Operating Systems

Distributed Systems

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February 11, 2011

Overview and Structure

- Introduction to operating systems
  - History
  - Architectures
- Processes
  - Processes, Threads, IPC, Scheduling
  - Synchronisation
  - Deadlocks
- Memory management
  - Paging
  - Segmentation
- Filesystems
- Security and Protection
- Distributed systems
- Cryptography

Outline

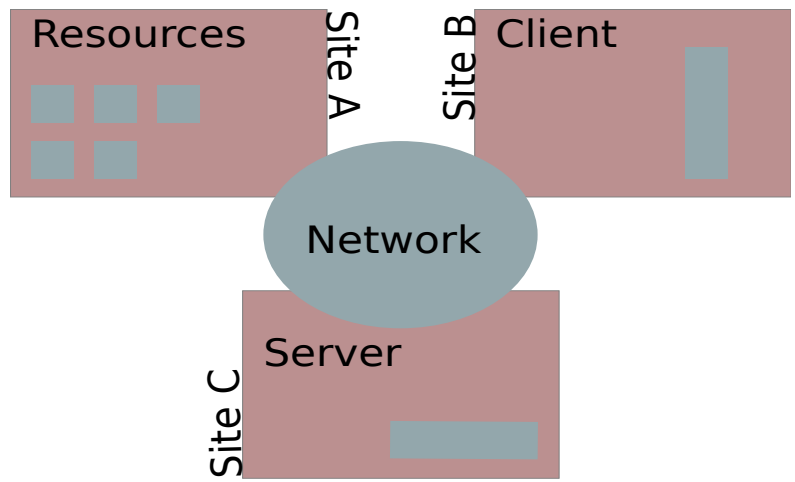
Distribured systems

1. Distributed systems
   - Distributed systems
   - Distributed file systems
   - Distributed synchronisation

Distributed systems

Introduction

- A distributed system is a collection of loosely coupled processors
- Interconnected by a communication network



Distributed systems

Introduction

Reasons for building distributed systems

- Resource sharing
- Computation speed-up
- Reliability
- Communication

Distributed systems

Introduction

Reasons for building distributed systems

Resource sharing :

- Different sites are connected to one another
- A user at one site may be able to use the resources available at another site

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Introduction

Reasons for building distributed systems

Computation speed-up :

- Partition computation into sub-computations can are run concurrently

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Introduction

Reasons for building distributed systems

Reliability :

- If one site fails in a distributed system, the remaining sites can continue operating
- This increases the reliability of the system

Distributed systems

Introduction

Reasons for building distributed systems

Communication :

- When several sites are connected, users at different physical locations can communicate

Distributed systems

Introduction

Types of network-based operating systems

- Network operating systems
  - Remote login
  - Remote file transfer
- Distributed operating systems
  - Data migration
  - Computation migration
  - Process migration

Distributed systems

Introduction

Network operating systems

- The network operating system provides an environment in which users can access remote resources.

Remote login :

- Users log in remotely
- Typically login and password required
- After login, the process used to access acts as a proxy for the user
- The remote user can provide any actions on the remote machine like a local user

Remote file transfer :

- File transfer from one machine to another
- ftp, scp, ...

Distributed systems

Introduction

Distributed operating systems

- In a distributed operating system, users access remote resources in the same way they access local resources
- Data and process migration is under the control of the distributed operating system

Data migration :

- User could work on a local copy of remote files
- Or only small parts of file are transferred and modifications are forwarded to remote host

Distributed systems

Introduction

Distributed operating systems

- In a distributed operating system, users access remote resources in the same way they access local resources
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Computation migration :

- Transfer computational load rather than data
- Message transfer to trigger remote computation
- Or execute a routine on a remote system via RPC (Method invoked on local system and result is returned to the method from the remote system)

Distributed systems

Introduction

Distributed operating systems

- In a distributed operating system, users access remote resources in the same way they access local resources
- Data and process migration is under the control of the distributed operating system

Process migration :

- Extension of computation migration
- Used for Load balancing, computational speed-up, hardware/software preference, Data access

Outline

Distributed systems

1. Distributed systems
   - Distributed systems
   - Distributed file systems
   - Distributed synchronisation

Distributed systems

Distributed file systems

Definition

A service is a software entity running on one or more machines and providing a particular type of function to clients

Definition

A client is a process can invoke a service using a set of operations that form its client interface

Definition

A server is the service software running on a single machine

Distributed systems

Distributed file systems

- A file system provides file services to clients
- A client interface for a file service is formed by a set of primitive file operations (create, delete, read, write)
- The primary hardware components that a file server controls is a set of local secondary-storage devices on which files are stored
- A distributed file system is a file system whose clients, servers and storage devices are dispersed among the machines of a distributed system

Distributed systems

Distributed file systems

naming

- Naming is a mapping between logical and physical objects
- In a local file system, symbolical file names are translated to a numerical identifier that is in turn mapped to disk blocks
- In a distributed file system, another abstraction layer (network) is added to this naming scheme

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Distributed file systems

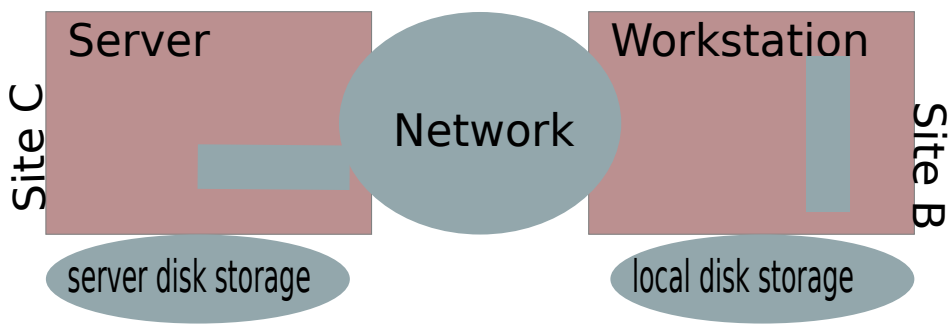
Remote file access

- When accessing a remote file, data from the file has to be transferred

  Basic caching scheme

  Cache update policy

  Consistency



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Basic caching scheme

- A copy of the data is brought to the client system
- Access is performed on the copy
- After some time or event the cached file is transferred back to the original location
- The challenge is to keep the cached copies and the master file consistent with reasonable network traffic

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Cache update policy

- The policy used to write modified data blocks back to the server's master copy has a critical effect on the system's performance and reliability
- Write through policy
  - Write data as soon as they are placed in any cache
  - Little information is lost when a client system crashes
  - Each write access has to wait until the information is sent to the server
- Delayed write policy(write-back caching)
  - Write data at a later time
  - Write accesses complete more quickly since the do not have to wait for data to be transferred
  - Data may be overwritten before they are written back
  - This reduces the required network traffic

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Distributed file systems

Consistency

- A client machine has to decide whether locally cached copy is consistent with master copy
- Client-initiated approach
  - Client initiates validity check if data is consistent
  - But: when and how often the check shall be done
  - Every access coupled with a validity check is delayed
- Server-initiated approach
  - Server records for each client the files that it caches
  - When the server detects a potential inconsistency, it must react (when two clients in conflicting modes access the file)
  - In UNIX, server and must be notified whenever a file is opened and the intended mode (read or write)
  - In conflicting cases, the server could e.g. disable caching for the particular file

Outline

Distributed systems

1. Distributed systems
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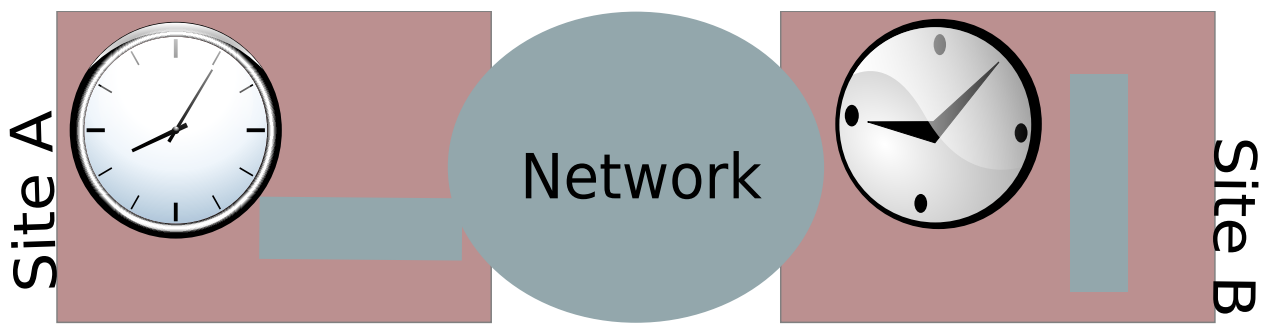
Distributed systems

Distributed synchronisation

Event ordering

- In a distributed system it might be hard to say for two events, which one occurred first
- The reason is, that no common clock may exist for these two events



Event ordering – The happened-before relation

- All events executed in a single process are totally ordered
- The happened before relation is defined as
  - If A and B are events in the same process and A was executed before B, then $A \rightarrow B$
  - If A is the event of sending a message by one process and B is the event of receiving that message by another process, then $A \rightarrow B$
  - If $A \rightarrow B$ and $B \rightarrow C$ then $A \rightarrow C$

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Event ordering – The happened-before relation

- If two events are not related by the happened before relation, A did not happen before B and B did not happen before A
- These events were executed concurrently
- Neither event can causally affect the other
- If $A \rightarrow B$ then A can affect B

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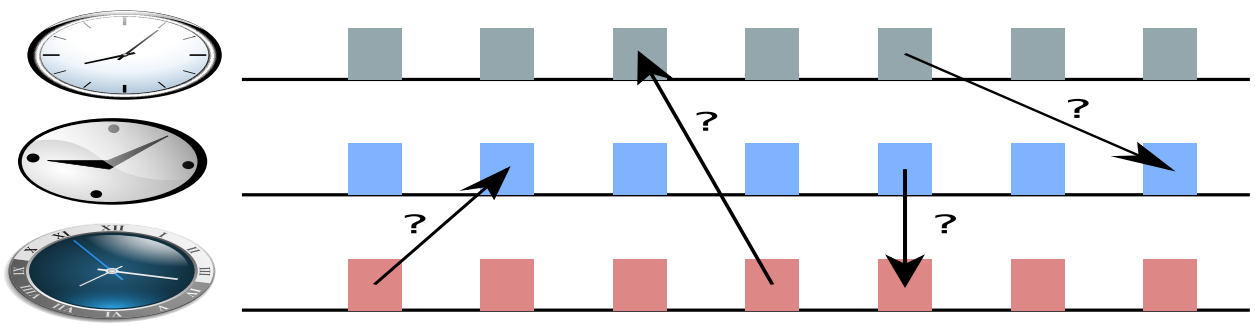
Event ordering – The happened-before relation

- We do not know which of the concurrent events happened first.
- Since neither event can affect the other, this is, however, not important
- This is important only for the processes that care about the order of two concurrent events agree on some order



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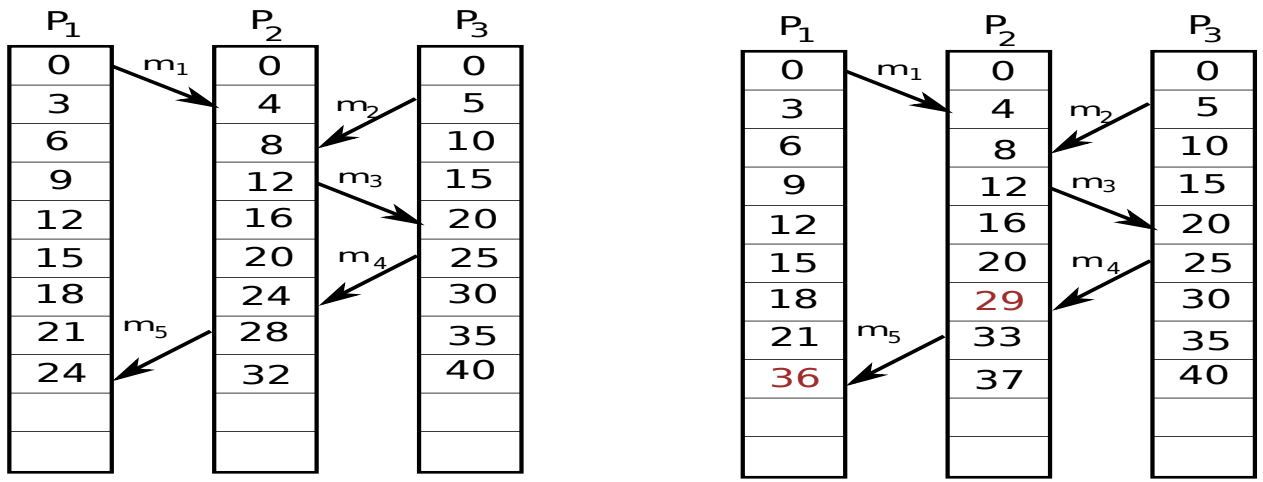
Event ordering – Lamport clocks

- To synchronise logical clocks on distributed systems, Lamport used the happened-before relation
- Messages are attached the creation time on their local machine
- Processes synchronised by Lamport clocks alter their clock value whenever an incorrect synchronisation becomes apparent due to message passing



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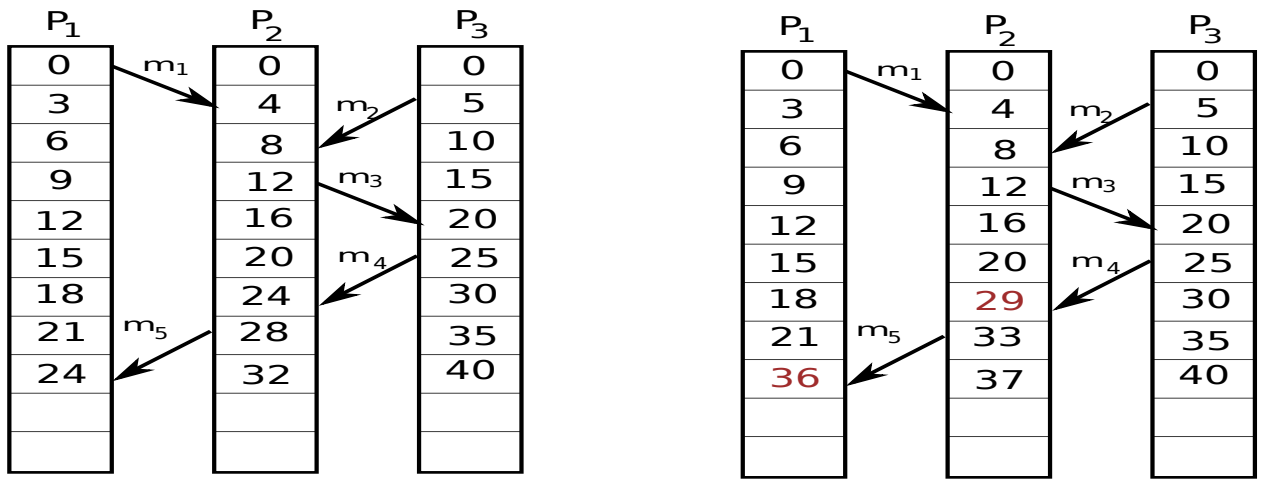
Distributed synchronisation

Event ordering – Lamport clocks

- With Lamport clocks, a total ordering of processes is possible
- However, nothing can be said about the relationship between two events a and b by merely comparing their time values.
- Example here: m_1 and m_2 – With Lamport clocks can not say, which event happened first



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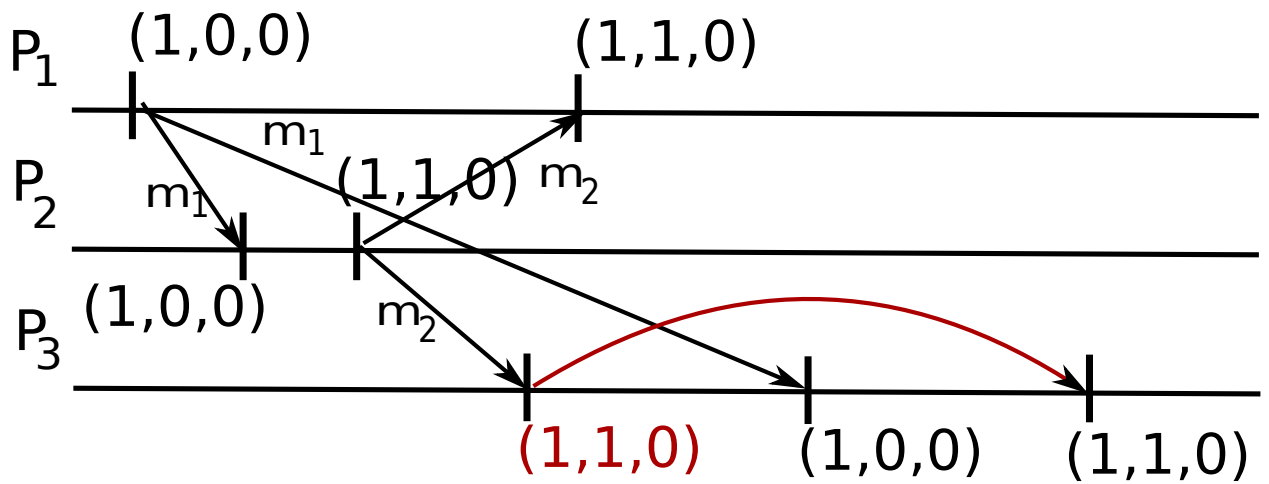
Event ordering – Implementation

- Vector clocks are designed to ensure that a message is delivered only if all messages that causally presede it have also been received as well.
- With vector clocks, processes maintain and update an event counter for all events in the system



Distributed systems

Distributed synchronisation

Approaches to implement mutual exclusion

- Assumptions
  - System consists of n processes
  - Each resides at different processor
  - Processes are numbered uniquely from 1 to n
  - Each process has its own processor

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Distributed synchronisation

Approaches to implement mutual exclusion

Centralised approach :

- One of the processes coordinates the entry to the critical section
- Each process that wants to invoke mutual exclusion sends a request message to the coordinator
- The process receives a reply message if request is positively approved
- Process then enters its critical section
- After exiting its critical section, the process sends a release message to the coordinator

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Distributed synchronisation

Approaches to implement mutual exclusion

Fully distributed approach :

- Distribute decision making across entire system
- When process P_i wants to enter critical section
  - Generates a new timestamp TS_i
  - Sends the message $request(P_i, TS_i)$ to all processes in the system
  - On receiving a request message a process may reply immediately or it may defer the reply
  - A process that received a reply message from all other processes enters its critical section
  - After leaving the critical section, process sends a reply message to all its deferred requests

Distributed systems

Distributed synchronisation

Approaches to implement mutual exclusion

Fully distributed approach :

- Positive aspects
  - Mutual exclusion is obtained
  - Freedom from deadlock is ensured
  - Freedom from starvation is ensured
  - The number of messages per critical section entry is $2 \cdot (n - 1)$

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Distributed synchronisation

Approaches to implement mutual exclusion

Fully distributed approach :

- Negative aspects
  - Processes need to know the identity of all other processes in the system
  - If one process fails , the entire scheme collapses
  - Processes that have not entered their critical section must pause frequently, to assure other processes that they intend to enter the critical section

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Distributed synchronisation

Approaches to implement mutual exclusion

Token passing approach :

- Token is circulated among processes
- Only the process with the token is allowed to access the critical section at a time
- Possible failure cases
  - When the token is lost, an election must be called to generate a new token
  - If a process fails a new logical ring must be established

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Distributed synchronisation

Atomicity

- In distributed systems, also atomic operations are required
- Example: Transaction that has to be executed by either none or all participating nodes
- To ensure atomicity, the following protocols can be implemented
  - Two-phase commit protocol
  - Three-phase commit protocol

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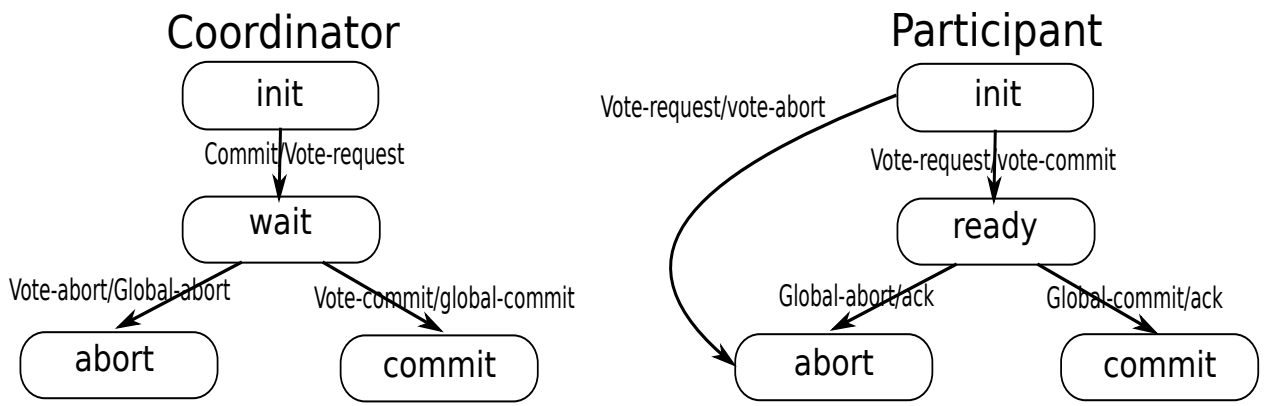
Atomicity – Two-phase commit

- In 1978, Gray introduced the two-phase commit protocol
- In the protocol, a coordinator asks all participating nodes to commit
- If only one of the nodes does not answer/agree, the commit is aborted
- Otherwise, all nodes commit simultaneously



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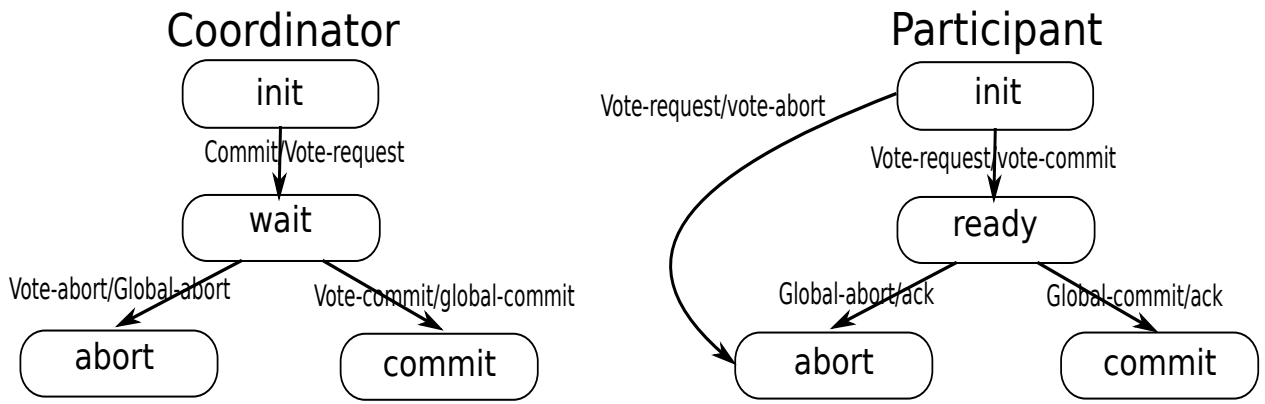
Atomicity – Two-phase commit

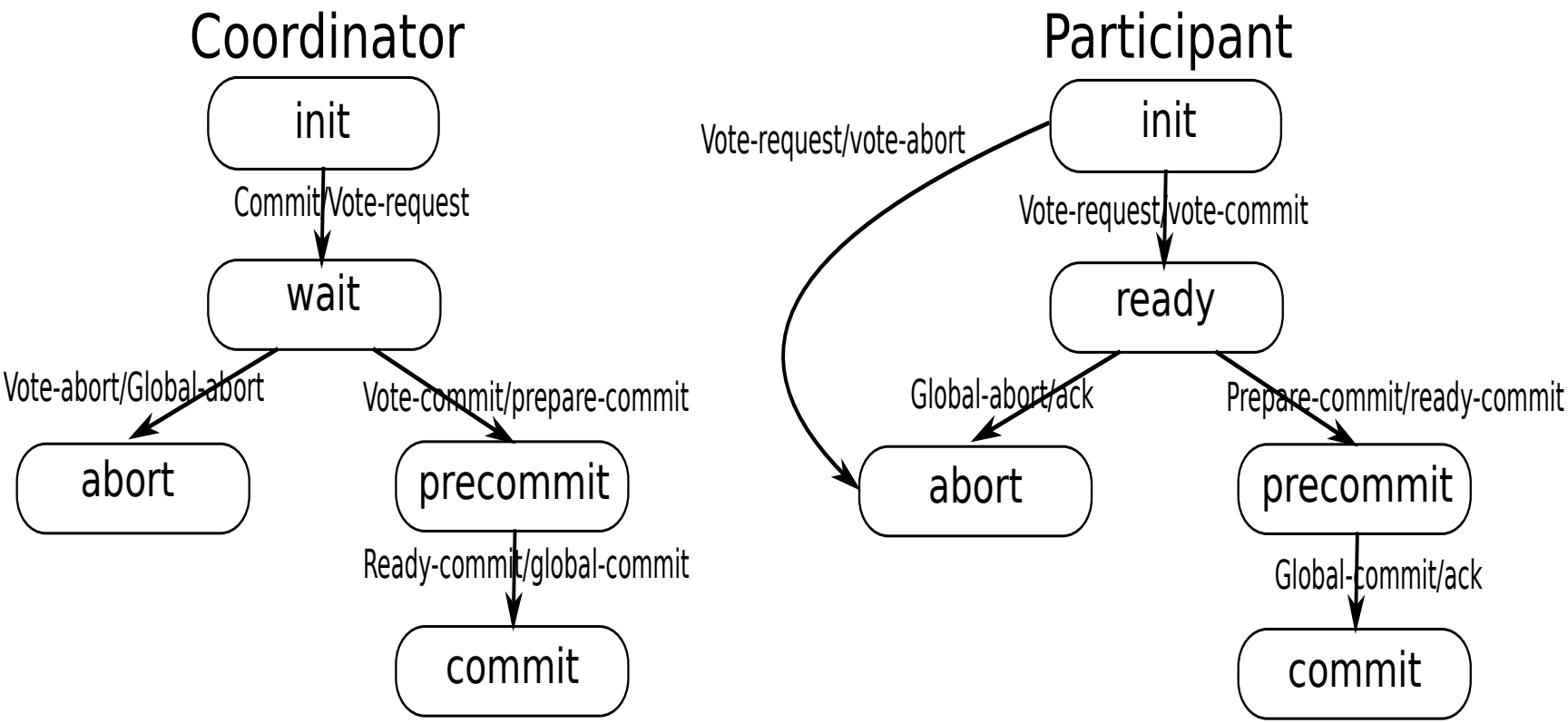
- The two-phase commit protocol has several problems when single nodes fail. This event will frequently result in blocking all participating nodes until the failed node recovers
- When the coordinator has to restart in its Wait state, it might miss some of the answers of the clients



Atomicity – Three-phase commit

- The three-phase commit protocol solves this problem by introducing an intermediate precommit state
- When the coordinator fails in precommit state, the distributed nodes can still take independent decisions
- It is only possible to arrive in precommit, when all nodes already agreed to commit
- Therefore, a node in precommit state can safely commit regardless of the current state of all other nodes

Atomicity – Three-phase commit



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Distributed synchronisation

Deadlock handling

- To handle deadlocks in distributed systems, the same deadlock-prevention and deadlock-avoidance algorithms as for non-distributed system can be applied
- However, some modifications must be applied
  - All resources in the whole distributed system must be assigned unique numbers (for resource ordering)
  - For the bankers algorithm, one process must hold all information necessary to carry out the algorithm

Deadlock handling

- A timestamp based deadlock prevention scheme for distributed systems (preemptive)
  - Each process is assigned a timestamp at creation time
  - Older processes are allowed to pre-empt newer processes

Deadlock handling

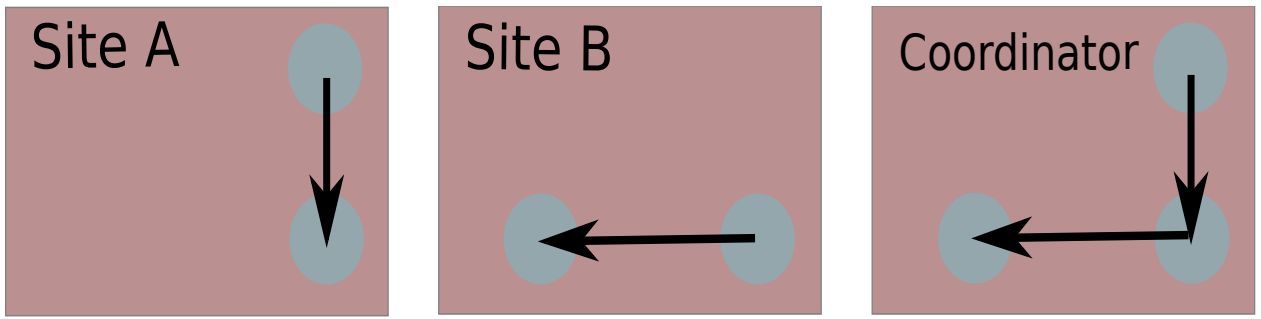
- A timestamp based deadlock prevention scheme for distributed systems (non-preemptive)
  - Each process is assigned a timestamp at creation time
  - Older processes wait for younger processes to finish their tasks
  - Younger processes quit and restart when encountering older processes holding desired resources
  - Processes that quit and restart keep their timestamp

Distributed systems

Distributed synchronisation

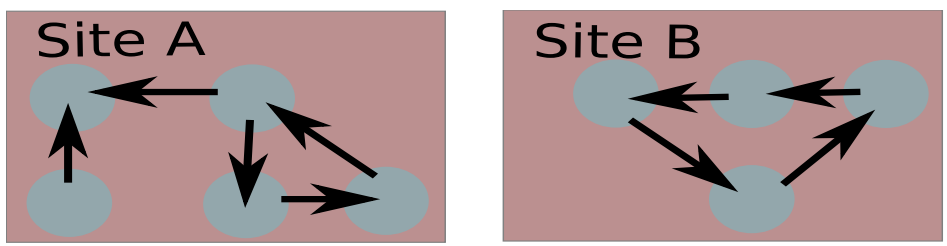
Deadlock detection

- Deadlocks can be detected by creating resource allocation graphs
- The challenge for distributed systems is to decide how to maintain the graph
  - Centralised approach
    - Local resource allocation graphs are merged to a global view
    - Due to delay in the network, the global view may differ temporarily from the actual situation



Deadlock detection – Fully distributed approach

- Fully distributed approach
  - Controllers share equally responsibility for detecting deadlock
  - Every site hosts a resource allocation graph
  - This graph contains an additional node P_{ex}
  - An arc $P_i \rightarrow P_{ex}$ indicates that P_i is waiting for a data item in another site held by any process
  - An arc $P_{ex} \rightarrow P_i$ indicates that any process at another cite waits to acquire P_i
  - Due to delay in the network, the global view may differ temporarily from the actual situation
  - A cycle including P_{ex} does not necessarily mean that the system is in a deadlocked state



Distributed systems

Distributed synchronisation

Election algorithms

- Many distributed algorithms employ a coordinator process
- Especially, the coordinator may fail so that a new coordinator must be elected
- Typically, processes are assigned unique priority numbers
- To choose an appropriate process as the coordinator, several election algorithms can be applied
  - The Bully algorithm
  - The Ring algorithm

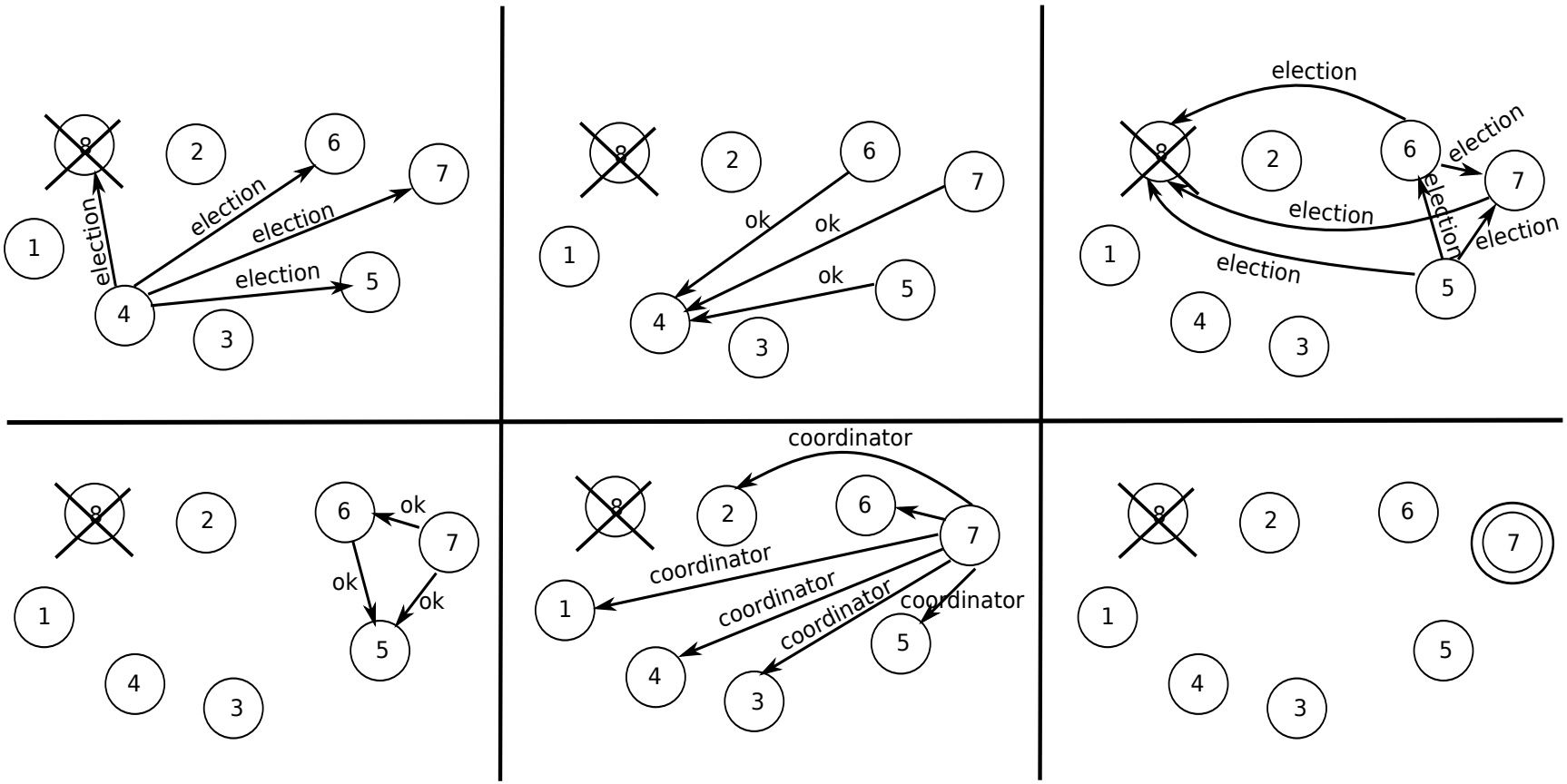
Election algorithms – The Bully algorithm

- A process that notices the absence of a coordinator sends an election message with his priority number to all processes with higher number
- If it does not receive an answer during a time interval T, it becomes the coordinator and informs all active processes
- A process receiving an election message answers only if it has a higher priority (and then starts an election itself)
- When the old coordinator becomes available again it also starts an election

Distributed systems

Distributed synchronisation

Election algorithms – The Bully algorithm



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Election algorithms – The Ring algorithm

- The ring algorithm assumes that processes are in an unambiguous order in which messages are sent
- A process that notices the absence of a coordinator creates a list with its priority value as first entry and sends this to its successor
- If the successor is down, the message is sent to the successors successor (and so on)
- A process receiving such a list adds its priority to the end of the list if its own number is not on the list and forwards the list to its successor
- If the own priority is already on the list, the process searches for the process with highest priority
- The message is then circulated a second time as coordinator message to inform all nodes of the new coordinator

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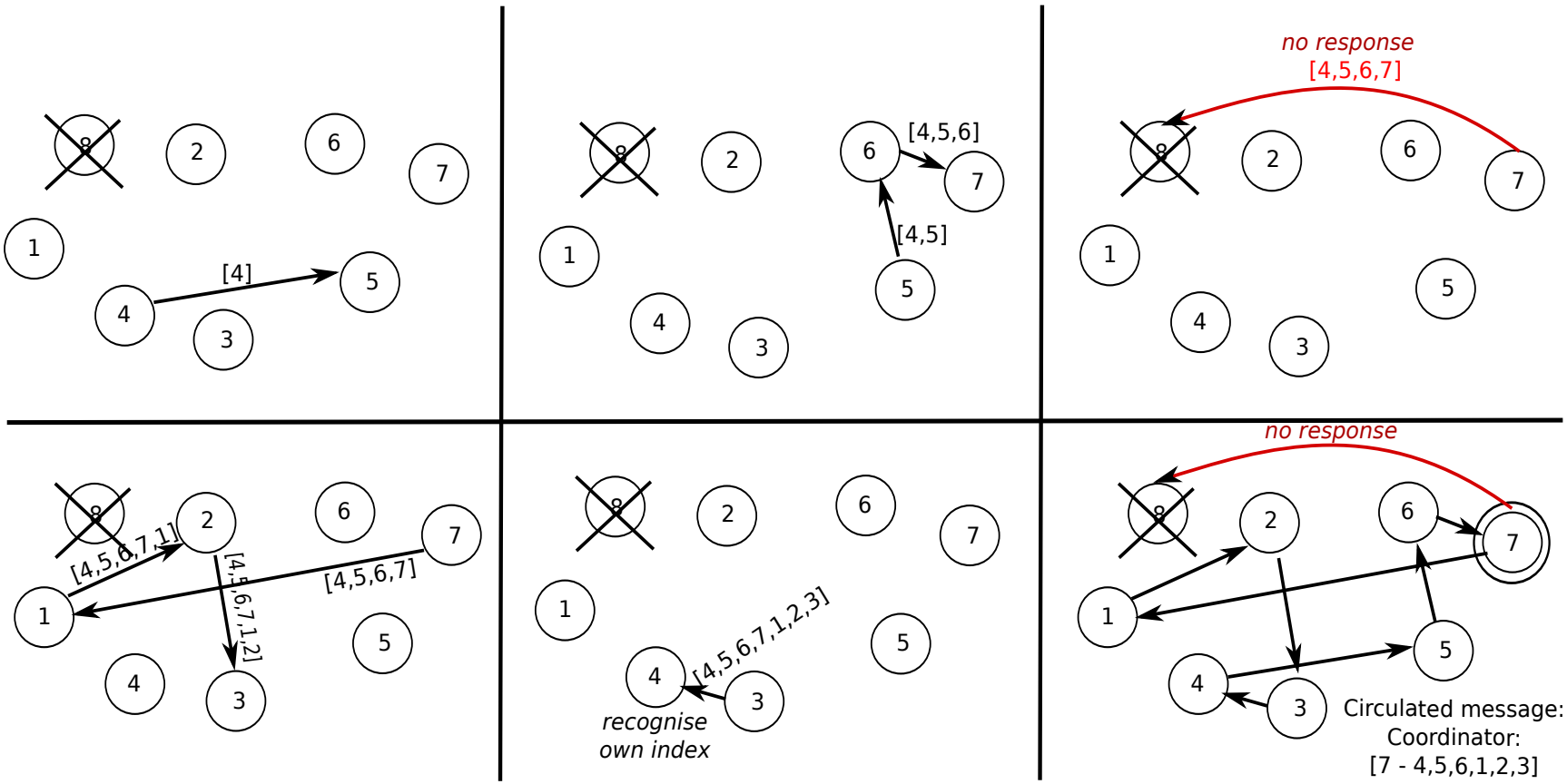
Distributed synchronisation

Election algorithms – The Ring algorithm



Distributed systems

Questions, discussion, remarks

Questions?

Literature

Recommended literature

- A. Tanenbaum, Moderne Betriebssysteme, 2nd edition, Prentice Hall, 2009.
- A. Tanenbaum, Modern operating systems, 3rd edition, Prentice Hall, 2008.
- A. Silberschatz et al. Operating system concepts, Wiley, 2004.
- W. Stallings, Operating systems, 6th edition, Prentice Hall, 2008.