Lecture Notes

Distributed System

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Contents

Chapter 1

Verteilte Systeme/Distributed Systems

1.1 Orga

VL Di 10-12 (nicht am 23.04.)
Ue Do 10-12

1.1.1 Elektisches

- (kvv)
- Website AG
- Sakai

1.1.2 Übungen

- ca. 5 Übungsblätter, 14-tägig
- Vorträge in Gruppen über „verteilte Systeme“

1.1.3 Material/Inhalt

1. Hälfte Distributed Systems (Tanenbaum, van Steen)
   - Architektur
   - Prozesse
   - Kommunikation
   - Namen
   - Synchronisation
   - Konsistenz
   - Replikation
   - Fehlertoleranz
2. Hälfte Distributed Algorithms (Nancy Lynch)
   - synchronous network algorithms

- network models (leader election, shortest path, distributed consensus, byzantine agreement)
- asynchronous network algorithms (shared memory, mutual exclusion, resource allocation, consensus)
- timing
- network resource allocation
- failure detectors

Chapter 2

Distributed Systems

Def: A distributed System is a collection of independent computers that appears to it's users as a single coherent system.

Characteristics:

- autonomous components
- appears as single system
- communication is hidden
- organisation is hidden
  (could be high-performance mainframe or sensor net)
- heterogenous system offers homogenous look/interface

There are 4 goals of distributed systems:

1. Making Resources Accessible
2. Distribution Transparency
3. Openness
4. Scalability

2.1 Making Resources Accessible

- provide users (and applications) access to remote resources (printer, storage, computing)
- share ressources in a controlled efficient way

2.2 Distribution Transparency

Hide the fact that processes and resources are physically distributed. A distributed system that is able to present itself to users and applications as if it were only a single computer system is said to be transparent.

- transparancy is desireable, but not always perfectly possible
- tradeoff between transparancy and complexity, maintainablility and performance

Types of transparancy:

access hide differences in data representation and how a resource is accessed
location hide where a resource is located
migration hide that a resource may move to another location
relocation hide that a resource may be moved to another location while in use
replication hide that a resource is replicated
concurrency hide that a resource may be shared by serveral competitive users
failure hide the failure and recovery of a resource

2.3 Openness

- An open distributed system is a system that offers services according to standard rules that describe the syntax and semantics of those services
- service interfaces (syntax) specified using Interface Definition Language (IDL)
- service specification (semantics) as text

2.4 Scalability

is an important property, distributed systems should be scalable in

size number of nodes, users, resources
geographic spread geographical distribution of users and resources (may lie far apart)
administration manageability, even if even if it spans many independent administrative organizations

2.4.1 Scaling in size

If more users or resources need to be supported, we are often confronted with the limitations of centralized services, data, and algorithms. Scalability in size is limited by:
centralized services A single server for all users (bottleneck)
centralized data A single on-line telephone book or non-distributed DNS
centralized algorithms Doing routing based on *complete* information

2.4.2 Geographical Scalability

- existing distributed systems were designed for LANs
- $\rightarrow$ LAN-based systems often use synchronous communication
- $\rightarrow$ LAN-based systems provide relatively reliable communication
- $\rightarrow$ in LAN-based systems broadcasting is possible
- all of this is not possible in WAN $\Rightarrow$ problems in geographical scalability

2.4.3 Scalability in administration

how to scale a distributed system across multiple, independent administrative domains. Important security questions arise:
selfprotection from malicious attacks from the new domain
domainprotection the domain protects itself from attacks from a new domain

2.4.4 Scaling techiques

hiding communication latencies use only asynchronous communication
distribution split components into smaller parts :)
replication of components, chaching, enables load balancing

2.5 Pitfalls

False assumptions that everyone makes when developing a distributed application for the first time:

1. The network is reliable.
2. The network is secure.
3. The network is homogeneous.
4. The topology does not change.
5. Latency is zero.
6. Bandwidth is infinite.
7. Transport cost is zero.
8. There is one administrator.

2.6 Types of distributed systems

2.6.1 Distributed Computing Systems

Cluster Computing Systems

- the underlying hardware consists of a collection of similar workstations or PCs
- these closely connected by means of a high speed local-area network
- each node runs the same operating system
- used for instance for the building of supercomputers using off-the-shelf technology by hooking up a collection of relatively simple computers in a high-speed network

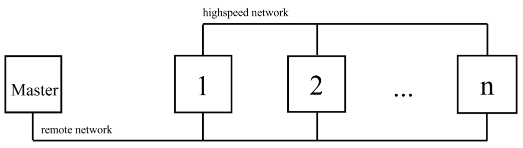


Figure 2.1: cluster computing

Grid Computing Systems

- grid computing systems have a high degree of heterogeneity: no assumptions are made concerning hardware, operating systems, networks, administrative domains, secu- rity policies, etc.
- virtual organization: resources from different organizations are brought together to allow the collaboration of a group of people or institutions
- geographically distributed

2.6.2 Distributed Information Systems

Transaction Processing Systems

A distributed system for processing transactions, e.g. a (distributed) database. Transactions are defined through fulfilling the **ACID** (atomicity, consistency, isolation, durability) properties:
Atomic To the outside world, the transaction, happens indivisibly
Consistens The transaction does not violate system invariants
Isolated Concurrent transactions do not interfere with each other
Duarble Once a transaction commits, the changes are permanent

Enterprise Application Integration

- the more applications became decoupled from the databases they were built upon, the more evident it became that facilities were needed to integrate applications independent from their databases
- application components should be able to communicate directly with each other and not merely by means of the request/reply behavior that was supported by transaction processing systems
- main idea was that existing applications could directly exchange information via communication middleware
- see RPC

Distributed Pervasive Systems

- The distributed systems we have been discussing so far are largely characterized by their stability: nodes are fixed and have a more or less permanent and high-quality connection to a network
- in distributed pervasive systems, instability is the default behavior
- often small, wireless, adhoc, no administration
- Examples: Home automation, Health systems, Sensor Networks

Chapter 3

Architectures 1: Architectural styles

- how to split software into components
  ⇒ Software architecture (aka architectural styles)
- how to build a system out of the components
  ⇒ System architecture

Middleware can help to create distribution transparency

3.1 Layered architecture

- components are organized in a layered fashion
- a component at layer L_n is allowed to call (request) components at the underlying layer L_{n-1}, but not the other way around
- control flows from layer to layer
- request down, reply up
- widely adopted in network stack

3.2 Object-based architectures

- interaction between components
- components are connected through a (remote) procedure call mechanism
- associated with client-server system architecture

3.3 Data-centered architectures

- processes communicate through a common (passive or active) repository
- Example: networked applications with shared distributed file system in which all communication takes place through files
- Example: Web-based distributed system: processes communicate through the use of shared database
- Example: distributed database

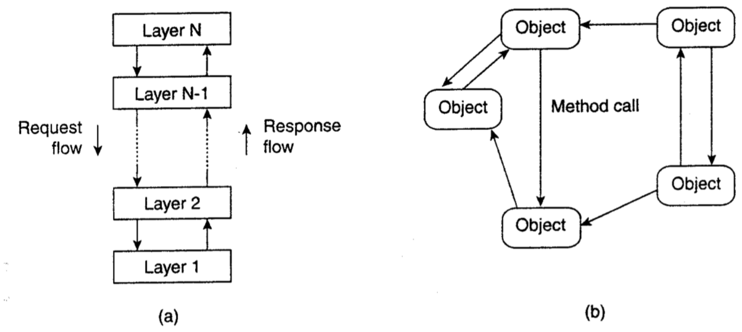


Figure 3.1: The (a) layered and (b) object-based architectural style.

3.4 Event-based architecture

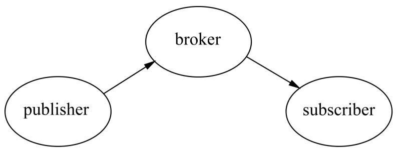


Figure 3.2: publish subsribe system

- aka publish-subscribe systems
- processes essentially through the propagation of events
- publisher announces events at broker
- only those processes that subscribed will receive the events
- $\Rightarrow$ loose coupling (publisher and subscriber need not to know each other), decoupled in space

- $\Rightarrow$ scalability better than client-server, parallel processing, caching

3.5 Shared data spaces

Event-based and data-based can be combined $\Rightarrow$ shared Data space

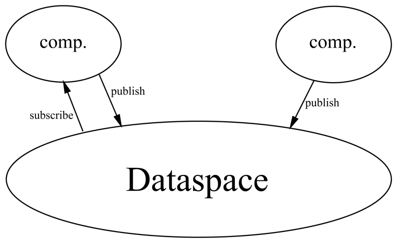


Figure 3.3: shared data space

Chapter 4

Architectures 2: System architectures

- **vertical distribution** (layering, multitiered architectures)
  - placing logically different components on different machines
    ⇒ centralized architectures / client-server
- **horizontal distribution**
  - replicated client/server operating on different data (different parts of the data)
  - all the machines fulfill in principal the same role
    ⇒ peer-to-peer systems

4.1 Centralized architectures

4.1.1 Client - server

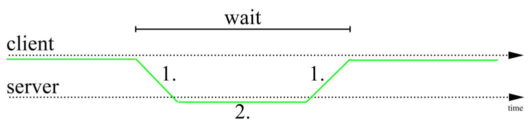


Figure 4.1: client server simple waiting situation

- processes in a distributed system are divided into two (possibly overlapping) groups
- **server:** a process implementing a specific service, for example, a file system service or a database service
- **client:** a process that requests a service from a server by sending it a request and subsequently waiting for the server's
- problems:
  - single point of failure
  - performance (server is bottleneck)
  - can request be repeated without harm? only if request is idempotent

Application layering

1. User interface
   - all that is necessary to directly interface with the user, such as display management

    - clients typically implement the user-interface level
2. processing level
    - contains the core functionality of an application
3. data level
    - contains the programs that maintain the actual data on which the applications operate

Multitiered Architectures

- physically distribute a client-server application across several machines
- direct consequence of dividing applications into a user-interface, processing components, and a data level
- different tiers correspond directly with the logical organization of applications
- three-tiered architecture: split user-interface, application server and database server
- Example: Website
    - Web server acts as an entry point to a site
    - requests are passed to an application server where the actual processing takes place
    - the application server interacts with a database server

⇒ a lot of waiting
⇒ does not scale

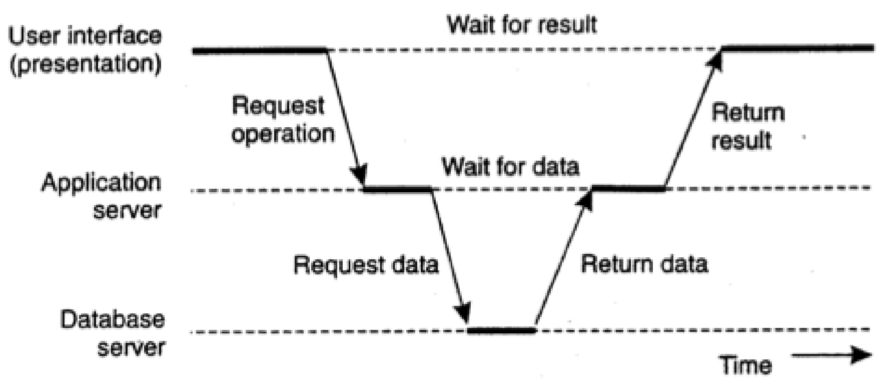


Figure 4.2: Application layering: example of a server acting as client.

4.2 Decentralized architectures

- processes that constitute a peer-to-peer system are (in principal) all equal
- functions that need to be carried out are represented by every process
- interaction between processes is symmetric: each process will act as a client and a server at the same time
- how to organize the processes in an **overlay network**
    - a network in which the nodes are formed by the processes and the links represent the possible communication channels

- hide physical structure by adding logical structure

4.2.1 Structured P2P architectures

- the overlay network is constructed using a deterministic procedure
- most-used procedure is distributed hash table (DHT)

DHT / Chrod

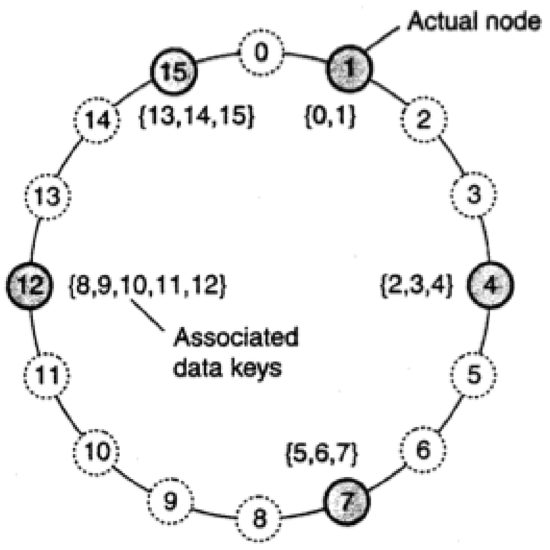


Figure 4.3: The mapping of data items onto nodes in Chord

- randomly 128 bit or 160 bit ke for data and nodes. Two or more duplicate keys are extremely unlikely
- efficient and deterministic scheme that uniquely maps the key of a data item to the identifier of a node
- when looking up a data item, the network address of the node responsible for that data item is returned
- Chord system arranges items in a ring
- data item k is assigned to node with smallest identifier $id \geq k$
  - item 1 belongs to node 1 (see 4.3
  - item 2 belongs to node 4 (see 4.3
- **succ(k)** for each item k_i $succ(k) = id$ returns the name of the node k is assigned to
- **lookaup(k)** to find data item k the function $lookup(k)$ returns the adress of $succ(k)$ in $\mathcal{O}(log(N))$
- **membership management**
  - join
    * create SHA1 identifier id
    * $lookup(id)$ will return $succ(id)$
    * contact $succ(id)$ and $pred(id)$ and insert itself in between
  - leave

        * node id informs $succ(id)$ and $pred(id)$ and assigns it's data to $succ(id)$

Content adressable network (CAN)

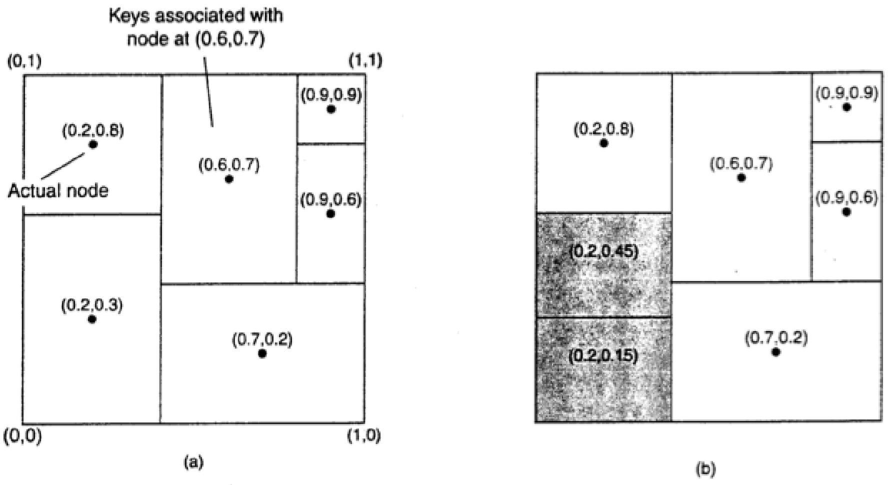


Figure 4.4: (a) The mapping of data items onto nodes in CAN. (b) Splitting a region when a node joins.

- d-dimensional cartesian space
- every node draws random number
- space is divided among nodes
- every data draws identifier (coodinates) which assigns a node
- join
  - select random point
  - half the square in which id falls
  - assign item to centers
- leave
  - one node takes the rectangle
    $\Rightarrow$ reassign rectangles periodically

4.2.2 Unstructured P2P Network

- rely on randomized algorithms for constructing an overlay network
- the goals of many unstructured peer-to-peer systems is to construct an overlay network that resembles a random graph
- basic model
  - each node maintains a list of c neighbors
  - each neighbor represents a randomly chosen *live* node from the current set of nodes
  - list of neighbors is also referred to as a *partial view*
  - nodes regularly exchange entries from their partial view
  - an entry identifies another node in the network
  - an has an associated age (indicates how old the reference is)

Basic algorithm for overlay construction

Active thread Select peer from partial view

PUSH

- select c/2 youngest entries+myself
- send to peer

PULL

- receive peer buffer
- construct new partial view
- increment age

Passive Thread Receive buffer from peer

PULL

- select c/2
- send to peer
- construct new partial view
- increment age

Chapter 5

Peersim

5.1 Kinds of simulation

cycle-based

- fixed cycles; every cycle the part in "next_cycle" is run
- **Observer:** after every cycle

event-based

- exchange of messages, the part in "processevent" is run (e.g. message delays)
- **Observer:** at specified point of time

5.2 Configuration

Specified are controls:

- protocols
- **Initializer:** run at the beginning of the simulation
- **Observer:** run during simulation, change nothing, at least one needed

experiments (number of repetitions), range (simulation is repeated with different parameters)

5.3 Initializer

- **wirekout** parameter k (number of nodes, normally random), creates a "wireplan" for the simulation
- **peekdistributioninitializer** creates one maximum and sets everything else to zero
- **lineardistributioninitializer** creates linear distribution from start to end value

5.4 Stats, order of parameters

```
obs_name time min max n avg variance ct_min ct_max
```

5.5 PeerSim simulation life-cycle

PeerSim was designed to encourage modular programming based on objects (building blocks). Every block is easily replaceable by another component implementing the same interface (i.e., the same functionality). The general idea of the simulation model is:

1. choose a network size (number of nodes)
2. choose one or more protocols to experiment with and initialize them
3. choose one or more Control objects to monitor the properties you are interested in and to modify some parameters during the simulation (e.g., the size of the network, the internal state of the protocols, etc)
4. run your simulation invoking the Simulator class with a configuration file, that contains the above information

5.6 Interfaces

Node, CDProtocol, Linkable, Control

5.7 Example: Average

5.7.1 AverageFunction

```java
package example.aggregation;

import peersim.cdsim.CDProtocol;
import peersim.config.FastConfig;
import peersim.core.CommonState;
import peersim.core.Linkable;
import peersim.core.Node;
import peersim.vector.SingleValueHolder;

/**
 * This class provides an implementation for the averaging function in the
 * aggregation framework. When a pair of nodes interact, their values are
 * averaged. The class subclasses {@link SingleValueHolder} in order to provide
 * a consistent access to the averaging variable value.
 *
 * Note that this class does not override the clone method, because it does not
 * have any state other than what is inherited from {@link SingleValueHolder}.
 */
public class AverageFunction extends SingleValueHolder implements CDProtocol {

    /**
     * Creates a new {@link example.aggregation.AverageFunction} protocol
     * instance.
     *
     * @param prefix
     *            the component prefix declared in the configuration file.
     */
    public AverageFunction(String prefix) {
        super(prefix);
    }

    /**
```

```java
     * Using an underlying {@link Linkable} protocol choses a neighbor and
     * performs a variance reduction step.
     *
     * @param node
     *            the node on which this component is run.
     * @param protocolID
     *            the id of this protocol in the protocol array.
     */
    public void nextCycle(Node node, int protocolID) {
        int linkableID = FastConfig.getLinkable(protocolID);
        Linkable linkable = (Linkable) node.getProtocol(linkableID);
        if (linkable.degree() > 0) {
            Node peer = linkable.getNeighbor(CommonState.r.nextInt(linkable
                    .degree()));

            // Failure handling
            if (!peer.isUp())
                return;

            AverageFunction neighbor = (AverageFunction) peer
                    .getProtocol(protocolID);
            double mean = (this.value + neighbor.value) / 2;
            this.value = mean;
            neighbor.value = mean;
        }
    }
}
```

5.7.2 AverageObserver

```java
package example.aggregation;

import peersim.config.*;
import peersim.core.*;
import peersim.vector.*;
import peersim.util.IncrementalStats;

/**
 * Print statistics for an average aggregation computation. Statistics printed
 * are defined by {@link IncrementalStats#toString}
 */
public class AverageObserver implements Control {
    /**
     * Config parameter that determines the accuracy for standard deviation
     * before stopping the simulation. If not defined, a negative value is used
     * which makes sure the observer does not stop the simulation
     *
     * @config
     */
    private static final String PAR_ACCURACY = "accuracy";

    /**
     * The protocol to operate on.
     *
     * @config
     */
    private static final String PAR_PROT = "protocol";

    /**
     * The name of this observer in the configuration. Initialized by the
     * constructor parameter.
     */
    private final String name;

    /**
     * Accuracy for standard deviation used to stop the simulation; obtained
     * from config property {@link #PAR_ACCURACY}.
     */
    private final double accuracy;

    /** Protocol identifier; obtained from config property {@link #PAR_PROT}. */
    private final int pid;

    /**
     * Creates a new observer reading configuration parameters.
     */
    public AverageObserver(String name) {
        this.name = name;
        accuracy = Configuration.getDouble(name + "." + PAR_ACCURACY, -1);
        pid = Configuration.getPid(name + "." + PAR_PROT);
    }

    /**
     * Print statistics for an average aggregation computation. Statistics
     * printed are defined by {@link IncrementalStats#toString}. The current
     * timestamp is also printed as a first field.
     *
     * @return if the standard deviation is less than the given
     *         {@value #PAR_ACCURACY}.
     */
    public boolean execute() {
        long time = peersim.core.CommonState.getTime();

        IncrementalStats is = new IncrementalStats();

        for (int i = 0; i < Network.size(); i++) {

            SingleValue protocol = (SingleValue) Network.get(i)
                    .getProtocol(pid);
            is.add(protocol.getValue());
        }

        /* Printing statistics */
        System.out.println(name + ": " + time + " " + is);

        /* Terminate if accuracy target is reached */
        return (is.getStD() <= accuracy);
    }
}
```

Chapter 6

Processes

6.1 Threads

6.1.1 Threads vs. processes

processes	**threads**
-execution of program	-several threads share CPU
-processor creates virtual processor	-thread context has little memory information, perhaps mutex lock
-for each program everyting is stored in process table	-threads avoid blocking application (e.g. spreadsheet,computation of dependent cells, intermediate backup)
-transparent sharing of resources,(processor, memory) separation	-thread switch is fast
-each virtual processor has it's own independent adress space	
-process switch is expensive, (save cpu context, pointers, translation lookaside buffer (TLB), memory management unit (MMU))	
-perhaps even swaps to disk, if memory exhausted	

Summary:

- Serveral threads share one process.
- Processes have own address space, threads don't.
- Processes and threads each have userland and kernel implementations

6.1.2 Thread implementation

- **thread package** operations to create and destroy threads, operations for synchronization (mutexes / condition variables)
- user-level thread library
  - it is cheap to create and destroy threads
  - switching thread context can often be done in just a few instructions

  - invocation of a blocking system call will immediately block the entire process to which the thread belongs, and thus also all the other threads in that process
- threads implemented in kernel-space
  - circumvents the blocking problem
  - thread operations need system calls
  - switching thread contexts may now become as expensive as switching process contexts
  - most of the performance benefits of using threads instead of processes then disappears

Two approaches to combine the advantages of user- and kernel space thread packages

1. **Light-weight processes**
   - hybrid form of user-level and kernel-level threads
   - LWP runs in the context of a single (heavy-weight) process, and there can be several LWPs per process
   - offers a user-level thread package
     $\Rightarrow$ all operations on threads are carried out without intervention of the kernel
   - thread package has a single routine to schedule the next thread
   - when an LWP finds a runnable thread, it switches context to that thread.
   - other LWPs may be looking for other runnable threads as well
   - thread may block on system call, then other LWP may run
   - Advantages of LWP and user-level thread package
     - creation, deletion etc is easy, no kernel intervention
     - blocking syscall does not suspend process if enough LWPs are available
     - applications do not see LWP. They only see user-level threads
     - LWP can run on different processors in multiprocessor systems
   - Disadvantage: LWP creation as expensive as creation of kernel-level thread

2. **Scheduler activation** upcall to achieve process switch
   - most essential difference between scheduler activations and LWPs is that when a thread blocks on a system call, the kernel does an upcall to the thread package, effectively calling the scheduler routine to select the next runnable thread
   - advantage: saves management of LWPs by the kernel
   - use of upcalls is considered less elegant, as it violates the structure of layered systems, in which calls only to the next lower-level layer are permitted

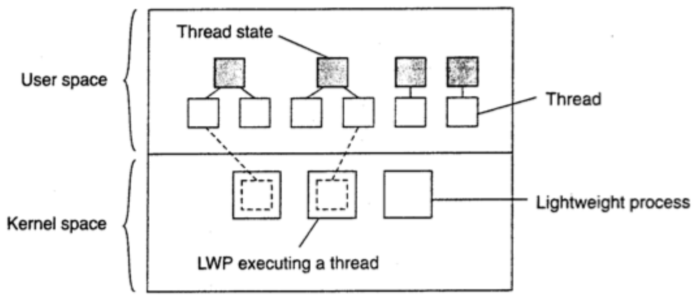


Figure 6.1: Combining kernel-level lightweight processes and user-level threads

6.1.3 Threads in Distributed Systems

Multithreaded Clients

- multiple thread may hide communication delay (distribution transparency)
- web browser opens several connections to load parts of a document/page
- web server may be replicated in same or different location
  $\Rightarrow$ truly parallel access to items and parallel download

Multithreaded Server

- single threaded, e.g. file server
  - thread serves incoming request, waits for disk, returns file
  - serves next
- multithreaded
  - dispatcher thread recieves request
  - hands over to worker thread
  - waits for disk etc.
  - dispatcher takes next request
- finite state machine
  - only one thread
  - examines request, either read from cache (do delay) or from disk (send message to disk, store request)
  - requests waiting for answer are stored in table (state)
  - while waiting for answers, e.g. from disk, serves next request
  - next message may either be a request for new work or a reply from the disk about a previous operation
  - if reply from disk, fetch info from table and reply to client
  - In effect, we are simulating threads and their stacks
  - process acts as finite state machine that receives messages and acts/changes state

model	**characteristics**
single thread	no parallelism, blocking syscalls
multithreaded	parallelism, blocking syscalls
finite state machine	parallelism, needs non-blocking syscalls

6.2 Virtualization

- (resource) virtualization pretends there are more resources then available
- application software is mostly always outliving its underlying systems software and hardware
  $\Rightarrow$ need for virtualization

6.2.1 The Role of Virtualization in Distributed Systems

- virtualization deals with extending or replacing an existing interface so as to mimic the behavior of another system
- networking has become pervasive
  - heterogeneous hardware environment

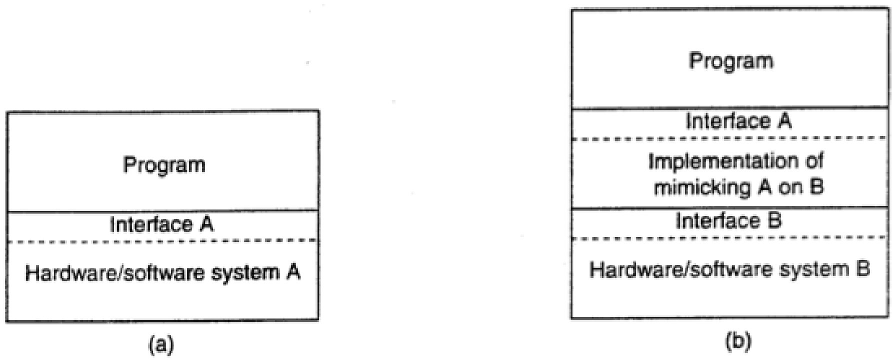

Program
Interface A
Hardware/software system A
(a)
Program
Interface A
Implementation of mimicking A on B
Interface B
Hardware/software system B
(b)

Figure 6.2: (a) General organization between a program, interface, and system. (b) General organization of virtualizing system A on top of system B.

- reduce diversity by letting applications run on its own virtual machine (possibly including libraries and OS)
  ⇒ improves portability

6.2.2 Architectures of Virtual Machines

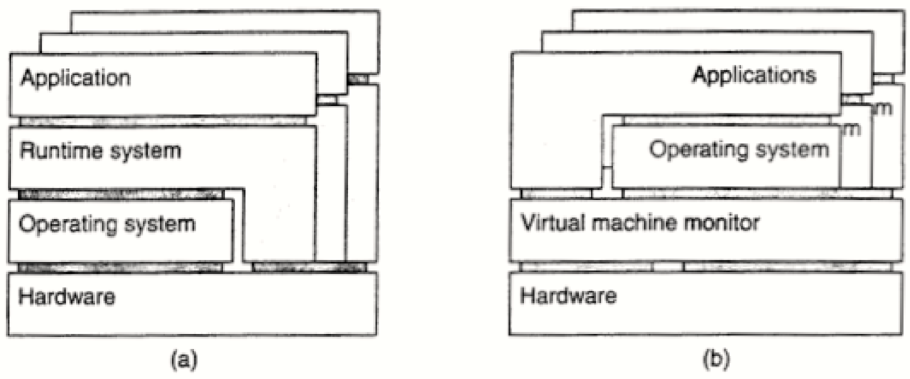


Figure 6.3: (a) A process virtual machine, with multiple instances of (application, runtime) combinations. (b) A virtual machine monitor. with multiple instances of (applications, operating system) combinations

1. **Process Virtual Machine**
   - provides an abstract instruction set that is to be used for executing applications
   - instructions can be interpreted (as is the case for the Java runtime environment) or
   - instructions can be emulated (e.g. Wine for running Windows applications on UNIX machines)
2. **Virtual machine monitor**
   - provide a system that is as a layer completely shielding the original hardware
   - offering the complete instruction set of that same (or other hardware) as an interface

- this interface can be offered simultaneously to different programs
  ⇒ run multiple and possibly different operating systems concurrently on the same platform
- Examples: VMware, Xen

6.3 Clients

A closer look of the clients (in the client-server model).

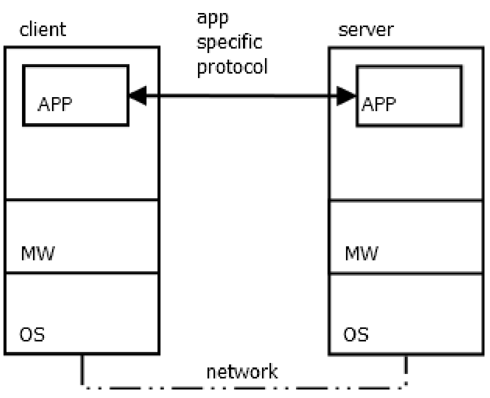


Figure 6.4: a) app specific communication

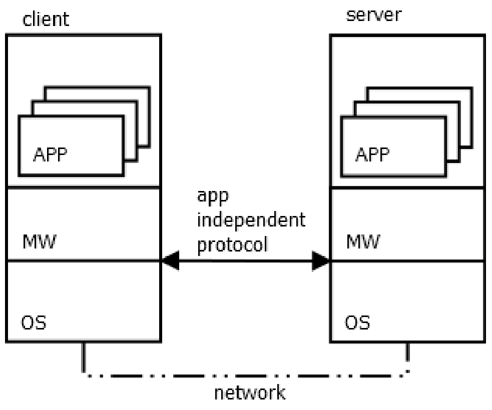


Figure 6.5: b) machine only communication

6.3.1 Different kinds of Clients

1. **Networked Application**
   - remote service has a separate counterpart on the client machine that communicates with the server
   - an application-level protocol will handle the synchronization
   - Example: agenda running on a user's PDA that needs to synchronize with a remote, possibly shared agenda
2. **Networked User Interface / Thin Client**
   - provide direct access to remote services by only offering a convenient user interface
   - client machine is used only as a terminal with no need for local storage (thin client)
   - application-neutral communication protocol solution (see 6.5)
   - thin client approach only works with good separation of application logic from user interaction
   - **Example: X-Windows**
     - example for thin client
     - bad separation between application logic and user interaction
       ⇒ lot of synchronous communication ⇒ bad performance
     - compression of interaction commands can alleviate problem
   - **Compound Documents**
     - a collection of documents, possibly of very different kinds (like text, images, spreadsheets, etc.

  - seamlessly integrated at the user-interface level
  - he applications associated with a compound document do not have to execute on the client's machine

6.4 Servers

- server is a process implementing a specific service on behalf of a collection of clients
- it waits for an incoming request from a client
- ensures that the request is taken care of
- waits for the next incoming request

6.4.1 Kinds of server

Iterative Server

- server itself handles the request and, if necessary, returns a response to the client

Concurrent Server

- does not handle the request itself, but passes it to a separate thread or another process
- after which it immediately waits for the next incoming request
- Example 1: multithreaded server
- Example 2: fork a new process for each new incoming request ($\rightarrow$ UNIX)

6.4.2 Communication Endpoints

- clients send re- quests to an end point (port), at the machine where the server is running
- each server listens to a specific end point.
- how do clients know the end point of a service?

Fixed Preassigned Endpoints

- globally assign end points for well-known services
- Example: HTTP server always listens to TCP port 80
- server listens to port, endpoint to the client; some ports are reserved for special services
- stateless servers, keeps no information on state of client $\rightarrow$ change state without informing the client, e.g. web server

Dynamically Assigned Endpoints: Daemons

- service gets dynamically assigned port
- client needs to look up the endpoint first
- daemon with well known endpoint keeps track of all running services
- daemon delivers endpoint to client

Dynamically Assigned Endpoints: Superserver

- a single superserver listening to each end point associated with a specific service
- when a request comes in, the daemon forks a process to take further care of the request
-

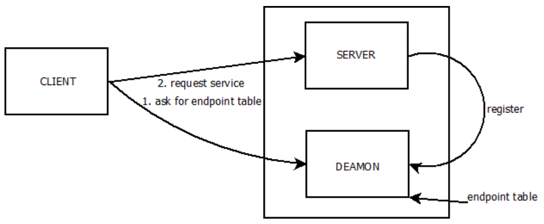


Figure 6.6: listener server

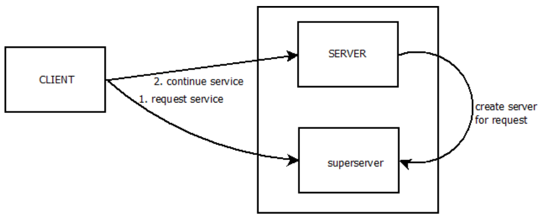


Figure 6.7: superserver

6.4.3 State

Stateless Server

- does not keep information on the state of its clients
- can change its own state without having to inform any client
- Example: Webserver
  - responds to incoming HTTP requests
  - when the request has been processed, the Web server forgets the client completely
- the server may maintain information on its clients, but if this information is lost, it will not lead to a disruption of the service offered
- cookies allow to share information for server upon next visit client sends it's cookies
  $\Rightarrow$ allows state information for stateless server

Softstate Server

- a particular form of a stateless design
- the server promises to maintain state on behalf of the client, but only for a limited time
- when time has expired, all information on client is discarded
- Example: a server promising to keep a client informed about updates, but only for a limited time

Stateful server

- maintains persistent information on its clients
- the information needs to be explicitly deleted by the server
- Example: Fileserver with update operations
  - allows client to keep copy of a file and perform update operations
  - server maintains a table with *(client, file)* associations
  - table allows server to keep track of which client currently has the update permissions on which file
- stateful servers often offer performance gains compared to stateless designs
- higher complexity, especially in cases of crashes (need for recovery)

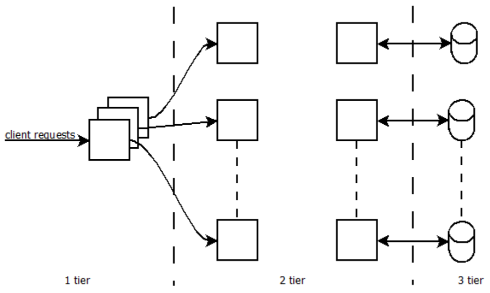


Figure 6.8: stateless server

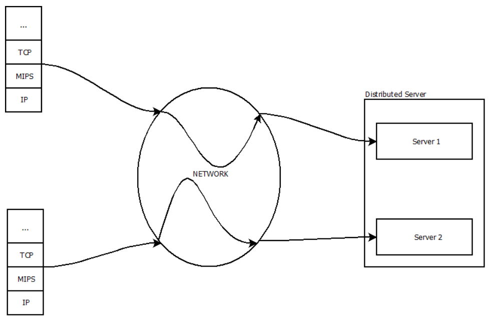


Figure 6.9: distributed server

6.4.4 Distributed Servers

- a possibly dynamically changing set of machines, with also possibly varying access points, but which nevertheless appears to the outside world as a single machine
- how to manage the endpoints of the different machines?
  1. DNS: servers in different locations with different IPs can have the same name in DNS
  2. MIPv6: mobility support for IPv6
     - mobile node has home network with stable home adress (HoA)
     - special router is home agent and takes care of traffic to the mobile node
     - mobile node receives care-of-adress (CoA), never seen by client
     - route optimisation avoids routing through home agent

6.5 Code Migration

- passing programs (code, not just data), possibly even while being executed
- traditionally: process migration: an entire process is moved from one machine to another
- Reasons for code migration
  - service placement in distributed system $\Rightarrow$ minimize communication cost
  - load balancing in multiprocessor machine or cluster $\Rightarrow$ performace
- Disadvantages: mostly security (downloading and executing external code)

6.5.1 Models for Code Migration

Process Models

A process consists of three segments:
1. **code segment** set of instructions that make up the program
2. **resource segment** references to external resources, e.g. files, printer, devices
3. **execution segment** execution state of a process (private data, stack, program counter)

Weak Mobility

- transfer only the code segment (1), along with perhaps some initialization data
- program is always started from one of several predefined starting positions
- Example: Java applets, always start execution from the beginning

- Advantage: Simplicity

Strong Mobility

- transfer code and execution segments
- a running process can be stopped, subsequently moved to another machine, and then resume execution where it left off
- much more general than weak mobility, but also much harder to implement

Migration and Local Resources

- code migration is difficult, because the resource segment cannot always be transferred without being changed
- Example 1: port is machine specific, can not simply be transferred
- Example 2: file as absolute URL, can be simply be transferred

Process-to-resource binding

1. binding by identifier (strongest), e.g. URL, ftp-server-name
2. binding by value, libraries for programming
3. binding by type (weakest), local device, monitor

Resource-machine-binding

1. **unattached** can be easily moved between different machines, typically (data) files associated only with the program that is to be migrated
2. **fastend** moving or copying may be possible, but high costs. Examples: local databases, complete Web sites
3. **fixed** intimately bound to a specific machine or environment and cannot be moved, e.g. local devices, ports

What to do when migrating resource segments

	unattached	fastened	fixed
by identifier	MV	GR(or MV)	GR
by value	CP	GR(or CP)	GR
by type	RB	RB(or GR, CP)	RB(or GR)

GR establish a global systemwide reference
MV move the resource
CP copy the value of the resource
RB rebind process to locally-available resource

Chapter 7

Communication

- Communication in distributed systems is always based on low-level message passing as offered by the underlying network
- message passing is harder than using primitives based on shared memory, as in nondistributed systems
- low-level communication facilities of computer networks are in many ways not suitable due to their lack of distribution transparency.

7.1 RPC - Remote Procedure Call

- allow programs to call procedures located on other machines
- When a process on machine A calls' a procedure on machine B, the calling process on A is suspended, and execution of the called procedure takes place on B.
- Remote procedure call uses stubs to pack parameters in message
- client stub: packs the parameters into a message and requests that message to be sent to the server
- server stub: transforms requests coming in over the network into local procedure calls
- No message passing at all is visible to the programmer
- neither client nor server need to be aware of the intermediate steps or the existence of the network

A remote procedure call occurs in the following steps:

1. The client procedure calls the client stub in the normal way.
2. The client stub builds a message and calls the local operating system.
3. The client's operating system sends the message to the remote operating system.
4. The remote operating system gives the message to the server stub.
5. The server stub unpacks the parameters and calls the server.
6. The server does the work and returns the result to the stub.
7. The server stub packs it in a message and calls its local operating system.
8. The server's as sends the message to the client's operating system.
9. The client's operating system gives the message to the client stub.
10. The stub unpacks the result and returns to the client.

Parameter Marshaling

parameter marshaling: packing parameters into a message is called

Passing Value Parameters

- values are packed into messages (client) and unpacked from messages (server)
- transfered byte-by-byte
- as long as the client and server machines are identical this model works fine
- in a large distributed system, it is common that multiple machine types are present
- $\Rightarrow$ problems because of different character encoding (EBCDIC vs ASCII), represetation of integers (one's complement vs two's complement) or endianness (little endian vs. big endian)

Passing Reference Parameters

- extremly difficult
- pointers are meaningful only within the address space of the process in which it is being used
- replace with copy/restore: copy the datastructure, send it to the server, work on it, send it back, restore at the client

7.2 Asynchronous RPC

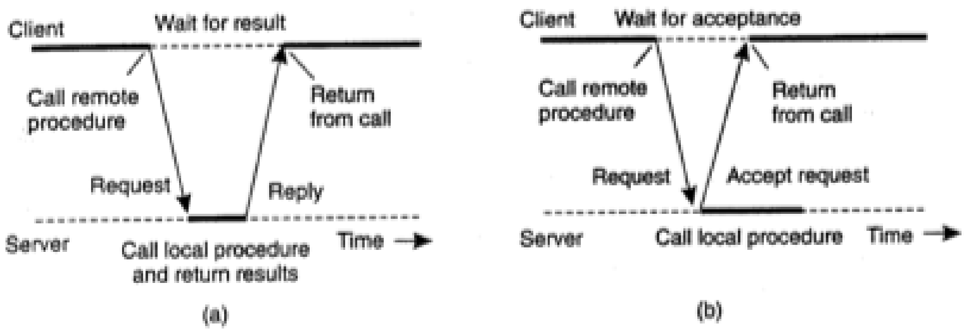


Figure 7.1: a: synchronous b: asynchronous RPC

- in conventional procedure calls, when a client calls a remote procedure, the client will block until a reply is returned
- asynchronous RPCs: the server immediately sends a reply back to the client the moment the RPC request is received. Reply acts as an acknowledgment.
- client will continue without further blocking as soon as it has received the server's acknowledgment
- Examples: transferring money from one account to another, adding entries into a database, starting remote services, batch processing...
- Asynchronous RPCs can also be useful when a reply will be returned but the client doesn't need to wait for it and can do nothing in the meantime
- One-Way RPCs: the client does not wait for an acknowledgment from the server

- deferred synchronous RPC: organize the communication between the client and server through two asynchronous RPCs
- foo

7.3 Message oriented communication

General Idea: avoid synchronous communication which blocks sender (RPC)

7.3.1 Message-Oriented Transient Communication

transient: flüchtig, vorrübergehend

Berkeley Sockets

A socket is a communication end point to which an application can write data that are to be sent out over the underlying network, and from which incoming data can be read. A socket forms an abstraction over the actual communication end point that is used by the local operating system for a specific transport protocol.

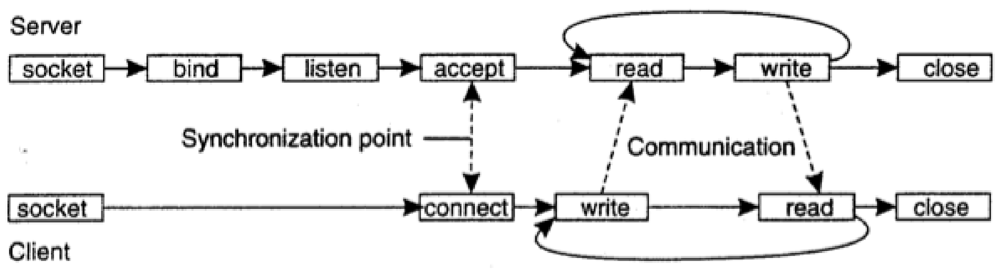


Figure 7.2: Connection-oriented communication pattern using sockets

- socket: create a new communication end point
- bind: attach a local addres to a socket
- listen: announce willingness to accept connections
- accept: block caller until a connection request arrives
- connect: actively attemt to establish a connection
- send: send some data over the connection
- receive: receive some data over the connection
- close: release the connection

Message-passing-interface (MPI)

- standad for message passing
- designed for parallel applications
- communication within groups of processes
- A $(groupID, processID)$ pair uniquely identifies the source or destination of a message (used instead of a transport-level address)

7.3.2 Message-Oriented Persistent Communication

aka Message-queuing-system, Message-oriented-middleware (MoM)

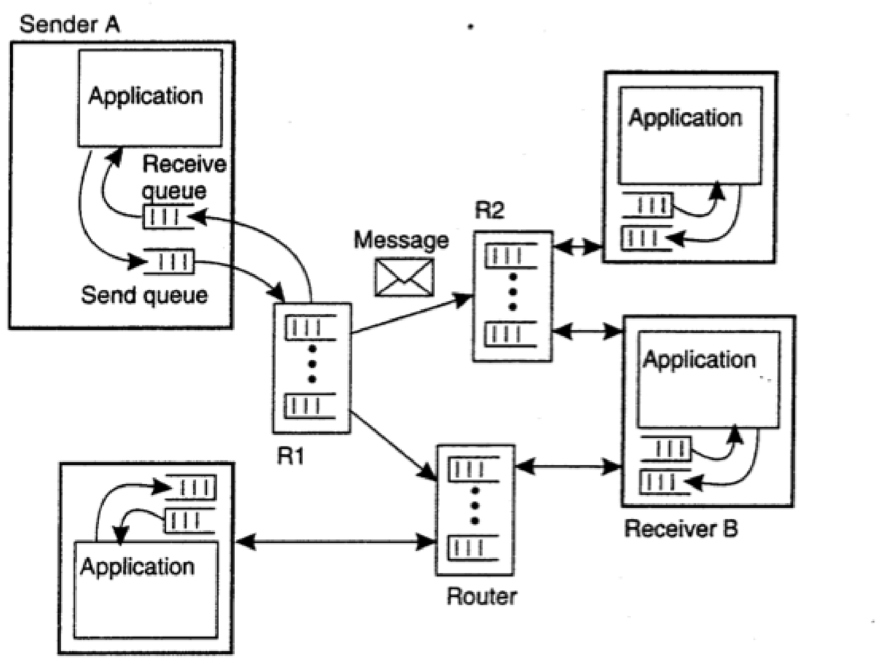


Figure 4-20. The general organization of a message-queuing system with routers.

Figure 7.3: general organization of a message-queuing system with routers

- asynchronous persistent communication
- offer intermediate-term storage capacity for messages, without requiring either the sender or receiver to be active during message transmission
- transfer may take minutes, not milliseconds
- applications communicate by inserting messages into queues
- messages are only put into and read from local queues
- the message-queuing system takes care that messages are transferred from their source to their destination queue
- message carries destination address
- queue managers
  - a queue manager interacts directly with the application that is sending or receiving a message
  - also special queue managers that operate as routers, or relays: they forward incoming messages to other queue managers
- message brokers transform type A into type B, using a set of rules
  - application-level gateway in a message-queuing system
  - convert incoming messages so that they can be understood by the destination application
  - transform messages of type A into type B, using a set of rules

- Examples: Email, workflow, batch processing, queries accross several databases

7.4 Stream Oriented Communication

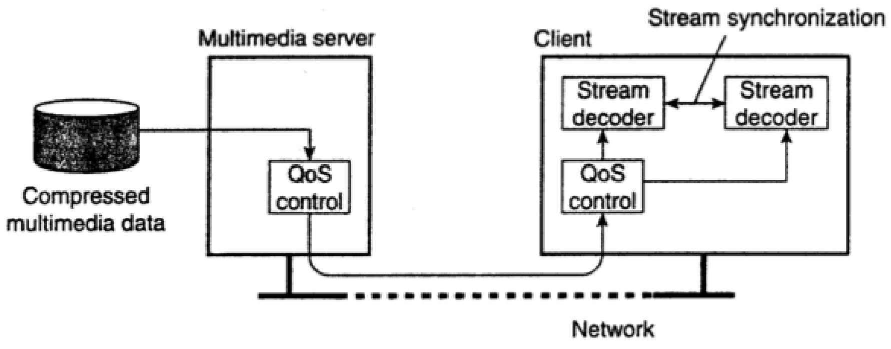


Figure 7.4: A general architecture for streaming stored multimedia data over a network

- form of communication in which timing plays a crucial role
- in continuous media, the temporal relationships between different data items are fundamental to correctly interpreting what the data actually means
- multimedia data will need to be compressed substantially in order to reduce the required network capacity
- simple stream: consists of only a single sequence of data
- complex stream: consists of several related (often time dependent) simple streams (substreams)
- QoS
  1. The required bit rate at which data should be transported.
  2. The maximum delay until a session has been set up (i.e., when an application can start sending data).
  3. The maximum end-to-end delay (i.e., how long it will take until a data unit makes it to a recipient).
  4. The maximum delay variance, or jitter.
  5. The maximum round-trip delay.
- synchronisation of streams
  - Synchronization of streams deals with maintaining temporal relations between streams
  - Synchronization takes place at the level of the data units of which a stream is made up
  - In other words, we can synchronize two streams only between data units
  - Example: Playing a movie in which the video stream needs to be synchronized with the audio

7.5 Multicast communication

7.5.1 Application Level Multicasting

- sending data to multiple receivers
- For many years, this topic has belonged to the domain of network protocol

- With the advent of peer-to-peer technology various application-level multicasting techniques have been introduced
- The basic idea in application-level multicasting is that nodes organize into an overlay network, which is then used to disseminate information to its members
- connections between nodes in the overlay network may cross several physical links, and as such, routing messages within the overlay may not be optimal in comparison to what could have been achieved by network-level routing

Approaches to building the overlay

- tree: nodes may organize themselves directly into a tree, meaning that there is a unique (overlay) path between every pair of nodes
- mesh network: nodes organize into a mesh network in which every node will have multiple neighbors and, in general, there exist multiple paths between every pair of nodes
- mesh network generally provides higher robustness

Example: Construct overlay tree for chord

- node that wants to start multicast generates key 128bit/160bit (mid) randomly
- lookup of succ(mid) finds node responsible for key mid
  $\Rightarrow$ succ(mid) becomes root of tree
- join multicast: lookup (mid) creates lookup message with join request routed from P to succ(mid)
- request is forwarded by Q (first time forward), Q becomes forwarder
  $\Rightarrow$ P child of Q
- request is then forwarded by R, R becomes forwarder
  $\Rightarrow$ Q becomes child of R
- if Q or R is already forwarder: no forward
  $\Rightarrow$ Q becomes child of R
- multicast: lookup(mid) sends message to the root
  multicast from root

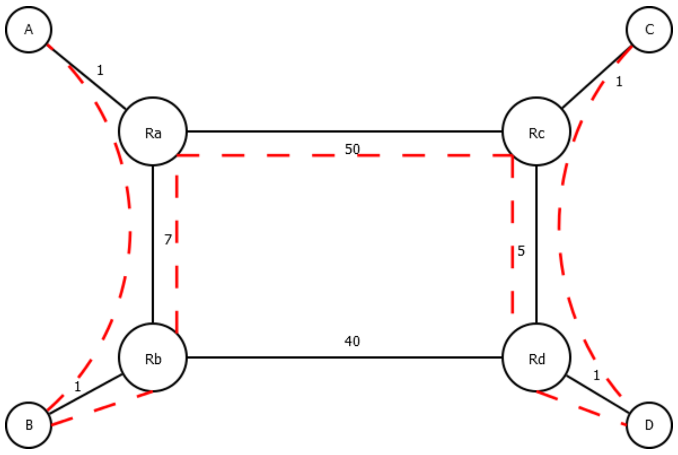


Figure 7.5: The relation between links in an overlay and actual network-level routes

Efficiency

- building a tree is not difficult once we have organized the nodes into an overlay
- building an efficient tree may be difficult
- The quality of an application-level multicast tree is generally measured by three different metrics
    1. Link stress: defined per link and counts how often a packet crosses the same link
    2. Stretch / Relative Delay Penalty (RDP)
       ratio in the delay between two nodes in the overlay, and the delay that those two nodes would experience in the underlying network: $\frac{\text{transmission time in overlay}}{\text{transmission time in delay/network}}$
       $\Rightarrow$ minimize aggregated stretch, average RDP over all note pairs
    3. tree cost: global metric, generally related to minimizing the aggregated link costs
       link cost = cost between end points
       $\Rightarrow$ find minimal spanning tree

7.5.2 Gossip-based-communication

- epidemic behaviour: model information dissemination in a (large) distributed system after the spreading of infectious diseases
- infected node: a node that holds data that it is willing to spread
- susceptible: a node does not yet have the new data
- removed: an updated node that is not willing or able to spread its data
- we assume we can distinguish old from new data, for example, because it has been timestamped or versioned

Anti-entropy-model

A node P picks another node Q at random, and subsequently exchanges updates with Q. There are three approaches to exchanging updates:

1. P only pushes its own updates to Q
    - updates can be propagated only by infected nodes
    - if many nodes are infected, the probability of each one selecting a susceptible node is relatively small
    - $\Rightarrow$ chances are that a particular node remains susceptible for a long period simply because it is not selected by an infected node
2. P only pulls in new updates from Q
    - spreading updates is essentially triggered by susceptible nodes
    - high probability to to contact an infected node and pull in the updates
    - $\Rightarrow$ pull-based approach works much better when many nodes are infected
3. P and Q send updates to each other (i.e., a push-pull approach)
    - if only one node is infected push/pull is best

- Round is period in which each node at least once selects a neighbor
- number of rounds needed to spread $\approx \mathcal{O}(\log(N)), N$ is number of nodes

Rumor spreading, gossiping

- if node P has just been updated for data item x, it contacts an arbitrary other node Q and tries to push the update to Q
- if Q was already updated by another node, P may lose (with some probability) interest in spreading the update any further

- P then becomes removed
-
- Fraction of nodes that never obtain data: $s = e^{-(k+1)(1-s)}$
  e.g. $k = 4, ln(s) = 4, 97$
  $\Rightarrow s = 0, 007$
  less than $0, 7\%$ remain without data

Removing Data

- problem: deletion of a data item destroys all information on that item
  $\Rightarrow$ when a data item is simply removed from a node, that node will eventually receive old copies of the data item and interpret those as updates on something it did not have before
- $\Rightarrow$ record the deletion of a data item as just another update, and keep a record of that deletion

Chapter 8

CHORD: Distributed Hash Tables

Chapter in the Book:

- Naming
  - Flat naming
    - Distributed Hash Tables

- Chord uses an m-bit identifier space (128 or 160 Bit) to assign randomly-chosen identifiers to nodes as well as keys to specific entities
- An entity with key k falls under the jurisdiction of the node with the smallest identifier id $\geq$ k (referred to as succ(k)

8.1 Joining

- node p wants to join
- p requests lookup for $succ(p)$
  - actually, p creates SHA1 identifier id, e.g. from its IP, which is then looked up
- contact $succ(id)$ and $pred(id)$ to join ring
- create finger table for p either by calculating all the entries or by copying the finger table of $succ(p)$ an let the stabilization protocol do the rest

8.2 Leaving

- node p informs $succ(p)$ and $pred(p)$
- $p's$ data is assigned to $succ(p)$

8.3 Routing

- searching, lookung
- Resolve key k to address of $succ(k)$

8.3.1 Option 1: Naive Approach (Linear search)

- each node p keeps succ(p+1) and pred(p)
- each node forwards request for key k to a neighbor
- if pred(p) < k $\leq$ p, return(p)
  $\Rightarrow$ not scalable

8.3.2 Option 2: Finger-table based lookup

- better solution: each Chord node maintains finger table of lenght m

$$\forall\, 1 \leq i \leq m : FT[i] = succ(p + 2^{i-1}) \mod 2^m$$

- the i-th entry points to the first node succeeding p by at least 2^{i-1}
- Example: Node 1: FT[1]=succ($p + 2^{i-1}$) = succ($1 + 2^{1-1}$) = succ($1 + 1$) = succ(2) (smallest id, sucht that id $\geq$ 2)
- to lookup key k, node p forwards request to node q with index j in $p's$ finger table: $q = FT_p[j] \leq k \leq FT_p[j+1]$
- lookup generally requires $O(log(N))$ steps, N nodes in system

8.4 Stabilization

- goals:
  - keep the finger tables up to date
  - make new nodes known to the rest of the network
  - preserve the structure of the ring
- two tasks, periodically run at each node
  1. fix_fingers
     - check (li.e. lookup) one, some or all entries in the the finger table
     - update the finger table accordingly
  2. stabilize
     - lookup $pred(succ(p))$ (should be p)
     - otherwise: update successor and predecessor information in p and the neighbors

Example 1: Routing

The example refers to Figure 5.4, p. 190, Tanenbaum.
Resolve k = 26 from node 1
$k = 26 > FT_1[5] \Rightarrow$ forward request to node
$18 = FT_1[5]$

- node 18 selects node $20 FT_{18}[2] \leq k < FT_{18}[3]$
- node 20 selects node $21 \Rightarrow 28$ which is responsible for key 26

Example 2: Superpeers

Assume a system for which k bits of an m-bit identifier space have been reserved for assigning to superpeers. If identifiers are randomly assigned, how many superpeers can one expect to have in an

N-node system?
Superpeers: 2^k, therefore 2^{m-k} normal nodes.
Probability that a node is a supernode: $n \cdot \frac{2^k}{2^m} = 2^{k-m} \cdot n$, with m number of bits, k is number of bits that mark superpeers, n is number of nodes (not maximum possible but the actual number).
Number of superpeers to be expected: $E(x) = n \cdot p$

Chapter 9

Synchronistation

9.1 Clock synchronisation algorithms

System model: each machine has timer that causes H interrupts per second

- clock C adds up ticks (interrupts)
- $C_p(t)$ is clock time on machine p
- perfect clock: $\forall\, p, t : C_p(t) = t$
  $\iff C'_p(t) = \frac{dC_p(t)}{dt} = 1$
  $\widehat{=}$ frequency of clock C_p at time t

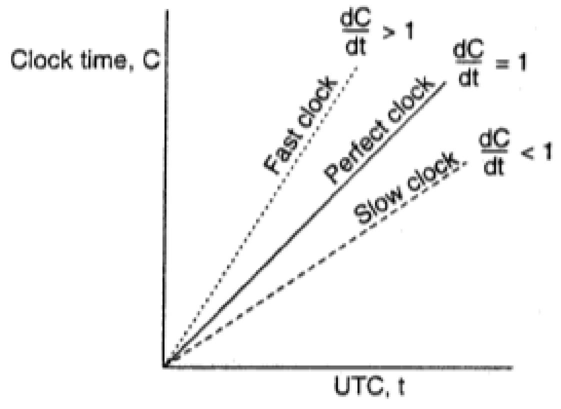


Figure 6-5. The relation between clock time and UTe when clocks, tick at different rates.

Figure 9.1: fast, slow & perfect clock

- $C'_p(t) - 1 \,\widehat{=}$ skew of p's clock, difference to perfect clock.
- $C_p(t) - t \,\widehat{=}$ offset
- real timers do not interrupt exactly H times per second
- maximum drift ρ is a constant guaranteed/specified by the vendor
  $1 - \rho \leq \frac{dC_p(t)}{dt} \leq 1 + \rho$

- at time Δt after two clocks were synchronized the drift can be max: $|C_2(\Delta t) - C_1(\Delta t)| \leq 2\rho\Delta t$
- if the difference should never exceed δ then synchronisation every $\frac{\delta}{2\rho}$ seconds is needed
- time always moves forward.

example: given values for C_1 and C_2:

$C_1 = \rho = 0.001$
$C_2 = \rho = 0.001$
$\frac{dC}{dt} = \frac{1}{2*0.001} = \frac{1}{0.002} = \frac{1}{2} * 10^3$
Clocks C_1 and C_2 need to be synchronized every $500s$ to keep time in the same second.

9.2 Network Time Protcol (NTP)

- nodes contact time server that has an accurate clock
- time server passive

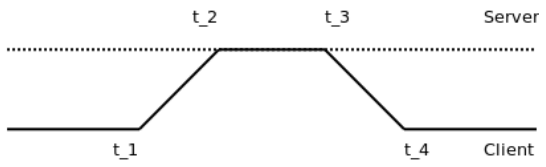


Figure 9.2: ntp

A estimates its offset to B as
$\Theta = \frac{(T_2 - T_1) + (T_4 - T_3)}{2}$
assuming communication time is symmetric
delay:
$\delta = (T_4 - T_1) - (T_3 - T_2) = (T_2 - T_1) + (T_4 - T_3)$

- A probes B, B probes A
- NTP stores 8 pairs (Θ, δ) per node pair using min(δ) for smallest delay
- either A or B can be more stable
- reference node has stratum 1 (clock has stratum 0) (stratum = # Servers to a reference clock)
- lower stratrum level is better, will be used.

9.3 Berkeley algorithm

- assumes no node has 'good' time
- time server polls all nodes for their time
- takes average and adjusts speed of nodes correspondingly
- all nodes agree on time, which may not be correct

9.4 Lamports Logical Clocks

- logical time need not correct in real time.
- needs 'happens before' relation a $\rightarrow$ b

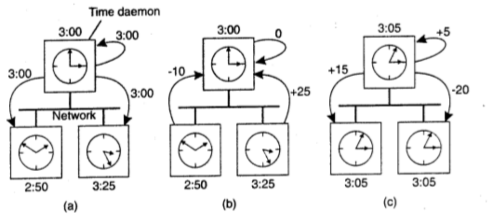


Figure 9.3: Berkley Clocks: (a) The time daemon asks all the other machines for their clock values (b) The machines anwer. (c) The time daemon tells everyone how to adjust their clock.

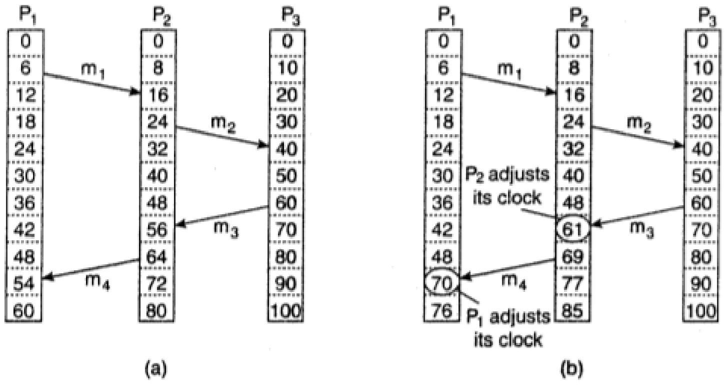


Figure 6-9. (a) Three processes, each with its own clock. The clocks run at different rates. (b) Lamport's algorithm corrects the clocks.

Figure 9.4: Lamport's clock

1. if a,b are events in the same process and a happens before b, than a $\rightarrow$ b is true
2. if a denotes the event of sending a message and b the event of receiving this message by another process then a $\rightarrow$ b is true

- happens before is transitive:
  $a \rightarrow b \wedge b \rightarrow c \Rightarrow a \rightarrow c$
- concurrency:
  if x, y happen in different processes and neither $x \rightarrow y$ nor $y \rightarrow x$, then x, y are concurrent (which means, it is not known which one comes first)
- $\forall$ events a, we can assign it a time $C(a)$ on which all processes aggree.
- if $a \rightarrow b$ then $C(a) < C(b)$
  if $C(a) < C(b)$ then not $a \overset{?}{\rightarrow} b$
  if $C(a) \not< C(b)$ then $a \not\rightarrow b$

- 4 properties of logical time
  1. No two events get assigned the same time.
  2. Logical times of events in each process are strictly increasing
  3. logical time of send event is strictly smaller than receive event for the same message
  4. for any $t \in T$ only finitely many events get assigned logical times smaller then t.

Algorithm

$C_i =$ local counter of process P_i

1. Before executing an event (sending a msg over the network, delivering a msg to an app, some internal events) P_i executes $C_i \leftarrow C_i + 1$
2. When process P_i sends message m to P_j it sets the timestamp $ts(m)$ of m to the current time $ts(m) \leftarrow C$.
3. upon receipt of a message m process P_j adjust its time to $C_j \leftarrow \max(C_j, ts(m) + 1)$

9.4.1 Totally ordered multicast

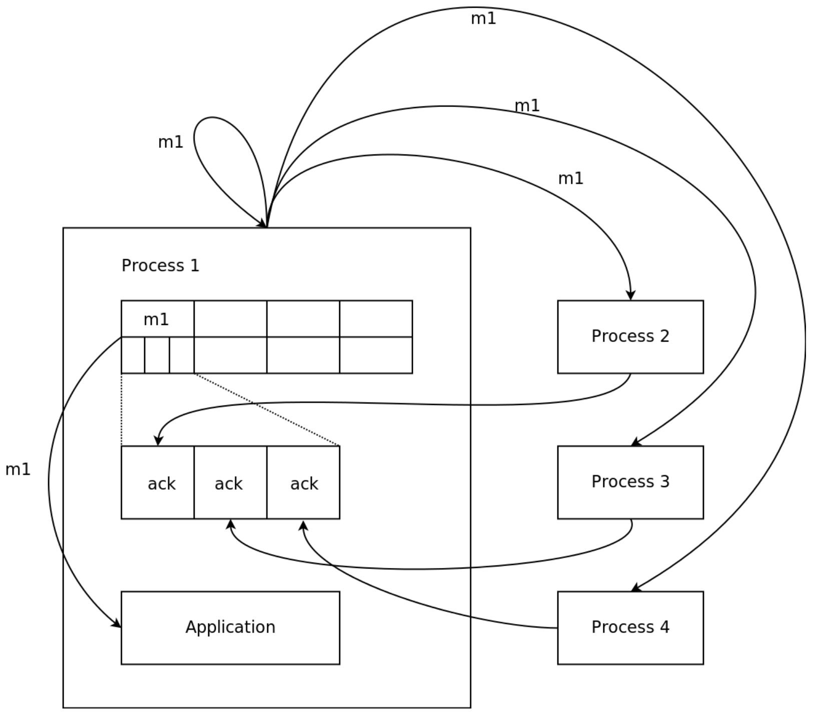


Figure 9.5: Totally Ordered Multicast

Example

Consider a bank with two data centers A and B, that need to be kept consistent. Each request uses the nearest copy.
Assume a customer has $1000,- in his bank account and decides to add $100,- using copy A. At the same time 1% interest is added to copy B. What happens? How can we solve the problem?

Algorithm

- every message is sent to all receivers+itself with timestamp
- Assumption 1: messages from the same sender are received in the order they were sent, and that no messages are lost

- Assumption 2: no two events get assigned the same time
- When msg is received
  1. put it into a local priority queue ordered to the msgs timestamp
  2. multicast an acknowledgment to all other processes (following Lamport $\Rightarrow ts(msg) < ts(ack)$)
- eventually all queues are identical $\Rightarrow$ total order
- Process delivers a queued msg to the app only when
  1. msg is at head of queue
  2. ack received from every process

9.5 Vector Clocks

- Problem with Lamport: does not capture causality
- By construction, we know that for each message $T_{sent}(m_i) < T_{recv}(m_i)$. But what can we conclude in general from$T_{recv}(m_i) < T_{sent}(m_j)$ [Lamport]

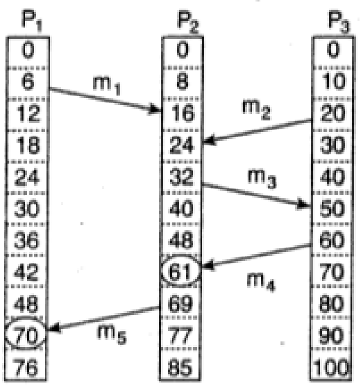


Figure 6-12. Concurrent message transmission using logical clocks.

- In the case $m_i = m_1$ and $m_j = m_3$ we know at P_2 that m_j was sent after m_i was received. This *may* indicate that sending of m_j has something to do with the receiving of m_i
- Vector Clocks:
  $VC(a) < VC(b)$ means, that event a is known to causally precede event b.
- Each process P_i maintains a Vector VC_i with the following properties:
  1. $VC_i[i]$ is the number of events that occured so far at P_i
     $VC_i[i]$ is the logial clock at P_i
  2. if $VC_i[j] = k$ then P_i knows, that k events have occured at P_j. It is thus P_i's knowledge of the local time at P_j
- To maintain properties:
  1. Before executing an event (i.e., sending a message over the network, delivering a message to an application, or some other internal event), P_i executes $VC_i[i] = VC_i[i] + 1$
  2. When process P_i sends a message m to P_j, it sets m's (vector) timestamp $ts(m)$ equal to VC_i after having executed the previous step
  3. Upon the receipt of a message m, process P_j adjusts its own vector by setting $VC_j[k] = max(VC_j[k], ts(m)[k])$ for each k, after which it executes the first step and delivers the message to the application.

- timestamp $ts(m)$ tells the receiver how many events in other processes have preceded the sending of m, and on which m may causally depend.

9.5.1 Causally-ordered multicast

- Causally-ordered mulsticast is weaker than totally ordered multicast
- delivery of message m from P_i to P_j to application layer will be delayed until:
  1. $ts(m)[i] = VC_j[i] + 1$
     = m is the next message that P_j was expecting from process P_i
  2. $ts(m)[k] \leq VC_j[k]\ \forall\, k \neq i$
     = P_j has seen all the messages that have been seen by P_i when it sent message m
- Better to be implemented on application layer, because the app knows which messages are causally related.

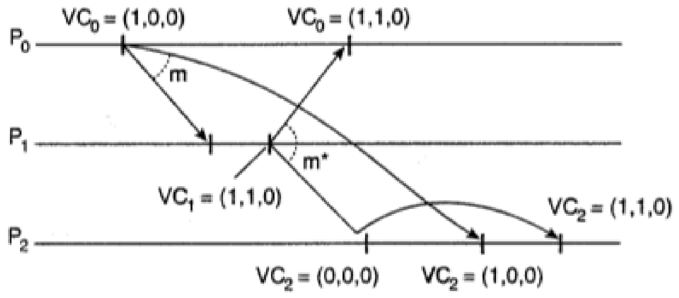


Figure 6-13. Enforcing causal communication.

9.5.2 Thoughts on causality and ordering

- causal ordering and (total) ordering are not the same
- causal ordering asks, which causal relationship the ordered items have
- lamport clocks and vector clocks both implement partial causal ordering
- vector clocks implement a stronger form of partial causal ordering (Tanenbaum p. 248 speaks here of total ordering, WP speaks of partial ordering)
- both can be forced to adhere to total ordering of events by implementing a mechanism deciding the ordering of concurrent events (if you do so, the total ordering then does not necessarily imply a causal ordering)

Chapter 10

Mutual Exclusion

Access to shared resources
2 types of algorithms: token-based and permission-based

- token is simple, reliability problem (lost token)
- permission difficult in distributed systems

10.1 Centralized algorithm

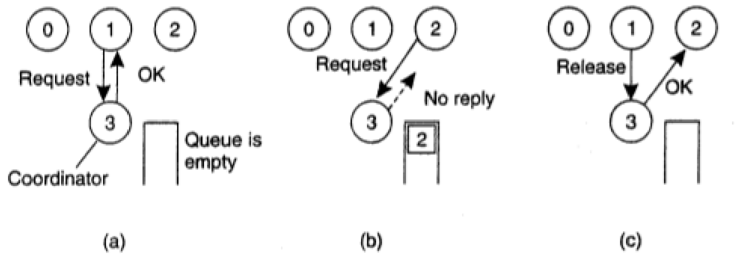


Figure 6-14. (a) Process 1 asks the coordinator for permission to access a shared resource. Permission is granted. (b) Process 2 then asks permission to access the same resource. The coordinator does not reply. (c) When process 1 releases the resource, it tells the coordinator, which then replies to 2.

Algorithm

- one process is coordinator
- when process wants access, it sends request to the coordinator
- coordinator allows access only to one process
- blocks competing processes by not replying and stores request in queue
- when process is finished, it sends a message to the coordinator
- coordinator takes the first item off the queue of deferred requests and sends that process a grant message

Properties

- simple
- fair, requests are processed in order of arrival
- no starvation: no process ever waits forever
- efficient: requires only three mes- sages per use of resource (request, grant, release)
- easy to implement

Problems

- coordinator is single point of failure
- processes cannot distinguish a dead coordinator from "permission denied" ($\rightarrow$ use non-blocking scheme with "permission denied" messages instead of blocking ungranted requests
- handle message loss with ack

10.2 Decentralized algorithm

- voting algorithm that can be executed using a DHT-based system

Algorithm

- resource is known under its unique name $rname$
- each resource is assumed to be replicated n times
- $rname_i$ is the unique name of the i-th replication of $rname$
- every replica has its own coordinator for controlling the access, reachable under $hash(rname_i)$
- given a resource's name, a process can generate the necessary n keys, lookup each coordinator and request permission
- permission to access the resource is granted, when a majority vote is acquired, i.e. $m > n/2$ permission messages from coordinators are received
- when a coordinator does not give permission, it will tell the requester
- If permission to the resource is denied (i.e., a process gets less than m votes), it is assumed that it will back off for a randomly chosen time, and make a next attempt later.

Properties

- makes the original centralized solution less vulnerable to failures of a single coordinator
- when a coordinator crashes, it recovers quickly but will have forgotten any vote it gave before it crashed
- coordinator may reset itself (i.e. crash) at arbitrary moments
- risk: reset will make the coordinator forget that it had previously granted permission to some process
- may incorrectly grant this permission again to another process after its recovery=
- Let p probability that a coordinator resets during Δt
- the probability $P[k]$ that k out of m coordinators reset during this Δt is: $P[k] = \left(\binom{m}{k}\right) p^k (1-p)^{m-k}$
- at least $2m - n \geq n + 2 - n = 2$ coordinators need to reset in order to violate the voting. This happens with probability $\sum\limits_{k=2m-n}^{n} P[k]$

- Example:
  $\Delta t = 10s, n = 32, m = 0,75n$
  Probability of violation is 10^{-40}

Problems

- heavy load $\Rightarrow$ drop in utilization
- there are so many nodes competing to get access that eventually no one is able to get enough votes leaving the resource unused
- according to Tanenbaum/van Steen solvable, but no solution given

10.3 A distributed algorithm aka Ricart and Agrawala's Algorithm

- deterministic
- uses total ordering of events
- assumption: no message loss
- process that wants to access a resource sends out message containing (resourcename, process no, current localtime) to all other processes and itself
- process receives a message. Either:
  1. if receiver does not want the resource: reply OK
  2. if it has resource: no reply, queues request
  3. if receiver wants resource too, compares time stamps
     - if time stamp from remote request < time stamp from own request $\rightarrow$ reply OK
     - else queue request, no reply
  4. As soon as all the permissions are in, process can access resource
  5. When finished, process sends OK messages to all processes in queue and empties queue

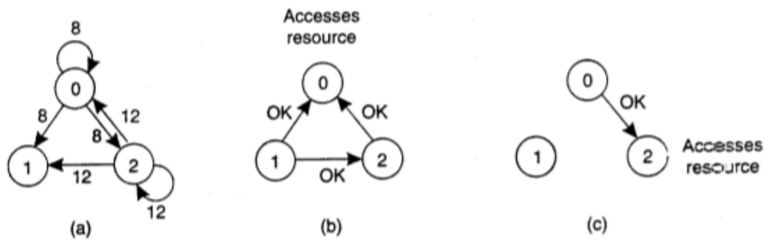


Figure 6-15. (a) Two processes want to access a shared resource at the same moment., (b) Process 0 has the lowest timestamp. so it wins. (c) When process 0 is done, it sends an *OK* also, so 2 can now go ahead.

Properties

- grants mutual exclusion without deadlocks or starvation

Problems

- node failure: single point of failure has been replaced by n points of failure. Any process crashes $\rightarrow$ no access granted

- load, all processes take part in decisions (needs 2(n-1) messages for n processes)
- algorithm is slower, more complicated, more expensive, less robust than centralized algorithm $\rightarrow$ not a good algorithm

10.4 Token Ring Algorithm

Algorithm

- processes form a logical ring
- token continuously circulates around the ring
- owner of token can access resource, passes token when finished (not allowed to immediately enter resource again)

Properties

- simple and efficient
- no starvation (once a process needs resource, at worst it will have to wait for every other process to use the resource once).

Problems

- If the token is ever lost, it must be regenerated
- detecting token loss is is difficult, since the amount of time between appearances of the token is unbounded
- crashing nodes pose problem, but recovery is easier than in the other cases (dead node detection via acks of token delivery)
- not fair under heavy load (according to Wolter, not Tanenbaum)

10.5 Comparison

Algorithm	messages per entry/exit	Delay before access	Problems
Centralised	3	2	coordinator crash
Decentralised	$3mk$	$2m$	starvation, low efficiency
Distributed	$2(n-1)$	$2(n-1)$	crash of any process
Token Ring	1 to ∞	0 to ∞	lost token, process crash, fairness?

messages per entry/exit the number of messages required for a process to access and release a shared resource

Delay before access the delay (in message times) before access can occur (assuming messages are passed sequentially over a network)

- all algorithms except the decentralized one suffer badly in the event of crashes
- the distributed algorithms are even more sensitive to crashes than the centralized one
- The decentralized algorithm is less sensitive to crashes, but processes may suffer from starvation and special measures are needed to guarantee efficiency

Chapter 11

Leader Election algorithms

- many distributed algorithms require one process to act as coordinator, initiator, or otherwise perform some special role
- usually, it does not matter which process takes on this responsibility
- but one process has to be elected to take over the role
- In general, election algorithms attempt to locate the process with the highest process number and designate it as coordinator

11.1 Leader election in a synchronous ring

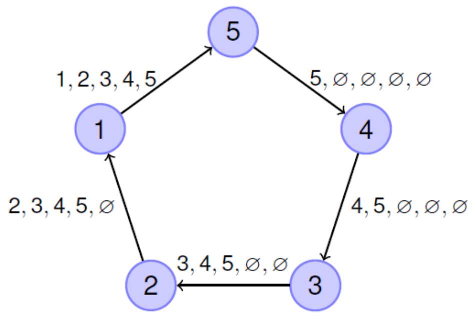
- Network is a graph G consisting of n nodes connected by unidirectional links. Use $\mod n$ for labels
- Synchronous time model: all processes operate in lock-step, i.e. messages are passed in synchronous rounds (needs notion of global time)
- elected node is "leader"
- leader election is not possible for identical processes/nodes

$\rightarrow$ processes have unique id (UID)

11.1.1 LCR algorithm

(Le Lann, Chang, Roberts)

- unidirectional communication
- ring size unknown
- only leader produces output
- algorithm compares UID
- One or more p_is can take the initiative and start an election, by sending an election message containing their id to p_{i+1}



Messages transmitted:

$\langle 1 \rangle$	1 times
$\langle 2 \rangle$	2 times
$\langle 3 \rangle$	3 times
$\langle 4 \rangle$	4 times
$\langle 5 \rangle$	5 times
total	15 times

Figure 11.1: LCR algorithm

Algorithm (from lecture)

```
For each node
  u = a UID, initially i's UID
  send = a UID or NULL, initially i's UID
  status ∈ {unknown, leader} initially unknown

message generation
  send = current value of send to node i+1

state transitions
  send = NULL
  if incoming message is v (a UID) then
    v > u:  send v
    v = u:  status=leader
    v < u:  do nothing
```

Algorithm (alternative formulation)

```
upon receiving no message
  send uid_$i$ to left (clockwise)

upon receiving m from right
  if m.uid > uid$_i$:
    send m to left
  if m.uid < uid$_i$:
    discard m
  if m.uid = uid$_i$:
    leader := i
    send <terminate, i> to left 12: terminate

upon receiving <terminate, i> from right
  leader := i
```

```
send <terminate, i> to left
terminate
```

Algorithm: Informal

- One or more p_i's can take the initiative and start an election, by sending an election message containing their id to p_{i+1}
- When a process receives a UID, it compares this one to its own:
  - If the incoming UID is greater, then it passes this UID to the next process.
  - If the incoming UID is smaller, then it discards it
  - If it is equal, then the process declares itself the leader.
- (the received uid is not saved, even if it is greater than the own uid, i.e. received uids are always compared against the own uid)

Correctness

Let max index of process with $max(UID)$ let u_{max} is its UID
Show:

(i) process max outputs "leader" after n rounds
(ii) no other process does the same
We clarify:

(iii) After n rounds status$_{max}$=leader
and

(iv) For $0 \leq r \leq n-1$ after r rounds
$send_{max} = u_{max}$
find UID at distance r from i_{max} as it has to go once around.

Show (iv) for all r: Induction
then (iii)

Complexity

- time complexity is n rounds
- communication complexity $\mathcal{O}(n^2)$
- not very expensive in time, but many messages

11.1.2 Algorithm of Hirschberg and Sinclair (HS-Alg)

- election needs to be started at every node, e.g. by a broadcast to all nodes to start leader election

Algorithm (informal)

- ring is bidirectional
- each process p_i operates in phases
- in each phase r, pi sends out "tokens" containing uidi in both direction
- Tokens are intended to travel distance 2^r and return to p_i

- however, tokens may not make it back
- Token continues outbound only if greater than tokens on path
- Otherwise discarded
- All processes always forward tokens moving inbound
- if p_i receives its own token while it is going outbound, p_i is the leader

Algorithm

```
each process has states with components
  u, UID: initially i's UID
  send+ containing NULL or (UID, flag{in, out}, hopcount): initially
      (i's UID, out, 1)
  send- as send+
  status ∈{unknown, leader} initailly unknown
  phase ∈ $N$: initially 0

message generation
  send current send+ to process i+1
  send current send- to process i-1

state transitions
  send+=NULL
  send-=NULL
  if message from (i-1) is (v, out, h) then
    v>u ∧ h>1: send+ = (v,out,h-1)
    v>u ∧ h=1: send- = (v,in,1)
    v=u status = leader
  if message from i+1 is (v, out, h) then
    v>u ∧ h>1: send- = (v,out, h-1)
    v>u ∧ h=1: send+ = (v,in,1)
    v=u status=leader
  if message from i-1 is (v,in,1) ∧$v \neq u$ then
    send+=(v,in,1)
  if message from i+1 is (v,in,1) ∧$v \neq u$ then
    send-=(v,in,1)
  if both messages from i-1 and i+1 are (u,in,1) then
    phase++
    send+=(u,out, $2^{phase}$)
    send-=(u,out, $2^{phase}$)
```

Complexity

- **Communication complexity**
  - Total number of phases is at most $8n(1 + \lceil \log(n) \rceil)$
  - the total number of messages is at most in $(1 + \lceil (\log(n)) \rceil$
  - $\Rightarrow \mathcal{O}(n \log n)$
- **Total time complexity**
  - is at most $3n$ if n power of 2 otherwise is $5n$

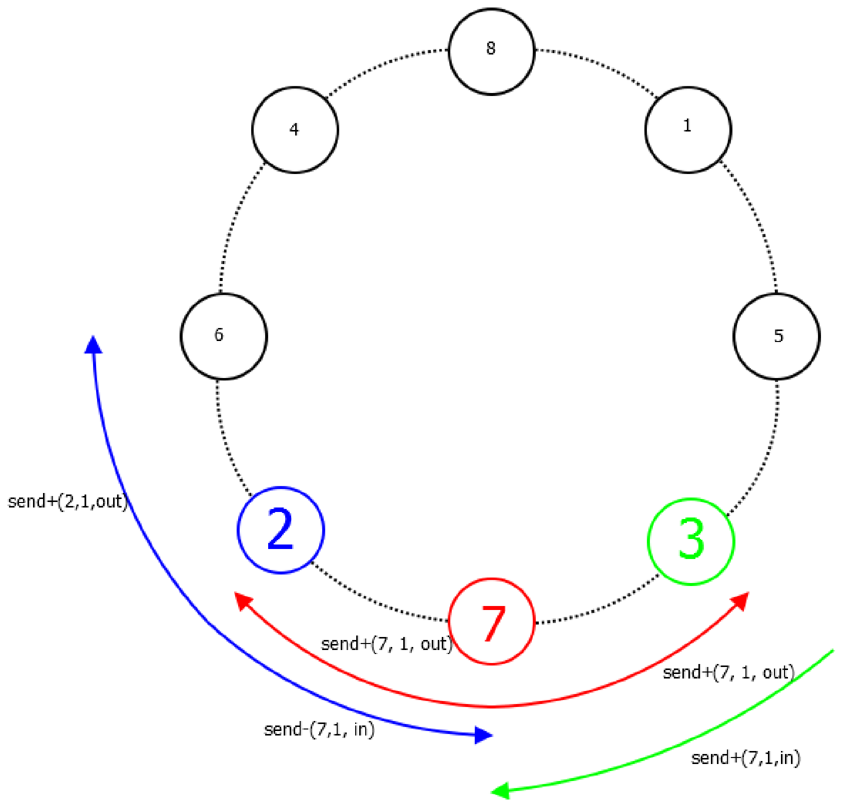


Figure 11.2: HS Phase 1

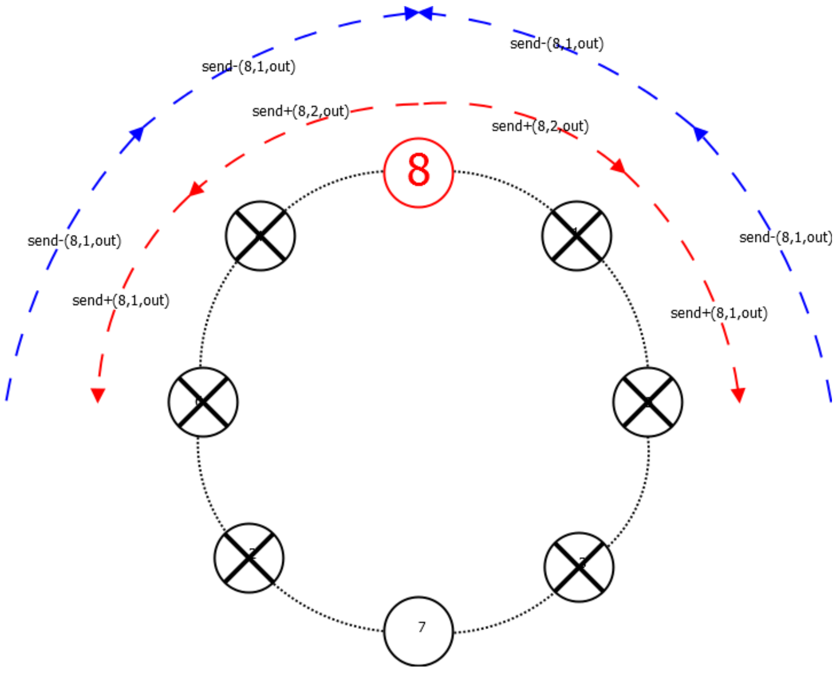


Figure 11.3: HS Phase 2

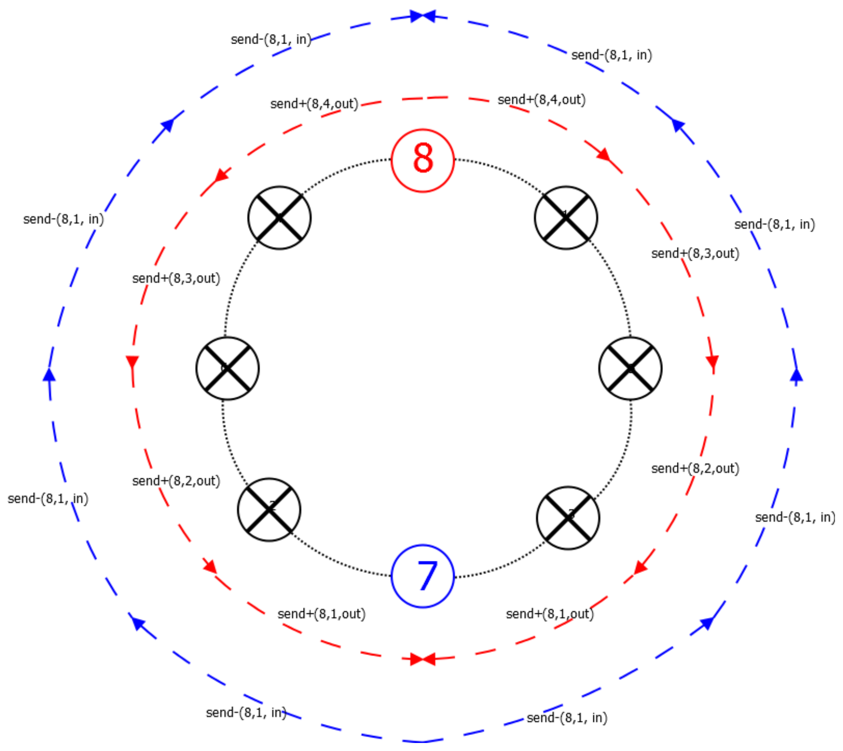


Figure 11.4: HS Phase 3

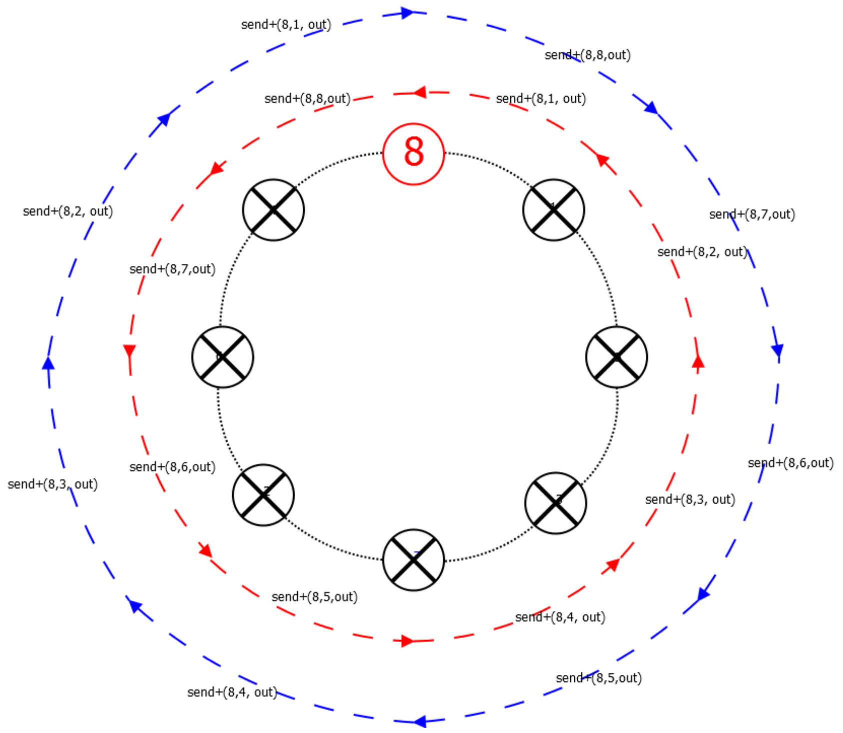


Figure 11.5: HS Phase 4

Show that the number of messages sent by the HS is at most $8n(1+\lceil logn\rceil)$, which means it is $O(nlog(n))$.
In Phase k können maximal $4\cdot 2^k$ Nachrichten (in und out) für einen Kandidaten (Knoten, der in seiner Nachbarschaft keinen größeren Knoten hat) existieren.
In Phase $k=0$ gibt es n Kandidaten $\Rightarrow 2n$ out Nachrichten und maximal $\frac{n}{2}\cdot 2$ in Nachrichten $=3n$
In Phase $k\geq 1$ gibt es maximal noch $\left\lfloor \frac{n}{2^{k-1}+1}\right\rfloor$ Kandidaten. $2^{k-1}+1$ ist der minimale Abstand zwischen zwei Gewinnern aus Phase $k-1$
$\Rightarrow$ die Anzahl der Nachrichten, die in Phase k gesendet werden ist $4\cdot 2^k\cdot\left\lfloor \frac{n}{2^{k-1}+1}\right\rfloor = 8n\cdot\left\lfloor \frac{2^{k-1}}{2^{k-1}+1}\right\rfloor$
Offensichtlich ist die maximale Anzahl der Phasen ist $\lceil logn\rceil+1$
Offensichtlich werden in der letzten Phase $2n$ Nachrichten gesendet

$$3n+\sum_{k=1}^{\lceil logn\rceil-1}\left(8n\cdot\left\lfloor \frac{2^{k-1}}{2^{k-1}+1}\right\rfloor\right)+2n\leq 5n+8n\cdot(\lceil logn\rceil-1)$$

11.1.3 Time slice algorithm

- ring size n is known
- unidirectional
- elects smallest UID
- Counter-example algorithm: impractical, but useful as lower bound
- TimeSlice is much more strongly based on synchronization than LCR
  - The fact that a node did not receive a message in a certain round provides information

```
phases with n rounds
in phase v consisting of rounds $(v-1)\cdot n+1$,...,v·n only a token
    carrying UID v is permitted
if a process with UID v exists and round $(v-1)\cdot n+1$ is reached
    without having received any messages, then it elects itself the
    leader and sends a token with it's UID
```

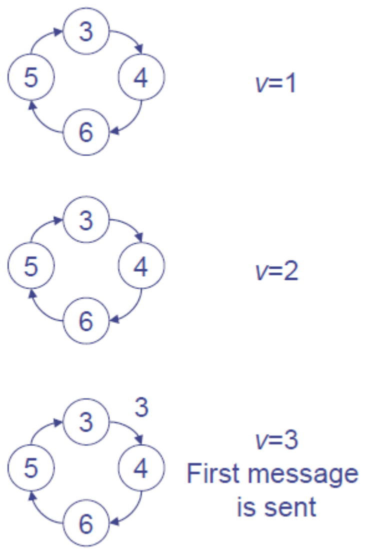


Figure 11.6: Timeslice algorithm

Complexity

Communication complexity number of messages is $\mathcal{O}(n)$
Time complexity $n \cdot uid_{min}$

11.1.4 Variable speeds algorithm

Algorithm

- each process i creates a token to travel around the ring, carrying UID u of origin
- tokens travel at differrent speed
- token carrying UID v travels 1 messages every 2^v rounds (slow down)
- each process memorises smallest UID
- return to origin elects UID (smallest UID is selected as leader)

Complexity

Communication complexity $\sum_{k=1}^{n} \frac{1}{2^{k-1}} (< 2n) \Rightarrow \mathcal{O}(n)$
Time complexity $n \cdot uid_{min}$ (i.e. slow)

11.2 Leader election in a wireless environment

- consider time needed for communication
- every node can initiate an election
- the select is based on information like battery lifetime or processing power (that is the value sent back in step 7/8)
- the nodes only participate in one election, also there are more than one initiating nodes

Algorithm

1. one node starts the election and sends ELECT to its neighbours
2. the node, which sended the ELECT message becomes the parent of the node
3. the node sends the request to all neighbours except the parent node
4. the node acknowledges the parent after all the children acknowledged the election
5. if a node recieves an ELECT message, but has already a parent, it responses immediately, that another node is its parent (i.e. an ack without a value)
6. if a the node has only neighbours, which are the parent or have other parents, the node becomes a leaf and sends back its value
7. the waiting nodes send the node id and the max value of the children (or himself) to the parent, after all acknowledged
8. in the end, the initiating node knows the node with the highest value and broadcast to all nodes, that this is the leader

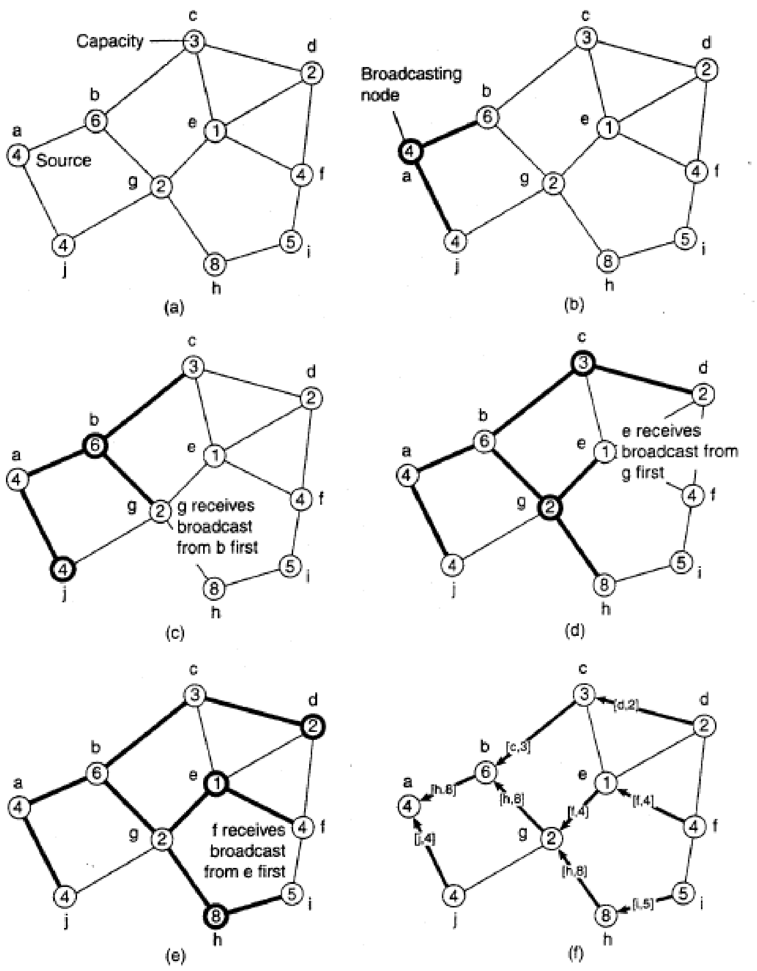

Capacity
Source
Broadcasting node
g receives broadcast from b first
e receives broadcast from g first
f receives broadcast from e first
[d,2]
[c,3]
[h,8]
[h,8]
[f,4]
[f,4]
[j,4]
[h,8]
[i,5]
(a)
(b)
(c)
(d)
(e)
(f)

Figure 6-22. Election algorithm in a wireless network, with node *a* as the source. (a) Initial network., (b)-(e) The build-tree phase (last broadcast step by nodes f and i not shown). (f) Reporting of best node to source.

Figure 11.7: Election in wireless networks

11.3 The Bully Algorithm(flooding) (Garcia-Mdina, 1982)

- process P holds election

1. P sends ELECT message to all processes with higher uid
2. P wins if there are no responses $\Rightarrow$ P is leader and sends COORDINATOR message to all available nodes.
3. if Q (with higher uid) answers with OK, Q takes over and sends ELECT to all higher nodes again.

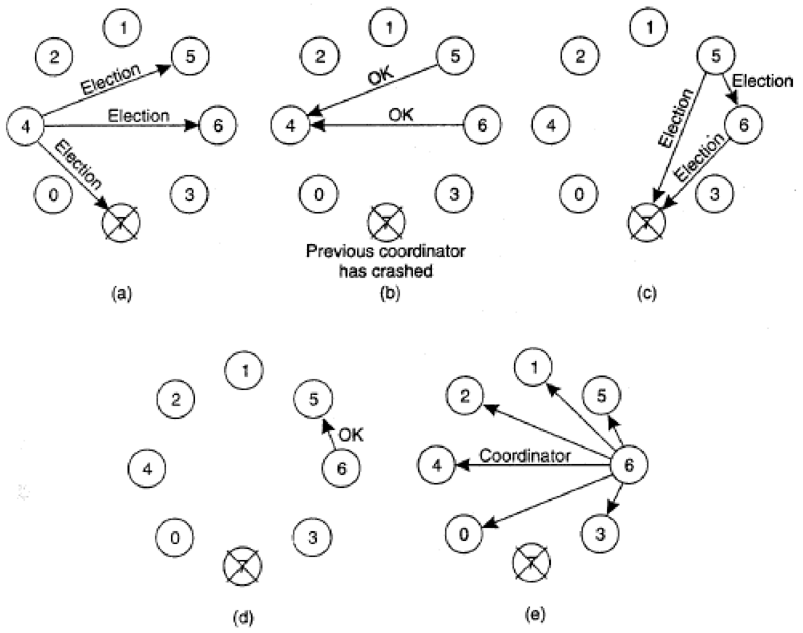


Figure 6-20. The bully election algorithm. (a) Process 4 holds an election. (b) Processes 5 and 6 respond, telling 4 to stop. (c) Now 5 and 6 each hold an election. (d) Process 6 tells 5 to stop. (e) Process 6 wins and tells everyone.

Figure 11.8: The bully election algorithm

Chapter 12

Consistency and Consensus

Anm.: Quelle ist hier der deutsche Tanenbaum/Steen, daher sind manche englischen Begriffe evtl. nicht korrekt gewählt.

- Distributed Systems use replication of data to improve *performance* and/or *reliability*
- replication for scalability
  How to keep replicas consistent?
  Many types of consistency
  - data-centric-constistency
  - client-centric-consistency
  - monotic reads: successive reads return the same or newer value
  - monitic write: a write op must be completed before the next write by the same process
  - read-your-own-write: write is always seen by read of same process
  - write-follows-read: write on previous read takes place on the same or more recent value
- Do not discuss replica placement
- Object-replication

12.1 Data-centric consistency

The more strict a model is, the stronger are the assumptions, that may be drawn from a series of events, but the harder to implement.

12.1.1 Strict consistency

Every read of x returns the value of the last write on x

Example strict consistency

```
P1: W(x)a
---------------------------
P2:         R(x)a
```

Non strict consistent example

```
P1: W(x)a
______________________________
P2:         R(x)Null  R(x)a
```

Simple and clear idea, but this definition requires existence of global time (hard to realise), so that the *last* write on a variable is unambiguous. This requirement is very hard to accomplish.

If a data storage fulfills this requirement, then every write must be visible globally (for every process in the system).

12.1.2 Sequential/linear consistency

Weak version of strict consistency, irrelevance of the chronological order of write events. That means, that there is no global time or chronology, but some order of the events is globally visible and the same for every process. Linear consistency just adds the requirement, that the events are ordered by a globally (mayhaps ambiguous) timestamp.

Example sequential consistency

```
P1: W(x)a
________________________________________
P2:         W(x)b
________________________________________
P3:                 R(x)b          R(x)a
________________________________________
P4:                       R(x)b   R(x)a
```

Example non-sequential consistency

```
P1: W(x)a
________________________________________
P2:         W(x)b
________________________________________
P3:                 R(x)b          R(x)a
________________________________________
P4:                       R(x)a   R(x)b
```

12.1.3 Causal consistency

Weak version of sequential consistency, only causally dependent events must appear strictly ordered on a global level. Two causally dependent events may be a write event *W(x)a*, a read event *R(x)a* followed by a write *W(x)b*, then the write *W(x)b* may be based on the value writte in *W(x)a*.

Example causal consistency

P1:	W(x)a			W(x)c		
P2:		R(x)a	W(x)b			
P3:		R(x)a			R(x)c	R(x)b
P4:		R(x)a			R(x)b	R(x)c

Example non-causal consistency

P1:	W(x)a				
P2:		R(x)a	W(x)b		
P3:				R(x)b	R(x)a
P4:				R(x)a	R(x)b

12.1.4 FIFO-consistency

Weak version of causal consitency. The writes of a single process (which are ordered and causally dependent) appear in this exact order globally, but the sequence of writes between multiple processes is not strictly ordered. In other words, only the casual dependencies inside one process appear in the correct order, dependencies between different processes may be mixed.

Example FIFO-consistency

P1:	W(x)a						
P2:		R(x)a	W(x)b	W(x)c			
P3:					R(x)b	R(x)a	R(x)c
P4:					R(x)a	R(x)b	R(x)c

12.1.5 Weak consistency

The idea of weak consistency is, that also the relatively weak assertions of FIFO-consistency often are too hard to implement or just unnecessary. The globally visible actions are reduced to critical sections (or areas) where the actions become globally visible only after leaving the critical section, so only the results of the actions become visible. To realise that behaviour a mechanism to synchronise on the current state of a synchronisation variable S is introduced, such that processes who are interested in the current status of this variable may update their data, but other processes are not bothered with updates.

In this consistency scheme, consistency is not defined absolutely but only temporarily (at synchronization points).

Example weak consistency

```
P1: W(x)a   W(x)b   S
--------------------------------------
P2:                 R(x)a   R(x)b   S
--------------------------------------
P3:                 R(x)b   R(x)a   S
```

Example non-weak consistency

```
P1: W(x)a   W(x)b   S
------------------------------
P2:                 S   R(x)a
```

12.1.6 Release-consistency

In the weak-consistency-scheme there is no difference between synchronising after a write (i.e. a write-through to all replications) and synchronising before reading data, but these two scenarios require different actions on lower layers. Two additional procedures are added *acquire(..)* and *release(..)*.

12.1.7 Entry-consistency

Similar to release-consistency, but synchronisation variables (and procedures acq(..), rel(..)) are responsible for a designated set of variables, not for all variables in the global scope.

12.2 Client-centric consistency

In contrast to the data-centric consistency models client-centric consistency models do not try to maintain a system wide consistent view, but rather try to hide inconsitencies on client level.

12.2.1 Eventual consistency

(popular example: Domain Name Service) Usually big, distributed, replicated databases, which tolerate a high amount of incostency, but eventually become consistent when there are no updates to the database. It is important that clients access the system via fixed nodes, otherwise client updates may take a while, until they are visible for the client itself which is a clear violation of local consistency (read your writes). Remember that in this section the consistency view is only local/client-specific!

12.2.2 Monotone read-consistency

When a datum x is read by a process, then every following read of x results in the same value, or in newer value.

12.2.3 Monotone write-consistency

When a process writes to a datum x, then all previous write operations have to be finished/applied.

12.2.4 Read your writes

The result of a previous write operation of a process on a datum x is always visible in a following read of the same process

12.2.5 Writes follow reads

A write by a process to a datum x, which follows a previous read of x, is performed on this read value, or a newer one.

12.2.6 Implementing client-side consistency

The idea here is to monitor the client's reads and writes and add an ID to each operation. When reading/writing to a server the current status of the client (a list of the reads/writes) is added to the query and the server checks, wether the local storage of the client has to be updatet before executing the query.

12.3 Reliable multicast protocols

- atomic multicast requirement
  all requests arrive at all servers in the same order

12.4 Distributed Commits

- distributed algorithms that coordinate all the processes that participate in a distributed atomic transaction on whether to commit or abort (roll back) the transaction
- specialized type of consensus protocol
- an operation is performed by group or non of the nodes of the group
- reliable multicast operation = delivery of message
- distributed transaction: operation = execution of transaction
- uses coordinator

12.4.1 Two-Phase commit (2PC) (Jim Gray, 1978)

- distributed transaction involves several processors each on a different machine
  1. coordinator $\xrightarrow{vote\ request}$ all participants
  2. participant $\xrightarrow[vote\ abort]{vote\ commit}$ coordinator
  3. if all commit
     coordinator $\xrightarrow{global-commit}$ all participants
     else
     coordinator $\xrightarrow{global-abort}$ all participants

4. if commit, then participants locally commit
   else participants locally abort

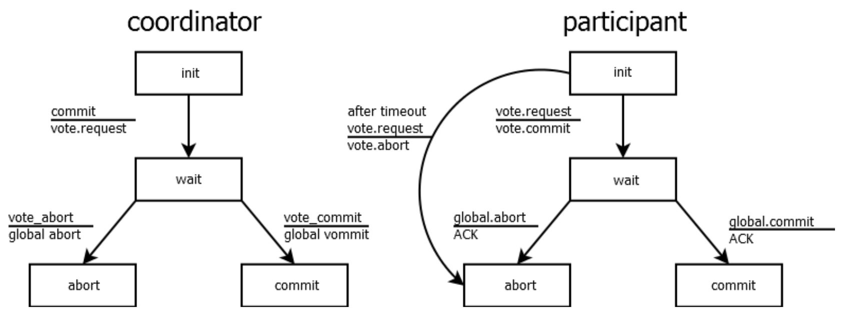


Figure 12.1: 2PC

Properties

- The protocol achieves its goal even in many cases of temporary system failure (involving either process, network node, communication, etc. failures)
- it is not resilient to all possible failure configurations
  - coordinator blocks in: wait
  - participant blocks in: ready, init
- $\Rightarrow$ blocking commit protocol

Variant: use timeouts to unblock

- repeat request
- in state ready P can contact Q
  if Q is in contact, then coordinator died after sending to Q
  before sending to P $\Rightarrow$ P can commit
  if Q is in abort $\Rightarrow$ abort
  if Q is in init $\Rightarrow$ abort
  if Q is in ready $\rightarrow$ abort or no decision contact R

12.4.2 One-Phase Commit

- performance optimization of 2PC
- eliminates the prepare/voting phase of 2PC
- 2PC: enables every participant in a transaction to abort if the ACID properties of the local transaction branches are not guaranteed
- 1PC makes the assumption that these properties are guaranteed at commit time for every local transaction branch
- In other words, the ACID properties of local transaction branches are supposed to be ensured before the 1PC protocol is triggered
- $\Rightarrow$ more efficient / performant, but needs stronger assumptions on the underlying transaction system
- Quelle: Maha Abdallah et al (1998): One-Phase Commit: Does it make sense?

12.4.3 Three-phase commit (3PC) (Steen, 1981)

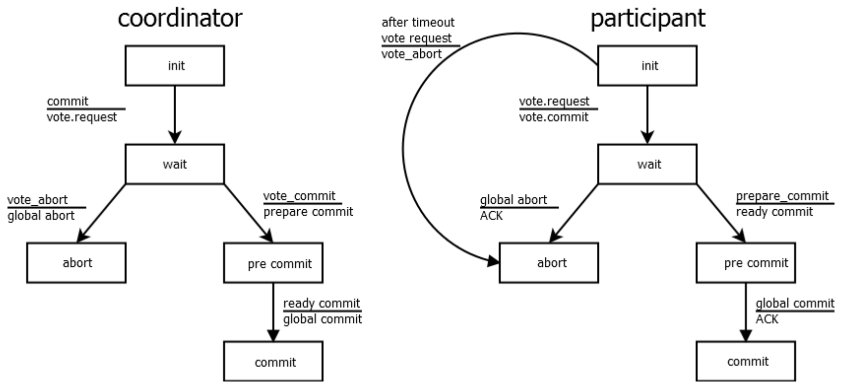

coordinator
init
commit / vote.request
wait
vote_abort / global abort
vote_commit / prepare commit
abort
pre commit
ready commit / global commit
commit
participant
after timeout vote request / vote_abort
init
vote.request / vote.commit
wait
global abort / ACK
prepare_commit / ready commit
abort
pre commit
global commit / ACK
commit

Figure 12.2: 3PC

- robustness optimization of 2PC
- avoids blocking in the presence of fail-stop crashes
- states satisfy the following conditions
    1. there is no state from which directly follow commit or abort follows
    2. there is no state in which it is not possible to make a final decision and from which a transaction to a commit state can be made
- ⇒ necessary and sufficient conditions for non-blocking commit protocol
- abort branch as in 2PC
- blocking states: paritcipant: init -> abort
  coordinator: wait –> abort
  precommit, knowing P voted for commit
  ⇒ global-commit+recovery of P
  participant: ready
  coordinator failed as in 2PC
  precommit: contact other participants: if Q in precommit ⇒ commit
  if Q is in init ⇒ abort
- Q can be in INIT only if no participant is in precommit
- participant can reach precommit only if coordinator was in precommit already
- In 2PC a crashed participant could recover to commit, while all others are still in ready
- if one process is in ready recovery can be only to states ready, init, abort, precommit
  ⇒ surviving processes can come to final solution

12.4.4 Paxos Commit (Leslie Lamport, late 80s)

- does not block with at most n/2-1 failures
  Paxos adds to 2PC:
    - ordering of proposals
    - majority voting for acceptance

  Duelling proposer

Chapter 13

Tips Exam

1. Aufgabe: Terminiologie (wichtige Konzepte, erklären, vergleichen, bla,bla) dann durch die Themen des Semsters, übungszettel, gerne ausrechnen (Fingertable, Metriken von overlaynetzen, komplexität von protokollen (wie viele nachrichten braucht ein protokoll), logische uhren (stellen oder so)), erklären, Peersimaufgabe(n) (programm angucken, was macht das programm?, überblick, wie modifizieren für fkt x, cycle driven vs event driven (was wofür)), last auf dem netz, kein gnuplot programm auf papier!!! Hilfsmittel: mitbringen, was man will, außer internet, telefon, freunde usw...