Distributed Systems

13C. Distributed Systems: Security
13I. Secure sessions
13D. Distributed Systems: Synchronization
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How does the OS ensure security?

- all key resources are kept inside of the OS
  - protected by hardware (mode, memory management)
  - processes cannot access them directly
- all users are authenticated to the OS
  - by a trusted agent that is (essentially) part of the OS
- all access control decisions are made by the OS
  - the only way to access resources is through the OS
  - we trust the OS to ensure privacy and proper sharing
- what if key resources could not be kept in OS?

Network Security – things get worse

- the OS cannot guarantee privacy and integrity
  - network transactions happen outside of the OS
- authentication
  - all possible agents may not be in local password file
- "man-in-the-middle" attacks
  - wire connecting the user to the system is insecure
- systems are open to vandalism and espionage
  - many systems are purposely open to the public
  - even supposedly private systems may be on internet

Man-in-the-Middle Attacks

- assume someone watching all network traffic
  - your traffic is being routed through many machines
  - most internet traffic is not encrypted
  - snooping utilities are widely available
  - passwords may be sent in clear text
- assume someone can forge messages from you
  - your traffic is being routed through many machines
  - some of them may be owned by bad people
  - they can hijack connection after you log in
  - they can replay previous messages, forge new ones

Goals of Network Security

- secure conversations
  - privacy: only you and your partner know what is said
  - integrity: nobody can tamper with your messages
- positive identification of both parties
  - authentication of the identity of message sender
  - assurance that a message is not a replay or forgery
  - non-repudiation: he cannot claim "I didn't say that"
- they must be assured in an insecure environment
  - messages are exchanged over public networks
  - messages are filtered through private computers

Elements of Network Security

- simple symmetric encryption
  - can be used to ensure both privacy and integrity
- cryptographic hashes
  - powerful tamper detection
- public key encryption
  - basis for modern digital privacy and authentication
- digital signatures and public key certificates
  - powerful tools to authenticate a message's sender
- delegated authority
  - enabling us to trust a stranger's credentials

A Principle of Key Use

- Both symmetric and PK crypto require secret keys
  - if key gets out, we lose both privacy and authentication
- The more you use a key, the less secure it becomes
  - the key stays around in various places longer
  - there are more opportunities for an attacker to get it
  - there is more incentive for attacker to get it
  - given enough time, any key can be brute forced
- Therefore:
  - use a given key as little as possible , change them often
  - the longer you keep it, the less you should use it

Practical Public Key Encryption

- Public Key Encryption algorithms are expensive
  - 10x to 100x as expensive as symmetric ones
  - key distribution is also complex and expensive
- We should use PKE as little as possible
  - for initial authentication/validation
  - to negotiate/exchange symmetric session keys
- Communication should use symmetric encryption
  - use short-lived, disposable, session keys
  - much less expensive to encrypt/decrypt

Symmetric *and* Asymmetric Encryption

- Use asymmetric to start the session
  - e.g. RSA or other Public Key mechanism
  - authenticate the parties
  - securely establish initial session key
- Use symmetric encryption for the session
  - e.g. DES or AES
  - very efficient algorithm based on negotiated key
- Periodically move to new session key
  - e.g. sequence based on initial session key
  - e.g. "switch to new key" message

example: Secure Socket Layer

- establishes secure two-way communication
  - privacy – nobody can snoop on conversation
  - integrity – nobody can generate fake messages
- certificate based authentication of server
  - client knows what server he is talking to
- optional certificate based authentication of client
  - if server requires authentication and non-repudiation
- uses PK to negotiate symmetric session keys
  - safety of public key, efficiency of symmetric

SSL session establishment

CLIENT → SERVER: algorithm selection, and random string A

SERVER → CLIENT: algorithm selection, and random string B

SERVER → CLIENT: server's Public Key certificate

CLIENT:
validate server's certificate
generate random string C
encrypt C with server's public key

CLIENT → SERVER: encrypted string C

CLIENT:
compute F(A,B,C)
use result to generate session keys

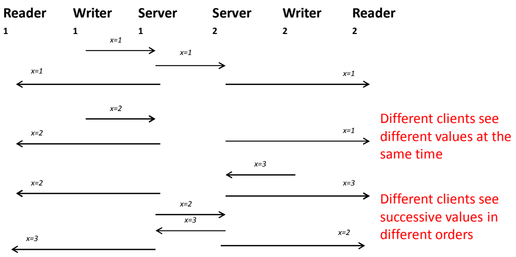
SERVER:
decrypt C with server's Private key
compute F(A,B,C)
use result to generate session keys

CLIENT ↔ SERVER: subsequent communication encrypted w/symmetric session keys

Distributed Synchronization

- spatial separation
  - different processes run on different systems
  - no shared memory for (atomic instruction) locks
  - they are controlled by different operating systems
- temporal separation
  - can't "totally order" spatially separated events
  - before/simultaneous/after lose their meaning
- independent modes of failure
  - one partner can die, while others continue

Distributed Temporal Separation



1. The system does not have a scalar state. State is a vector.
2. There is no total ordering; There are only partial orderings.

Distributed Locking - Leases

- Synchronization must be centralized
  - a single server is responsible for issuing locks
  - traditional mechanisms can ensure atomicity
  - locks should be managed with message exchanges
- Authorization must be distributed
  - lock servers issue signed "cookies"
  - servers verify cookies before performing requests
- Client failures must be recoverable
  - locks automatically expire after lease time
  - automatic preemption prevents deadlock

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Leases and Enforcement

- all requests are exchanged via messages
  - in general, all resources are on other nodes
  - client does not have direct access to resources
- each request includes a lease "cookie"
  - from resource manager (possibly signed)
  - identifies client, resource, and lease period
  - lease automatically expires at end of period
- validate cookies before performing operation
  - requests with *stale cookies* should be rejected
- handles a wide range of failures
  - process, client node, server node, network

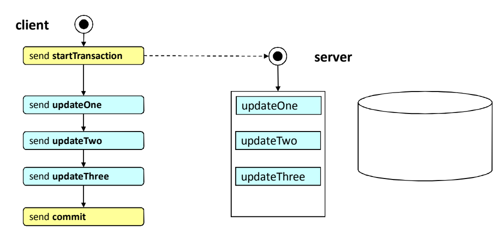
Lock Breaking and Recovery

- revoking an expired lease is fairly easy
  - lease cookie includes a "good until" time
  - any operation involving a "stale cookie" fails
- this makes it safe to issue a new lease
  - old lease-holder can no longer access object
  - was object left in a "reasonable" state?
- object must be restored to last "good" state
  - roll back to state prior to the aborted lease
  - implement all-or-none transactions

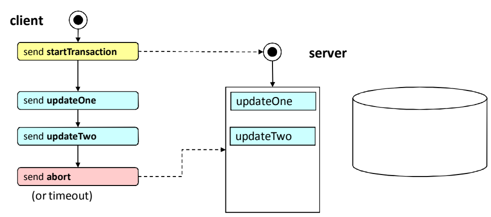
Atomic Transactions

- guaranteed uninterrupted, all-or-none execution
- solves multiple-update race conditions
  - all updates are made part of a transaction
    - updates are journaled, but not actually made
  - after all updates are made, transaction is committed
  - otherwise the transaction is aborted
    - e.g. if client, server, or network fails before the commit
- resource manager guarantees "all-or-none"
  - even if it crashes in the middle of the updates
  - journal can be replayed during recovery

Successful Atomic Transaction



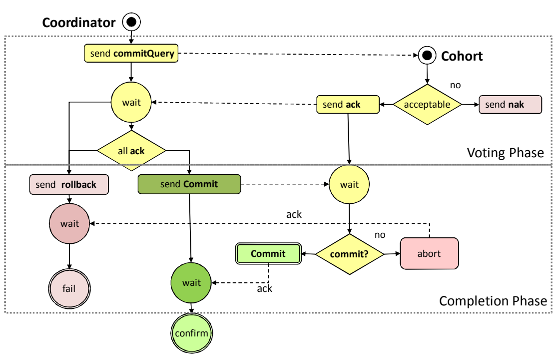
Aborted Atomic Transaction



Distributed Atomic Transactions

- single node transactions are simple: all or none
  - we ack after journaling the commit
  - if it is in the journal, it happened
  - if it is not in the journal, it did not happen
- single node transactions are not durable
  - disk or node failure can lose previously saved data
  - we need to persist transactions to multiple nodes
- multi-node transactions have new failure modes
  - one node saw the commit, another node did not
  - after recovery different journals may not agree
  - we need more powerful commitment protocols

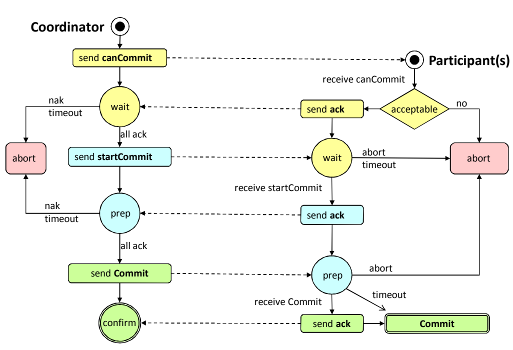
Two Phase Commit



Two Phase Commit – Limitations

- It achieves consensus
  - transaction only succeeds if cohort agrees
- It achieves all or none atomicity
  - all resources locked from proposal to commit
- It is subject to unbounded delays
  - cohort is blocked if coord fails after they ack
    - locks are held until commit or abort
  - coord cannot recover w/o entire cohort present
    - failed member might have been only one to commit

Three Phase Commit



Three Phase Commit

- First phase is only a proposal
  - any cohort member can reject this proposal
  - if it times out, transaction is aborted
- Second phase is preparation to commit
  - all cohort has already agreed to proposal
  - **startCommit** announces intention to go forward
  - if it times out, cohort will go forward w/commit
- Third phase is the actual commit & confirmation
  - it can still be aborted by the coordinator
  - but the default (e.g. on timeout) is to commit
  - confirm from coordinator means all cohort agree

Three Phase Commit – Limitations

- It achieves consensus
  - transaction only succeeds if cohort agrees
- It achieves all or none atomicity
  - all resources locked from proposal to commit
- It is non-blocking
  - automatically commit or abort after timeout
- It can tolerate node failures
  - but it cannot tolerate network partitioning

Summary

- Distributed Consensus is difficult
  - the protocols are complex
- Crash recovery is complicated
  - no single node's journal can be trusted
  - we must union and compare all nodes' journals
- There are robust consensus protocols
  - they are extremely complex
  - they trade-off availability vs. partition tolerance

Commitment Protocols

- used to implement distributed commitment
  - provide for atomic all-or-none transactions
  - simultaneous commitment on multiple hosts
- challenges
  - asynchronous conflicts from other hosts
  - nodes fail in the middle of the commitment process
- multi-phase commitment protocol:
  - Confirm no conflicts from any participating host.
  - All participating hosts are told to prepare for commit.
  - All participating hosts are told to "make it so".

Distributed Consensus

- achieving simultaneous, unanimous agreement
  - even in the presence of node & network failures
  - required: agreement, termination, validity, integrity
  - desired: bounded time
- consensus algorithms tend to be complex
  - and may take a long time to converge
- they tend to be used sparingly
  - e.g. use consensus to elect a leader
  - who makes all subsequent decisions by fiat

Typical Consensus Algorithm

1. Each interested member broadcasts his nomination.
2. All parties evaluate the received proposals according to a <u>fixed and well known</u> rule.
3. After allowing a reasonable time for proposals, each voter acknowledges the best proposal it has seen.
4. If a proposal has a majority of the votes, the proposing member broadcasts a claim that the question has been resolved.
5. Each party that agrees with the winner's claim acknowledges the announced resolution.
6. Election is over when a quorum acknowledges the result.

Remote Data Access: Goals

- Transparency
  - indistinguishable from local files for <u>all</u> uses
  - all clients see all files from anywhere
- Performance
  - per-client: at least as fast as local disk
  - scalability: unaffected by the number of clients
- Cost
  - capital: less than local (per client) disk storage
  - operational: zero, it requires no administration
- Capacity: unlimited, it is never full
- Availability: 100%, no failures or down-time

Remote Data Access: Challenges

- Transparency
  - despite Deutch's warnings
  - creating global file name-spaces
- Security
  - despite insecure networks and heterogeneous systems
- Preserving ACID semantics, Posix consistency
  - despite lack of shared memory and atomic instructions
- Performance
  - despite everything being done with messages
- Reliability and Scalability
  - despite having more parts and modes of failure

Key Characteristics of Solutions

- APIs and Transparency
  - how do users and processes access remote files
  - how closely do remote files mimic local files
- Performance and Robustness
  - are remote files as fast and reliable as local ones
- Architecture
  - how is solution integrated into clients and servers
- Protocol and Work Partitioning
  - what messages exchanged, who does what work

Client/Server Models

- Peer-to-Peer
  - most systems have resources (e.g. disks, printers)
  - they cooperate/share with one-another
- Thin Client
  - few local resources (e.g. CPU, NIC, display)
  - most resources on work-group or domain servers
- Cloud Services
  - clients access services rather than resources
  - clients do not see individual servers

Remote File Transfer

- explicit commands to copy remote files
  - OS specific: *scp(1)*, *rsync(1)*, **S3** tools
  - IETF protocols: FTP, SFTP
- implicit remote data transfers
  - browsers (transfer files with HTTP)
  - email clients (move files with IMAP/POP/SMTP)
- advantages: efficient, requires no OS support
- disadvantages: latency, lack of transparency

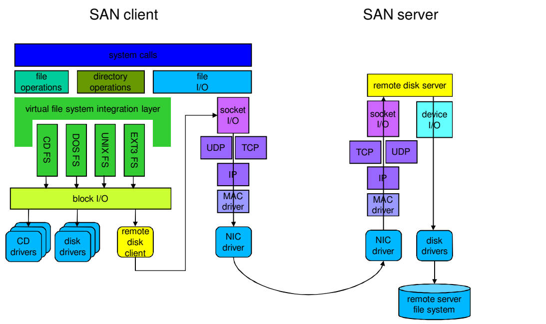
Remote Data Access

- OS makes remote files appear to be local
  - remote disk access (e.g. Storage Area Network)
  - remote file access (e.g. Network Attached Storage)
  - distributed file systems (NAS on steroids)
- advantages
  - transparency, availability, throughput
  - scalability, cost (capital and operational)
- disadvantages
  - complexity, issues with shared access

Remote Disk Access

- Goal: complete transparency
  - normal file system calls work on remote files
  - all programs "just work" with remote files
- Typical Architectures
  - Storage Area Network (SCSI over Fibre Chanel)
    - very fast, very expensive, moderately scalable
  - iSCSI (SCSI over ethernet)
    - client driver turns reads/writes into network requests
    - server daemon receives/serves requests
    - moderate performance, inexpensive, highly scalable

Remote Disk Access Architecture



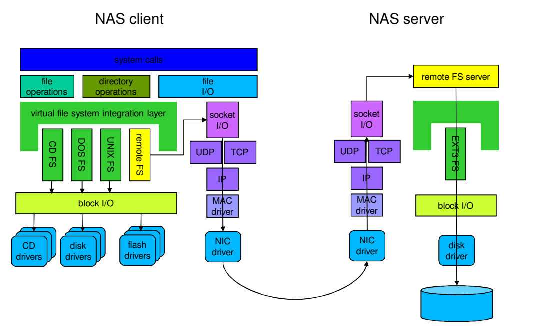
Rating Remote Disk Access

- Advantages:
  - provides excellent transparency
  - decouples client hardware from storage capacity
  - performance/reliability/availability per back-end
- Disadvantages
  - inefficient fixed partition space allocation
  - can't support file sharing by multiple client systems
  - message losses can cause file system errors
- This is THE model for Virtual Machines

Remote File Access

- Goal: complete transparency
  - normal file system calls work on remote files
  - support file sharing by multiple clients
  - performance, availability, reliability, scalability
- Typical Architecture
  - Network Attached Storage Protocols: NFS, CIFS
  - exploits client-side plug-in file systems
    - client-side file system is a local proxy
    - translates file operations into RPC requests
  - server-side daemon receives/process requests
    - translates them into operations on local file system

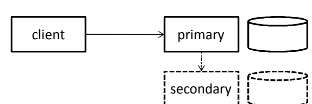
Remote File Access Architecture



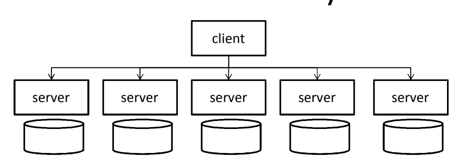
Rating Remote File Access

- Advantages
  - very good application level transparency
  - very good functional encapsulation
  - able to support multi-client file sharing
  - potential for good performance and robustness
- Disadvantages
  - at least part of implementation must be in the OS
  - client and server sides tend to be fairly complex
- This is THE model for client/server storage

Remote Disk/File Access



Distributed File System



(Remote vs. Distributed FS)

- Remote File Access (e.g. NFS, CIFS)
  - client talks to (per FS) primary server
  - secondary server may take over if primary fails
  - advantages: simplicity
- Distributed File System (e.g. Ceph, RAMCloud)
  - data is spread across numerous servers
  - client may talk directly to many/all of them
  - advantages: performance, scalability
  - disadvantages: complexity++

Assignments

- For next lecture
  - Arpaci C49 (Andrew File System)
  - Wikipedia: ACID semantics
- Lab
  - Project 4C … SSL sessions are unforgiving

Supplementary Slides

Conclusion

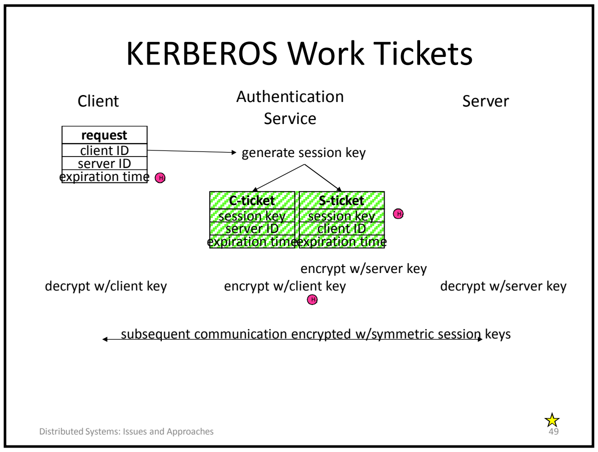
- Distributed systems offer us much greater power than one machine can provide
- They do so at costs of complexity and security risk
- We handle the complexity by using distributed systems in a few carefully defined ways
- We handle the security risk by proper use of cryptography and other tools

example: Kerberos

- establishes secure two-way session
  - privacy – nobody can snoop on conversation
  - integrity – nobody can generate fake messages
- independent authentication of client & server
  - each side is assured of other side's identity
- based on secret symmetric encryption keys
  - DES key, known only to owner and Kerberos
- Kerberos generates symmetric session keys
  - distributes them securely to client and server

example: KERBEROS

- establishes a secure client/server session
  - each side is assured of partner's identity
  - session is secure against "man in middle" attacks
- digital signatures using symmetric encryption
  - every agent has a secret (symmetric) key
  - that key is known only to agent, and to KERBEROS
- request to KERBEROS encrypted w/client key
  - KERBEROS can decrypt it, authenticating requester
- response from KERBEROS is two-part work ticket
  - part 1: encrypted with client's key
    - symmetric session key, part 2 (to be forwarded to server)
  - part 2: encrypted with server's key
    - client ID, ticket duration, and symmetric session key


KERBEROS Work Tickets
Client
Authentication Service
Server
request
client ID
server ID
expiration time
generate session key
C-ticket
session key
server ID
expiration time
S-ticket
session key
client ID
expiration time
encrypt w/server key
decrypt w/client key
encrypt w/client key
decrypt w/server key
subsequent communication encrypted w/symmetric session keys
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