CS162
Operating Systems and Systems Programming
Lecture 25

Protection and Security in Distributed Systems

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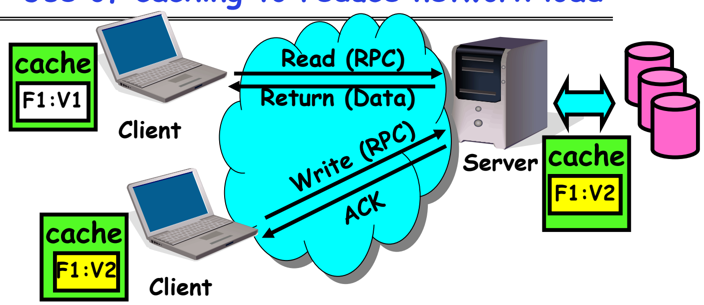
Review: Testing

- Testing Goals
  - Reveal faults
  - Clarify Specification
- Testing Frameworks:
  - Provide mechanism for applying tests (driver), checking results, reporting problems
  - Oracle: simpler version of code for testing outputs
  - Assertions: Documents (and checks) important invariants
- Levels of Tests:
  - Unit testing: per module
  - Integration Testing: tying modules together
  - Code Inspections:
    - » One person explains to others how a piece of code works
    - » Finds 70%-90% of bugs
  - Regression Testing: making sure bugs don't reappear
    - » When you find a bug, Write a test that exhibits the bug,
    - » And always run that test when the code changes

Review: Use of caching to reduce network load

read(f1)→V1
read(f1)→V1
read(f1)→V1
read(f1)→V1

write(f1)→OK
read(f1)→V2



- Idea: Use caching to reduce network load
  - In practice: use buffer cache at source and destination
- Advantage: if open/read/write/close can be done locally, don't need to do any network traffic…fast!
- Problems:
  - Failure:
    - » Client caches have data not committed at server
  - Cache consistency!
    - » Client caches not consistent with server/each other

Goals for Today

- Finish discussing distributed file systems/Caching
- Security Mechanisms
  - Authentication
  - Authorization
  - Enforcement
- Cryptographic Mechanisms

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne. Many slides generated from my lecture notes by Kubiatowicz.

Network File System (NFS)

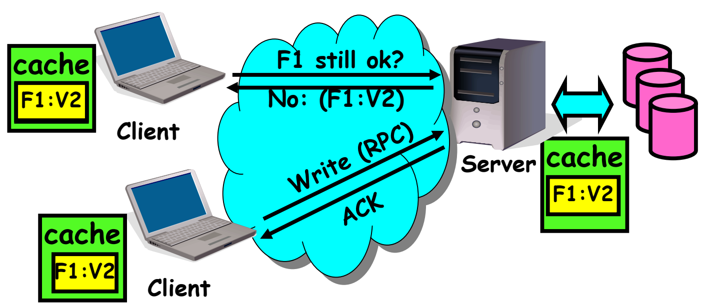
- Three Layers for NFS system
  - UNIX file-system interface: open, read, write, close calls + file descriptors
  - VFS layer: distinguishes local from remote files
    - » Calls the NFS protocol procedures for remote requests
  - NFS service layer: bottom layer of the architecture
    - » Implements the NFS protocol
- NFS Protocol: RPC for file operations on server
  - Reading/searching a directory
  - manipulating links and directories
  - accessing file attributes/reading and writing files
- Write-through caching: Modified data committed to server's disk before results are returned to the client
  - lose some of the advantages of caching
  - time to perform write() can be long
  - Need some mechanism for readers to eventually notice changes! (more on this later)

NFS Continued

- NFS servers are stateless; each request provides all arguments require for execution
  - E.g. reads include information for entire operation, such as `ReadAt(inumber,position)`, not `Read(openfile)`
  - No need to perform network open() or close() on file – each operation stands on its own
- Idempotent: Performing requests multiple times has same effect as performing it exactly once
  - Example: Server crashes between disk I/O and message send, client resend read, server does operation again
  - Example: Read and write file blocks: just re-read or re-write file block – no side effects
  - Example: What about "remove"? NFS does operation twice and second time returns an advisory error
- Failure Model: Transparent to client system
  - Is this a good idea? What if you are in the middle of reading a file and server crashes?
  - Options (NFS Provides both):
    - » Hang until server comes back up (next week?)
    - » Return an error. (Of course, most applications don't know they are talking over network)

NFS Cache consistency

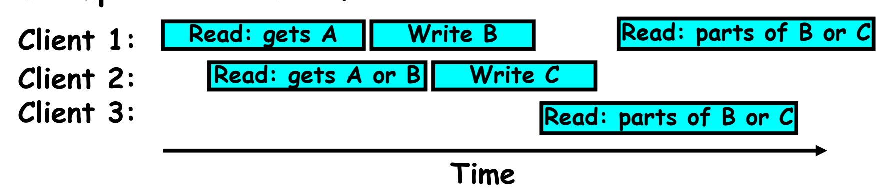
- NFS protocol: weak consistency
  - Client polls server periodically to check for changes
    - » Polls server if data hasn't been checked in last 3-30 seconds (exact timeout it tunable parameter).
    - » Thus, when file is changed on one client, server is notified, but other clients use old version of file until timeout.



  - What if multiple clients write to same file?
    - » In NFS, can get either version (or parts of both)
    - » Completely arbitrary!

Sequential Ordering Constraints

- What sort of cache coherence might we expect?
  - i.e. what if one CPU changes file, and before it's done, another CPU reads file?
- Example: Start with file contents = "A"



- What would we actually want?
  - Assume we want distributed system to behave exactly the same as if all processes are running on single system
    - » If read finishes before write starts, get old copy
    - » If read starts after write finishes, get new copy
    - » Otherwise, get either new or old copy
  - For NFS:
    - » If read starts more than 30 seconds after write, get new copy; otherwise, could get partial update

NFS Pros and Cons

- NFS Pros:
  - Simple, Highly portable
- NFS Cons:
  - Sometimes inconsistent!
  - Doesn't scale to large # clients
    - » Must keep checking to see if caches out of date
    - » Server becomes bottleneck due to polling traffic

Andrew File System

- Andrew File System (AFS, late 80's) → DCE DFS (commercial product)
- Callbacks: Server records who has copy of file
  - On changes, server immediately tells all with old copy
  - No polling bandwidth (continuous checking) needed
- Write through on close
  - Changes not propagated to server until close()
  - Session semantics: updates visible to other clients only after the file is closed
    - » As a result, do not get partial writes: all or nothing!
    - » Although, for processes on local machine, updates visible immediately to other programs who have file open
- In AFS, everyone who has file open sees old version
  - Don't get newer versions until reopen file

Andrew File System (con't)

- Data cached on local disk of client as well as memory
  - On open with a cache miss (file not on local disk):
    - » Get file from server, set up callback with server
  - On write followed by close:
    - » Send copy to server; tells all clients with copies to fetch new version from server on next open (using callbacks)
- What if server crashes? Lose all callback state!
  - Reconstruct callback information from client: go ask everyone "who has which files cached?"
- AFS Pro: Relative to NFS, less server load:
  - Disk as cache ⇒ more files can be cached locally
  - Callbacks ⇒ server not involved if file is read-only
- For both AFS and NFS: central server is bottleneck!
  - Performance: all writes→server, cache misses→server
  - Availability: Server is single point of failure
  - Cost: server machine's high cost relative to workstation

Administrivia

- Project 4 design document
  - Due Tomorrow (November 28th
- MIDTERM II: Monday December 4th!
  - 4:00-7:00pm, 10 Evans
  - All material from last midterm and up to previous class
  - Includes virtual memory
  - One page of handwritten notes, both sides
- Final Exam
  - December 16th,8:00-11:00, Bechtel Auditorium
  - Covers whole course
  - Two pages of handwritten notes, both sides
- Final Topics: Any suggestions?

World Wide Web

- Key idea: graphical front-end to RPC protocol
- What happens when a web server fails?
  - System breaks!
  - Solution: Transport or network-layer redirection
    - » Invisible to applications
    - » Can also help with scalability (load balancers)
    - » Must handle "sessions" (e.g., banking/e-commerce)
- Initial version: no caching
  - Didn't scale well – easy to overload servers

WWW Caching

- Use client-side caching to reduce number of interactions between clients and servers and/or reduce the size of the interactions:
  - Time-to-Live (TTL) fields – HTTP "Expires" header from server
  - Client polling – HTTP "If-Modified-Since" request headers from clients
  - Server refresh – HTML "META Refresh tag" causes periodic client poll
- What is the polling frequency for clients and servers?
  - Could be adaptive based upon a page's age and its rate of change
- Server load is still significant!

WWW Proxy Caches

- Place caches in the network to reduce server load
  - But, increases latency in lightly loaded case
  - Caches near servers called "reverse proxy caches"
    - » Offloads busy server machines
  - Caches at the "edges" of the network called "content distribution networks"
    - » Offloads servers and reduce client latency
- Challenges:
  - Caching static traffic easy, but only ~40% of traffic
  - Dynamic and multimedia is harder
    - » Multimedia is a big win: Megabytes versus Kilobytes
  - Same cache consistency problems as before
- Caching is changing the Internet architecture
  - Places functionality at higher levels of comm. protocols

Protection vs Security

- Protection: one or more mechanisms for controlling the access of programs, processes, or users to resources
  - Page Table Mechanism
  - File Access Mechanism
- Security: use of protection mechanisms to prevent misuse of resources
  - Misuse defined with respect to policy
    - » E.g.: prevent exposure of certain sensitive information
    - » E.g.: prevent unauthorized modification/deletion of data
  - Requires consideration of the external environment within which the system operates
    - » Most well-constructed system cannot protect information if user accidentally reveals password
- What we hope to gain today and next time
  - Conceptual understanding of how to make systems secure
  - Some examples, to illustrate why providing security is really hard in practice

Preventing Misuse

- Types of Misuse:
  - Accidental:
    - » If I delete shell, can't log in to fix it!
    - » Could make it more difficult by asking: "do you really want to delete the shell?"
  - Intentional:
    - » Some high school brat who can't get a date, so instead he transfers $3 billion from B to A.
    - » Doesn't help to ask if they want to do it (of course!)
- Three Pieces to Security
  - Authentication: who the user actually is
  - Authorization: who is allowed to do what
  - Enforcement: make sure people do only what they are supposed to do
- Loopholes in any carefully constructed system:
  - Log in as superuser and you've circumvented authentication
  - Log in as self and can do anything with your resources; for instance: run program that erases all of your files
  - Can you trust software to correctly enforce Authentication and Authorization?????

Authentication: Identifying Users

- How to identify users to the system?
  - Passwords
    - » Shared secret between two parties
    - » Since only user knows password, someone types correct password ⇒ must be user typing it
    - » Very common technique
  - Smart Cards
    - » Electronics embedded in card capable of providing long passwords or satisfying challenge → response queries
    - » May have display to allow reading of password
    - » Or can be plugged in directly; several credit cards now in this category

  - Biometrics
    - » Use of one or more intrinsic physical or behavioral traits to identify someone
    - » Examples: fingerprint reader, palm reader, retinal scan
    - » Becoming quite a bit more common

Passwords: Secrecy

- System must keep copy of secret to check against passwords
  - What if malicious user gains access to list of passwords?
    - » Need to obscure information somehow
  - Mechanism: utilize a transformation that is difficult to reverse without the right key (e.g. encryption)
- Example: UNIX /etc/passwd file
  - passwd→one way transform(hash)→encrypted passwd
  - System stores only encrypted version, so OK even if someone reads the file!
  - When you type in your password, system compares encrypted version
- Problem: Can you trust encryption algorithm?
  - Example: one algorithm thought safe had back door
    - » Governments want back door so they can snoop
  - Also, security through obscurity doesn't work
    - » GSM encryption algorithm was secret; accidentally released; Berkeley grad students cracked in a few hours

Passwords: How easy to guess?

- Ways of Compromising Passwords
  - Password Guessing:
    - » Often people use obvious information like birthday, favorite color, girlfriend's name, etc…
  - Dictionary Attack:
    - » Work way through dictionary and compare encrypted version of dictionary words with entries in /etc/passwd
  - Dumpster Diving:
    - » Find pieces of paper with passwords written on them
    - » (Also used to get social-security numbers, etc)
- Paradox:
  - Short passwords are easy to crack
  - Long ones, people write down!
- Technology means we have to use longer passwords
  - UNIX initially required lowercase, 5-letter passwords: total of 26^5=10million passwords
    - » In 1975, 10ms to check a password→1 day to crack
    - » In 2005, .01μs to check a password→0.1 seconds to crack
  - Takes less time to check for all words in the dictionary!

Passwords: Making harder to crack

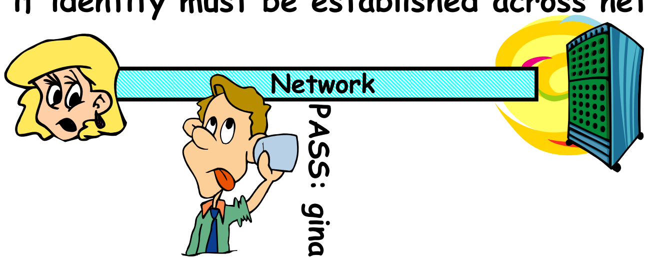
- How can we make passwords harder to crack?
  - Can't make it impossible, but can help
- Technique 1: Extend everyone's password with a unique number (stored in password file)
  - Called "salt". UNIX uses 12-bit "salt", making dictionary attacks 4096 times harder
  - Without salt, would be possible to pre-compute all the words in the dictionary hashed with the UNIX algorithm: would make comparing with /etc/passwd easy!
  - Also, way that salt is combined with password designed to frustrate use of off-the-shelf DES hardware
- Technique 2: Require more complex passwords
  - Make people use at least 8-character passwords with upper-case, lower-case, and numbers
    - » $70^8 = 6\times10^{14}$=6million seconds=69 days@0.01μs/check
  - Unfortunately, people still pick common patterns
    - » e.g. Capitalize first letter of common word, add one digit

Passwords: Making harder to crack (con't)

- Technique 3: Delay checking of passwords
  - If attacker doesn't have access to /etc/passwd, delay every remote login attempt by 1 second
  - Makes it infeasible for rapid-fire dictionary attack
- Technique 4: Assign very long passwords
  - Long passwords or pass-phrases can have more entropy (randomness→harder to crack)
  - Give everyone a smart card (or ATM card) to carry around to remember password
    - » Requires physical theft to steal password
    - » Can require PIN from user before authenticates self
  - Better: have smartcard generate pseudorandom number
    - » Client and server share initial seed
    - » Each second/login attempt advances to next random number
- Technique 5: "Zero-Knowledge Proof"
  - Require a series of challenge-response questions
    - » Distribute secret algorithm to user
    - » Server presents a number, say "5"; user computes something from the number and returns answer to server
    - » Server never asks same "question" twice
  - Often performed by smartcard plugged into system

Authentication in Distributed Systems

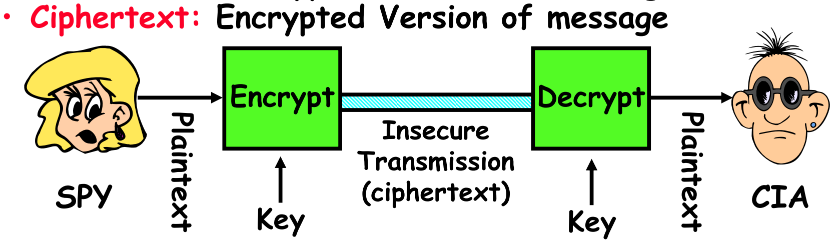
- What if identity must be established across network?



  - Need way to prevent exposure of information while still proving identity to remote system
  - Many of the original UNIX tools sent passwords over the wire "in clear text"
    - » E.g.: telnet, ftp, yp (yellow pages, for distributed login)
    - » Result: Snooping programs widespread
- What do we need? Cannot rely on physical security!
  - Encryption: Privacy, restrict receivers
  - Authentication: Remote Authenticity, restrict senders

Private Key Cryptography

- Private Key (Symmetric) Encryption:
  - Single key used for both encryption and decryption
- Plaintext: Unencrypted Version of message
- Ciphertext: Encrypted Version of message

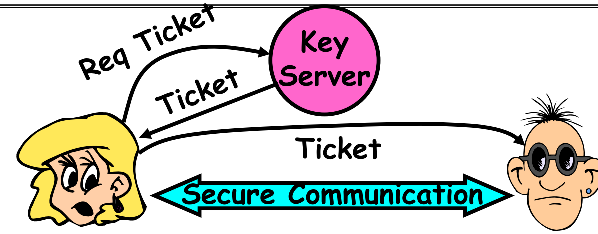


- Important properties
  - Can't derive plain text from ciphertext (decode) without access to key
  - Can't derive key from plain text and ciphertext
  - As long as password stays secret, get both secrecy and authentication
- Symmetric Key Algorithms: DES, Triple-DES, AES

Key Distribution

- How do you get shared secret to both places?
  - For instance: how do you send authenticated, secret mail to someone who you have never met?
  - Must negotiate key over private channel
    - » Exchange code book
    - » Key cards/memory stick/others
- Third Party: Authentication Server (like Kerberos)
  - Notation:
    - » K_{xy} is key for talking between x and y
    - » $(\ldots)^K$ means encrypt message (…) with the key K
    - » Clients: A and B, Authentication server S
  - A asks server for key:
    - » A→S: [Hi! I'd like a key for talking between A and B]
    - » Not encrypted. Others can find out if A and B are talking
  - Server returns *session* key encrypted using B's key
    - » S→A: Message [Use K_{ab} (This is A! Use K_{ab})^{Ksb}] ^{Ksa}
    - » This allows A to know, "S said use this key"
  - Whenever A wants to talk with B
    - » A→B: Ticket [This is A! Use K_{ab}]^{Ksb}
    - » Now, B knows that K_{ab} is sanctioned by S

Authentication Server Continued



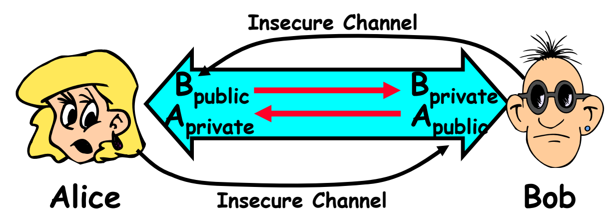
- Details
  - Both A and B use passwords (shared with key server) to decrypt return from key servers
  - Add in timestamps to limit how long tickets will be used to prevent attacker from replaying messages later
  - Also have to include encrypted checksums (hashed version of message) to prevent malicious user from inserting things into messages/changing messages
  - Want to minimize # times A types in password
    - » A→S (Give me temporary secret)
    - » S→A (Use $K_{temp\text{-}sa}$ for next 8 hours)^{Ksa}
    - » Can now use $K_{temp\text{-}sa}$ in place of K_{sa} in prototcol

Public Key Encryption

- Can we perform key distribution without an authentication server?
  - Yes. Use a Public-Key Cryptosystem.
- Public Key Details
  - Don't have one key, have two: K_{public}, $K_{private}$
    - » Two keys are mathematically related to one another
    - » Really hard to derive K_{public} from $K_{private}$ and vice versa
  - Forward encryption:
    - » Encrypt: $(\text{cleartext})^{Kpublic} = \text{ciphertext}_1$
    - » Decrypt: $(\text{ciphertext}_1)^{Kprivate} = \text{cleartext}$
  - Reverse encryption:
    - » Encrypt: $(\text{cleartext})^{Kprivate} = \text{ciphertext}_2$
    - » Decrypt: $(\text{ciphertext}_2)^{Kpublic} = \text{cleartext}$
  - Note that $\text{ciphertext}_1 \neq \text{ciphertext}_2$
    - » Can't derive one from the other!
- Public Key Examples:
  - RSA: Rivest, Shamir, and Adleman
    - » K_{public} of form (k_{public}, N), $K_{private}$ of form ($k_{private}$, N)
    - » N = pq. Can break code if know p and q
  - ECC: Elliptic Curve Cryptography

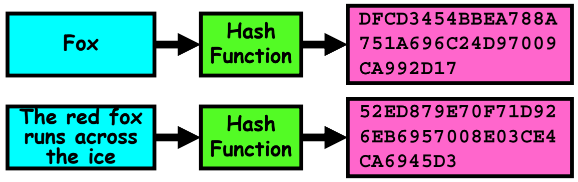
Public Key Encryption Details

- Idea: K_{public} can be made public, keep $K_{private}$ private



- Gives message privacy (restricted receiver):
  - Public keys (secure destination points) can be acquired by anyone/used by anyone
  - Only person with private key can decrypt message
- What about authentication?
  - Use combination of private and public key
  - Alice→Bob: [(I'm Alice)^{Aprivate} Rest of message]^{Bpublic}
  - Provides restricted sender and receiver
- But: how does Alice know that it was Bob who sent her B_{public}? And vice versa…

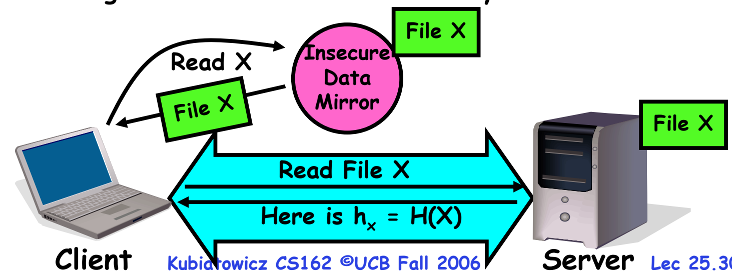
Secure Hash Function



- Hash Function: Short summary of data (message)
  - For instance, $h_1=H(M_1)$ is the hash of message M_1
    - » h_1 fixed length, despite size of message M_1.
    - » Often, h_1 is called the "digest" of M_1.
- Hash function H is considered secure if
  - It is infeasible to find M_2 with $h_1=H(M_2)$; ie. can't easily find other message with same digest as given message.
  - It is infeasible to locate two messages, m_1 and m_2, which "collide", i.e. for which $H(m_1) = H(m_2)$
  - A small change in a message changes many bits of digest/can't tell anything about message given its hash

Use of Hash Functions

- Several Standard Hash Functions:
  - MD5: 128-bit output
  - SHA-1: 160-bit output
- Can we use hashing to securely reduce load on server?
  - Yes. Use a series of insecure mirror servers (caches)
  - First, ask server for digest of desired file
    - » Use secure channel with server
  - Then ask mirror server for file
    - » Can be insecure channel
    - » Check digest of result and catch faulty or malicious mirrors



Signatures/Certificate Authorities

- Can use X_{public} for person X to define their identity
  - Presumably they are the only ones who know $X_{private}$.
  - Often, we think of X_{public} as a "principle" (user)
- Suppose we want X to sign message M?
  - Use private key to encrypt the digest, i.e. $H(M)^{Xprivate}$
  - Send both M and its signature:
    - » Signed message = $[M, H(M)^{Xprivate}]$
  - Now, anyone can verify that M was signed by X
    - » Simply decrypt the digest with X_{public}
    - » Verify that result matches H(M)
- Now: How do we know that the version of X_{public} that we have is really from X???
  - Answer: Certificate Authority
    - » Examples: Verisign, Entrust, Etc.
  - X goes to organization, presents identifying papers
    - » Organization signs X's key: $[X_{public}, H(X_{public})^{CAprivate}]$
    - » Called a "Certificate"
  - Before we use X_{public}, ask X for certificate verifying key
    - » Check that signature over X_{public} produced by trusted authority
- How do we get keys of certificate authority?
  - Compiled into your browser, for instance!

Conclusion

- User Identification
  - Passwords/Smart Cards/Biometrics
- Passwords
  - Encrypt them to help hid them
  - Force them to be longer/not amenable to dictionary attack
  - Use zero-knowledge request-response techniques
- Distributed identity
  - Use cryptography
- Symmetrical (or Private Key) Encryption
  - Single Key used to encode and decode
  - Introduces key-distribution problem
- Public-Key Encryption
  - Two keys: a public key and a private key
    - » Not derivable from one another
- Secure Hash Function
  - Used to summarize data
  - Hard to find another block of data with same hash