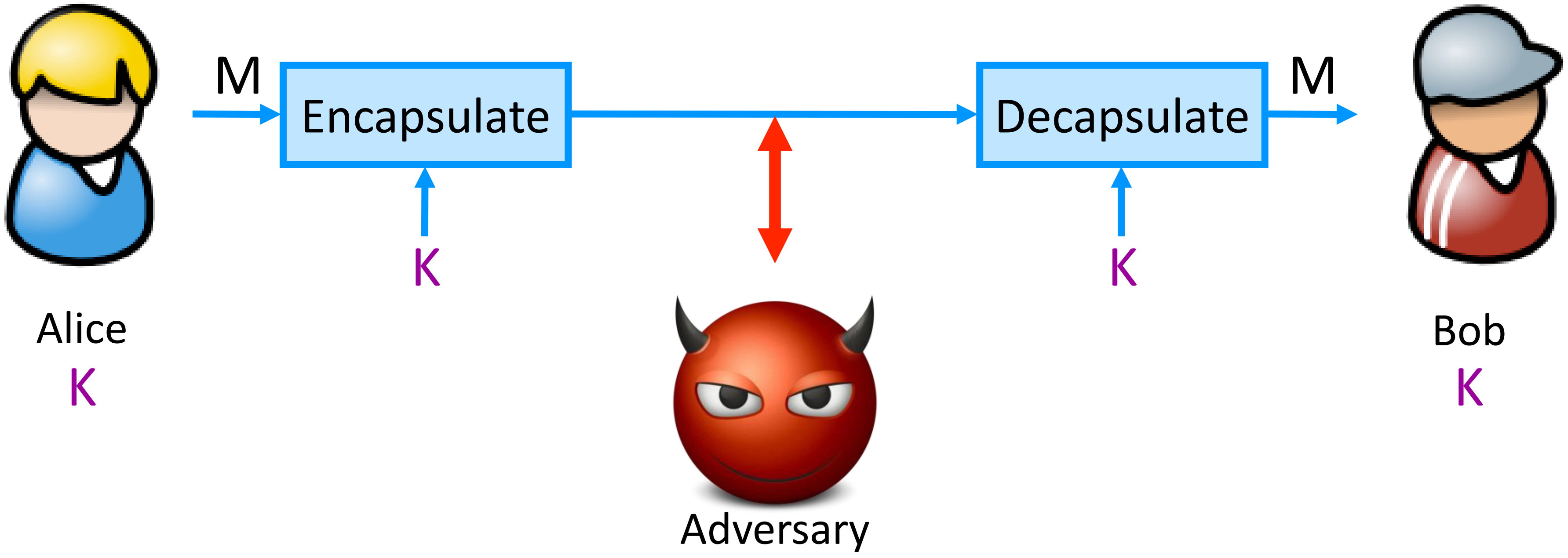
- Be careful about inventing your own! (If you just want to use some crypto in your system, use vetted libraries!)

Flavors of Cryptography

- Symmetric cryptography
  - Both communicating parties have access to a shared random string K, called the key.
- Asymmetric cryptography
  - Each party creates a public key pk and a secret key sk.
  - *Hard concept to understand, and revolutionary! Inventors won Turing Award* ☺

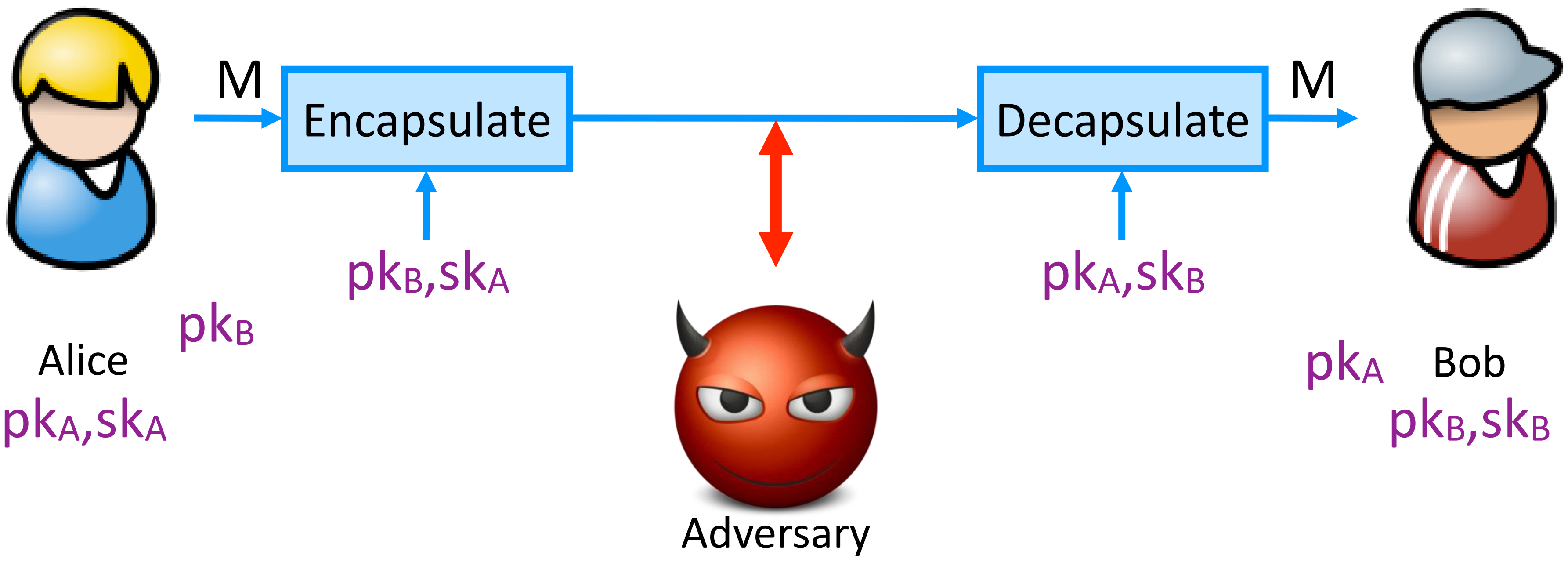
Symmetric Setting

Both communicating parties have access to a shared random string K, called the key.



Asymmetric Setting

Each party creates a public key pk and a secret key sk.



Flavors of Cryptography

- Symmetric cryptography
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- Asymmetric cryptography
  - Each party creates a public key pk and a secret key sk.

Flavors of Cryptography

- Symmetric cryptography
  - Both communicating parties have access to a shared random string K, called the key.
  - Challenge: How do you privately share a key?
- Asymmetric cryptography
  - Each party creates a public key pk and a secret key sk.
  - Challenge: How do you validate a public key?

Ingredient: Randomness

- Many applications (especially security ones) require randomness
- Explicit uses:
  - Generate secret cryptographic keys
  - Generate random initialization vectors for encryption
- Other “non-obvious” uses:
  - Generate passwords for new users
  - Shuffle the order of votes (in an electronic voting machine)
  - Shuffle cards (for an online gambling site)

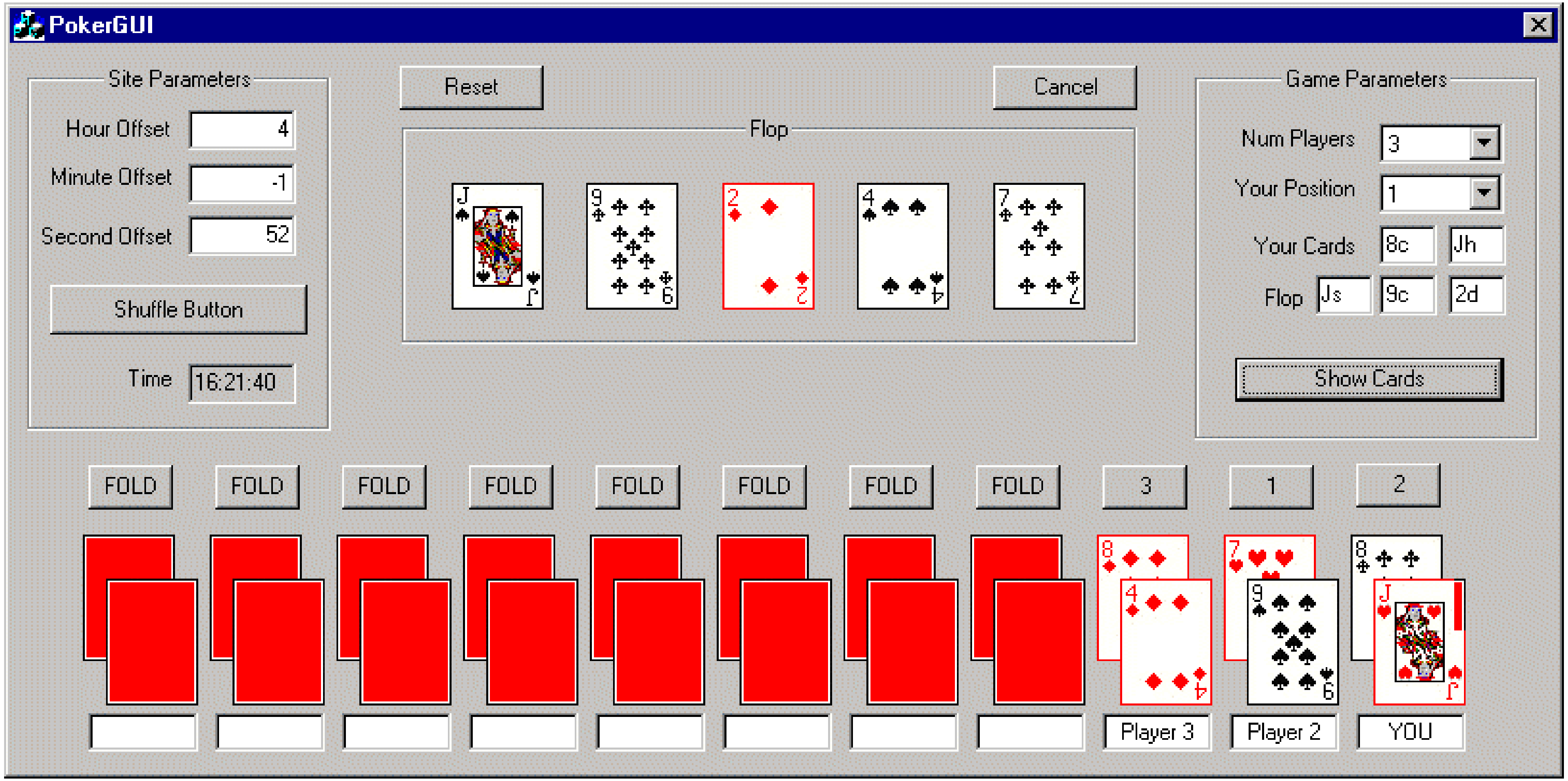
C’s rand() Function

- C has a built-in random function: rand()

```
unsigned long int next = 1;
/* rand:  return pseudo-random integer on 0..32767 */
int rand(void) {
    next = next * 1103515245 + 12345;
    return (unsigned int)(next/65536) % 32768;
}
/* srand:  set seed for rand() */
void srand(unsigned int seed) {
    next = seed;
}
```

- Problem: don’t use rand() for security-critical applications!
  - Given a few sample outputs, you can predict subsequent ones


A World of Action!
Help
Suggestions
Fold in Turn
$0
jonnyboy
Fold
Check
Bet ($5)
brute
RickG
mamajoe
Options
Sit Out
Leave
584330
mamajoe: Hey guys, Big B is in!
Dealer Text



More details: "How We Learned to Cheat at Online Poker: A Study in Software Security"
http://www.cigital.com/papers/download/developer_gambling.php

PS3 and Randomness

Hackers obtain PS3 private cryptography key due to epic programming fail? (update)

http://www.engadget.com/2010/12/29/hackers-obtain-ps3-private-cryptography-key-due-to-epic-programm/

- 2010/2011: Hackers found/released private root key for Sony's PS3
- Key used to sign software – now can load any software on PS3 and it will execute as "trusted"
- Due to bad random number: same "random" value used to sign all system updates

Another real world example

```
byte buffer[256];
int index = 0;

setup(){
	for (i=0; i < 256; i++){
		buffer[i] = i;
	}
	shuffle_array(buffer);
}
```

```
random(){
	byte ret = buffer[index];
	if(index == 255){
		index = 0;
	}
	else{
		index++;
	}
}
```

Obtaining Pseudorandom Numbers

- For security applications, want "cryptographically secure pseudorandom numbers"
- Libraries include cryptographically secure pseudorandom number generators (CSPRNG)

Obtaining Pseudorandom Numbers

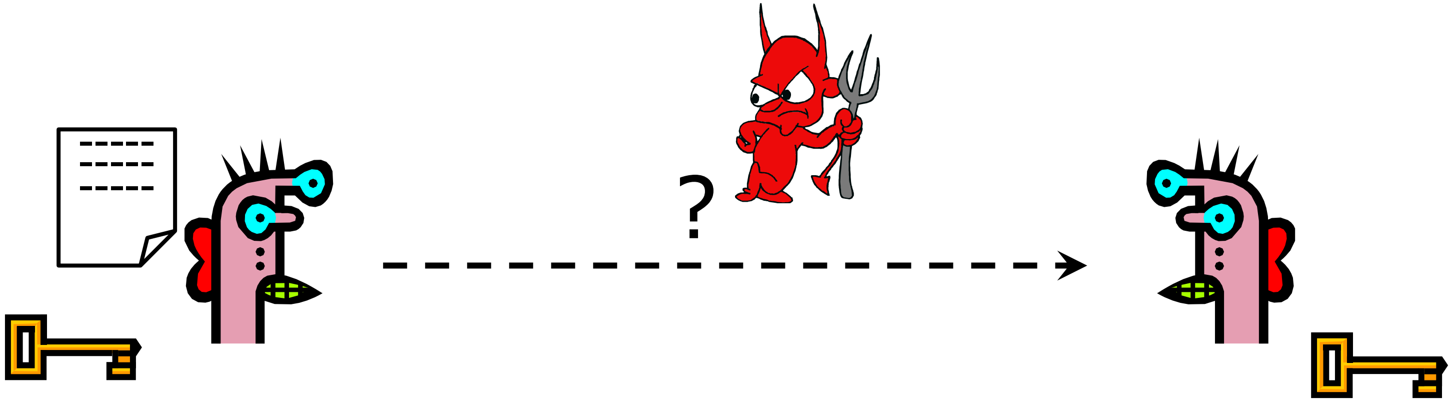
- Linux:
  - /dev/random
  - /dev/urandom - nonblocking, possibly less entropy
  - getrandom() – syscall!
- Internally:
  - Entropy pool gathered from multiple sources
    - e.g., mouse/keyboard/network timings
- Challenges with embedded systems, saved VMs

Obtaining *Random* Numbers

- Better idea:
  - AMD/Intel's on-chip random number generator
    - RDRAND
- Hopefully no hardware bugs!

Now: Symmetric Encryption

Confidentiality: Basic Problem



Given (Symmetric Crypto): both parties know the same secret.

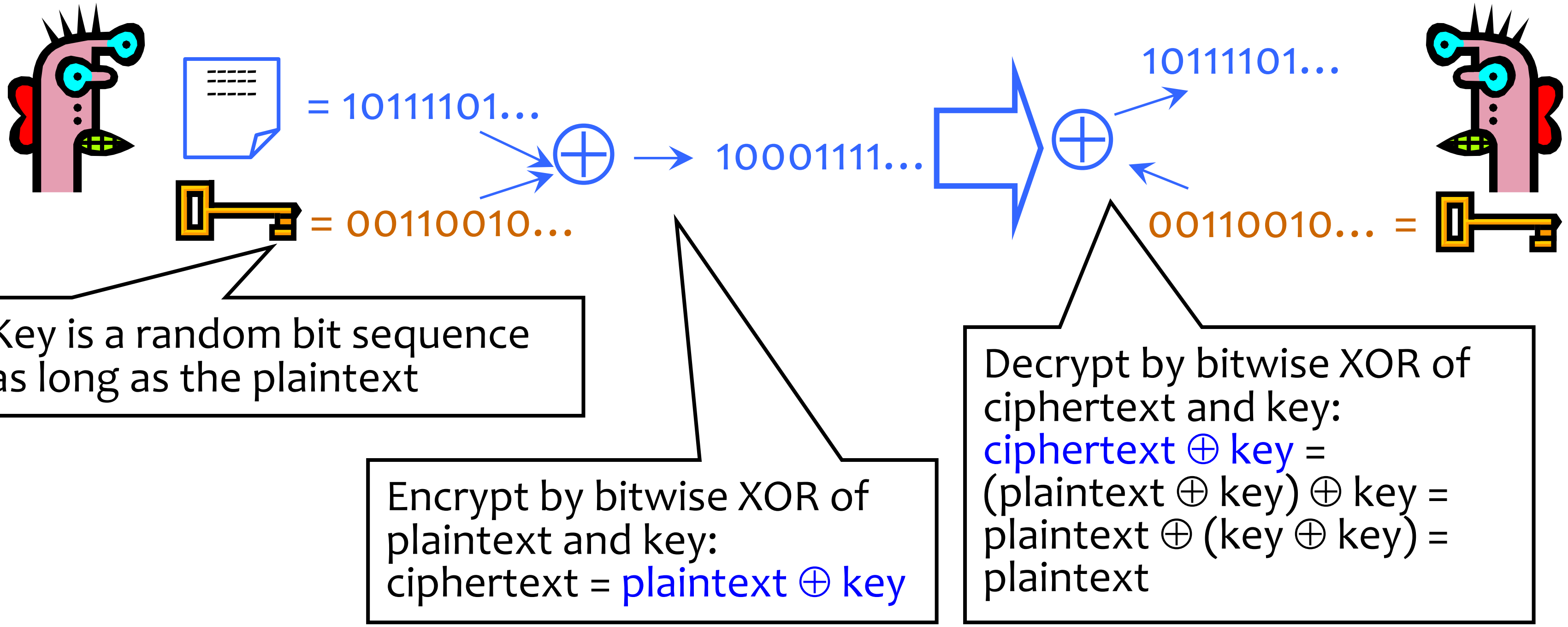
Goal: send a message confidentially.

Ignore for now: How is this achieved in practice??

One weird trick to hide your bits

- XOR!
  - Just XOR with a random bit!
- Why?
  - Uniform output
  - Independent of ‘message’ bit

One-Time Pad



Cipher achieves perfect secrecy if and only if there are as many possible keys as possible plaintexts, and every key is equally likely (Claude Shannon, 1949)

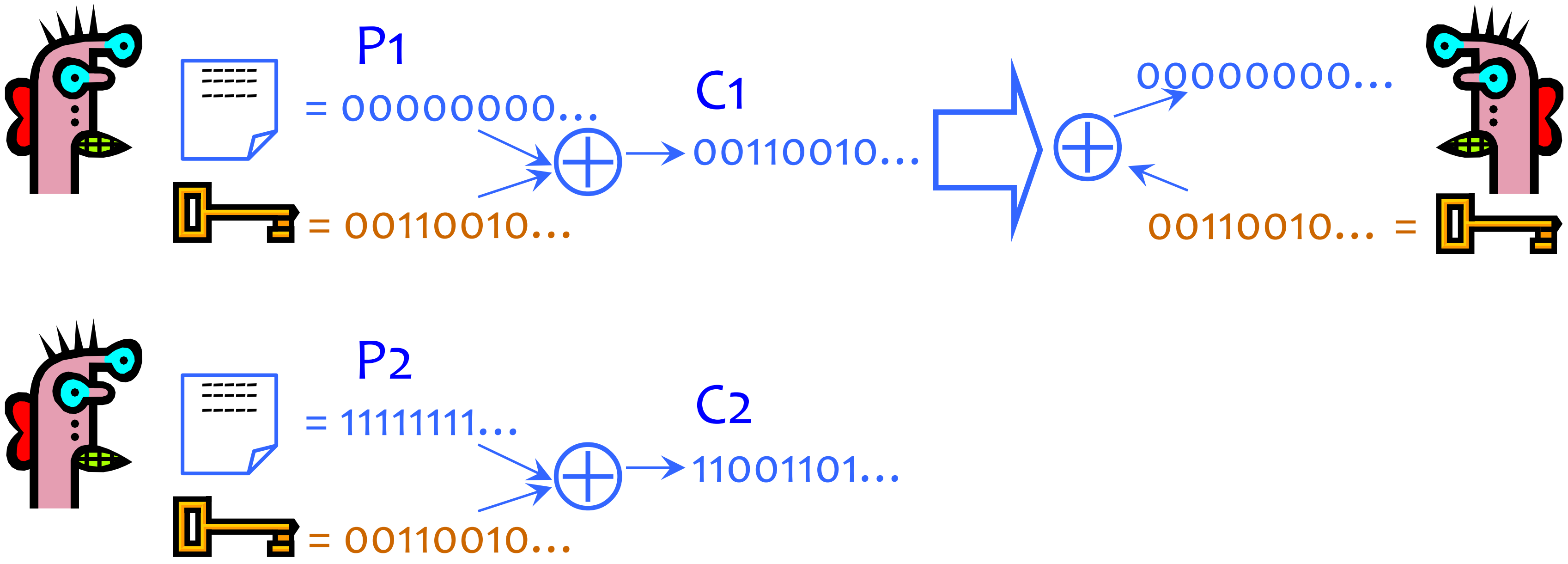
Advantages of One-Time Pad

- Easy to compute
  - Encryption and decryption are the same operation
  - Bitwise XOR is very cheap to compute
- As secure as theoretically possible
  - Given a ciphertext, all plaintexts are equally likely, regardless of attacker's computational resources
  - …as long as the key sequence is truly random
    - True randomness is expensive to obtain in large quantities
  - …as long as each key is same length as plaintext
    - But how does sender communicate the key to receiver?

Problems with One-Time Pad

- (1) Key must be as long as the plaintext
  - Impractical in most realistic scenarios
  - Still used for diplomatic and intelligence traffic
- (2) Insecure if keys are reused

Dangers of Reuse



Learn relationship between plaintexts

$C1 \oplus C2 = (P1 \oplus K) \oplus (P2 \oplus K) =$

$(P1 \oplus P2) \oplus (K \oplus K) = P1 \oplus P2$

Problems with One-Time Pad

- (1) Key must be as long as the plaintext
  - Impractical in most realistic scenarios
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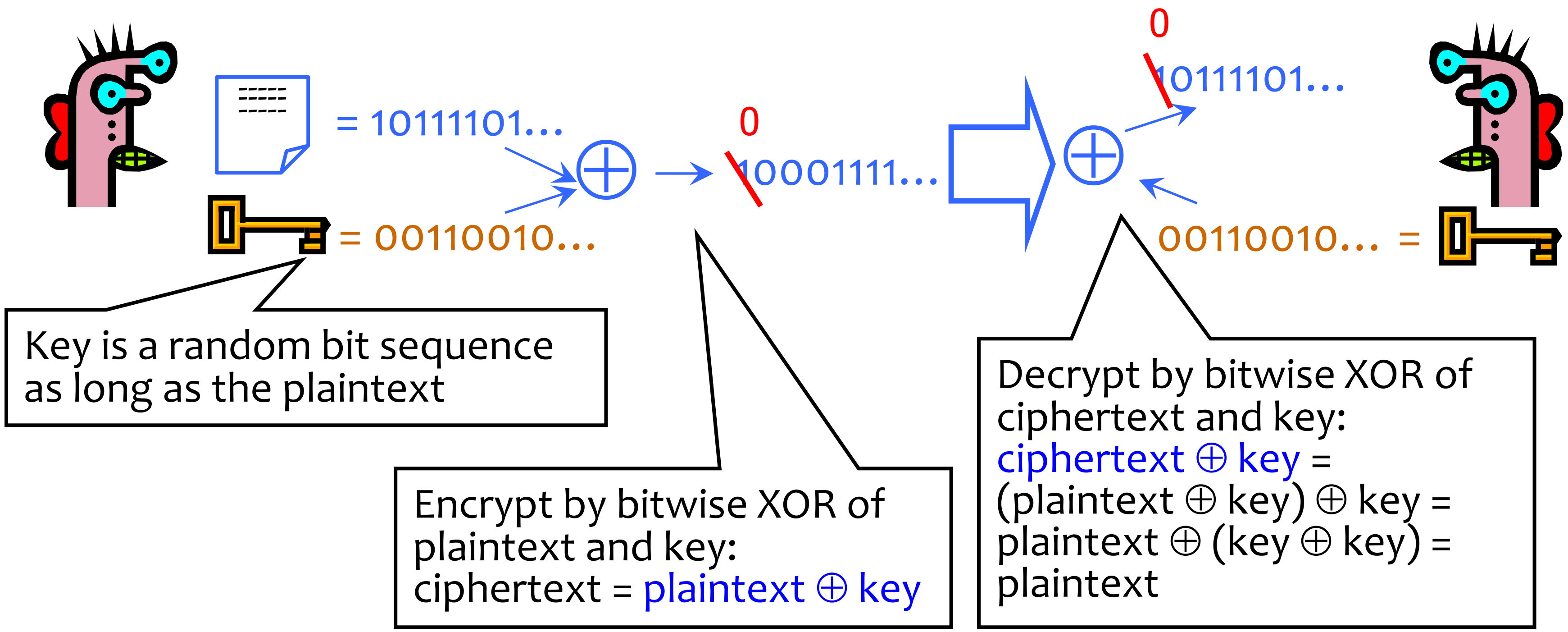
- **(2) Insecure if keys are reused**
  - **Attacker can obtain XOR of plaintexts**

Integrity?



= 10111101…
= 00110010…
0
10001111…
0
10111101…
00110010… =
Key is a random bit sequence as long as the plaintext
Encrypt by bitwise XOR of plaintext and key:
ciphertext = plaintext ⊕ key
Decrypt by bitwise XOR of ciphertext and key:
ciphertext ⊕ key =
(plaintext ⊕ key) ⊕ key =
plaintext ⊕ (key ⊕ key) =
plaintext

Problems with One-Time Pad

- (1) Key must be as long as the plaintext
  - Impractical in most realistic scenarios
  - Still used for diplomatic and intelligence traffic
- (2) Insecure if keys are reused
  - Attacker can obtain XOR of plaintexts
- **(3) Does not guarantee integrity**
  - **One-time pad only guarantees confidentiality**
  - **Attacker cannot recover plaintext, but can easily change it to something else**

Reducing Key Size

- What to do when it is infeasible to pre-share huge random keys?
  - When one-time pad is unrealistic…
- Use special cryptographic primitives: block ciphers, stream ciphers
  - Single key can be re-used (with some restrictions)
  - Not as theoretically secure as one-time pad

Stream Ciphers

- One-time pad: Ciphertext(Key,Message)=Message⊕Key
  - Key must be a random bit sequence as long as message
- Idea: replace "random" with "pseudo-random"
  - Use a pseudo-random number generator (PRNG)
  - PRNG takes a short, truly random secret seed and expands it into a long "random-looking" sequence
    - E.g., 128-bit seed into a 10^6-bit pseudo-random sequence

No efficient algorithm can tell this sequence from truly random

- Ciphertext(Key,Msg)=Msg⊕PRNG(Key)
  - Message processed bit by bit (like one-time pad)

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)