CSE 486/586 Distributed Systems
Security --- 1

Steve Ko
Computer Sciences and Engineering
University at Buffalo

Security Threats

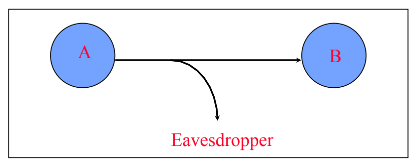
- Leakage: An unauthorized party gains access to a service or data.
  - Attacker obtains knowledge of a withdrawal or account balance
- Tampering: Unauthorized change of data, tampering with a service
  - Attacker changes the variable holding your personal checking $$ total
- Vandalism: Interference with proper operation, without gain to the attacker
  - Attacker does not allow any transactions to your account

Security Properties

- Confidentiality: Concealment of information or resources
- Authenticity: Identification and assurance of origin of info
- Integrity: Trustworthiness of data or resources in terms of preventing improper and unauthorized changes
- Availability: Ability to use desired info or resource
- Non-repudiation: Offer of evidence that a party indeed is sender or a receiver of certain information
- Access control: Facilities to determine and enforce who is allowed access to what resources (host, software, network, …)

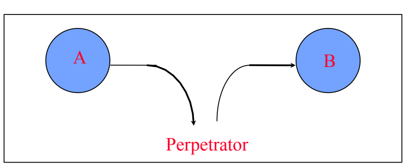
Attack on Confidentiality

- Eavesdropping
  - Unauthorized access to information
  - Packet sniffers and wiretappers (e.g. tcpdump)
  - Illicit copying of files and programs



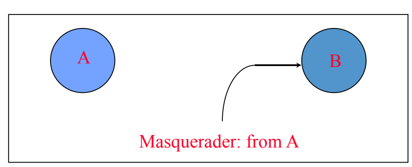
Attack on Integrity

- Tampering
  - Stop the flow of the message
  - Delay and optionally modify the message
  - Release the message again



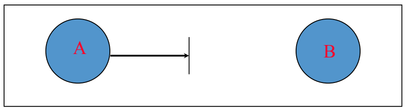
Attack on Authenticity

- Fabrication
  - Unauthorized assumption of other's identity
  - Generate and distribute objects under identity



Attack on Availability

- Destroy hardware (cutting fiber) or software
- Modify software in a subtle way
- Corrupt packets in transit
- Blatant *denial of service* (DoS):
  - Crashing the server
  - Overwhelm the server (use up its resource)



Designing Secure Systems

- Your system is only as secure as your weakest component!
- Need to make worst-case assumptions about attackers:
  - exposed interfaces, insecure networks, algorithms and program code available to attackers, attackers may be computationally very powerful
  - Tradeoff between security and performance impact/difficulty
  - Typically design system to withstand a known set of attacks (Attack Model or Attacker Model)
- It is not easy to design a secure system.
- And it's an arms race!

CSE 486/586 Administrivia

- CSE 622 Advanced Computer Systems
  - Probably on Android platform
  - Will be open for registration either today or tomorrow
- More practice problems & example final posted
- PhoneLab hiring
  - Testbed developer/administrator
- Anonymous feedback form still available.
- Please come talk to me!

Cryptography

- Comes from Greek word meaning "secret"
  - Primitives also can provide integrity, authentication
- Cryptographers invent secret codes to attempt to hide messages from unauthorized observers

plaintext $\xrightarrow{\textbf{encryption}}$ **ciphertext** $\xrightarrow{\textbf{decryption}}$ **plaintext**

- Modern encryption:
  - *Algorithm* public, *key* secret and provides security
  - May be symmetric (secret) or asymmetric (public)
- Cryptographic algorithms goal
  - Given key, relatively easy to compute
  - Without key, hard to compute (invert)
  - "Level" of security often based on "length" of key

Three Types of Functions

- Cryptographic hash Functions
  - Zero keys
- Secret-key functions
  - One key
- Public-key functions
  - Two keys

Cryptographic Hash Functions

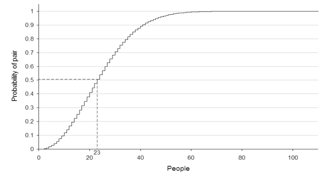
- Take message, m, of arbitrary length and produces a smaller (short) number, $h(m)$
- Properties
  - Easy to compute $h(m)$
  - Pre-image resistance: Hard to find an m, given $h(m)$
    - » *"One-way function"*
  - Second pre-image resistance: Hard to find two values that hash to the same $h(m)$
    - » *E.g.* discover collision: $h(m) == h(m')$ for $m != m'$
  - Often assumed: output of hash fn's "looks" random

How Hard to Find Collisions?

- Birthday paradox
  - In a set of *n* random people, what's the probability of two people having the same birthday?
- Calculation
  - Compute probability of *different* birthdays
  - Random sample of *n* people taken from *k*=365 days

Birthday Paradox

- Probability of no repetition:
  - *P = 1 – (1) (1 - 1/365) (1 – 2/365) (1 – 3/365) … (1 – (n-1)/ 365)*
  - *(k = # of slots, e.g., 365) P* ≈ $1 – e^{-(n(n-1)/2k}$
  - For *p*, it takes roughly sqrt(2k * ln(1/(1-p))) people to find two people with the same birthday.
- With p = 50%,



How Many Bits for Hash?

- If *m* bits, how many numbers do we need to find (weak) collision?
  - It's not 2^m!
  - It takes $2^{m/2}$ to find weak collision
  - Still takes 2^m to find strong (pre-image) collision
- 64 bits, takes 2^{32} messages to search
- MD5 (128 bits) considered too little
- SHA-1 (160 bits) getting old

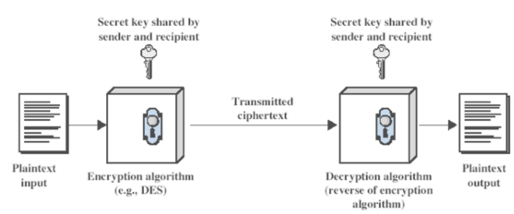
Example: Password

- Password hashing
  - Can't store passwords in a file that could be read
  - Concerned with insider attacks!
- Must compare typed passwords to stored passwords
  - Does hash (typed) === hash (password)?
- Actually, a salt is often used: hash (input || salt)
  - Avoids precomputation of all possible hashes in "rainbow tables" (available for download from file-sharing systems)

Symmetric (Secret) Key Crypto

- Also: "conventional / private-key / single-key"
  - Sender and recipient share a common key
  - All classical encryption algorithms are private-key
  - Dual use: confidentiality (encryption) or authentication/ integrity (message authentication code)
- Was only type of encryption prior to invention of public-key in 1970's
  - Most widely used
  - More computationally efficient than "public key"

Symmetric Cipher Model



Requirements

- Two requirements
  - Strong encryption algorithm
  - Secret key known only to sender/receiver
- Goal: Given key, generate 1-to-1 mapping to ciphertext that looks random if key unknown
  - Assume *algorithm* is known (no security by obscurity)
  - Implies secure channel to distribute key

Uses

- Encryption
  - For confidentiality
  - Sender: Compute $C = AES_K(M)$ & Send C
  - Receiver: Recover $M = AES'_K(C)$
- Message Authentication Code (MAC)
  - For integrity
  - Sender: Compute $H = AES_K(SHA1(M))$ & Send <M, H>
  - Receiver: Computer $H' = AES_K(SHA1(M))$ & Check H' == H

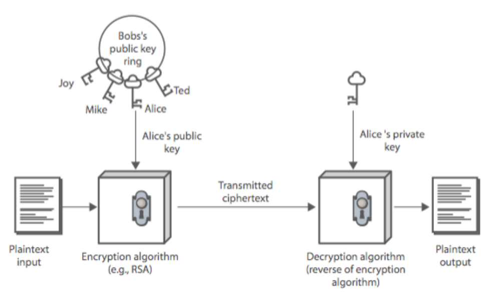
Public (Asymmetric) Key Crypto

- Developed to address two key issues
  - Key distribution: secure communication without having to trust a key distribution center with your key
  - Digital signature: verifying that a message comes from the claimed sender without prior establishment
- Public invention Diffie & Hellman in 1976
  - Known earlier to classified community

Public (Asymmetric) Key Crypto

- Involves two keys
  - Public key: can be known to anybody, used to encrypt and verify signatures
  - Private key: should be known only to the recipient, used to decrypt and sign signatures
- Asymmetric
  - Can encrypt messages or verify signatures w/o ability to decrypt msgs or create signatures
  - If "one-way function" goes $c \leftarrow F(m)$, then public-key encryption is a "trap-door" function:
    - » Easy to compute $c \leftarrow F(m)$
    - » Hard to compute $m \leftarrow F^{-1}(c)$ without knowing k
    - » Easy to compute $m \leftarrow F^{-1}(c,k)$ by knowing k

Public (Asymmetric) Key Crypto



Security of Public Key Schemes

- Like private key schemes, brute force search possible
  - But keys used are too large (e.g., >= 1024 bits)
- Security relies on a difference in computational difficulty b/w easy and hard problems
  - RSA: exponentiation in composite group vs. factoring
  - ElGamal/DH: exponentiation vs. discrete logarithm in prime group
  - Hard problems are known, but computationally expensive
- Requires use of very large numbers
  - Hence is slow compared to private key schemes
  - RSA-1024: 80 us / encryption; 1460 us / decryption [cryptopp.com]
  - AES-128: 109 MB / sec = 1.2us / 1024 bits

(Simple) RSA Algorithm

- Security due to cost of factoring large numbers
  - Factorization takes $O(e^{\log n \log \log n})$ operations (hard)
  - Exponentiation takes $O((\log n)^3)$ operations (easy)
- To encrypt a message M the sender:
  - Obtain public key {e,n}; compute $C = M^e \bmod n$
- To decrypt the ciphertext C the owner:
  - Use private key {d,n}; computes $M = C^d \bmod n$
- Note that msg M must be smaller than the modulus n
- Otherwise, hybrid encryption:
  - Generate random symmetric key *r*
  - Use public key encryption to encrypt *r*
  - Use symmetric key encryption under *r* to encrypt *M*

Typical Applications

- Secure digest
  - A fixed-length that characterizes an arbitrary-length message
  - Typically produced by cryptographic hash functions, e.g., SHA-1 or MD5.
- Digital signature
  - Verifies a message or a document is an unaltered copy of one produced by the signer
  - Signer: compute H = RSA_K(SHA1(M)) & send <M, H>
  - Verifier: compute H' = SHA1(M) & verify $RSA_{K'}$(H) == H'
- MAC (Message Authentication Code)
  - Digital signatures with secret keys
  - Verifies the authenticity of a message
  - Sender: compute H = AES_K(SHA1 (M)) & send <M, H>
  - Receiver: computer H' = AES_K(SHA1 (M)) & check H' == H

Summary

- Security properties
  - Confidentiality, authenticity, integrity, availability, non-repudiation, access control
- Three types of functions
  - Cryptographic hash, symmetric key crypto, asymmetric key crypto
- Applications
  - Secure digest, digital signature, MAC, digital certificate

Acknowledgements

- These slides contain material developed and copyrighted by Indranil Gupta (UIUC), Jennifer Rexford (Princeton) and Michael Freedman (Princeton).