Warmup: An unfortunately simple bug

```
// Remote user sends us a ‘heartbeat’
// Job of the heartbeat is to echo back a message and say
// “hey I’m still working”
// heartbeat consists of 2 parts: length and a message
struct echo_msg_struct echo_msg;
read_max_string_from_network(echo_msg.buffer, 64);
read_int_from_network(echo_msg.size);

// Send the heartbeat back!
send_to_remote(echo_msg.buffer, echo_msg.size);
```

```
struct echo_msg_struct {
 unsigned int size;
 char buffer[64];
};
```

CSE 484: Computer Security and Privacy

Closing basics of software security
Starting cryptography

Spring 2024

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

Logistics + more

- Lab 1a due Wednesday (11:59:00)
  - Note there are two things to turn in: individual writeup, group sploits thing

- HW1 grades should be out soon

- Ed questions:
  - Please make sure to copy-paste and format text, not screenshot
  - Give us the details we need to help you!
    - The best questions include your code, what you think is happening, and what you've tried so far.

General Principles

- Check inputs
- Check all return values
- Least privilege
- Securely clear memory (passwords, keys, etc.)
- Failsafe defaults
- Defense in depth
    - Also: prevent, detect, respond

General Principles

- Reduce size of trusted computing base (TCB)
- Simplicity, modularity
  - But: Be careful at interface boundaries!
- Minimize attack surface
- Use vetted components
- Security by design
  - But: tension between security and other goals
- Open design? Open source? Closed source?
  - Different perspectives

Does Open Source Help?

- Different perspectives…

- Positive example?
  - Linux kernel backdoor attempt thwarted (2024!)
    (https://www.openwall.com/lists/oss-security/2024/03/29/4)

- Negative example?
  - Heartbleed (2014)
    - Vulnerability in OpenSSL that allowed attackers to read arbitrary memory from vulnerable servers (including private keys)

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?

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: Cryptography

Terminology Note: “crypto”

- For this course: crypto means “cryptography”

“If you think cryptography will solve your problem, you don't understand cryptography and you don't understand your problem”

- A cryptographer (its complicated)

“If you think cryptography will solve your problem, you don't understand cryptography and you don't understand your problem”

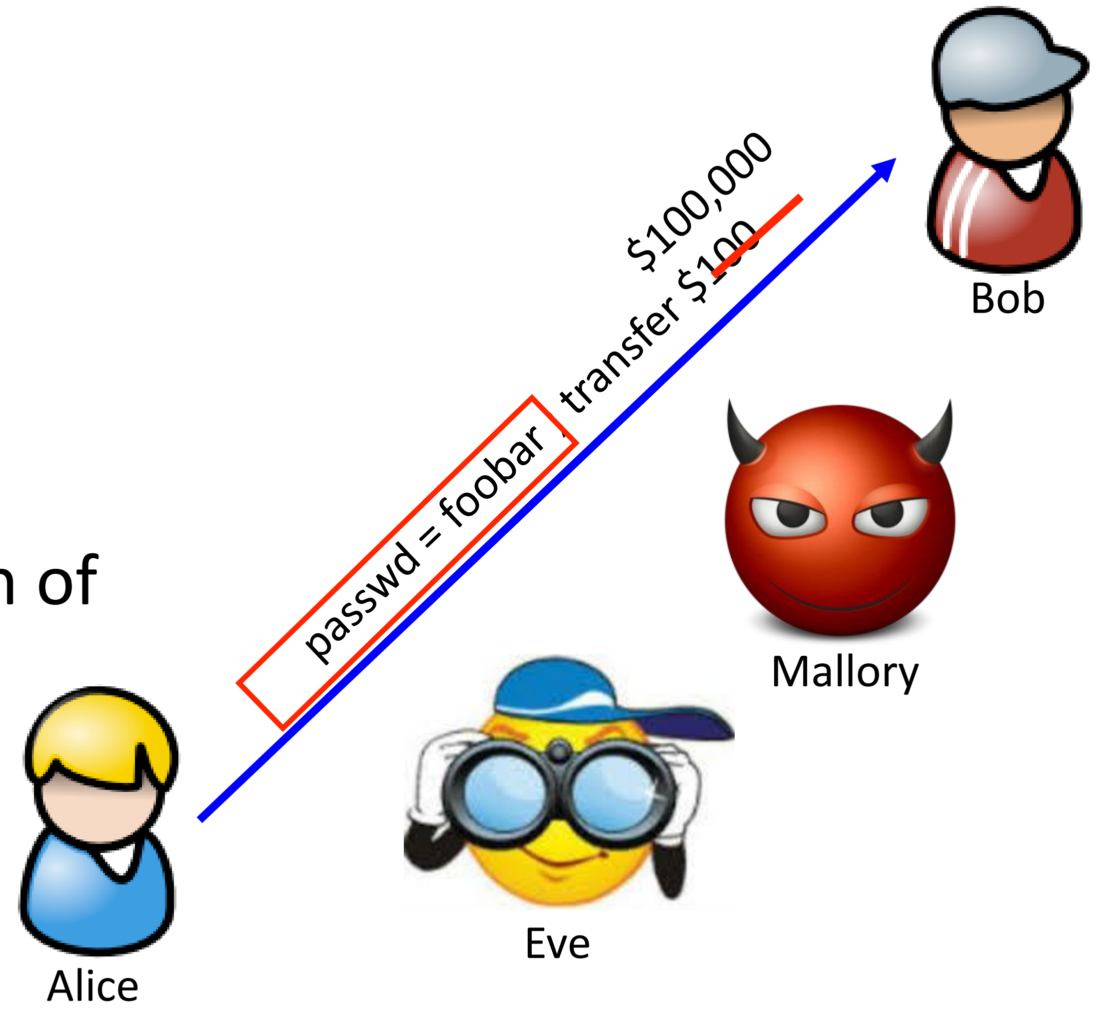
- A cryptographer (its complicated)

Probably either Jim Morris or Lampson or Needham

Common Communication Security Goals

Privacy of data:
Prevent exposure of information

Integrity of data:
Prevent modification of information

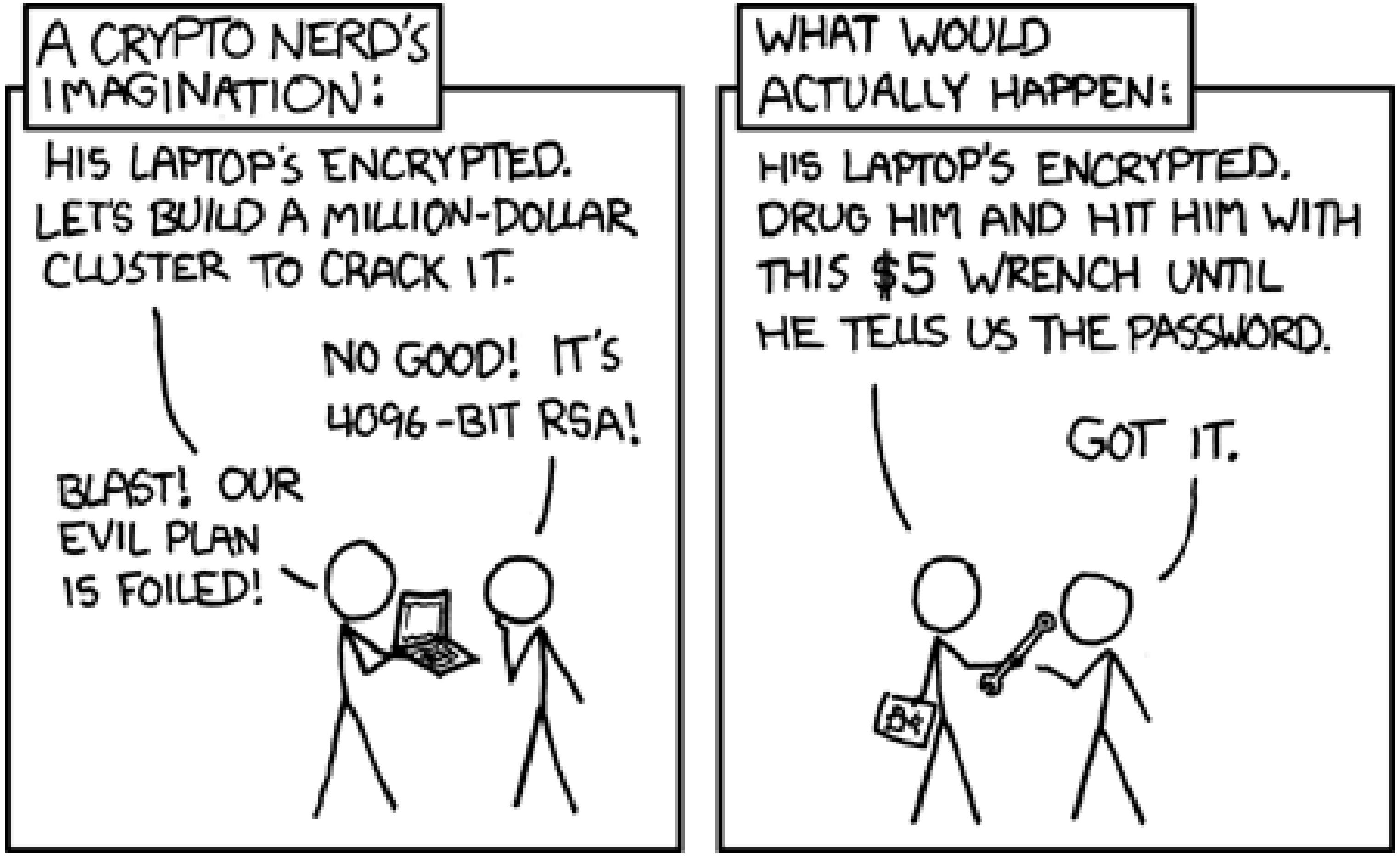


Recall Bigger Picture

- 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

Rubber-hose cryptanalysis: http://xkcd.com/538/

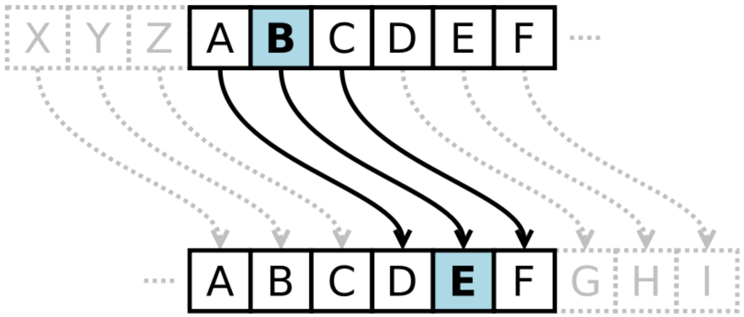


History of cryptography

- Substitution Ciphers
  - Caesar Cipher
- Transposition Ciphers
- Codebooks
- Machines

History: Caesar Cipher (Shift Cipher)

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



a

- Example:
  - Plaintext: The quick brown fox jumps over the lazy dog
  - Key: Shift 3

    ABCDEFGHIJKLMNOPQRSTUVWXYZ

    DEFGHIJKLMNOPQRSTUVWXYZABC
  - 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.

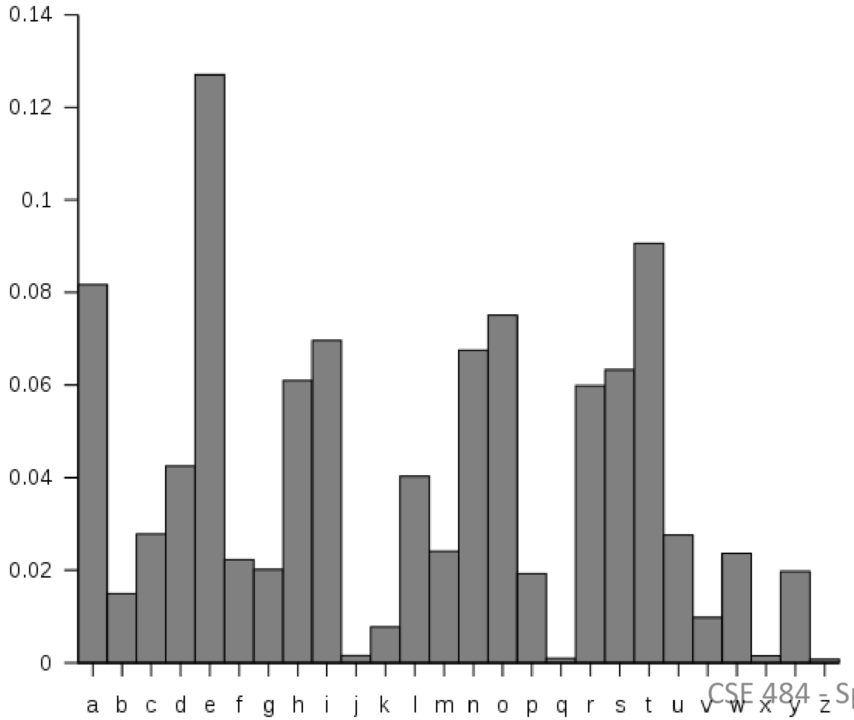
History: Substitution Cipher

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

History: Substitution Cipher

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

26! ~= 2^88



Bigrams:

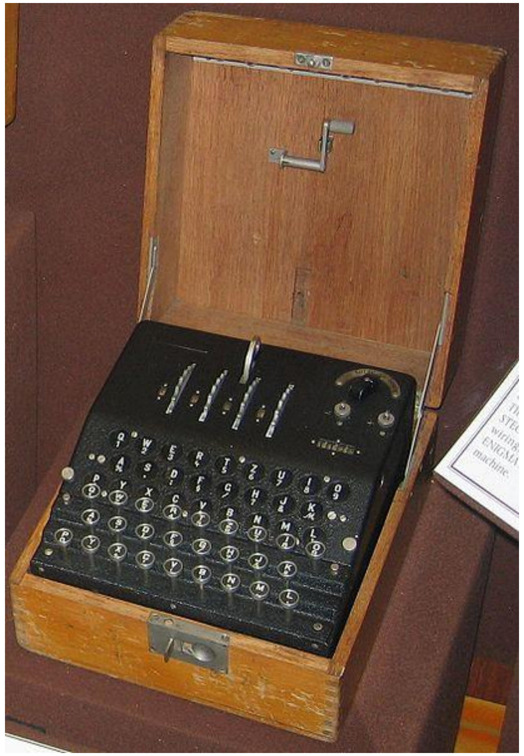
th 1.52%	en 0.55%	ng 0.18%
he 1.28%	ed 0.53%	of 0.16%
in 0.94%	to 0.52%	al 0.09%
er 0.94%	it 0.50%	de 0.09%
an 0.82%	ou 0.50%	se 0.08%
re 0.68%	ea 0.47%	le 0.08%
nd 0.63%	hi 0.46%	sa 0.06%
at 0.59%	is 0.46%	si 0.05%
on 0.57%	or 0.43%	ar 0.04%
nt 0.56%	ti 0.34%	ve 0.04%
ha 0.56%	as 0.33%	ra 0.04%
es 0.56%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

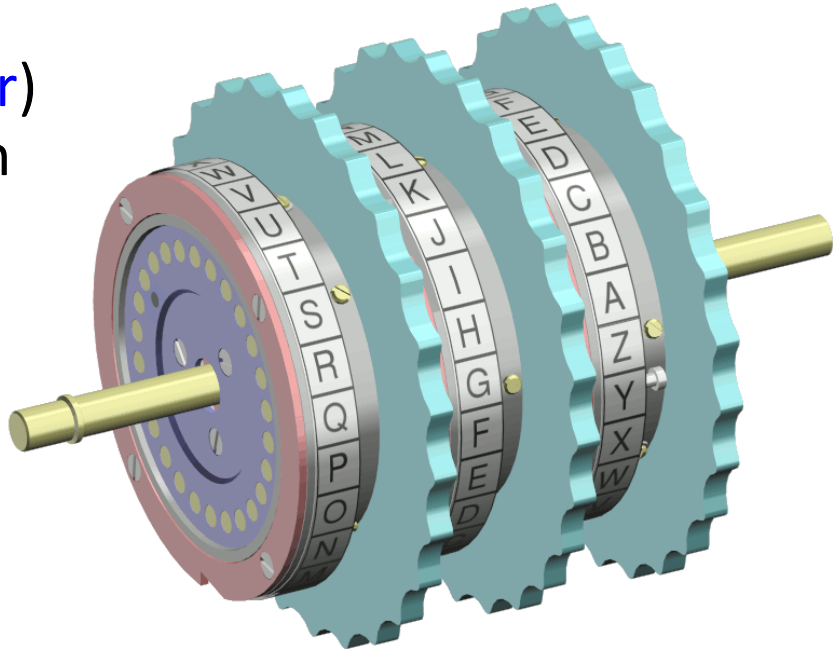
Trigrams:

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)
- Security proofs based on assumptions *(not this course)*

- Don't go inventing your own! (If you just want to use some crypto in your system, use vetted libraries!)

The Cryptosystem Stack

- Primitives:
  - AES / DES / etc
  - RSA / ElGamal / Elliptic Curve (ed25519)
- Modes:
  - Block modes (CBC, ECB, CTR, GCM, …)
  - Padding structures
- Protocols:
  - TLS / SSL / SSH / tc
- Usage of Protocols:
  - Browser security
  - Secure remote logins

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.

- Foreshadow: Need for randomness – the key to keep private

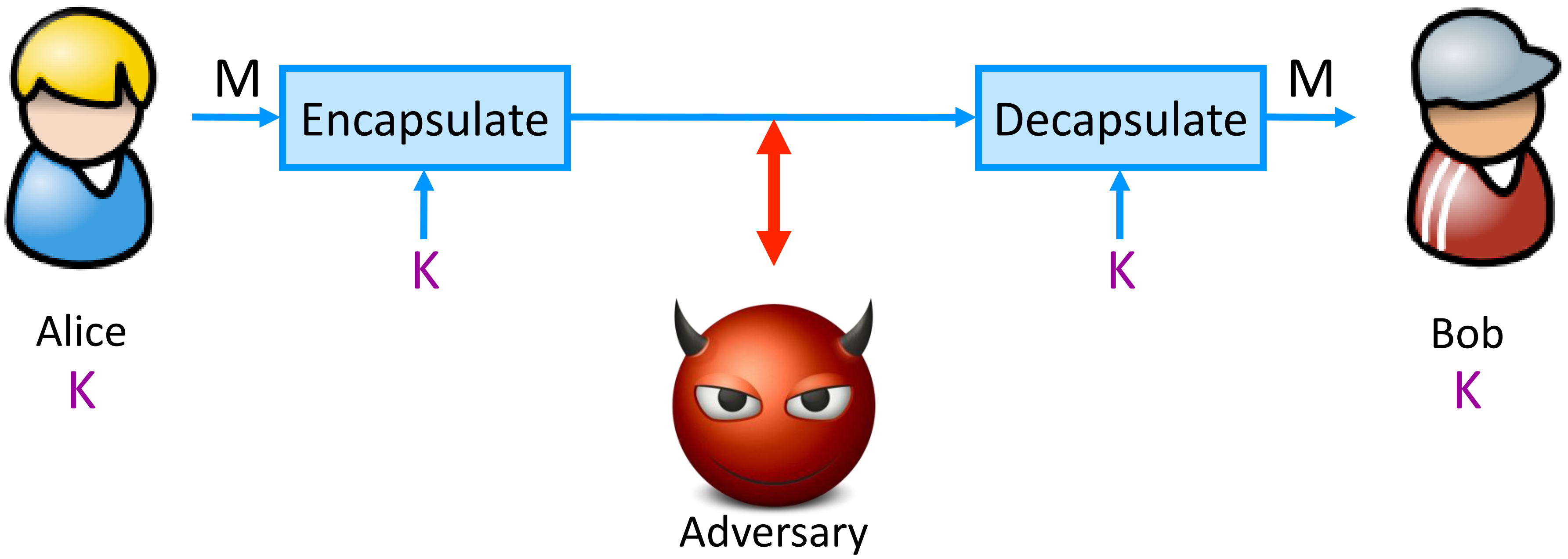
Flavors of Cryptography

- 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 Turing Award* ☺

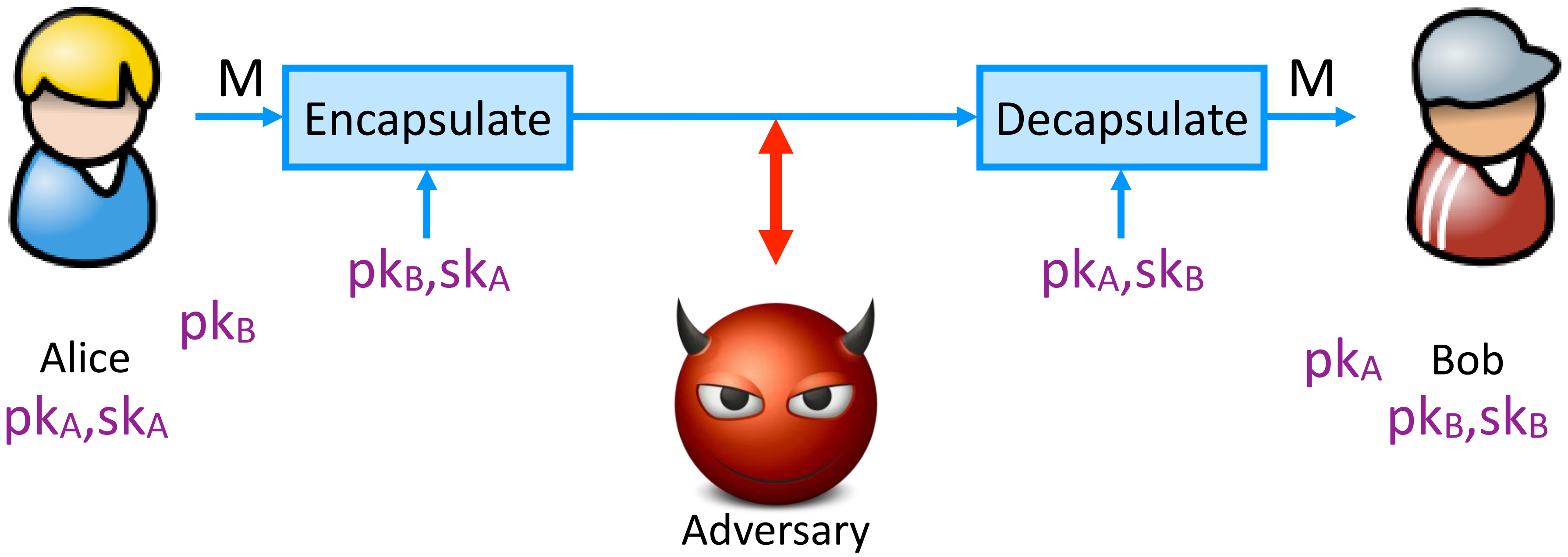
Symmetric Setting

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.



Properties of asymmetric cryptography

- We have a funny situation here:
  - Public keys are shared with everyone
  - Secret keys are not

- What is are some security properties we would want of:
  - Knowing a public key?
  - Encrypting a message with a secret key?

Public keys, Private keys, Secret keys…

- Secret key
  - The single key used in symmetric encryption
  - The non-public key in asymmetric
- Private keys
  - The non-public key in asymmetric
- Public key
  - The… public key in asymmetric
- Key
  - Generally means private/secret

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 – Gradescope!

- 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?

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 won't know and can't predict and can't figure out