Last Class

- Distributed Snapshots
  - Termination detection
- Election algorithms
  - Bully
  - Ring

Today: Still More Canonical Problems

- Distributed synchronization and mutual exclusion
- Distributed transactions

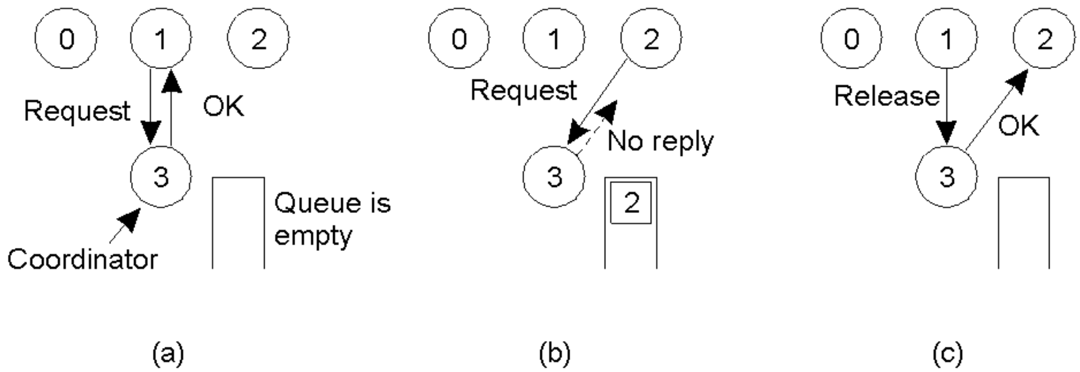
Distributed Synchronization

- Distributed system with multiple processes may need to share data or access shared data structures
  - Use critical sections with mutual exclusion
- Single process with multiple threads
  - Semaphores, locks, monitors
- How do you do this for multiple processes in a distributed system?
  - Processes may be running on different machines
- Solution: lock mechanism for a distributed environment
  - Can be centralized or distributed

Centralized Mutual Exclusion

- Assume processes are numbered
- One process is elected coordinator (highest ID process)
- Every process needs to check with coordinator before entering the critical section
- To obtain exclusive access: send request, await reply
- To release: send release message
- Coordinator:
  - Receive *request*: if available and queue empty, send grant; if not, queue request
  - Receive *release*: remove next request from queue and send grant

Mutual Exclusion: A Centralized Algorithm



a) Process 1 asks the coordinator for permission to enter a critical region. Permission is granted
b) Process 2 then asks permission to enter the same critical region. The coordinator does not reply.
c) When process 1 exits the critical region, it tells the coordinator, when then replies to 2

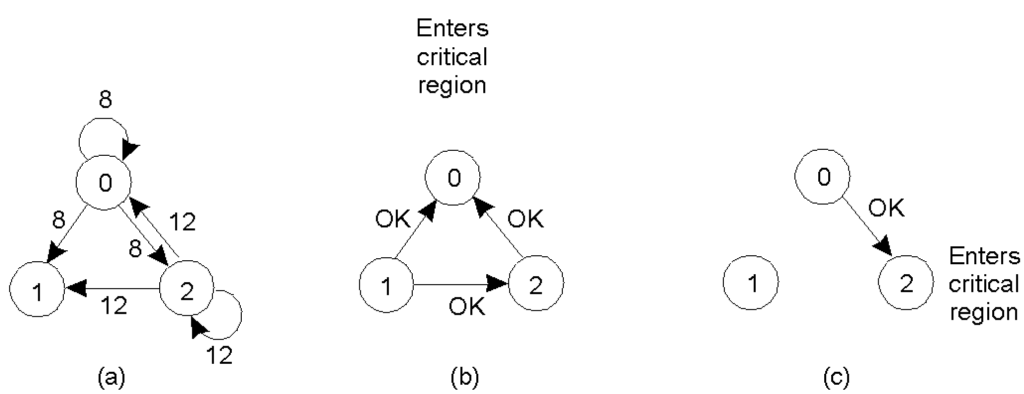
Properties

- Simulates centralized lock using blocking calls
- Fair: requests are granted the lock in the order they were received
- Simple: three messages per use of a critical section (request, grant, release)
- Shortcomings:
  - Single point of failure
  - How do you detect a dead coordinator?
    - A process can not distinguish between "lock in use" from a dead coordinator
      - No response from coordinator in either case
  - Performance bottleneck in large distributed systems

Distributed Algorithm

- [Ricart and Agrawala]: needs 2(n-1) messages
- Based on event ordering and time stamps
  - Assumes total ordering of events in the system (Lamport's clock)
- Process *k* enters critical section as follows
  - Generate new time stamp $TS_k = TS_k+1$
  - Send *request*(k, TS_k) all other $n-1$ processes
  - Wait until *reply(j)* received from all other processes
  - Enter critical section
- Upon receiving a *request* message, process *j*
  - Sends *reply* if no contention
  - If already in critical section, does not reply, queue request
  - If wants to enter, compare TS_j with TS_k and send reply if $TS_k<TS_j$, else queue

A Distributed Algorithm

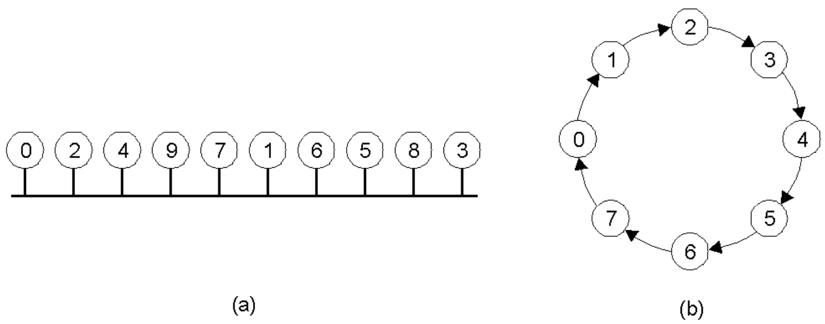


a) Two processes want to enter the same critical region at the same moment.
b) Process 0 has the lowest timestamp, so it wins.
c) When process 0 is done, it sends an OK also, so 2 can now enter the critical region.

Properties

- Fully decentralized
- *N* points of failure!
- All processes are involved in all decisions
  - Any overloaded process can become a bottleneck

A Token Ring Algorithm



a) An unordered group of processes on a network.
b) A logical ring constructed in software.

- Use a token to arbitrate access to critical section
- Must wait for token before entering CS
- Pass the token to neighbor once done or if not interested
- Detecting token loss in non-trivial

Comparison

Algorithm	Messages per entry/exit	Delay before entry (in message times)	Problems
Centralized	3	2	Coordinator crash
Distributed	2 (n – 1)	2 (n – 1)	Crash of any process
Token ring	1 to ∞	0 to n – 1	Lost token, process crash

- A comparison of three mutual exclusion algorithms.

Transactions

- Transactions provide higher level mechanism for *atomicity* of processing in distributed systems
  - Have their origins in databases
- Banking example: Three accounts A:\$100, B:\$200, C:\$300
  - Client 1: transfer \$4 from A to B
  - Client 2: transfer \$3 from C to B
- Result can be inconsistent unless certain properties are imposed on the accesses

Client 1	Client 2
Read A: \$100	
Write A: \$96	
	Read C: \$300
	Write C:\$297
Read B: \$200	
	Read B: \$200
	Write B:\$203
Write B:\$204	

ACID Properties

- *Atomic:* all or nothing
- *Consistent*: transaction takes system from one consistent state to another
- *Isolated*: Immediate effects are not visible to other (serializable)
- *Durable:* Changes are permanent once transaction completes (commits)

Client 1	Client 2
Read A: $100	
Write A: $96	
Read B: $200	
Write B:$204	
	Read C: $300
	Write C:$297
	Read B: $204
	Write B:$207

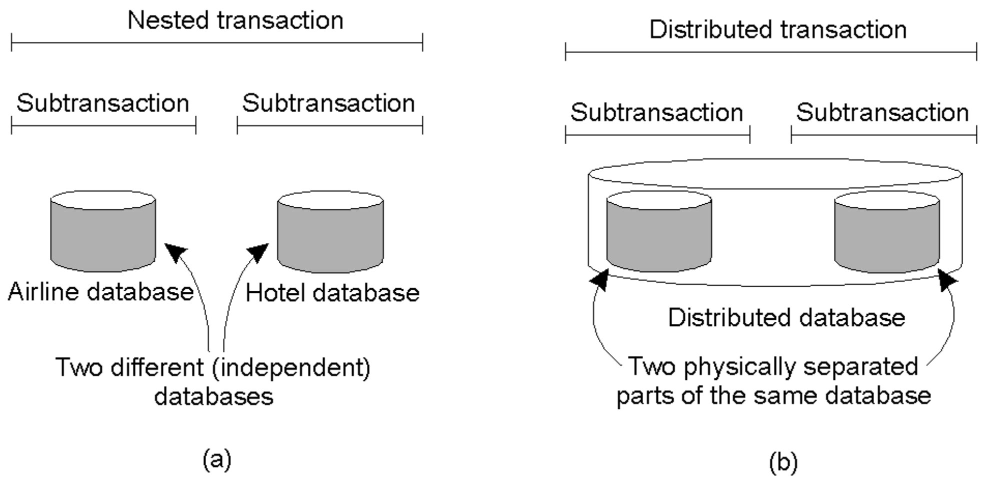
Transaction Primitives

Primitive	Description
BEGIN_TRANSACTION	Make the start of a transaction
END_TRANSACTION	Terminate the transaction and try to commit
ABORT_TRANSACTION	Kill the transaction and restore the old values
READ	Read data from a file, a table, or otherwise
WRITE	Write data to a file, a table, or otherwise

Example: airline reservation

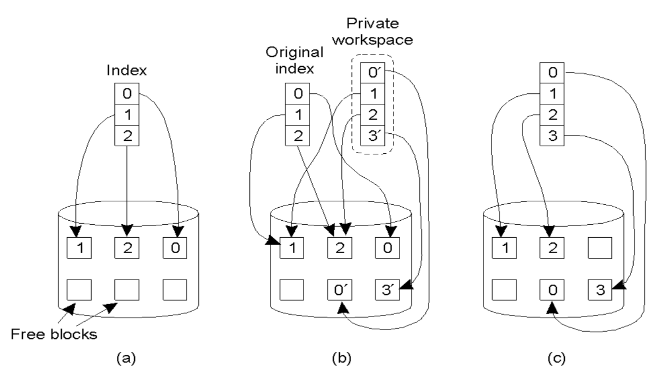
```
Begin_transaction
    if(reserve(NY,Paris)==full) Abort_transaction
    if(reserve(Paris,Athens)==full)Abort_transaction
    if(reserve(Athens,Delhi)==full) Abort_transaction
End_transaction
```

Distributed Transactions



Implementation: Private Workspace

- Each transaction get copies of all files, objects
- Can optimize for reads by not making copies
- Can optimize for writes by copying only what is required
- Commit requires making local workspace global



Option 2: Write-ahead Logs

- *In-place updates*: transaction makes changes *directly* to all files/objects
- *Write-ahead log:* prior to making change, transaction writes to log on *stable storage*
  - Transaction ID, block number, original value, new value
- Force logs on commit
- If abort, read log records and undo changes [*rollback*]
- Log can be used to rerun transaction after failure

- Both workspaces and logs work for distributed transactions
- Commit needs to be *atomic* [will return to this issue in Ch. 7]

Writeahead Log Example

(a)	(b)	(c)	(d)
x = 0;	Log	Log	Log
y = 0;			
BEGIN_TRANSACTION;			
x = x + 1;	[x = 0 / 1]	[x = 0 / 1]	[x = 0 / 1]
y = y + 2		[y = 0/2]	[y = 0/2]
x = y * y;			[x = 1/4]
END_TRANSACTION;			

- a) A transaction
- b) – d) The log before each statement is executed