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];
};
Closing basics of software security
Starting cryptography

Spring 2024

David Kohlbrenner
dkohlbre@cs

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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!)

• 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
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.

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

  - Ciphertext: WKHTX LFNEU RZQIR AMXPS VRYHU WKHOD CBGRJ

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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.

![Histogram of letter frequencies]

26! \approx 2^{88}

**Bigrams:**
- th 1.52%
- en 0.55%
- he 1.28%
- ed 0.53%
- in 0.94%
- to 0.52%
- er 0.94%
- it 0.50%
- an 0.82%
- ou 0.50%
- re 0.68%
- ea 0.47%
- nd 0.63%
- hi 0.46%

**Trigrams:**
- the 6.1%
- ion 1.1%
- and 7.1%
- tio 0.43%
- hai 8.04%
- for 1.3%
- tis 7.04%
- ent 9.0%
- nde 1.4%
- oft 5.86%
- has 1.5%
- sth 0.56%
  
- is 0.46%
- ar 0.57%
- ve 7.04%
- ra 8.05%
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
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
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• 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