

# CSE 484 / CSE M 584: Applied Cryptography

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# Vulnerability Analysis and Disclosure

- What do you do if you've found a security problem in a real system?
- Say
  - A commercial website?
  - UW grade database?
  - Boeing 787?
  - TSA procedures?

**What would you do? What ethical questions come up?**

# Vulnerability Analysis and Disclosure

- Suppose companies A, B, and C all have a vulnerability, but have not made the existence of that vulnerability public
- Company A has a software update prepared and ready to go that, once shipped, will fix the vulnerability; but B and C are still working on developing a patch for the vulnerability
- Company A learns that attackers are exploiting this vulnerability in the wild
- *Should Company A release their patch, even if doing so means that the vulnerability now becomes public and other actors can start exploiting Companies B and C?*
- *Or should Company A wait until Companies B and C have patches?*

Next major section of the course:

# Applied Cryptography

**Terminology note: “blockchain” and “crypto”**

- Rising interest, mostly in the cryptocurrency space
- For this course: crypto means “cryptography”

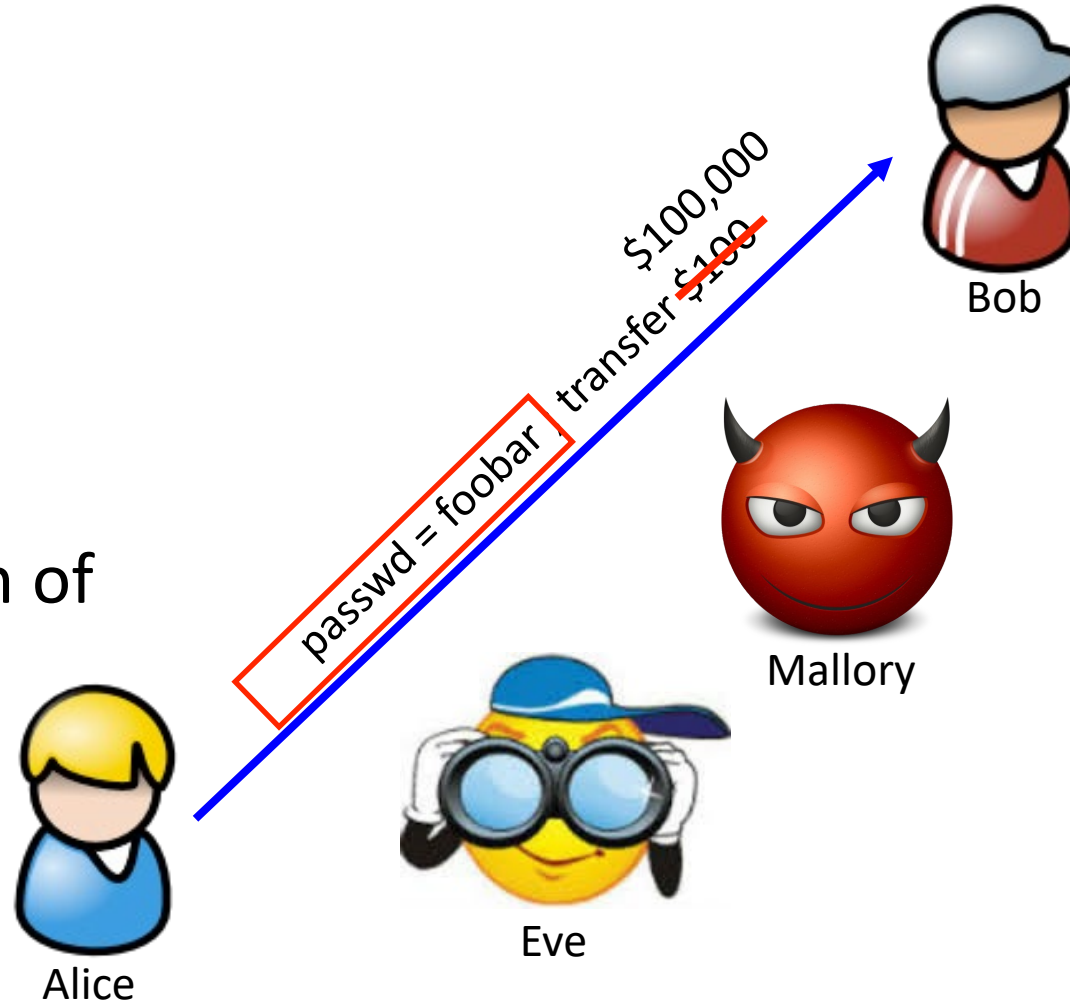
# Common Communication Security Goals

## Privacy of data:

Prevent exposure of information

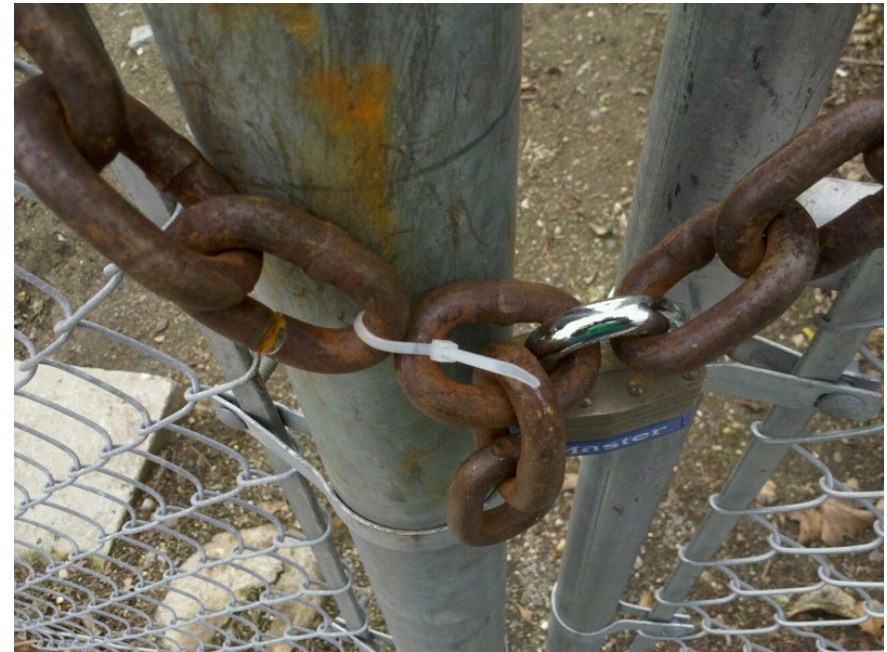
## Integrity of data:

Prevent modification of information

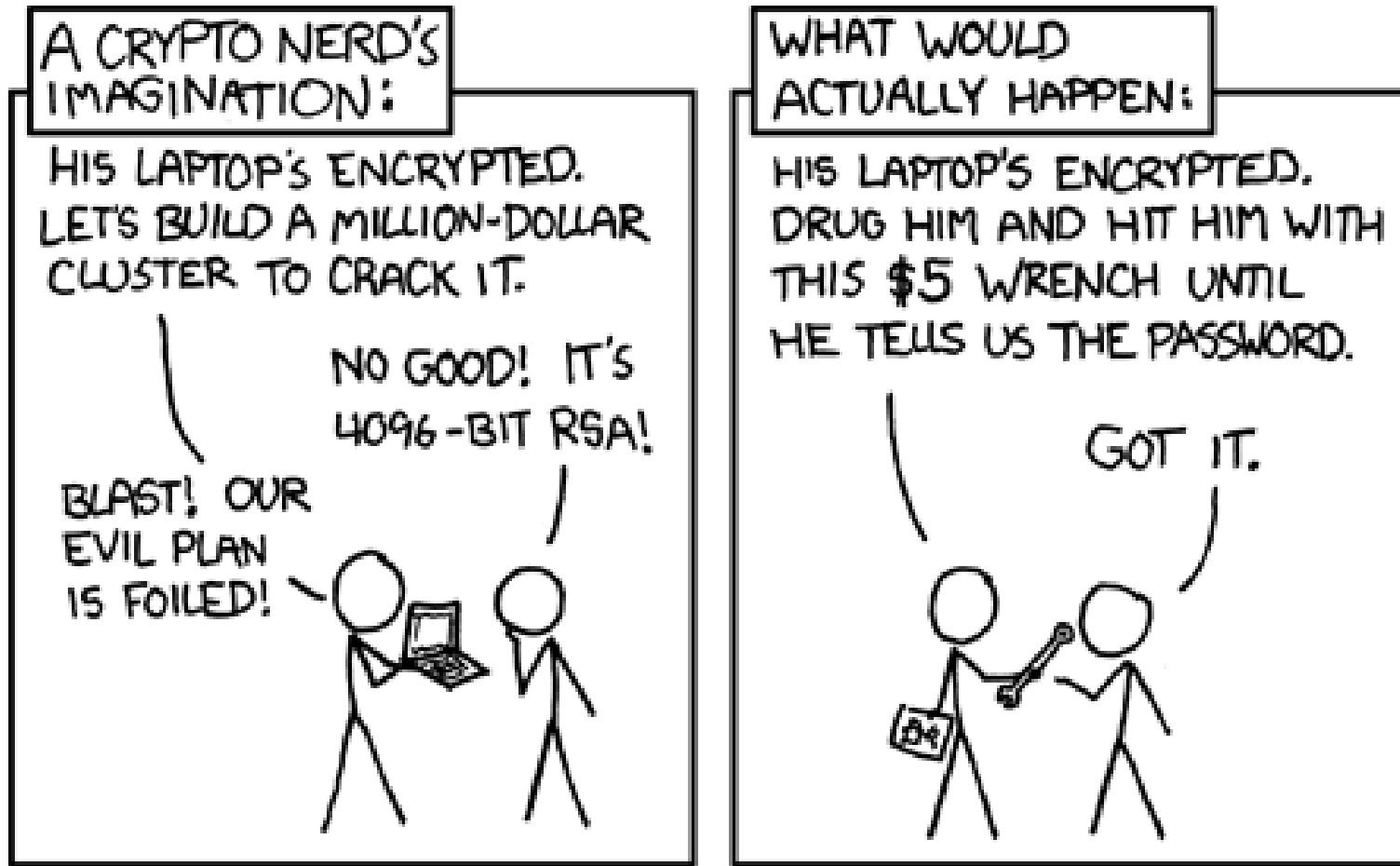


# Recall Bigger Picture

- Cryptography only one small piece of a larger system
- Must protect entire system
  - Physical security
  - Operating system security
  - Network security
  - Users
  - Cryptography (following slides)
- Recall the weakest link
- Still, cryptography is a crucial part of our toolbox



# XKCD: <http://xkcd.com/538/>



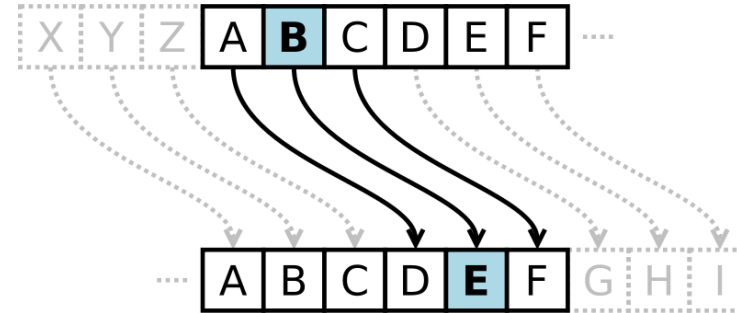
# History

- Substitution Ciphers
  - Caesar Cipher
- Transposition Ciphers
- Codebooks
- Machines
  
- Recommended Reading: **The Codebreakers** by David Kahn and **The Code Book** by Simon Singh.



# History: Caesar Cipher (Shift Cipher)

- Plaintext letters are replaced with letters a fixed shift away in the alphabet.
- Example:



– Plaintext: `The quick brown fox jumps over the lazy dog`

– Key: Shift 3

`ABCDEFGHIJKLMN OPQRSTUVWXYZ`

`DEFGHIJKLMN OPQRSTUVWXYZABC`

– Ciphertext: `WKHTX LFNEU RZQIR AMXPS VRYHU WKHOD CBGRJ`

# History: Caesar Cipher (Shift Cipher)

- ROT13: shift 13 (encryption and decryption are symmetric)
- What is the key space?
  - 26 possible shifts.
- How to attack shift ciphers?
  - Brute force.

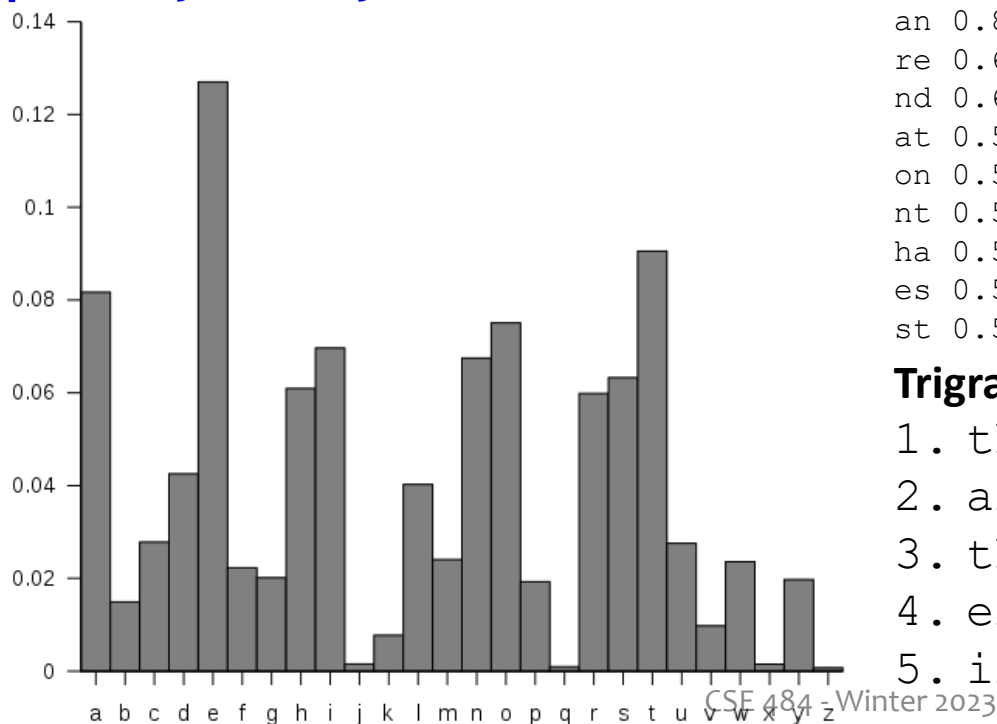


# History: Substitution Cipher

- **Superset of shift ciphers:** each letter is substituted for another one.
- One way to implement: **Add a secret key**
- Example:
  - Plaintext: ABCDEFGHIJKLMNOPQRSTUVWXYZ
  - Cipher: ZEBRASCDEFGHIJKLMNOPQTUVWXY
- “State of the art” for thousands of years

# History: Substitution Cipher

- What is the key space?
- How to attack?
  - Frequency analysis.



$$26! \approx 2^{88}$$

## Bigrams:

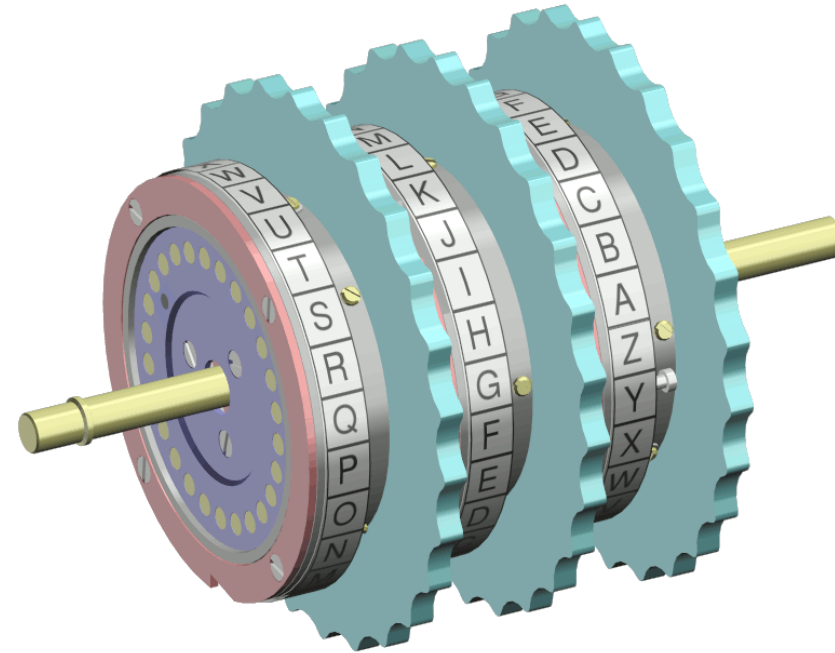
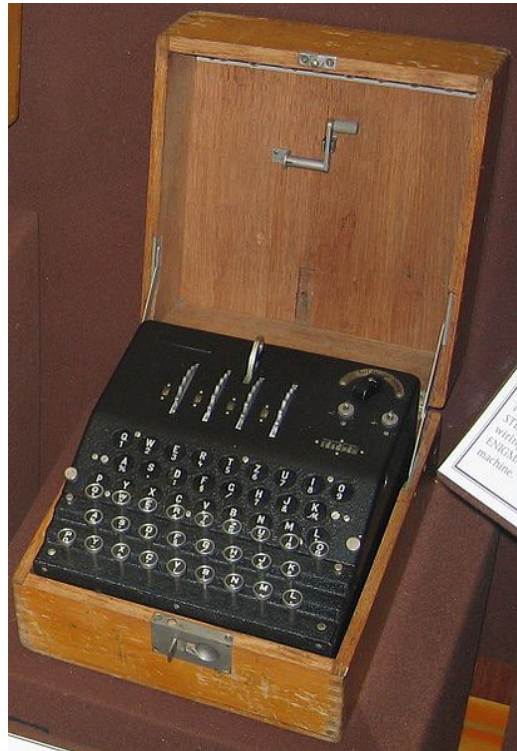
th 1.52%	en 0.55%	ng 0.18%
he 1.28%	ed 0.53%	of 0.16%
in 0.94%	to 0.52%	al 0.09%
er 0.94%	it 0.50%	de 0.09%
an 0.82%	ou 0.50%	se 0.08%
re 0.68%	ea 0.47%	le 0.08%
nd 0.63%	hi 0.46%	sa 0.06%
at 0.59%	is 0.46%	si 0.05%
on 0.57%	or 0.43%	ar 0.04%
nt 0.56%	ti 0.34%	ve 0.04%
ha 0.56%	as 0.33%	ra 0.04%
es 0.56%	te 0.27%	ld 0.02%
st 0.55%	et 0.19%	ur 0.02%

## Trigrams:

1. the	6. ion	11. nce
2. and	7. tio	12. edt
3. tha	8. for	13. tis
4. ent	9. nde	14. oft
5. ing	10. has	15. sth

# History: Enigma Machine

Uses rotors (substitution cipher) that change position after each key.



Key = initial setting of rotors

Key space?

$26^n$  for  $n$  rotors

# 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 – next slide)
- 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!)

# Kerckhoff's Principle

- Security of a cryptographic object should depend only on the secrecy of the secret (private) key.
- Security should not depend on the secrecy of the algorithm itself.
- (Foreshadowing: Need for randomness – the key to keep private)

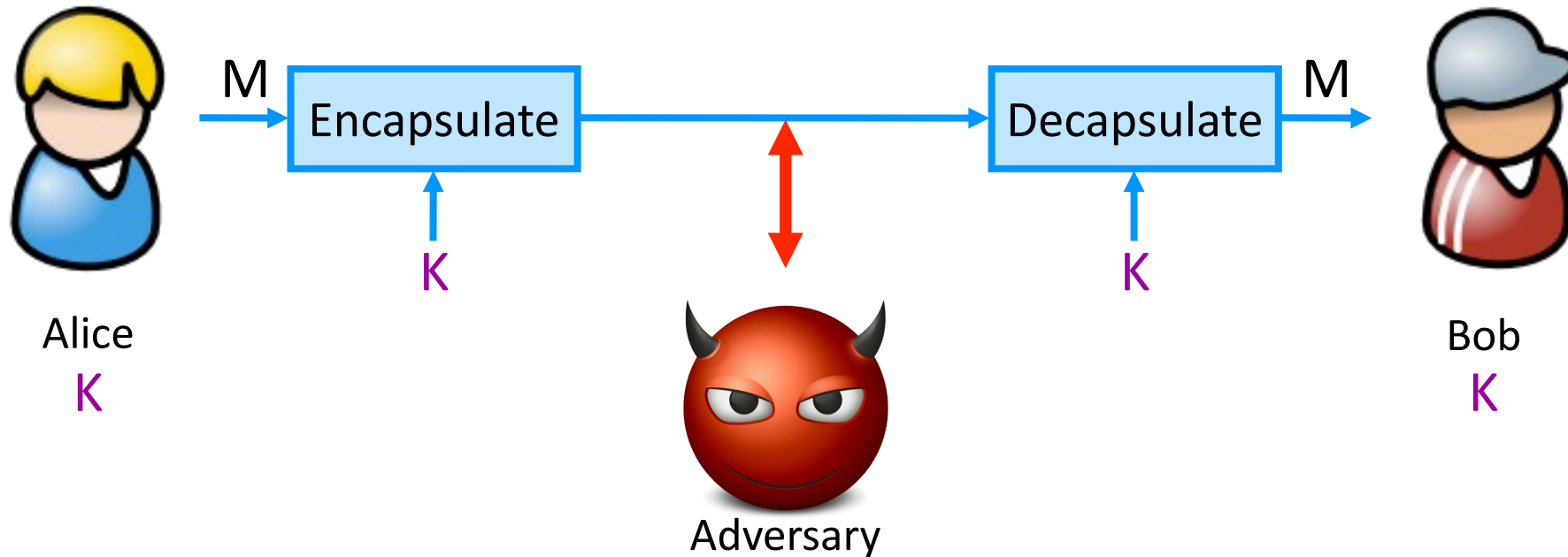
# Flavors of Cryptography

- 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 the Turing Award 😊*



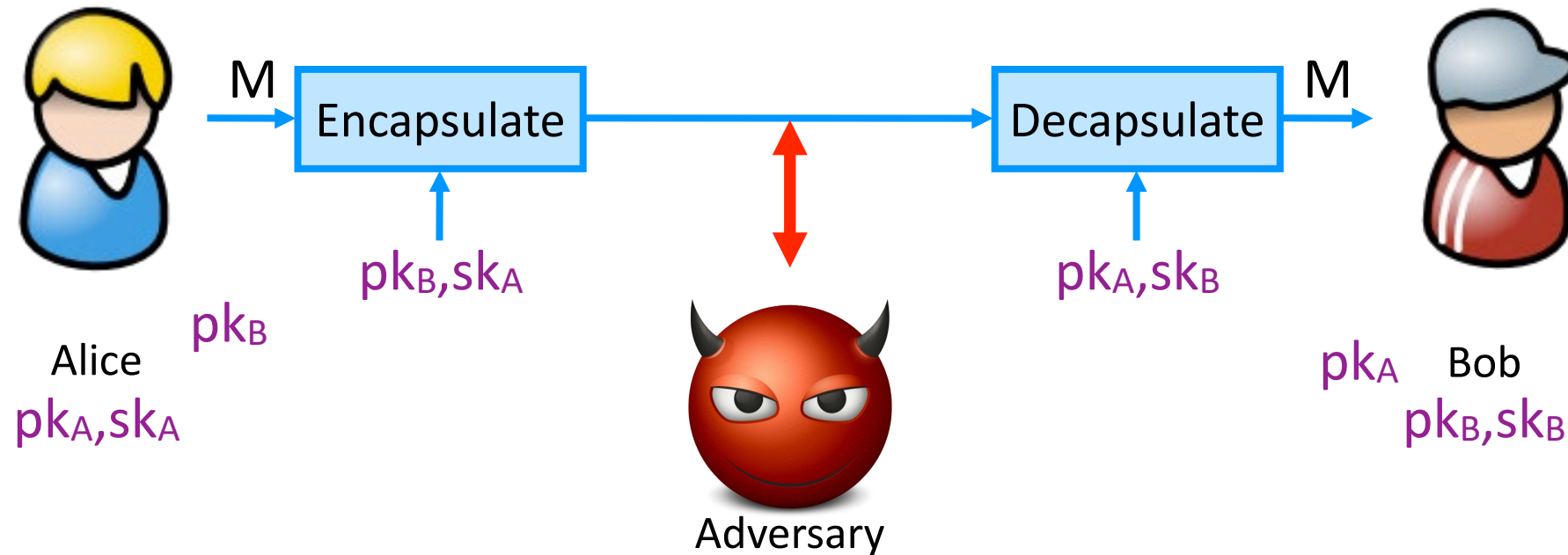
# Symmetric Setting

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  $sk$ .



Received April 4, 1977

## A Method for Obtaining Digital Signatures and Public-Key Cryptosystems

R.L. Rivest, A. Shamir, and L. Adleman\*

### Abstract

An encryption method is presented with the novel property that publicly revealing an encryption key does not thereby reveal the corresponding decryption key. This has two important consequences:

1. Couriers or other secure means are not needed to transmit keys, since a message can be enciphered using an encryption key publicly revealed by the intended recipient. Only he can decipher the message, since only he knows the corresponding decryption key.
2. A message can be "signed" using a privately held decryption key. Anyone can verify this signature using the corresponding publicly revealed encryption key. Signatures cannot be forged, and a signer cannot later deny the validity of his signature. This has obvious applications in "electronic mail" and "electronic funds transfer" systems.

# 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  **$sk$** .

# 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?**
- **Key building block: Randomness** – something that the adversaries don't know, can't predict, can't figure out

# 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

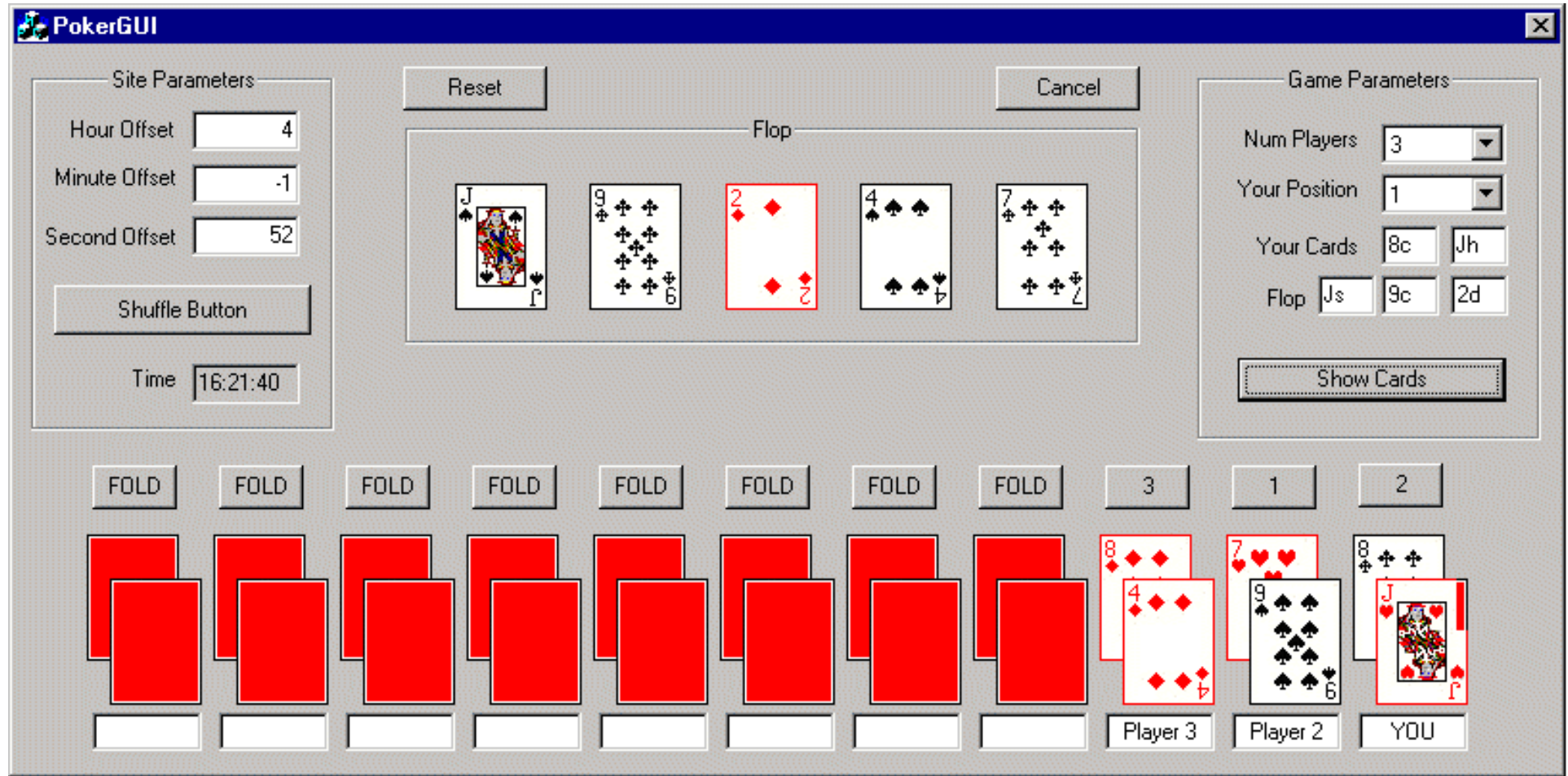
- C has a built-in random function: `rand()`

```
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







More details: “How We Learned to Cheat at Online Poker: A Study in Software Security”

[http://www.cigital.com/papers/download/developer\\_gambling.php](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**

# How might we get “good” random numbers?

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

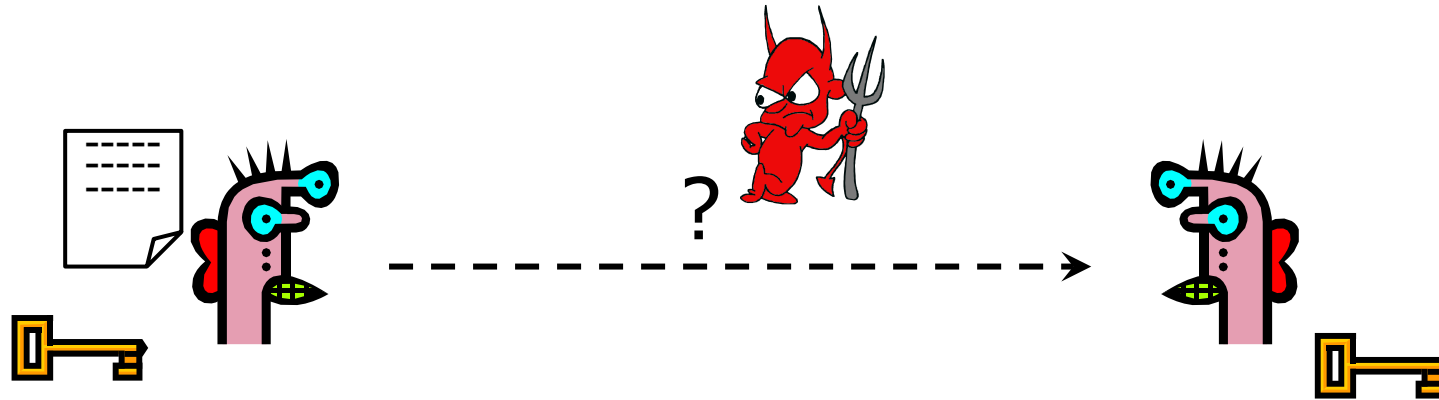
# Obtaining *Random Numbers*

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

# Crypto Roadmap

- Symmetric cryptography
  - For confidentiality
  - For integrity/authenticity
  - For both
- Asymmetric cryptography
  - For confidentiality
  - For integrity/authenticity
  - For both

# Confidentiality: Basic Problem



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

Goal: send a message confidentially.

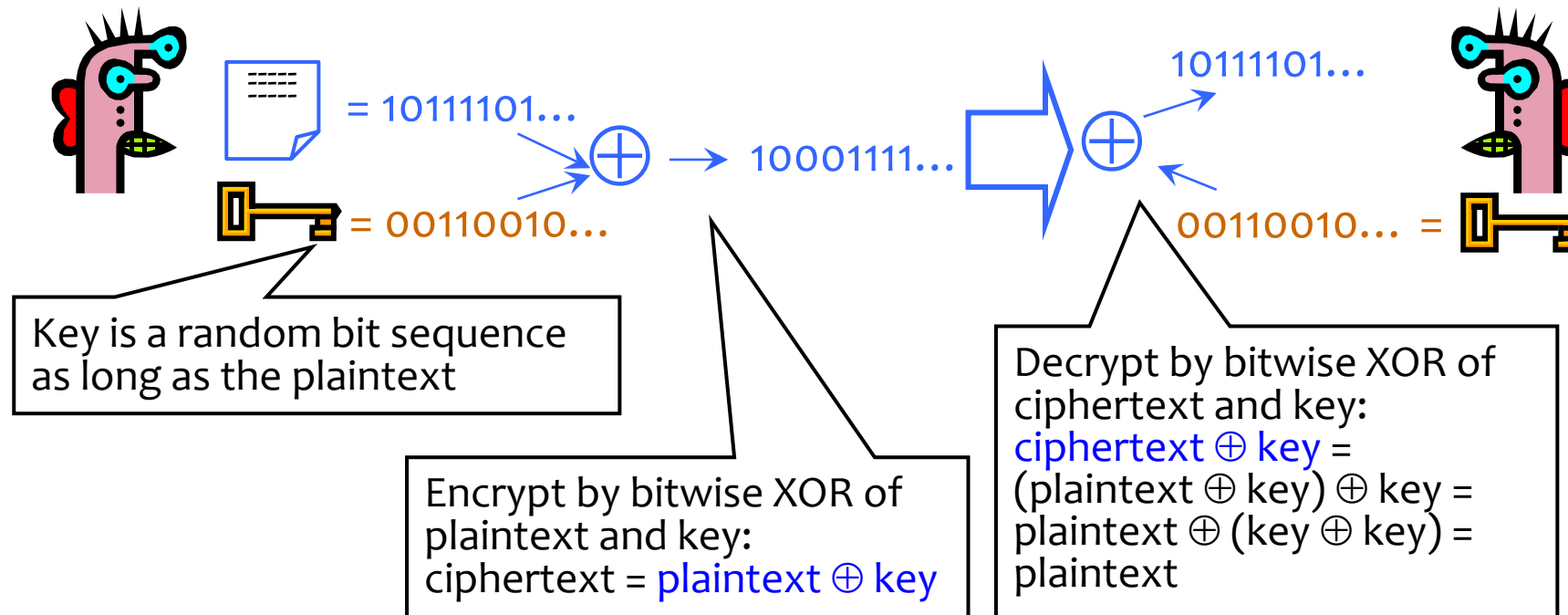
Ignore for now: How is this achieved in practice??



# One weird bit-level trick

- 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 the One-Time Pad?

- What potential security problems do you see with the one-time pad?