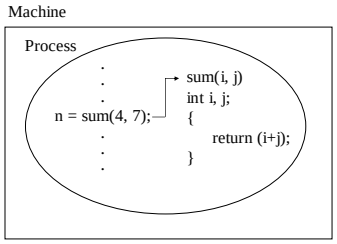
CS 194: Distributed Systems
Review

Scott Shenker and Ion Stoica
Computer Science Division
Department of Electrical Engineering and Computer Sciences
University of California, Berkeley
Berkeley, CA 94720-1776

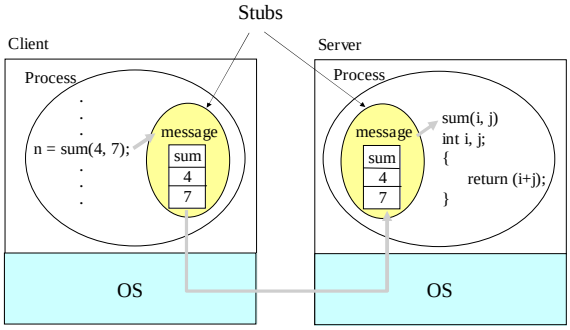
Overview

- Remote Procedure Call (RPC)
- Threads
- Agreement
- Group communication
- Distributed commit
- Security

Example: Local Procedure Call

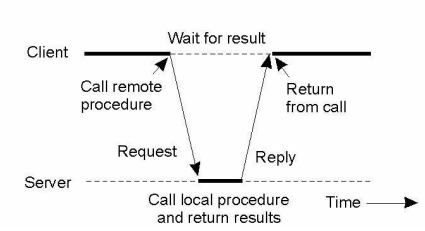


Example: Remote Procedure Call



Client and Server Stubs

- Principle of RPC between a client and server program



Parameter Passing

- Server and client may encode parameters differently
  - E.g., big endian vs. little endian
- How to send parameters “call-by-reference”?
  - Basically do “call-by-copy/restore”
  - Woks when there is an array of fixed size
  - How about arbitrary data structures?

RPC Semantics: Discussion

- The original goal: provide the same semantics as a local call
- Impossible to achieve in a distributed system
  - Dealing with remote failures fundamentally affects transparency
- Ideal interface: balance the easy of use with making visible the errors to users

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Process vs. Thread

- Process: unit of allocation
  - Resources, privileges, etc
- Thread: unit of execution
  - PC, SP, registers
- Each process has one or more threads
- Each thread belong to one process

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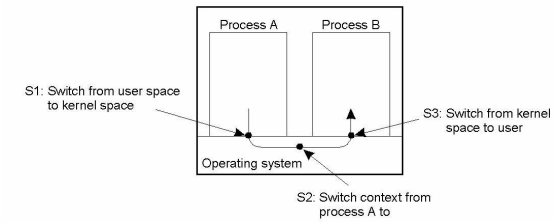
Process vs. Thread

- Processes
  - Inter-process communication is expensive: need to context switch
  - Secure: one process cannot corrupt another process



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Process vs. Thread

- Threads
  - Inter-thread communication cheap: can use process memory and may not need to context switch
  - Not secure: a thread can write the memory used by another thread

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User Level vs. Kernel Level Threads

- User level: use user-level thread package; totally transparent to OS
  - Light-weight
  - If a thread blocks, all threads in the process block
- Kernel level: threads are scheduled by OS
  - A thread blocking won't affect other threads in the same process
  - Can take advantage of multi-processors
  - Still requires context switch, but cheaper than process context switching

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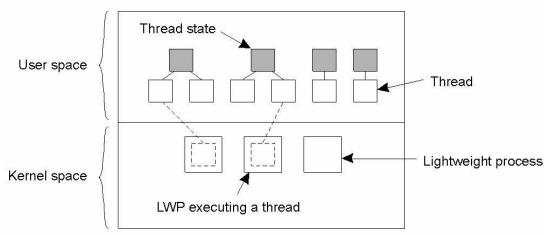
Thread Implementation

- Combining kernel-level lightweight processes and user-level threads
  - LWPs are transparent to applications
  - A thread package can be shared by multiple LWPs
  - A LWP looks constantly after runnable threads



User-level, Kernel-level and Combined

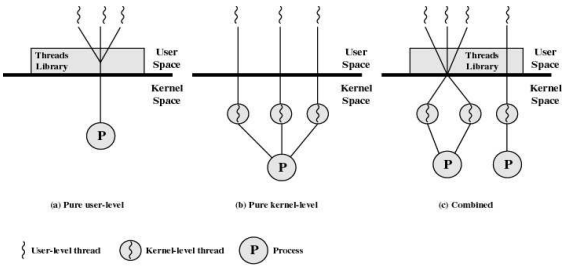
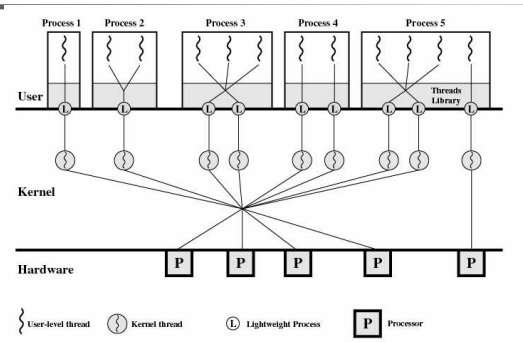


Figure 4.6 User-Level and Kernel-Level Threads

(Operating Systems, Stallings)

Example of Combined Threads



(Operating Systems, Stallings)

Figure 4.15 Solaris Multithreaded Architecture Example

Trade-offs

Model	Characteristics
Threads	Parallelism, blocking system calls
Single-threaded process	No parallelism, blocking system calls

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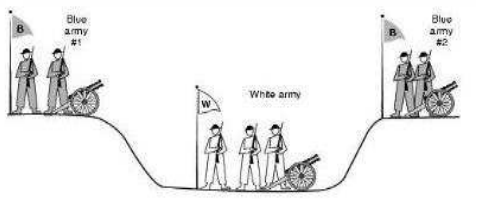
Agreement in Faulty Systems

- Many things can go wrong…
- Communication
  - Message can be lost
  - Time taken to deliver a message is unbounded
  - Adversary can intercept messages
- Processes
  - Can fail or collude with other processes to produce wrong results
- Agreement very hard, sometime impossible, to achieve!

Two-Army Problem

- "Two blue armies need to simultaneously attack the white army to win; otherwise they will be defeated. The blue army can communicate only across the area controlled by the white army which can intercept the messengers."



- What is the solution?

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Byzantine Agreement [Lamport et al. (1982)]

- Goal:
  - Each process learn the true values sent by correct processes
- Assumptions:
  - Every message that is sent is delivered correctly
  - The receiver knows who sent the message
  - Message delivery time is bounded

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Byzantine Agreement Result

- In a system with m faulty processes agreement can be achieved only if there are $2m+1$ functioning correctly
- Note: This result only guarantees that each process receives the true values sent by correct processors, but it does not identify the correct processors!

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  - Reliable multicast
  - Atomic multicast
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Reliable Group Communication

- **Reliable multicast**: all non-faulty processes which do not join/leave during communication receive the message
- **Atomic multicast**: all messages are delivered in the same order to all processes

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Scalable Reliable Multicast (SRM) [Floyd et al '95]

- Receivers use timers to send NACKS and retransmissions
  - Randomized: prevent implosion
  - Uses latency estimates
    - Short timer → cause duplicates when there is reordering
    - Long timer → causes excess delay
- Any node retransmits
  - Sender can use its bandwidth more efficiently
  - Overall group throughput is higher
- Duplicate NACK/retransmission suppression

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Repair Request Timer Randomization

- Chosen from the uniform distribution on

$$2^i[C_1 d_{S,A}, (C_1 + C_2) d_{S,A}]$$

  - A – node that lost the packet
  - S – source
  - C_1, C_2 – constants
  - $d_{S,A}$ – latency between source (S) and A
  - i – iteration of repair request tries seen
- Algorithm
  - Detect loss → set timer
  - Receive request for same data → cancel timer, set new timer
  - Timer expires → send repair request

Timer Randomization

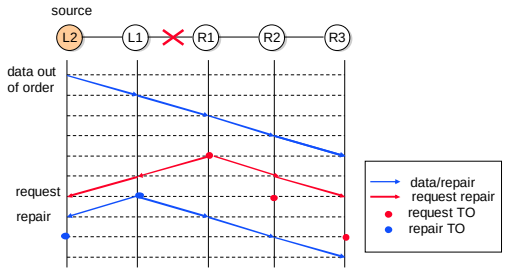
- Repair timer similar
  - Every node that receives repair request sets repair timer
  - Latency estimate is between node and node requesting repair
  - Use following formula:

$$2^i[D_1 d_{R,A}, (D_1 + D_2) d_{R,A}]$$

    - D_1, D_2 – constants
    - $d_{R,A}$ – latency between node requesting repair (R) and A
- Timer properties – minimize probability of duplicate packets
  - Reduce likelihood of implosion (duplicates still possible)
  - Reduce delay to repair

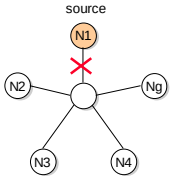
Chain Topology

- $C_1 = D_1 = 1$, $C_2 = D_2 = 0$ → timers = 1, 1
- All link distances are 1



Star Topology

- $C_1 = D_1 = 0$, → timers = [0, $2C_2$], [0, $2D_2$]
- Tradeoff between (1) number of requests and (2) time to receive the repair
- $C_2 <= 1$
  - E(# of requests) = g –1
- $C_2 > 1$
  - E(# of requests) = 1 + (g-2)/C_2
  - E(time until first timer expires) = $2C_2$/g
- $C_2 = \sqrt{g}$
  - E(# of requests) = $\sqrt{g}$
  - E(time until first timer expires) = $1/\sqrt{g}$



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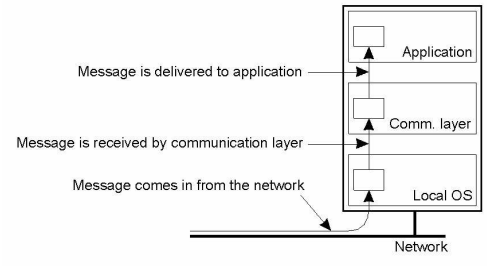
Atomic Multicast

- All messages are delivered in the same order to “all” processes
- **Group view**: the set of processes known by the sender when it multicast the message
- **Virtual synchronous multicast**: a message m multicast to a group view G is delivered to all non-faulty processes in G
  - If sender fails “before” m reaches a non-faulty process, none of the processes deliver m

Virtual Synchrony System Model



- The logical organization of a distributed system to distinguish between message receipt and message delivery

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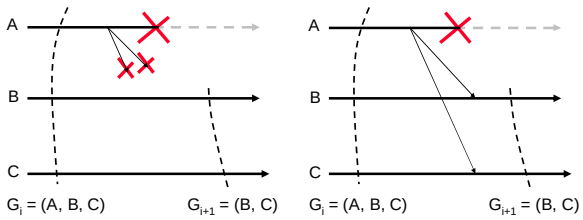
Virtual Synchronous Multicast

a) Message is **not** delivered

b) Message is delivered



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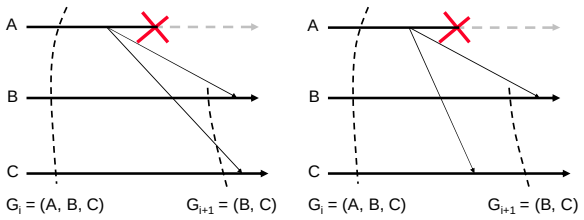
Virtual Synchronous Multicast

a) Message is **not** delivered

b) Message is **not** delivered



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Virtual Synchrony Implementation: [Birman et al., 1991]

- Only **stable** messages are delivered
- **Stable message**: a message received by all processes in the message's group view
- Assumptions (can be ensured by using TCP):
  - Point-to-point communication is reliable
  - Point-to-point communication ensures FIFO-ordering

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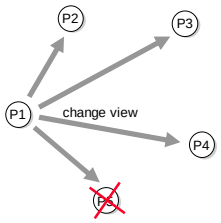
Virtual Synchrony Implementation: Example

- G_i = {P1, P2, P3, P4, P5}
- P5 fails
- P1 detects that P5 has failed
- P1 send a "view change" message to every process in G_{i+1} = {P1, P2, P3, P4}



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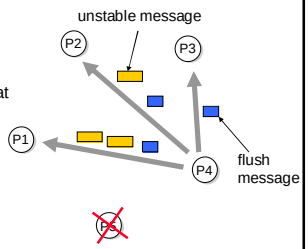
Virtual Synchrony Implementation: Example

- Every process
  - Send each unstable message m from G_i to members in G_{i+1}
  - Marks *m* as being stable
  - Send a flush message to mark that all unstable messages have been sent



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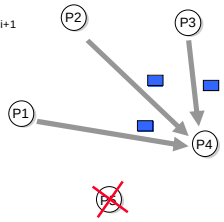
Virtual Synchrony Implementation: Example

- Every process
  - After receiving a flush message from any process in G_{i+1} installs G_{i+1}



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Message Ordering and Atomicity

Multicast	Basic Message Ordering	Total-ordered Delivery?
Reliable multicast	None	No
FIFO multicast	FIFO-ordered delivery	No
Causal multicast	Causal-ordered delivery	No
Atomic multicast	None	Yes
FIFO atomic multicast	FIFO-ordered delivery	Yes
Causal atomic multicast	Causal-ordered delivery	Yes

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Distributed Commit

- **Goal**: Either **all** members of a group decide to perform an operation, or **none** of them perform the operation

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Assumptions

- Failures:
  - Crash failures that can be recovered
  - Communication failures detectable by timeouts
- Notes:
  - Commit requires a set of processes to agree…
  - …similar to the Byzantine general problem…
  - … but the solution much simpler because stronger assumptions

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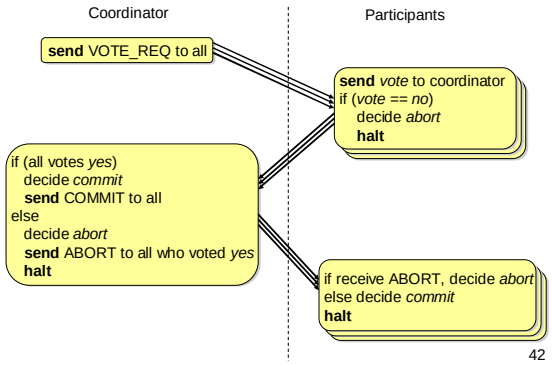
Two Phase Commit (2PC)



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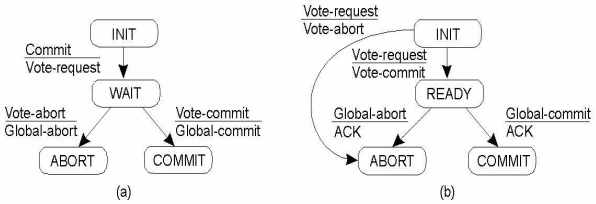
2PC State Machine



a) The finite state machine for the coordinator in 2PC
b) The finite state machine for a participant

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- Remote Procedure Call (RPC)
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  - Cryptographic Algorithms (Confidentiality and Integrity)
  - Authentication

Security Requirements

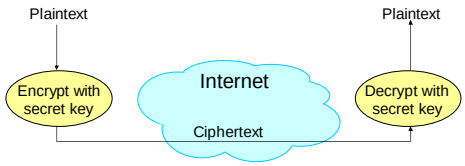
- **Authentication**: ensures that sender and receiver are who they are claiming to be
- **Data integrity**: ensure that data is not changed from source to destination
- **Confidentiality**: ensures that data is red only by authorized users
- **Non-repudiation**: ensures that the sender has strong evidence that the receiver has received the message, and the receiver has strong evidence of the sender identity (not discussed here)
  - The sender cannot deny that it has sent the message and the receiver cannot deny that it has received the message

Cryptographic Algorithms

- Security foundation: cryptographic algorithms
  - Secret key cryptography, Data Encryption Standard (DES)
  - Public key cryptography, RSA algorithm
  - Message digest, MD5

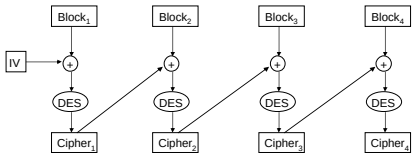
Symmetric Key

- Both the sender and the receiver use the same secret keys



Encrypting Larger Messages

- Initialization Vector (IV) is a random number generated by sender and sent together with the ciphertext



DES Properties

- Provide confidentiality
  - No mathematical proof, but practical evidence suggests that decrypting a message without knowing the key requires exhaustive search
  - To increase security use triple-DES, i.e., encrypt the message three times

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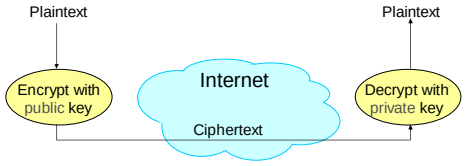
Public-Key Cryptography: RSA (Rivest, Shamir, and Adleman)

- Sender uses a public key
  - Advertised to everyone
- Receiver uses a private key



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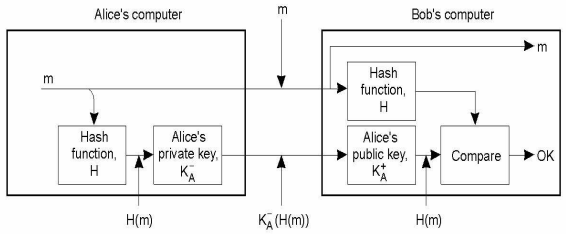
Digital Signature

- In practice someone cannot alter the message without modifying the digest
  - Digest operation very hard to invert
- Encrypt digest with sender's private key
- K_A^-, K_A^+: private and public keys of A



Digital Signature Properties

- Integrity: an attacker cannot change the message without knowing A's private key
- Confidentiality: if needed, encrypt message with B's public key

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Authentication

- Goal: Make sure that the sender an receiver are the ones they claim to be
- Solutions based on secret key cryptography (e.g., DES)
  - Three-way handshaking
  - Trusted third party (key distribution center)
- One solution based on public key cryptography (e.g., RSA)
  - Public key authentication

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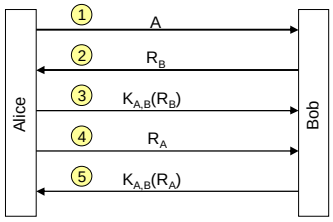
Authentication

- Authentication based on a shared secret key
  - A, B: sender and receiver identities
  - $K_{A,B}$: shared secret key
  - R_A,R_B: random keys exchanged by A and B to verify identities



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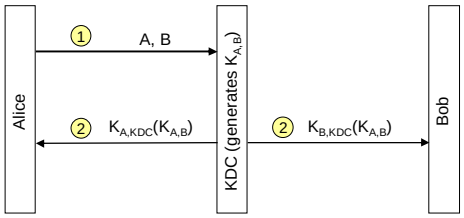
Authentication using KDC (Basic Protocol)

- KDC – Key Distribution Center
- Maintain only N keys in the system: one for each node



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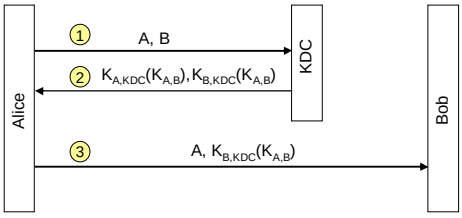
Authentication using KDC (Ticket Based)

- No need for KDC to contact Bob



- Vulnerable to replay attacks if Chuck gets hold on $K_{B,KDC}^{old}$

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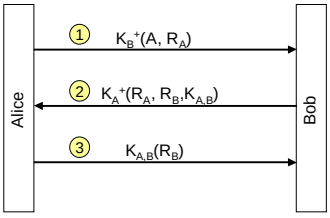
Authentication Using Public-Key Cryptography

- K_A^+, K_B^+: public keys



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Midterm Information

- Closed books; 8,5”x11” crib sheet (both sides)
- No calculators, PDAs, cell phones with cameras, etc
- Please use PENCIL and ERASER
- Expect also questions from project (e.g., XML-RMI)

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