# Distributed Systems

- What is a distributed system?
  - need a “network”
    - wire or wireless, Ethernet, high-speed interconnect, Myrnet, Infiniband, ...
  - CPU, disk (boot, data), memory, services, applications all accessed “remotely”, not “locally”
- Why use distributed systems?
  - share resources efficiently
  - parallel processing, manual or automated
  - reliability
  - communication over distance
  - Metcalfe's Law
- Examples
  - Internet, clusters, grids, P2P, Kazaa, Napster, SETI@home
- Types and topologies
  - LAN, WAN, Star, bus, tree, ...

# Distributed System Problems

- same as single-system / single-OS...
  - process scheduling, memory/resource management,synchgronization, caching, efficiency, administration/managment
- ...but some are harder to solve
  - component failure
  - time synchronization
    - what TIME is it?
  - control coordination
    - who's in charge?
  - validatng actions

## Deutsch's 8 Fallacies of Distributed Computing

- the network is reliable
- latency is zero
- bandwidth is infinite
- the network is secure
- topology doesn't change
- there is ONE network administrator
- transport cost is zero
- the network is homogeneous

# Distributed Systems Papers and Projects

- must relate to core OS and core DS concepts
- required:
  - 2 short papers, AND...
  - ...ONE of the following
    - long research paper
    - project
    - final exam
- select topic from course website, or propose & get approval for DS topic of your choice
- submission requirements
  - PDF prefered for report
  - send to hfoxwell@cs.gmu.edu
  - include appropriate citations & bibliography
  - use formated tables or fixed-width font for columnar data

# Chapter 17  Distributed Coordination

- Event Ordering
- Mutual Exclusion
- Atomicity
- Concurrency Control
- Deadlock Handling
- Election Algorithms
- Reaching Agreement

## Event Ordering

- Happened-before relation (denoted by $<$ ).
  - If A and B are events in the same process, and A was executed before B, then $A < B$.
  - If A is the event of sending a message by one process and B is the event of receiving that message by another process, then $A < B$.
  - If $A < B$ and $B < C$ then $A < C$.
  - simple, right?

## Implementation of <

- Associate a timestamp with each system event. Require that for every pair of events A and B, if A < B, then the timestamp of A is less than the timestamp of B.
- Within each process Pi a logical clock, LCi is associated. The logical clock can be implemented as a simple counter that is incremented between any two successive events executed within a process.
- A process advances its logical clock when it receives a message whose timestamp is greater than the current value of its logical clock.
  - why?
- If the timestamps of two events A and B are the same, then the events are concurrent. We may use the process identity numbers to break ties and to create a total ordering.

## Distributed Mutual Exclusion (DME)

- Assumptions
  - The system consists of n processes; each process $P_i$ resides at a different processor.
  - Each process has a critical section that requires mutual exclusion.
- Requirement
  - If $P_i$ is executing in its critical section, then no other process $P_j$ is executing in its critical section.
- We present two algorithms to ensure the mutual exclusion execution of processes in their critical sections.

# DME:  Centralized Approach

- One of the processes in the system is chosen to coordinate the entry to the critical section.
- A process that wants to enter its critical section sends a request message to the coordinator.
- The coordinator decides which process can enter the critical section next, and its sends that process a reply message.
- When the process receives a reply message from the coordinator, it enters its critical section.
- After exiting its critical section, the process sends a release message to the coordinator and proceeds with its execution.
- This scheme requires three messages per critical-section entry:
  - request
  - reply
  - release
- what makes this difficult?

## DME:  Fully Distributed Approach

- When process $P_i$ wants to enter its critical section, it generates a new timestamp, TS, and sends the message request ($P_i$, TS) to all other processes in the system.
- When process $P_j$ receives a request message, it may reply immediately or it may defer sending a reply back.
- When process $P_i$ receives a reply message from all other processes in the system, it can enter its critical section.
- After exiting its critical section, the process sends reply messages to all its deferred requests.
- what makes this difficult?

## DME: Fully Distributed Approach (Cont.)

- The decision whether process $P_j$ replies immediately to a request($P_i$, TS) message or defers its reply is based on three factors:
  - If $P_j$ is in its critical section, then it defers its reply to $P_i$.
  - If $P_j$ does not want to enter its critical section, then it sends a reply immediately to $P_i$.
  - If $P_j$ wants to enter its critical section but has not yet entered it, then it compares its own request timestamp with the timestamp TS.
    - If its own request timestamp is greater than TS, then it sends a reply immediately to $P_i$ ($P_i$ asked first).
    - Otherwise, the reply is deferred.

## Desirable Behavior of Fully Distributed Approach

- Freedom from Deadlock is ensured.
- Freedom from starvation is ensured, since entry to the critical section is scheduled according to the timestamp ordering. The timestamp ordering ensures that processes are served in a first-come, first served order.
- The number of messages per critical-section entry is

  $$2 \times (n - 1).$$

  This is the minimum number of required messages per critical-section entry when processes act independently and concurrently.
- this is a lot of overhead

## Three Undesirable Consequences

- The processes need to know the identity of all other processes in the system, which makes the dynamic addition and removal of processes more complex.
- If one of the processes fails, then the entire scheme collapses. This can be dealt with by continuously monitoring the state of all the processes in the system.
- Processes that have not entered their critical section must pause frequently to assure other processes that they intend to enter the critical section. This protocol is therefore suited for small, stable sets of cooperating processes.

## Atomicity

- Either all the operations associated with a program unit are executed to completion, or none are performed.
- Ensuring atomicity in a distributed system requires a transaction coordinator, which is responsible for the following:
  - Starting the execution of the transaction.
  - Breaking the transaction into a number of subtransactions, and distribution these subtransactions to the appropriate sites for execution.
  - Coordinating the termination of the transaction, which may result in the transaction being committed at all sites or aborted at all sites.

## Two-Phase Commit Protocol (2PC)

- Assumes fail-stop model.
- Execution of the protocol is initiated by the coordinator after the last step of the transaction has been reached.
- When the protocol is initiated, the transaction may still be executing at some of the local sites.
- The protocol involves all the local sites at which the transaction executed.
- Example: Let T be a transaction initiated at site $S_i$ and let the transaction coordinator at $S_i$ be $C_i$.

## Phase 1: Obtaining a Decision

- $C_i$ adds <prepare T> record to the log.
- $C_i$ sends <prepare T> message to all sites.
- When a site receives a <prepare T> message, the transaction manager determines if it can commit the transaction.
  - If no: add <no T> record to the log and respond to $C_i$ with <abort T>.
  - If yes:
    - add <ready T> record to the log.
    - force all log records for T onto stable storage.
    - transaction manager sends <ready T> message to $C_i$.

# Phase 1 (Cont.)

- Coordinator collects responses
  - All respond “ready”,
    decision is commit.
  - At least one response is “abort”,
    decision is abort.
  - At least one participant fails to respond within time out period,
    decision is abort.

## Phase 2: Recording Decision in the Database

- Coordinator adds a decision record
  - <abort T> or <commit T> to its log and forces record onto stable storage.
- Once that record reaches stable storage it is irrevocable (even if failures occur).
- Coordinator sends a message to each participant informing it of the decision (commit or abort).
- Participants take appropriate action locally.

## Failure Handling in 2PC – Site Failure

- The log contains a <commit T> record.  In this case, the site executes redo(T).
- The log contains an <abort T> record.  In this case, the site executes undo(T).
- The contains a <ready T> record; consult $C_i$.  If $C_i$ is down, site sends query-status T message to the other sites.
- The log contains no control records concerning T.  In this case, the site executes undo(T).

## Failure Handling in 2PC – Coordinator $C_i$ Failure

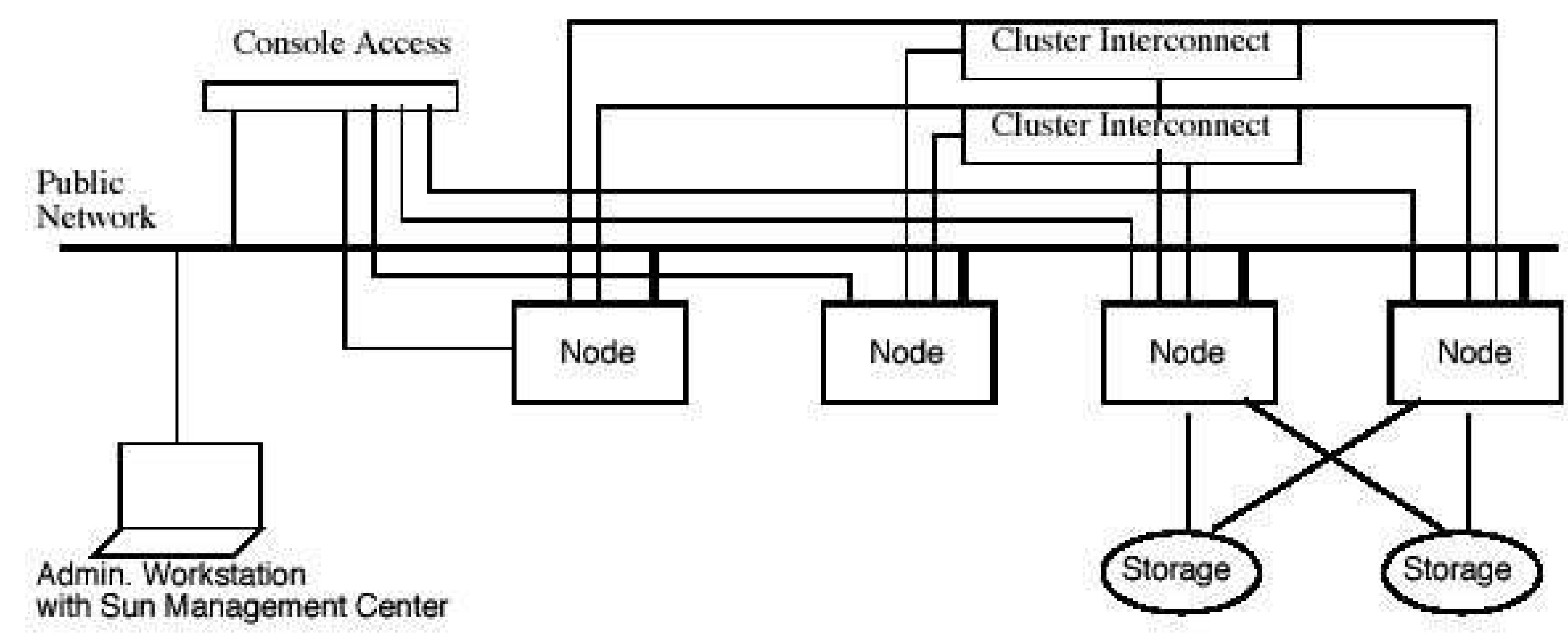
- If an active site contains a <commit T> record in its log, the T must be committed.
- If an active site contains an <abort T> record in its log, then T must be aborted.
- If some active site does not contain the record <ready T> in its log then the failed coordinator $C_i$ cannot have decided to commit T. Rather than wait for $C_i$ to recover, it is preferable to abort T.
- All active sites have a <ready T> record in their logs, but no additional control records. In this case we must wait for the coordinator to recover.
  - Blocking problem – T is blocked pending the recovery of site $S_i$.

## Distributed System Technologies

- Cluster
  - Generally configured for availability, then scalability
    - “Five nines” (0.99999 uptime)
    - No singe points of failure
- Grid
  - Generally configured for scalability, then availability
    - Needed  for highly parallelizable tasks
      - Expecially high-performance scientific computing
    - Hundreds or thousands of small systems
- Self-organizing networks
  - Jini
- Peer-to-Peer
  - JXTA

# Typical Cluster
# Goal: Availability, No SPF

**Figure 1.** A Typical Sun Cluster 3 configuration



## Cluster "Heartbeat"

**Figure 30.** Two Point-to-Point Interconnects in a two node cluster

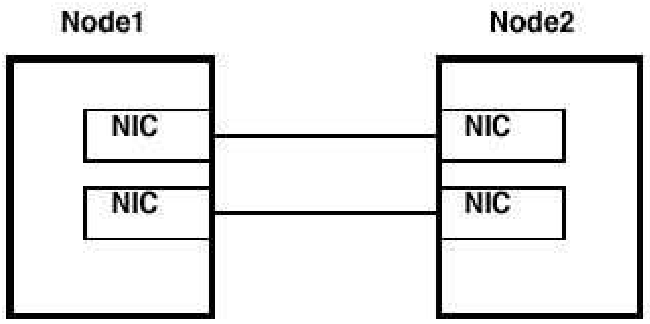
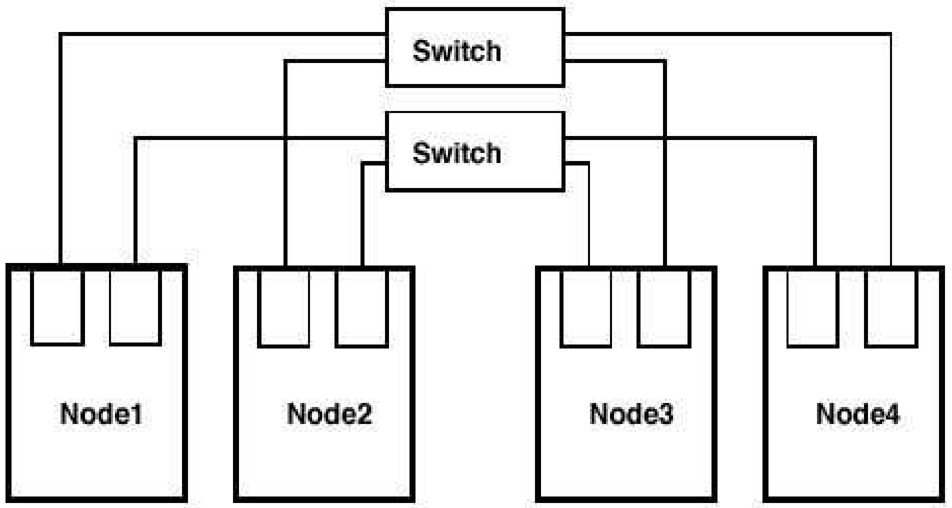


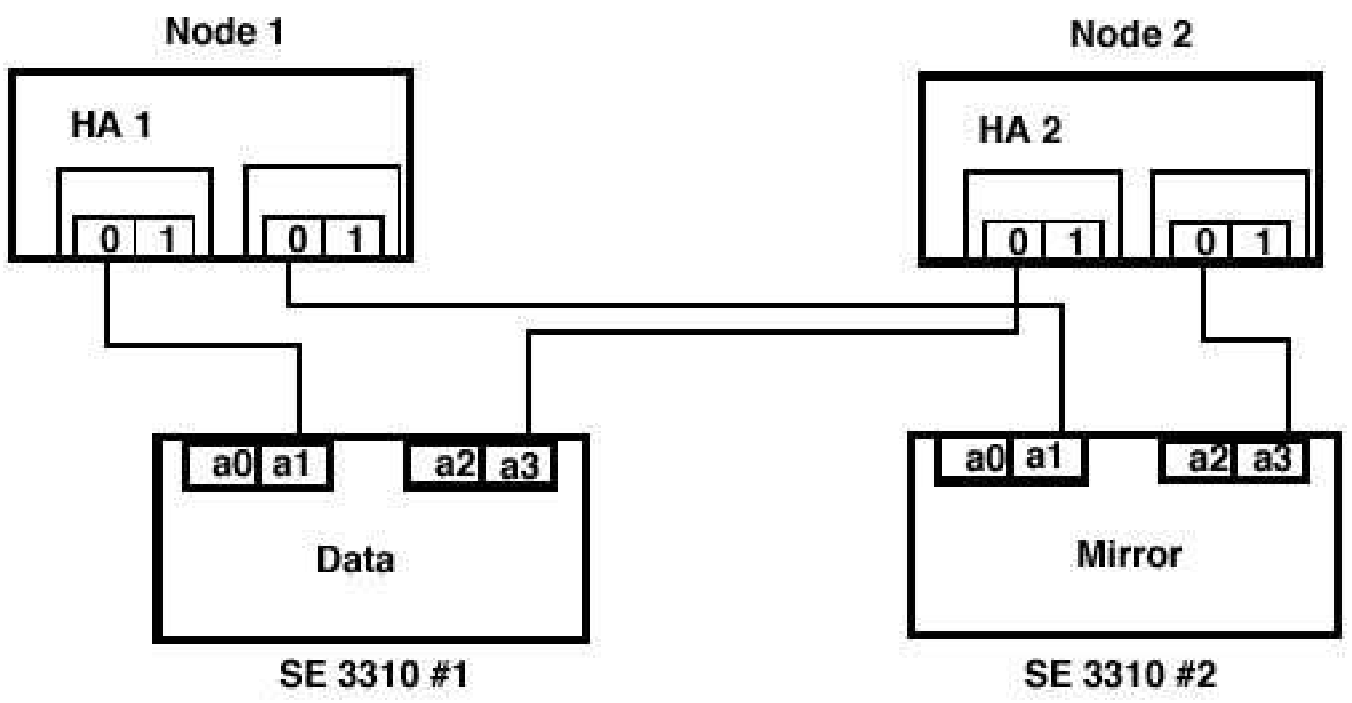
**Figure 31.** Two Junction-based Interconnects in an N-node cluster (N <=8)



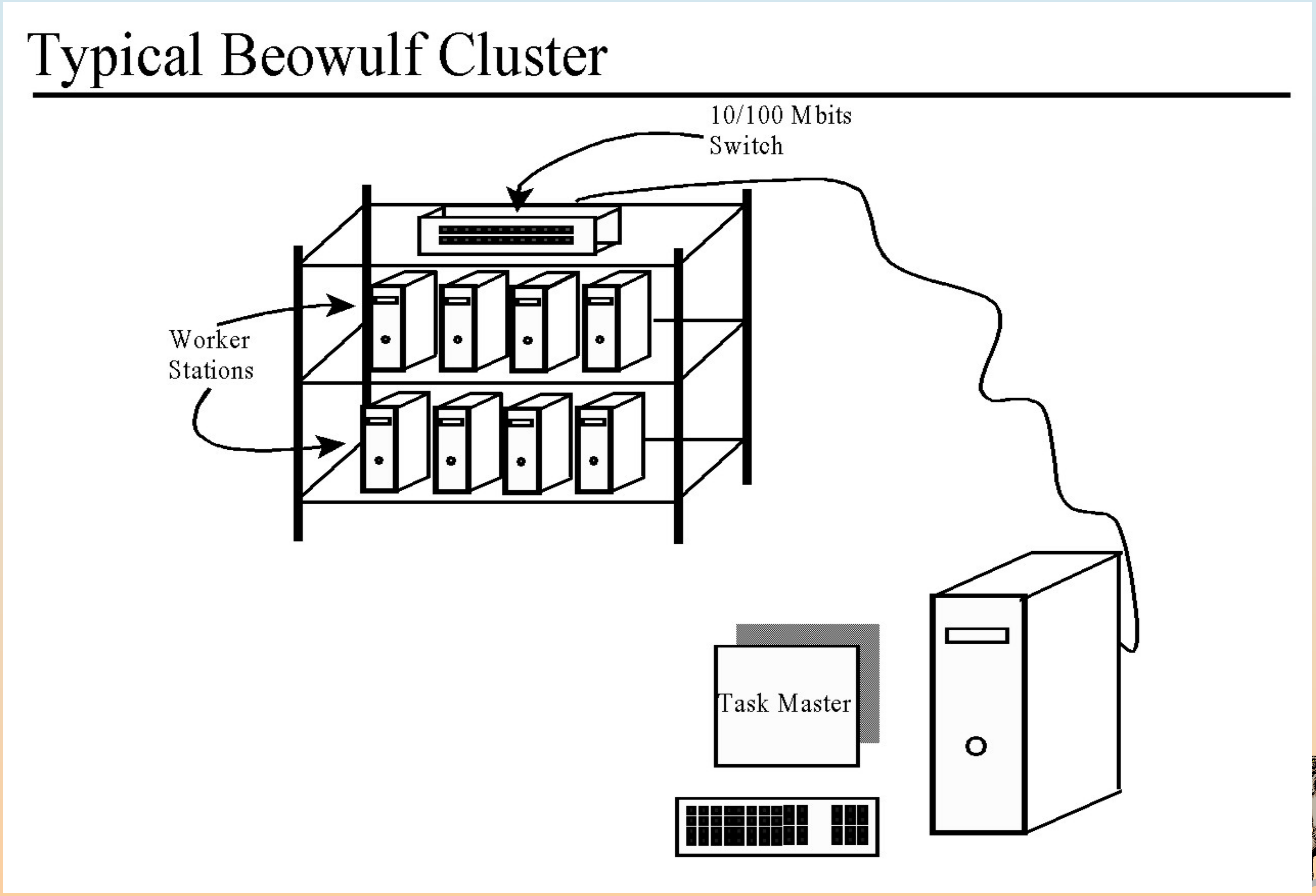
# Typical Cluster Storage
# Goal: Availability, No SPF

Storage Configuration

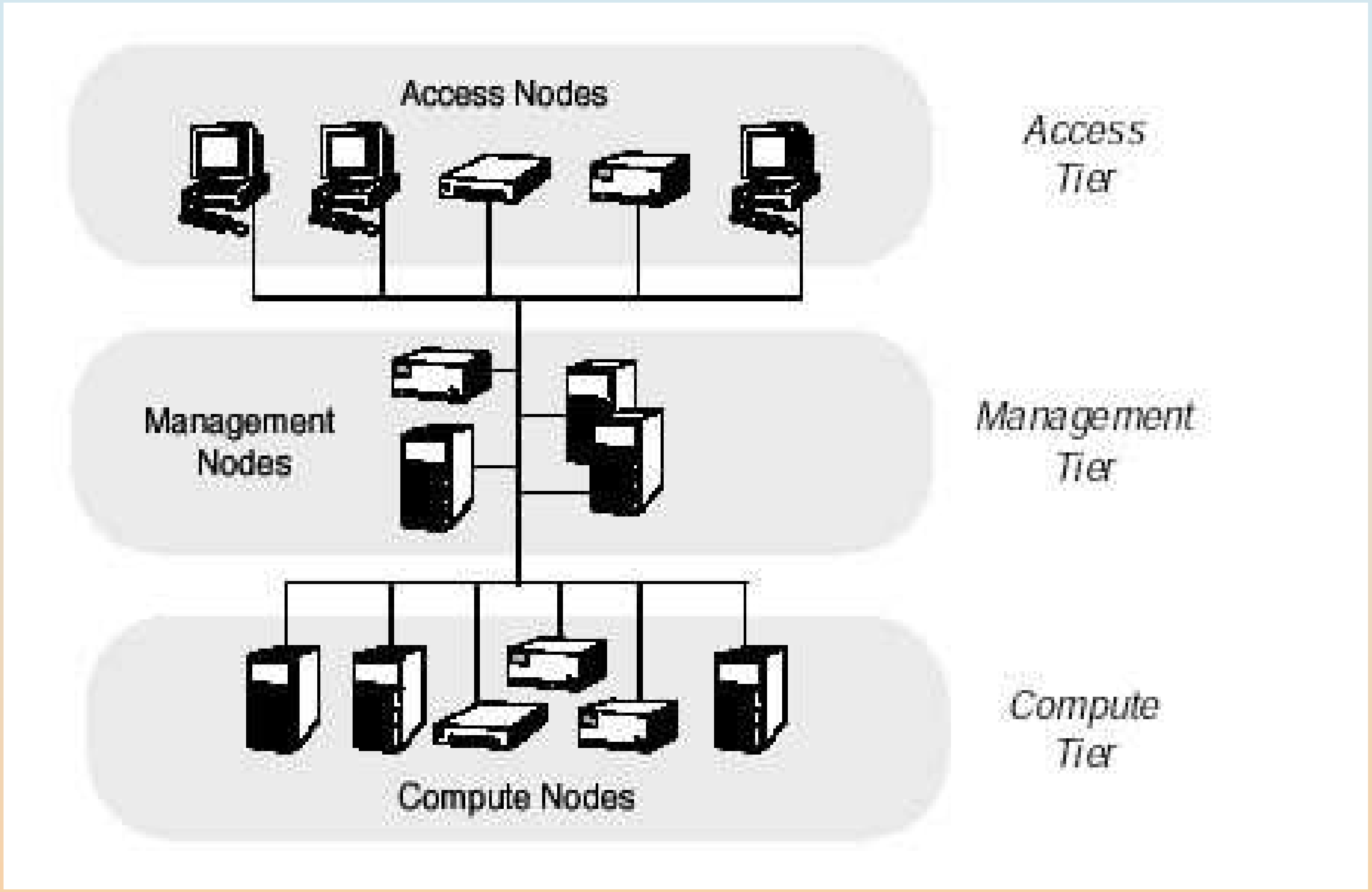
**Figure 28.** Direct-attached SE 3310 RAID configuration.



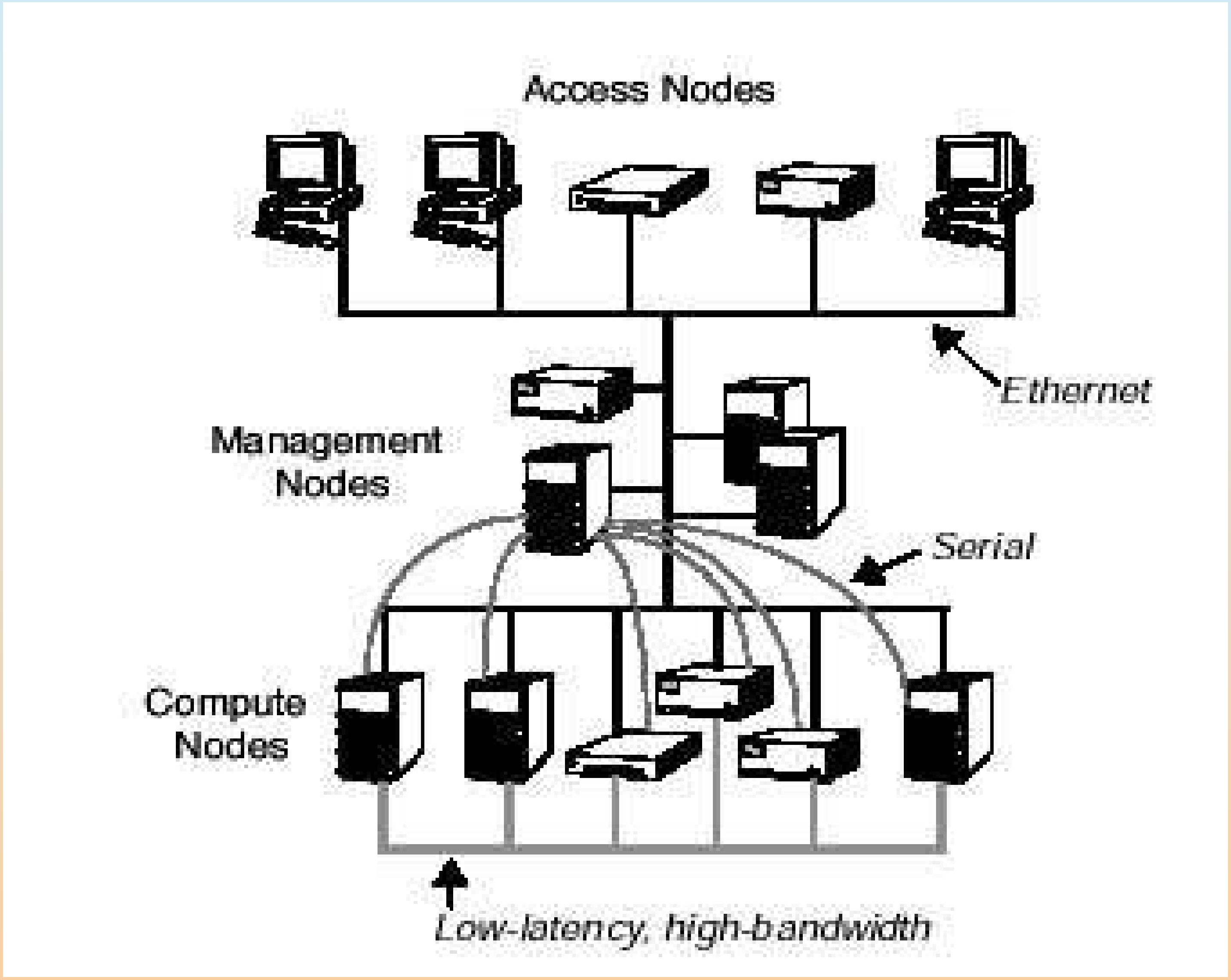
# Beowulf "Cluster" Goal: Scalability



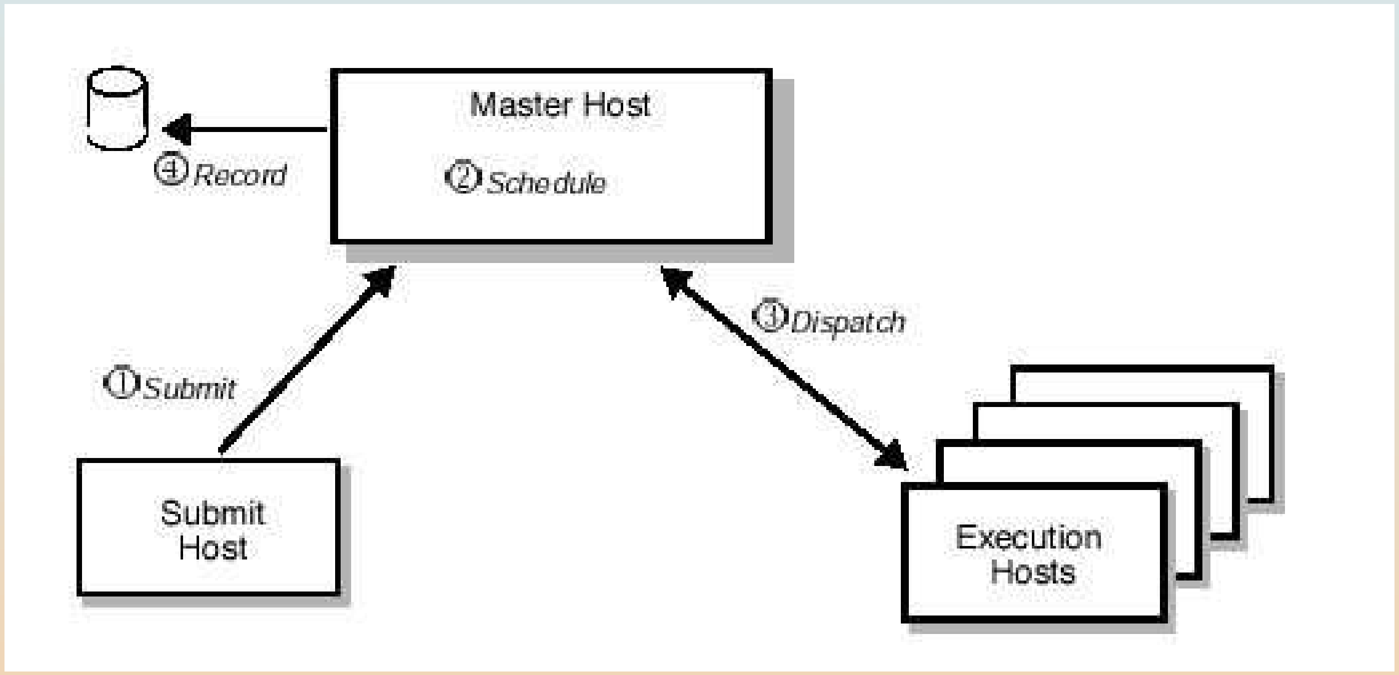
# Typical Grid Architecture



# Grid Network Interconnects



# Grid Job Submission



## Jini
## Self-Configuring Networks

Read “A Note on Distributed Computing” by Jim Waldo

See www.jini.org, java.sun.com

Lookup Service
- Services register
- Clients discover and lookup and lookup services
- Events and Transactions

Services (Includes Lookup Service)
- Lease Jini resources
- Register by supplying info and code

Client
- Discovery - Bootstrap
- Lookup Service using templates
- Access Service through downloaded java code
- Interact directly with the service

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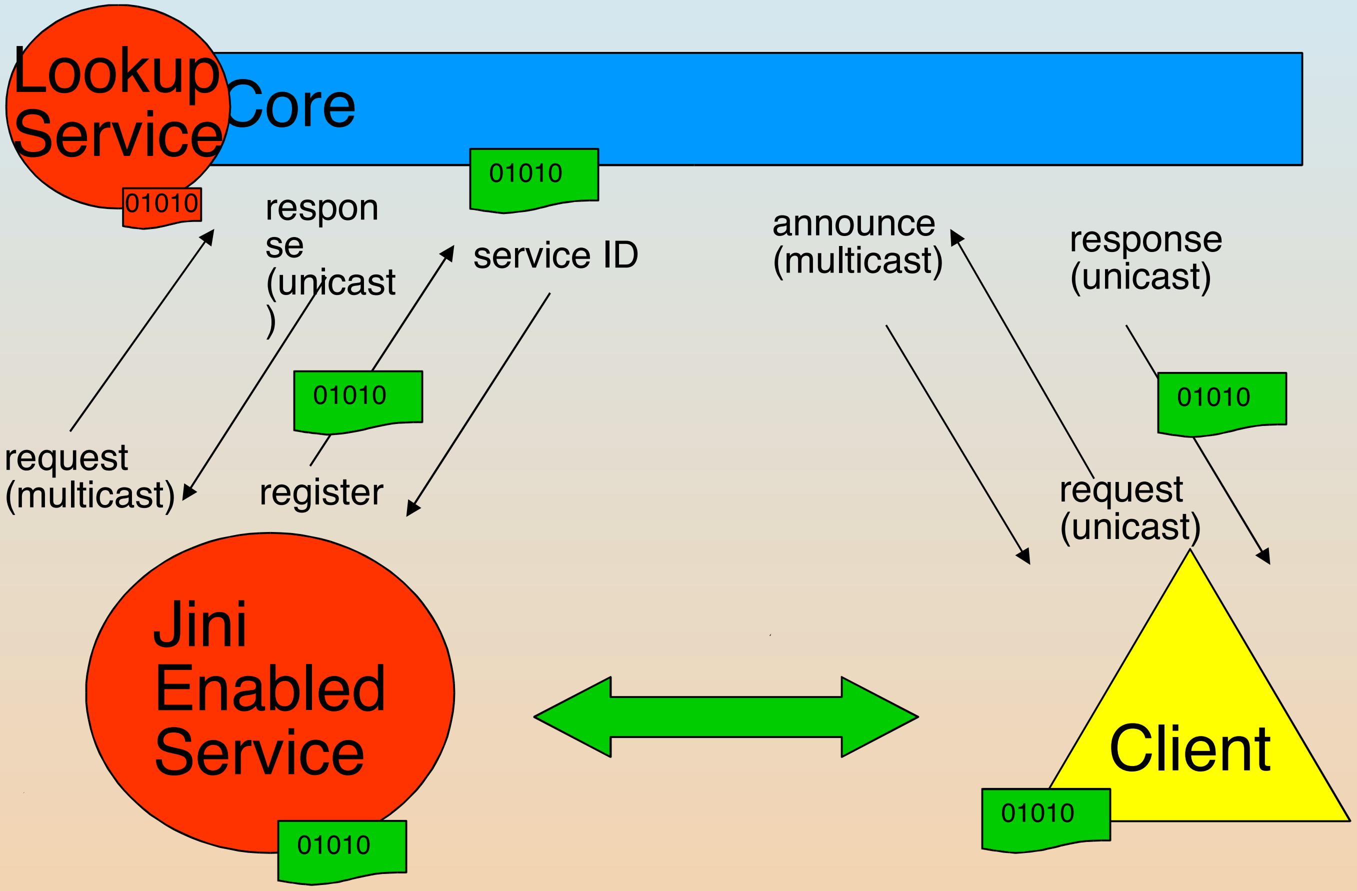
# Jini


Lookup Service
Core
01010
01010
respon se (unicast )
service ID
announce (multicast)
response (unicast)
01010
01010
request (multicast)
register
request (unicast)
Jini Enabled Service
Client
01010
01010

## Jini

- Spontaneous and Self recovering
  - Services come and go
  - No Jini administration required
  - ‘Plug and Play’
- Redundant
- Scalable
  - Instances
  - Performance

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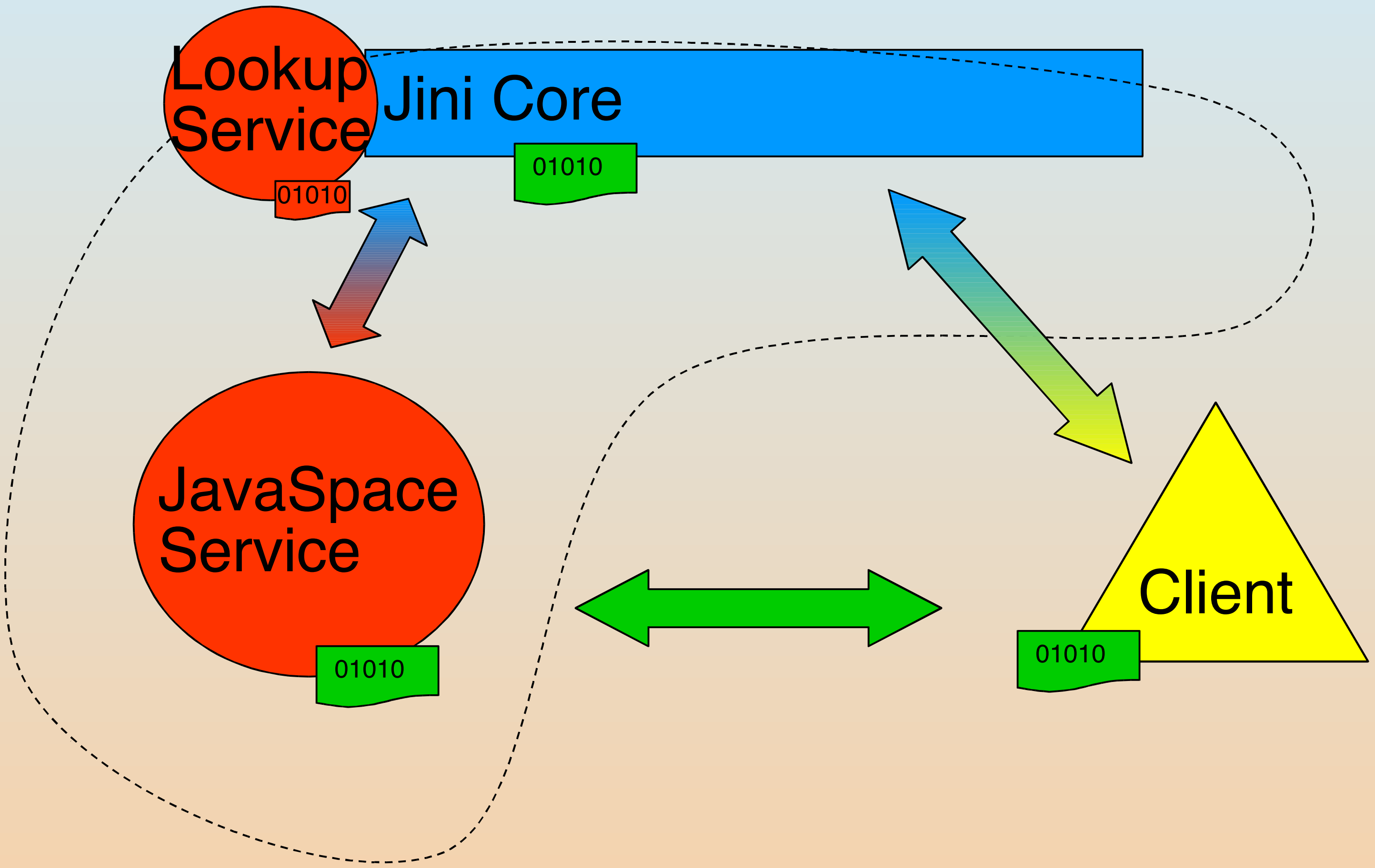
## Jini/JavaSpaces

- A Jini Service
- Distributed Shared Memory
  - Replication
- Persistent Storage
  - Object Based
- Search
  - Entry: values, class…
- Entry Interface
  - Write, Read, Take - IfExists

# Jini/JavaSpaces



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## Jini

Jini
- Lookup Services, Additional Knowledge Base Services

JavaSpaces
- Object Storage

Knowledge Base
- Application

Motive
- Needed  tool to store, share, and manage information
- Community friendly knowledge base
- Emerging technology
- Learn best by doing, experiments!

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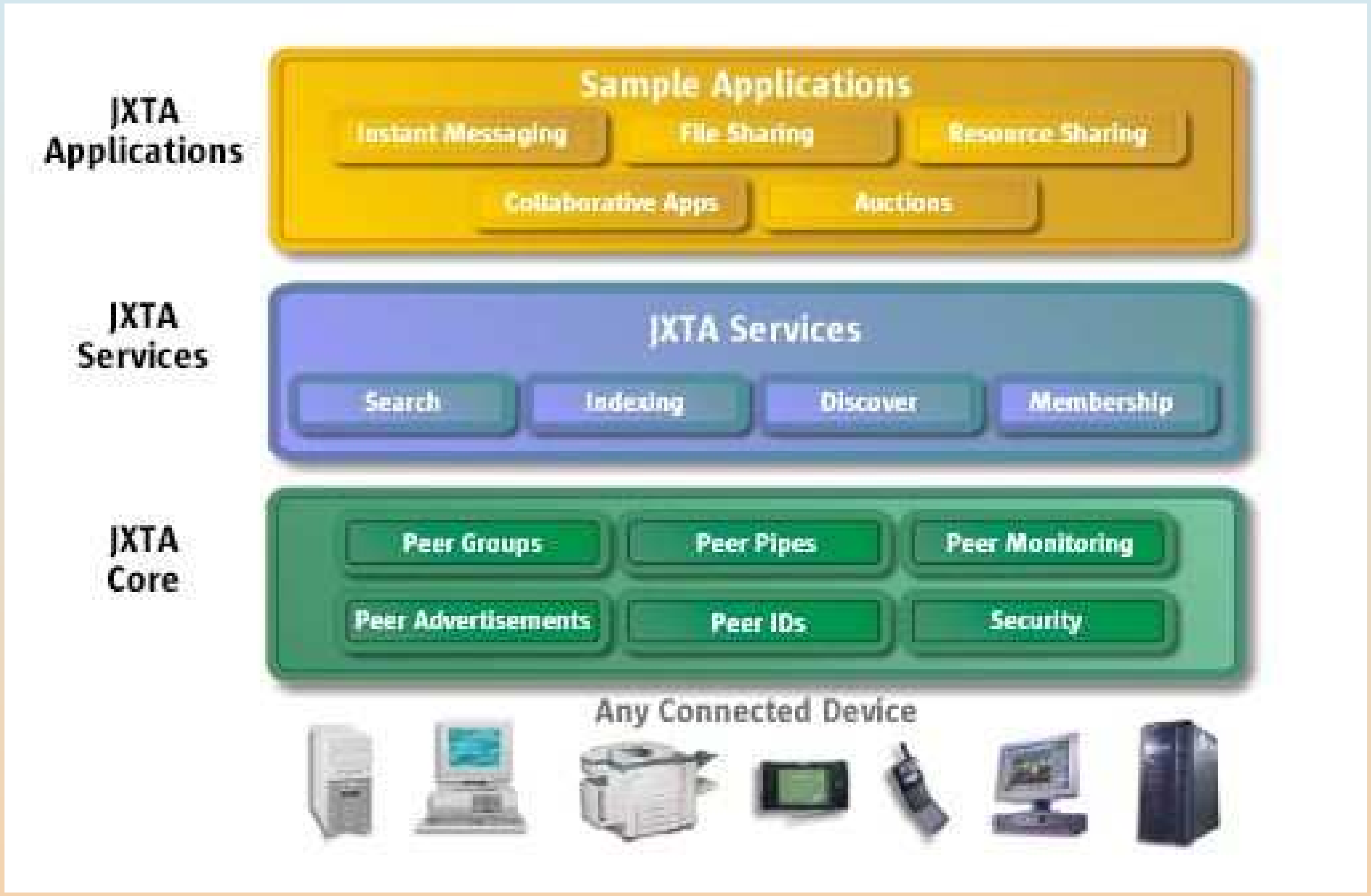
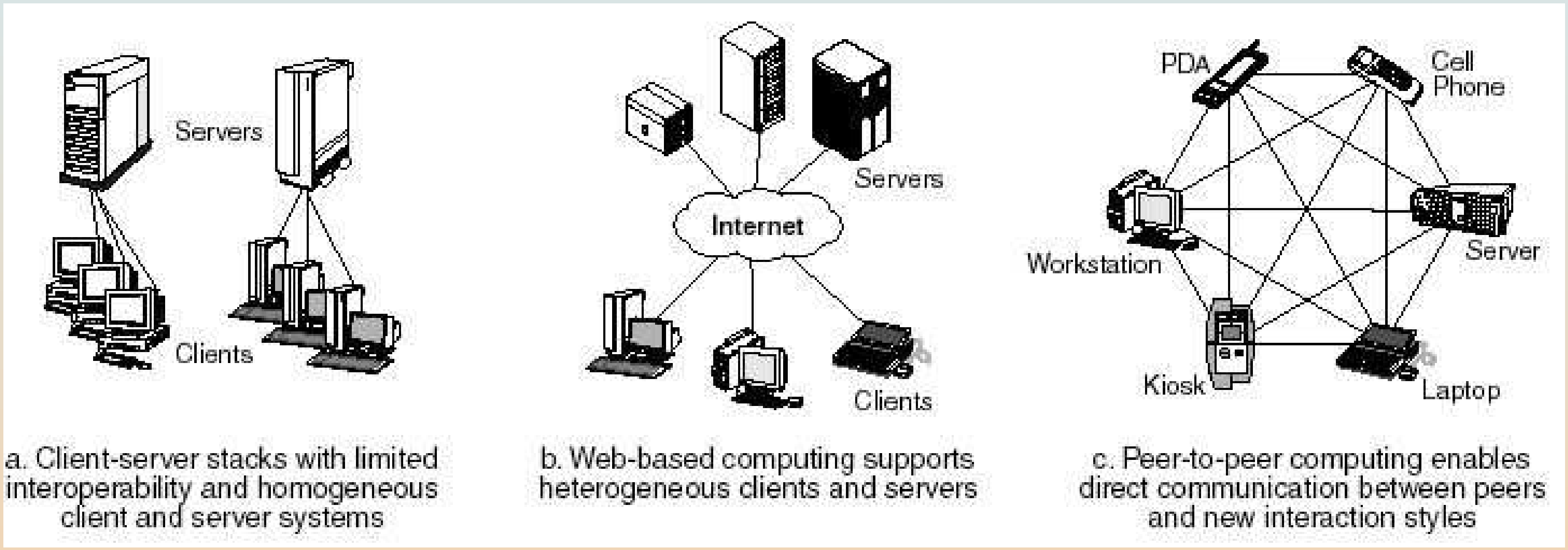
# JXTA
# Goal: P2P



# JXTA
# see www.jxta.org, java.sun.com

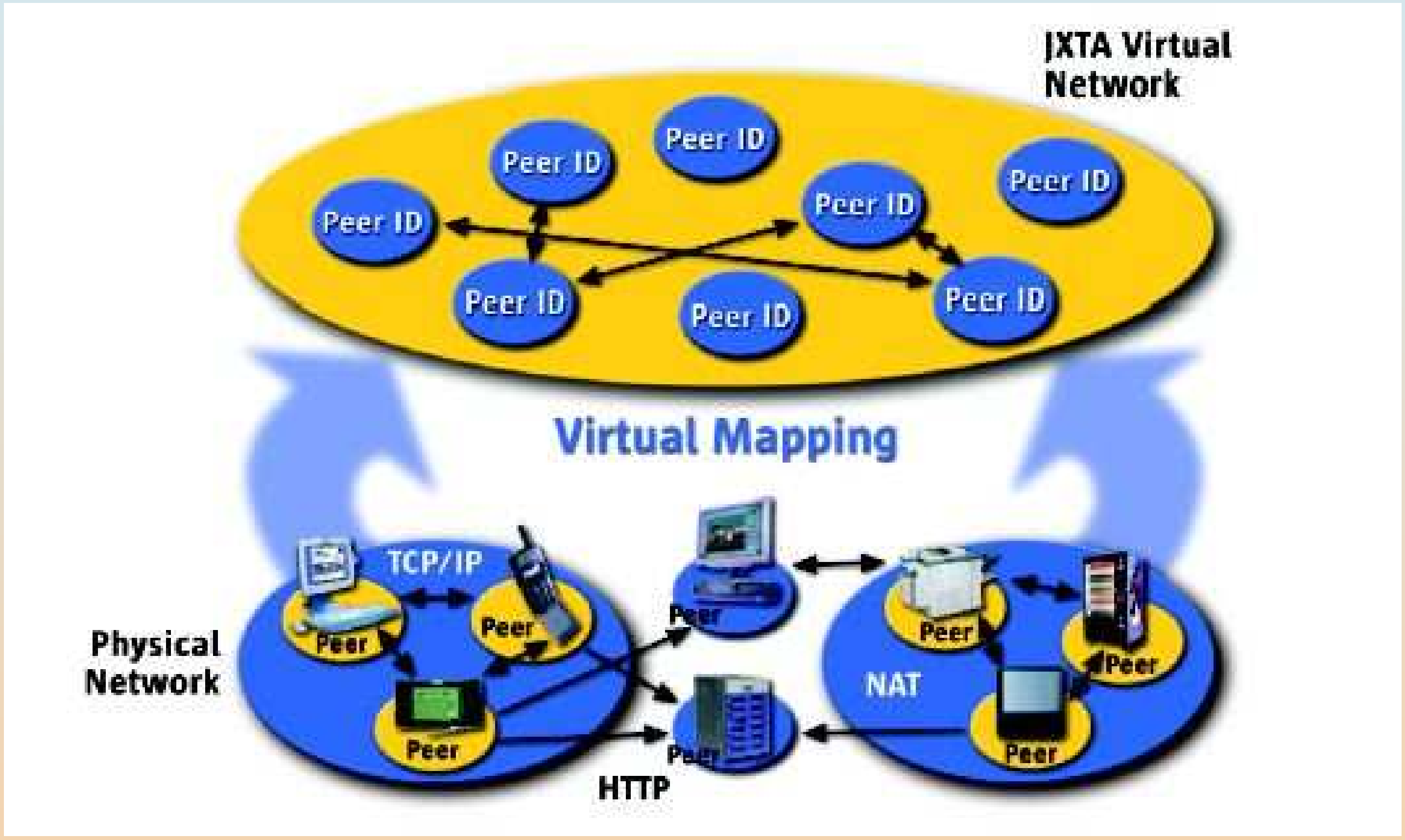


a. Client-server stacks with limited interoperability and homogeneous client and server systems

b. Web-based computing supports heterogeneous clients and servers

c. Peer-to-peer computing enables direct communication between peers and new interaction styles

# JXTA


JXTA Virtual Network
Peer ID
Peer ID
Peer ID
Peer ID
Peer ID
Peer ID
Peer ID
Peer ID
Virtual Mapping
TCP/IP
Physical Network
Peer
Peer
Peer
Peer
Peer
NAT
Peer
Peer
Peer
HTTP