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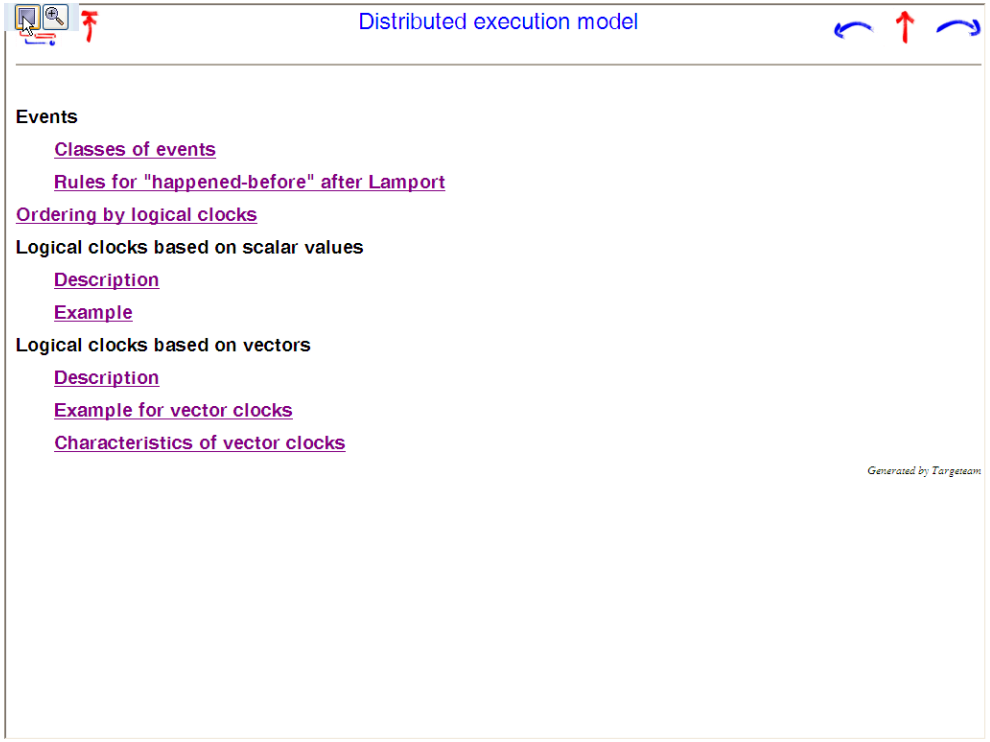

Distributed execution model

Events

- Classes of events
- Rules for "happened-before" after Lamport

Ordering by logical clocks

Logical clocks based on scalar values

- Description
- Example

Logical clocks based on vectors

- Description
- Example for vector clocks
- Characteristics of vector clocks

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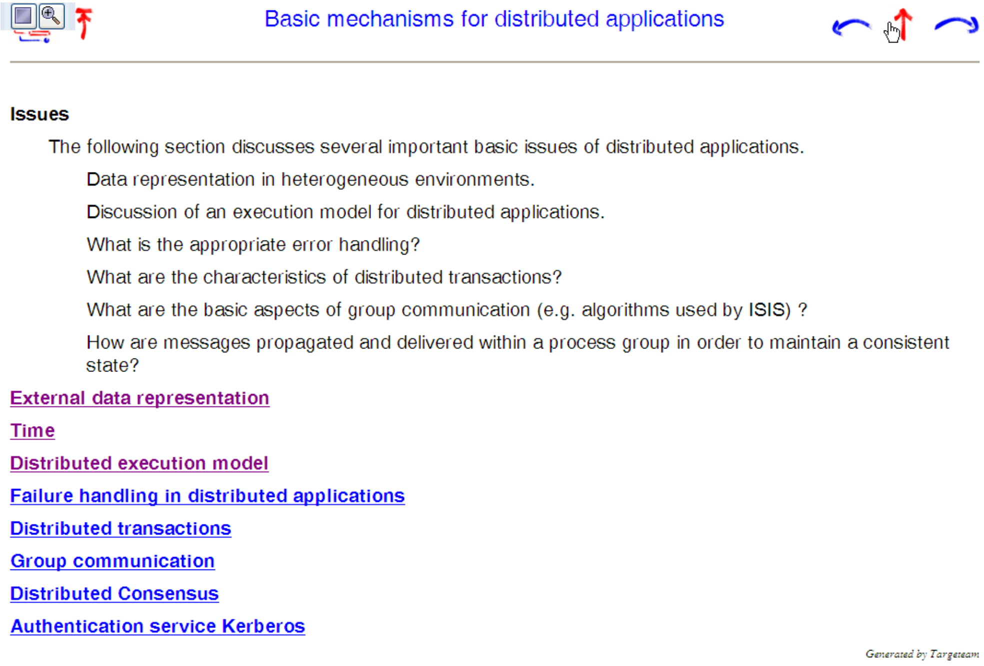

Basic mechanisms for distributed applications

Issues

The following section discusses several important basic issues of distributed applications.

- Data representation in heterogeneous environments.
- Discussion of an execution model for distributed applications.
- What is the appropriate error handling?
- What are the characteristics of distributed transactions?
- What are the basic aspects of group communication (e.g. algorithms used by ISIS) ?
- How are messages propagated and delivered within a process group in order to maintain a consistent state?

External data representation

Time

Distributed execution model

Failure handling in distributed applications

Distributed transactions

Group communication

Distributed Consensus

Authentication service Kerberos

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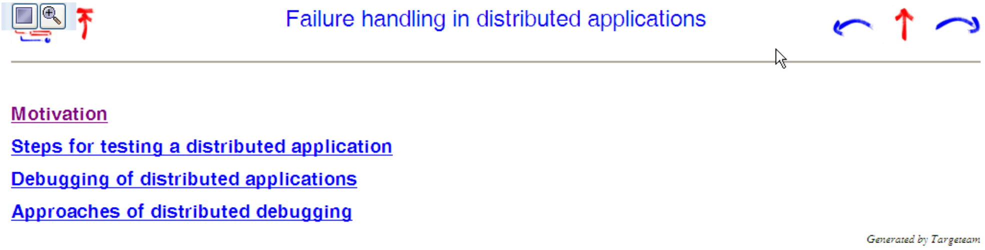

Failure handling in distributed applications

Motivation

Steps for testing a distributed application

Debugging of distributed applications

Approaches of distributed debugging

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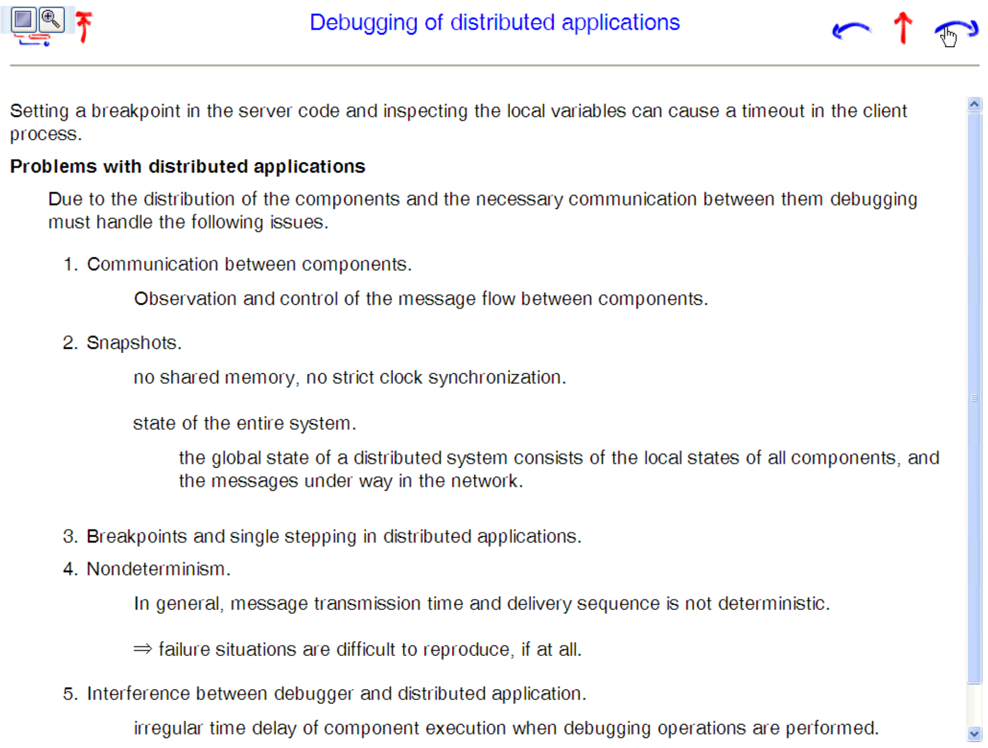


Debugging of distributed applications

Setting a breakpoint in the server code and inspecting the local variables can cause a timeout in the client process.

Problems with distributed applications

Due to the distribution of the components and the necessary communication between them debugging must handle the following issues.

1. Communication between components.

   Observation and control of the message flow between components.

2. Snapshots.

   no shared memory, no strict clock synchronization.

   state of the entire system.

   the global state of a distributed system consists of the local states of all components, and the messages under way in the network.

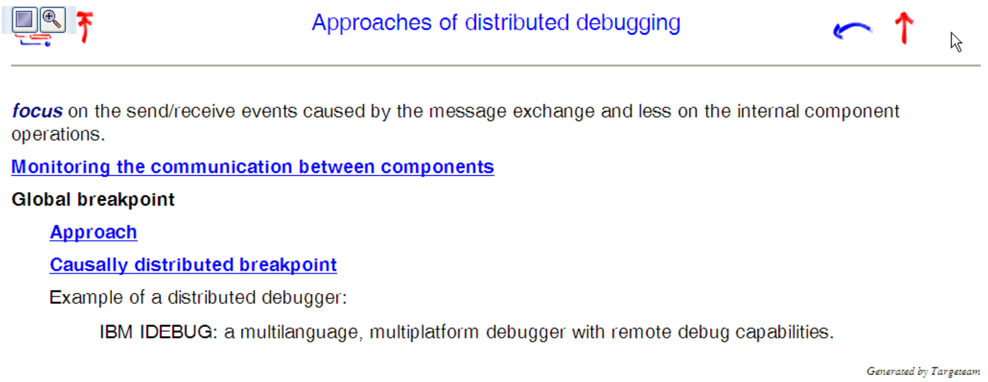
3. Breakpoints and single stepping in distributed applications.
4. Nondeterminism.

   In general, message transmission time and delivery sequence is not deterministic.

   ⇒ failure situations are difficult to reproduce, if at all.

5. Interference between debugger and distributed application.

   irregular time delay of component execution when debugging operations are performed.



Approaches of distributed debugging

focus on the send/receive events caused by the message exchange and less on the internal component operations.

[Monitoring the communication between components]

Global breakpoint

[Approach]

[Causally distributed breakpoint]

Example of a distributed debugger:

IBM IDEBUG: a multilanguage, multiplatform debugger with remote debug capabilities.

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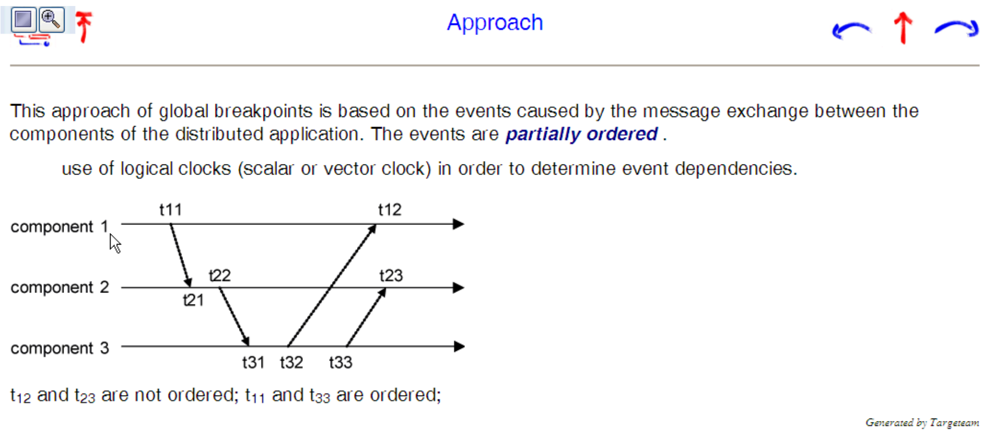

Approach

This approach of global breakpoints is based on the events caused by the message exchange between the components of the distributed application. The events are ***partially ordered*** .

use of logical clocks (scalar or vector clock) in order to determine event dependencies.

t_{12} and t_{23} are not ordered; t_{11} and t_{33} are ordered;

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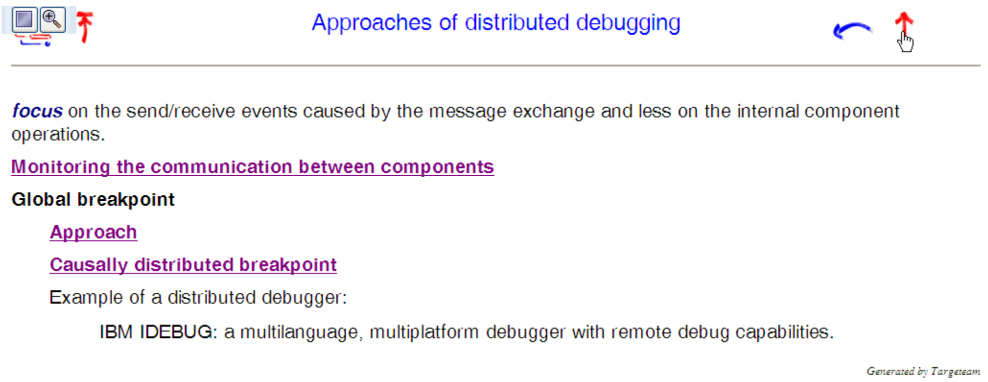

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Distributed transactions

Distributed transactions are an important paradigm for designing reliable and fault tolerant distributed applications; particularly those distributed applications which access shared data concurrently.

General observations

Isolation

Atomicity and persistence

Two-phase commit protocol (2PC)

Distributed Deadlock

General observations

Several requests to remote servers (e.g. RPC calls) may be bundled into a transaction.

```
begin-transaction
    callrpc ($OP_1$ , ...., )
    .....
    callrpc ($OP_n$ , ...., )
end-transaction
```

A distributed transaction involves activities on multiple servers, i.e. within a transaction, services of several servers are utilized.

Transactions satisfy the ***ACID*** property: Atomicity, Consistency, Isolation, Durability.

1. ***atomicity*** : either all operations or no operation of the transaction is executed, i.e. the transaction is a success (commit) or else has no consequence (abort).
2. ***durability*** : the results of the transaction are persistent, even if afterwards a system failure occurs.
3. ***isolation*** : a not yet completed transaction does not influence other transactions; the effect of several concurrent transactions looks like as if they have been executed in sequence.
4. ***consistency*** : a transaction transfers the system from a consistent state to a new consistent state.

Isolation

Isolation refers to the serializability of transactions. All involved servers are responsible for the serialization of distributed transactions. Example:

let U, T be distributed transactions accessing shared data on the two servers R and S.

if the transactions at server R are successfully executed in the sequence U before T, then the same commit sequence must apply to server S.

Timestamp ordering

Locking

Optimistic concurrency control

if conflicts are rare, optimistic concurrency control may be useful: no additional coordination necessary during transaction execution.

The check for access conflicts occurs when transactions are ready to "commit";

Examples

Timestamp ordering

In a single server transaction, the server issues a unique timestamp to each transaction when it starts.

In a distributed transaction each server is able to issue globally unique timestamps.

for distributed transactions, the timestamp is the pair

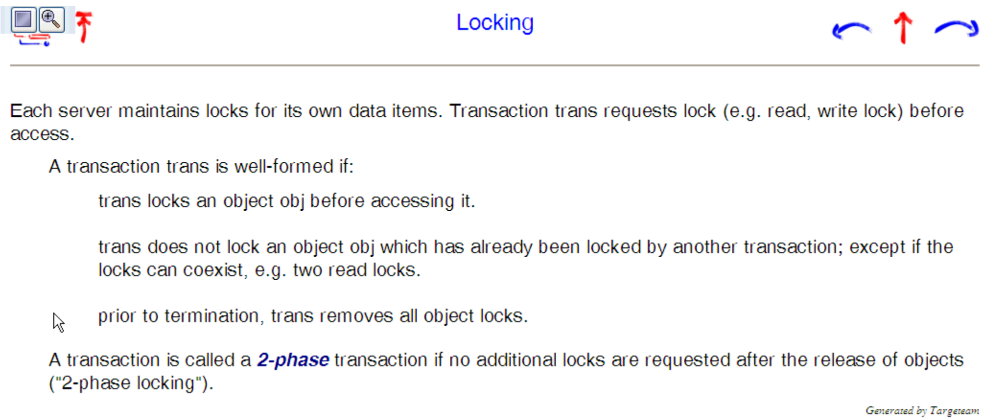
(local timestamp, server-ID)

The local timestamp refers to the first server which issued the transaction timestamp.

Assume: timestamp(trans) = t_{trans} and timestamp(obj) = t_{obj}

transaction trans accesses object obj

```
if ($t_{trans} < t_{obj}$) then abort(trans) else access obj;
```



Locking

Each server maintains locks for its own data items. Transaction trans requests lock (e.g. read, write lock) before access.

A transaction trans is well-formed if:

trans locks an object obj before accessing it.

trans does not lock an object obj which has already been locked by another transaction; except if the locks can coexist, e.g. two read locks.

prior to termination, trans removes all object locks.

A transaction is called a ***2-phase*** transaction if no additional locks are requested after the release of objects ("2-phase locking").

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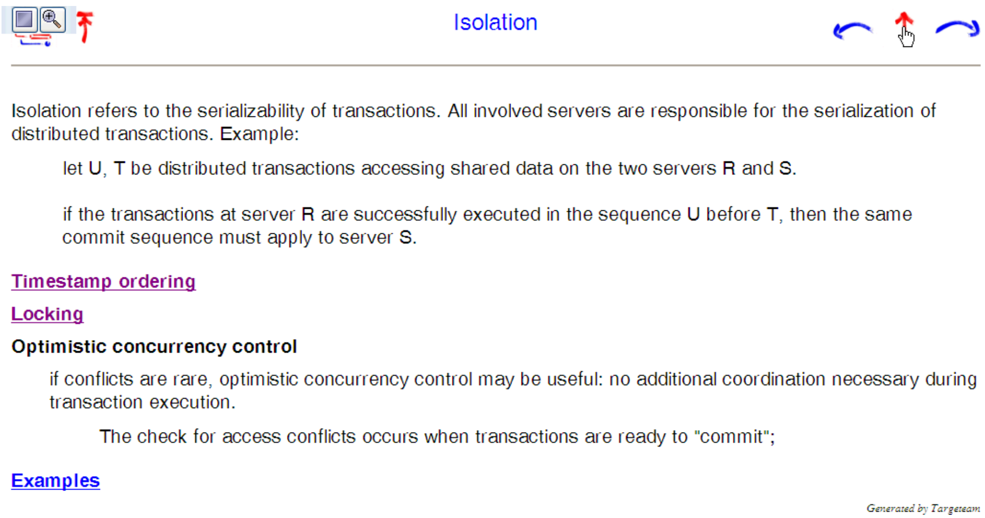

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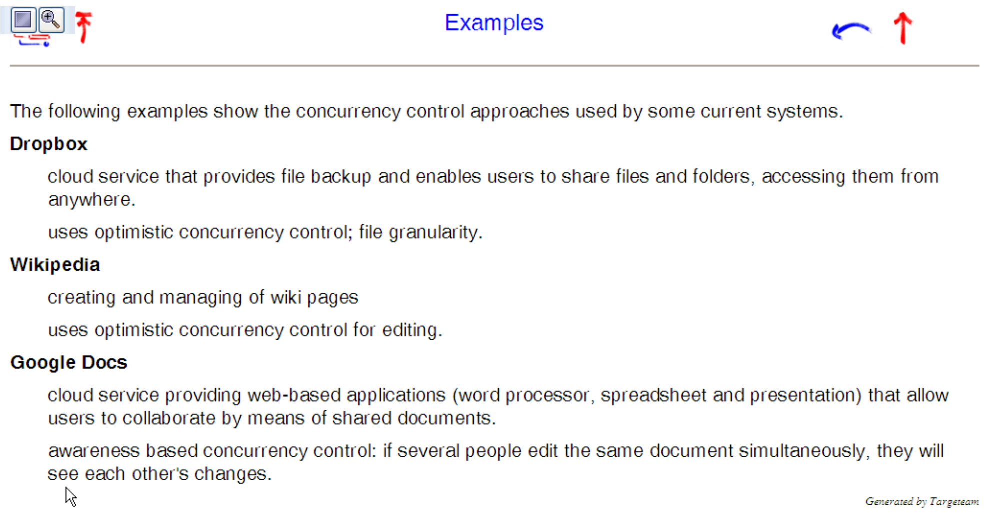

Examples

The following examples show the concurrency control approaches used by some current systems.

Dropbox

cloud service that provides file backup and enables users to share files and folders, accessing them from anywhere.

uses optimistic concurrency control; file granularity.

Wikipedia

creating and managing of wiki pages

uses optimistic concurrency control for editing.

Google Docs

cloud service providing web-based applications (word processor, spreadsheet and presentation) that allow users to collaborate by means of shared documents.

awareness based concurrency control: if several people edit the same document simultaneously, they will see each other's changes.

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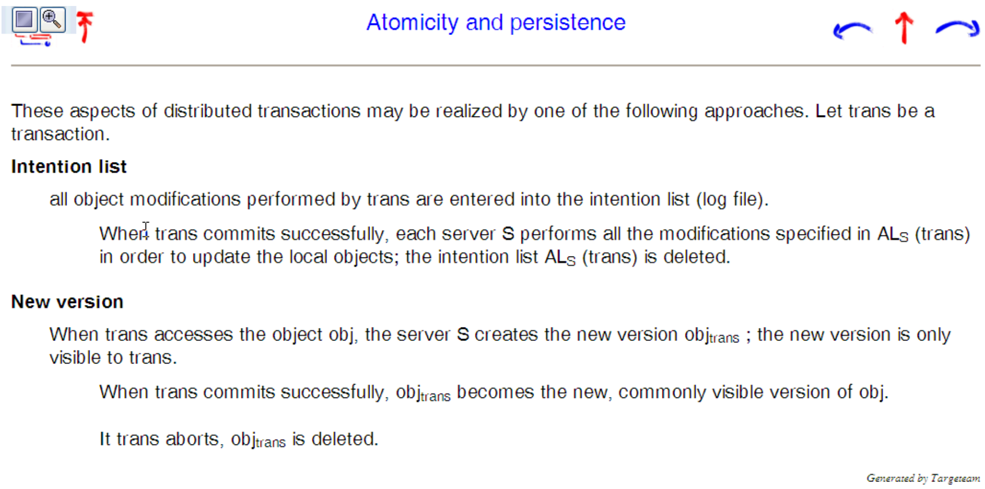

Atomicity and persistence

These aspects of distributed transactions may be realized by one of the following approaches. Let trans be a transaction.

Intention list

all object modifications performed by trans are entered into the intention list (log file).

When trans commits successfully, each server S performs all the modifications specified in AL_S (trans) in order to update the local objects; the intention list AL_S (trans) is deleted.

New version

When trans accesses the object obj, the server S creates the new version obj_{trans} ; the new version is only visible to trans.

When trans commits successfully, obj_{trans} becomes the new, commonly visible version of obj.

It trans aborts, obj_{trans} is deleted.

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Two-phase commit protocol (2PC)

This protocol supports the communication between all involved servers of the distributed transaction in order to jointly decide if the transaction should commit or abort.

We can distinguish between two phases

> ***Voting phase*** : the servers submit their vote whether they are prepared to commit their part of the distributed transaction or they abort it.
>
> ***Completion phase*** : it is decided whether the transaction can be successfully committed or it has to be aborted; all servers must carry out this decision.

Steps of the two-phase commit protocol

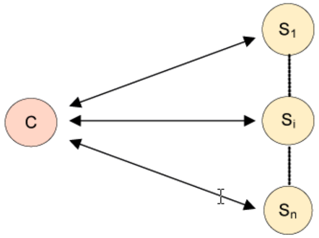
Operations

Communication in the two-phase commit protocol

Problems

Steps of the two-phase commit protocol

One component (e.g. the client initiating the transaction or the first server in the transaction) becomes the ***coordinator*** for the commit process. In the following we assume, client **C** is the coordinator.



1. Coordinator C contacts all servers S_i of the distributed transaction trans requesting their status for the commit (CanCommit?)
   - if server S_k is not ready, i.e. it votes no, then the transaction part at S_k is aborted;
   - $\exists i$ with S_i is not ready

     then trans is aborted; the coordinator sends an abort message to all those servers who have voted with ready (i.e. yes).
2. $\forall i$ with S_i is ready, i.e. commit transaction trans. Coordinator sends a commit message to all servers.
3. Servers send an acknowledgement to the coordinator.

Two-phase commit protocol (2PC)

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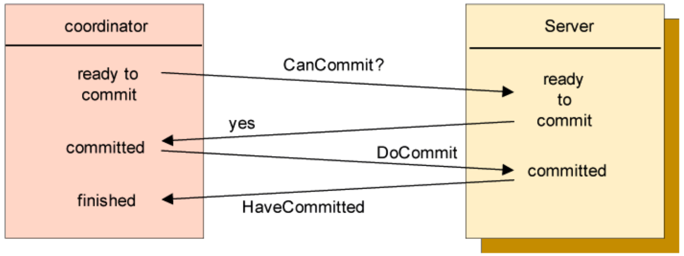

Number of messages: 4 * N messages for N servers.

Problems

During the 2PC process several failures may occur

one of servers crashes.

the coordinator crashes.

depending on their state, this may result in blocking situations, e.g. the coordinator waits for the commit acknowledge of a server, or a server waits for the final decision (commit or abort).

Extended 2PC

Three-Phase Commit protocol (3PC) is another approach to overcome blocking of servers until the crashed coordinator recovers.

Extended 2PC

```
Coordinator:
    multicast: ok to commit?
    collect replies
        all ok =>
                log commit to outcomes table
                wait until saved to persistent store
                send commit
        else   => send abort
    collect acknowledgements
    garbage collect data from outcomes table

After Failure:
    for each pending protocol in outcomes table
        send outcome (commit or abort)
        wait for acknowledgements
        garbage collect data from outcomes table
```

```
Server: first time message (CanCommit) received
    ok to commit =>
        save data to temp area (persistent store)
        reply ok
    commit =>
        make change permanent
        send acknowledgement
    abort   => delete temp area

message is a duplicate (recovering coordinator)
    send acknowledgement

After Failure:
    for each pending protocol
        contact coordinator to learn outcome
```

Problems

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Extended 2PC

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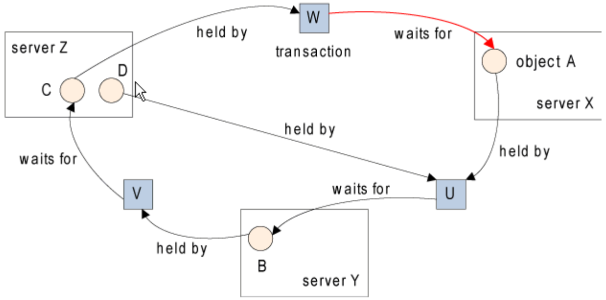
Distributed Deadlock

Multiple transactions may access objects of multiple servers resulting in a distributed deadlock.

at object access the server lock manager locks the object for the transaction.

deadlock detection schemes try to find cycles in a wait-for graph.



theory: construct a global wait-for graph from all local wait-for graphs of the involved servers. Problems:

the central server is a single point of failure.

communication between servers take time.

Edge Chasing

Edge Chasing

distributed approach to deadlock detection

- no global wait-for graph is constructed.
- each involved server has some knowledge about the edges of the wait-for graph.
- servers attempt to find cycles by forwarding messages (called probes).

each distributed transaction T starts at a server ⇒ the ***coordinator*** of T.

the coordinator records whether T is active or waiting for a particular object on a server.

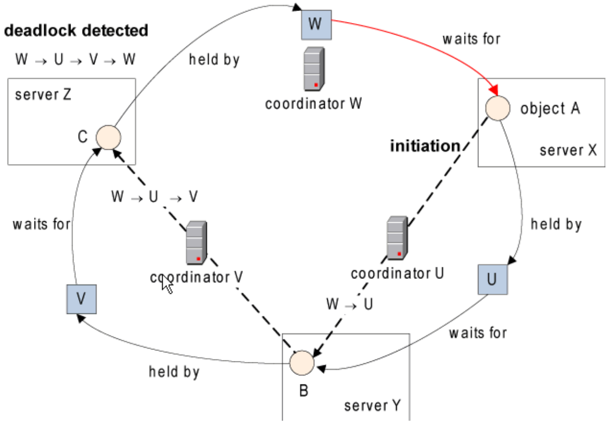
lock manager informs coordinator of T when T starts waiting for an object and when T acquires finally the lock.

Edge Chasing Algorithm

Transaction Priorities

Edge Chasing Algorithm

The algorithm consists of 3 steps: initiation, detection and resolution.



initiation : server X notes that W is waiting for another transaction U; it sends the probe "W → U" to the server of B via the coordinator of U.

detection : detection consists of receiving probes and deciding whether a deadlock has occurred and whether to forward the probes.

Server Y receives the probe "W → U"; it notes B is held by transaction V and appends V to the probe to produce "W → U → V"; probe is forwarded to server Z via coordinator of V.

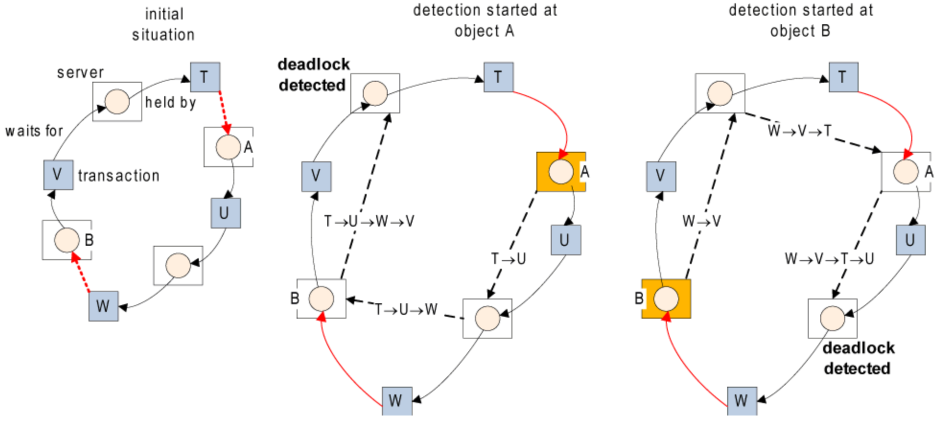
Transaction Priorities

Every transaction involved in a deadlock cycle may cause the initiation of deadlock detection

- several servers initiate deadlock detection in parallel
- ⇒ possible more than one transaction in a cycle is aborted.

Example:

- transaction T attempts to access an object A locked by U
- transaction W attempts to access an object B locked by V



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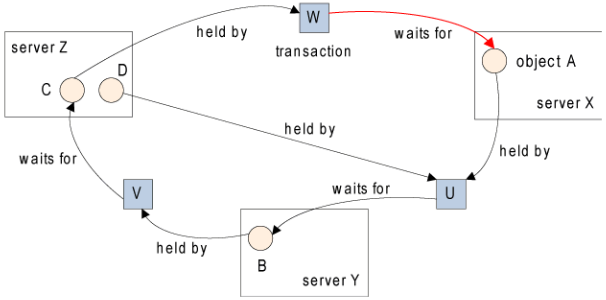

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Edge Chasing