A Robust Persistent Storage Architecture for ACE

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Overview

- Pervasive Computing
- ACE project
- Background
- Design
- Implementation
- Properties of the system
- Conclusions and Future work
- Related work

Pervasive Computing

- Diverse computing environment
- Myriad devices
- Storage and Computation distributed across heterogeneous network
- Robust and user-friendly
- Devices, storage, computation processes transparent
- Research challenges
  - Storage architecture, low-latency network protocols, etc

ACE Project

- Solution to Pervasive computing
- Smart rooms
- Personal workspaces
- Embedded devices
- ACE Services
- ASD – ACE Service Directory

Persistent Store

- User contexts should survive failures
- Objects – uninterpreted bytes
  - Text files, binary files, user contexts, etc
- Namespace – collection of objects
- Robust and highly available
- Consistent view

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Background

- Replication of services
- Well-defined interface to clients
- Failures in parts of the system
- Data consistency
- Synchronization among servers
- Servers being aware of status of other servers
- Organization of stored data

Consistency Model

- Data consistency in distributed systems
- Semantics of the abstraction provided by the store
- ‘read’ and ‘write’ operations
- Set of acceptable orderings
- Strong and weak consistency models
  - Correctness vs Performance
  - Examples

Strong consistency models

- Strict Consistency
  - Strongest consistency model
  - Global clock
  - Non-zero propagation delay. So, impractical
- Linearizability
  - Operations ordered in some sequential fashion consistent with read-write semantics
  - Non-overlapping operations ordered in the same way as real-time ordering
- Sequential Consistency
  - Restriction on non-overlapping operations removed
- Desired programming model – deciding factor

Failures

- Machine failures
  - Crash failures
  - Disk failures
  - Denial of service attacks
- Network failures
  - Message loss and corruption
  - Network partitions
- Degree of robustness
  - Types of failures that are detected
  - Recovery mechanisms

Programming Model

- Concurrent execution of tasks
- Multithreaded model
  - Different threads perform independent tasks
  - Easier to design
  - Difficult to debug
- Event-driven model
  - Server behaves like a finite state machine
  - Event handlers
  - Difficult to design

Issues in multithreading

- Mutual exclusion
  - Locks to protect shared data structures
  - Programmer's responsibility
- Deadlock
  - Circular wait
  - Programmer's responsibility
- Starvation
  - Same thread keeps acquiring the lock
  - Design of thread scheduler

Properties

- Safety
  - System does not do anything wrong
  - Deadlock freedom
- Liveness
  - System does something right
  - Starvation freedom
- Behavior of the server

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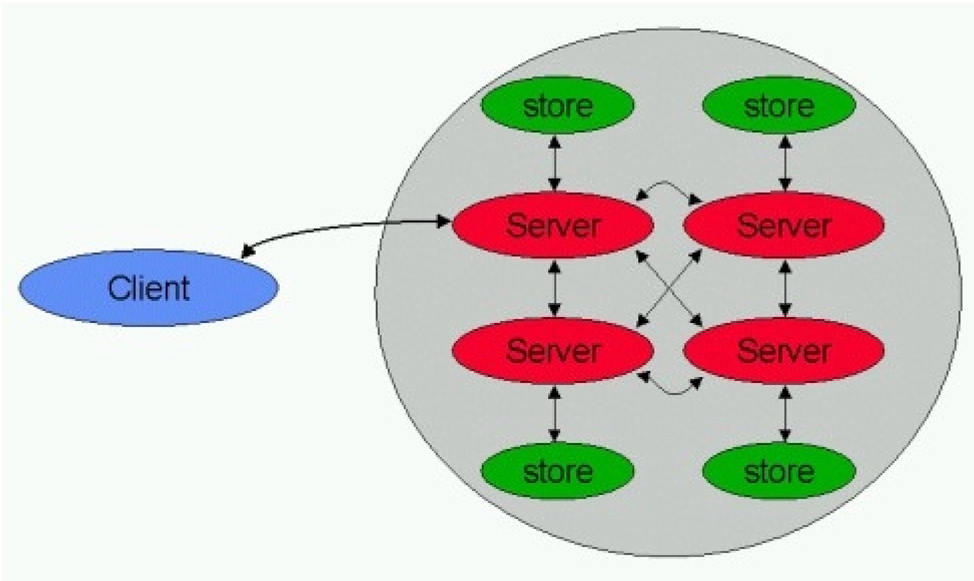
Design

- Peer-to-peer server architecture
- Objects and Namespaces in store

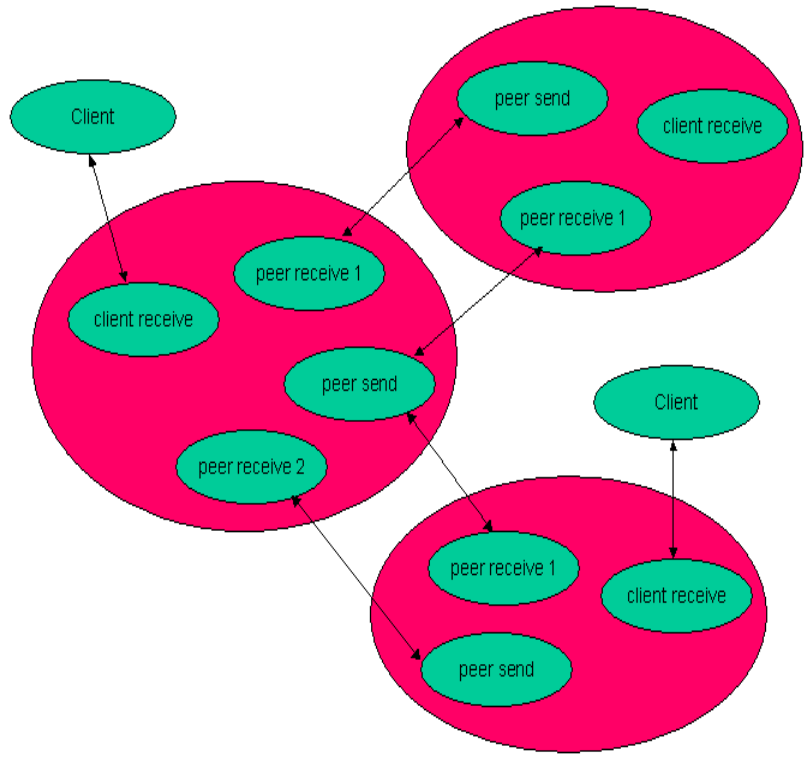


Client

- Services offered to client
  - Object commands
    - *store_object*
    - *retrieve_object*
    - *store_unique_object*
    - *delete_object*
    - *list_objects*
  - Namespace commands
    - *create_namespace*
    - *delete_namespace*
    - *clear_namespace*
    - *list_namespaces*

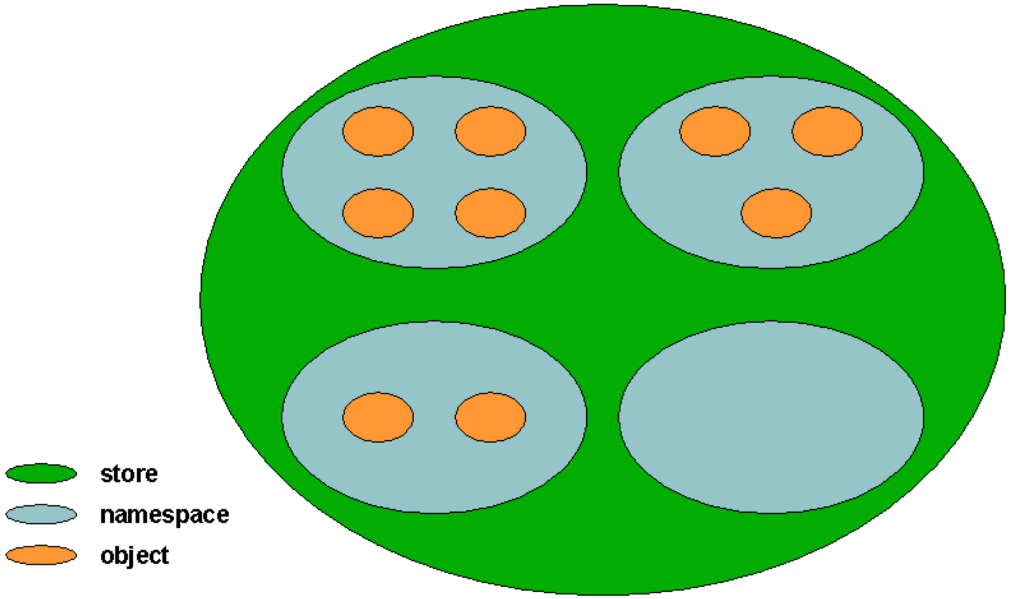
Server

- Client discovers server address from config. files
- Client randomly selects a server
- Concurrent processing of multiple client and server requests



Store

- Any non-volatile storage can be used
- Collection of objects and namespaces



Object commands

- store_object – store named object in the namespace
  - namespace
  - name
  - object
  - replication flag
- retrieve_object – retrieve named object from the namespace
  - namespace
  - name
- list_objects – list all objects in the namespace
  - namespace

Object commands

- store_unique_object – choose a unique name and store the object in the namespace
  - namespace
  - object
  - replication flag
- delete_object – delete named object from the namespace
  - namespace
  - name

Namespace commands

- create_namespace – create a namespace
  - namespace
- clear_namespace – delete all objects, but namespace remains
  - namespace
- delete_namespace – delete the namespace and all objects
  - namespace
- list_namespaces – list all namespaces

Consistency Model

- Linearizability
  - Example 1
    - P1: w(x)1
    - P2: r(x)0 r(x)1
  - Example 2
    - P1: w(x)1
    - P2: r(x)0 r(x)1
- Local property
  - Every object is linearizable => system is linearizable
- Two-phase commit protocol

Restart Mechanism

- Recovery after failure
- Incarnation File
  - stored in a specific location in the server machine
  - contains incarnation number
  - deleted during normal shutdown
- Incarnation Number
  - set to 0 when file is created
  - incremented after recovery
  - included with every message for updating store
  - checked before updating the store

Server joining and leaving

- Joining
  - has to be atomic
  - two-phase commit needed
  - client requests not processed during joining
- Leaving
  - crash detected by *sigpipe* handler
  - two-phase commit not necessary

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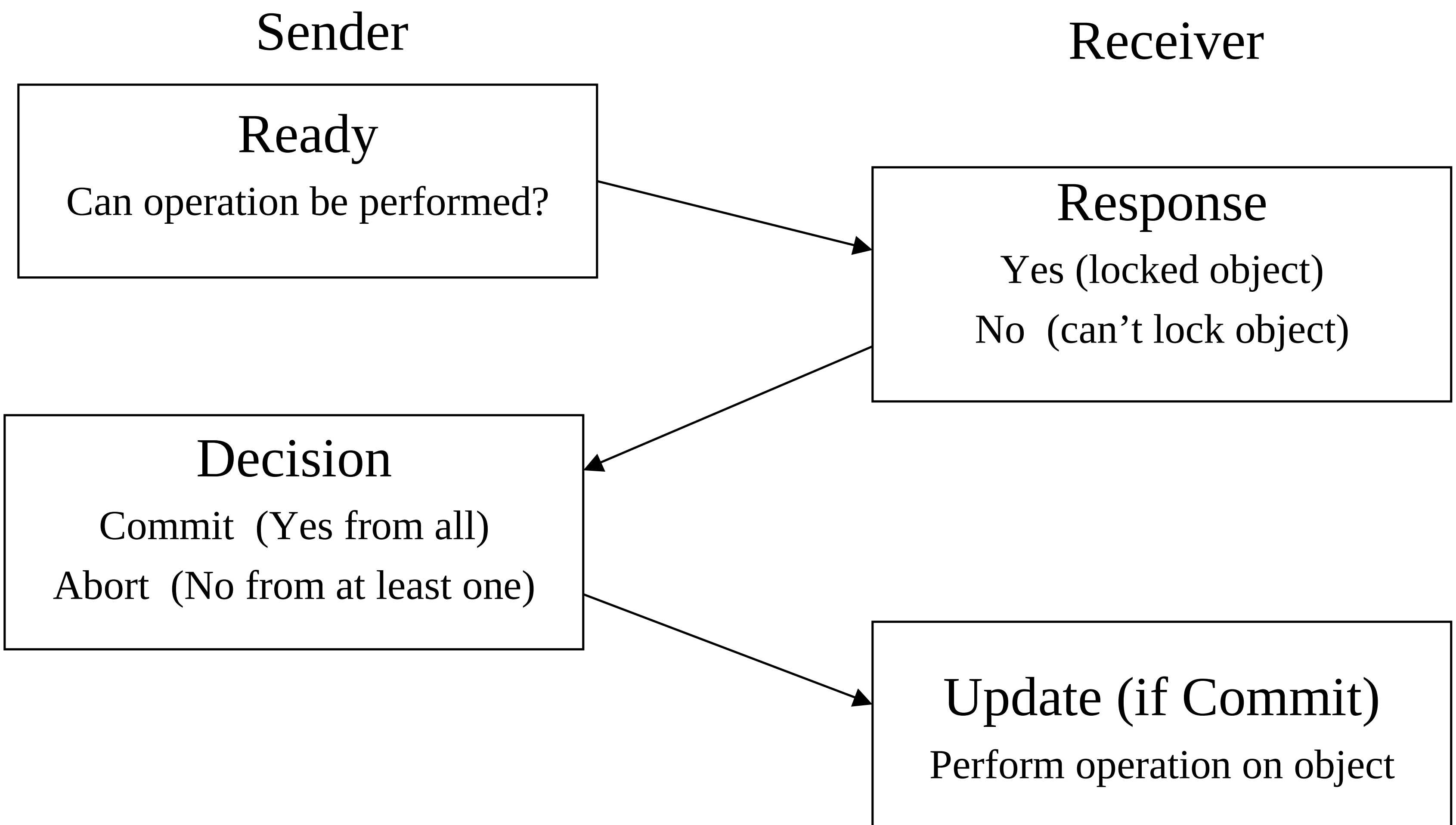
Two-phase commit



Failure Detection

- Implementation using TCP/IP sockets
- Crash Failures
  - EPIPE error with socket related system calls
  - SIGPIPE handler invoked
- Disk Failures
  - Unable to perform disk I/O operations
  - Inform peer servers
- Status of peer servers updated

Data Structures

- Namespace Hash table
- peer_attributes
  - Peer identifier
  - Peer state
  - Socket id
  - Thread id
  - Incarnation number
- cond_var_array
  - Condition variable
  - Associated mutex variable
  - Flag1 (used or not)
  - Flag2 (status of two-phase commit)
- Object linked list
- client_request_list
  - Request type
  - Request parameters
  - Object
  - Incarnation number
  - Index in cond_var_array

Mutex and Condition variables

- Mutex variables
  - mutex_peer_attributes
  - mutex_client_request_list
  - mutex_cond_var_array
  - mutex_hash_table
- Condition variables
  - cond_peer_join
  - cond_var_array

Main thread

initialize peer_attributes

initialize array of condition variables

initialize hash table

install signal handlers

update incarnation file

create client_receive, peer_send and peer_receive threads

client receive

```
get requests from clients
parse the request
if server need not inform peers
     do local i/o and respond to the client
 else
      add  the request to client_request_list
      wait for the result of two-phase commit
      if signaled and two-phase commit is success
         do local i/o and inform the client of success
      else
         inform the client of failure
```

peer send

read client_request_list

initiate two_phase_commit

wait for responses from peers (finite wait using select)

receive two_phase_commit_yes or two_phase_commit_no

send commit message or abort message

signal condition variable

delete request from client_request_list

peer receive

check peer_attributes
start two_phase_commit if not already initiated by another server
create child thread

update peer_attributes

forever
  do
    receive request from peer server
    case request_type:

    incarnation_number : update peer_attributes with incarnation number

    i_am_dead : update peer_attributes
                        terminate this thread

    peer_server_dead : update peer_attributes
                                terminate receive thread corresponding to the dead peer

peer receive

two_phase_commit_ready :

- parse the request
- acquire lock for namespace or object
- break ties based on server id
- send two_phase_commit_yes or two_phase_commit_no

two_phase_commit_commit :

- receive the object
- do local i/o
- if disk failure, send i_am_dead message.
- release lock for namespace or object

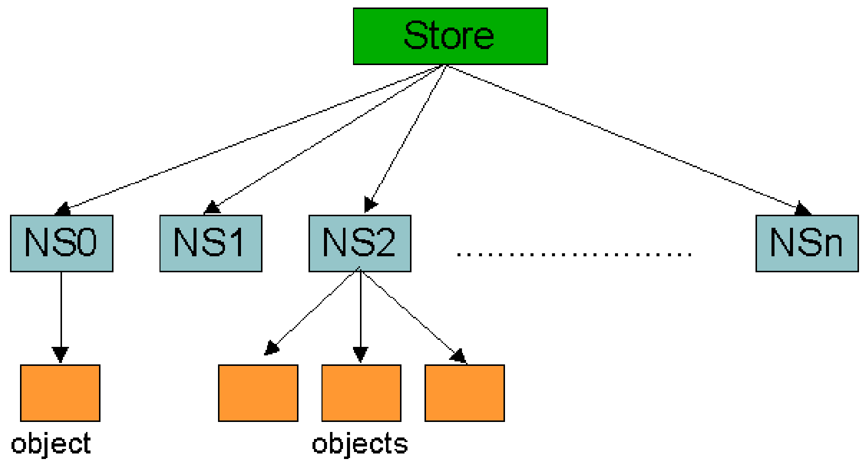
two_phase_commit_abort :

- release lock for namespace or object.

done

Directory structure of the store

- Store - specific directory in the server machine
- Namespaces – subdirectories
- Objects - files



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Assumptions

- Thread package (Linux pthreads library)
  - The thread scheduler is starvation free
  - Creating a child thread does not block
  - Terminating a child thread does not block
- Communication mechanism (TCP/IP sockets)
  - All messages that are sent are eventually delivered when there is no crash. Messages are not lost, corrupted or misdirected
  - Every crash is eventually detected
  - We have a perfect failure detector. So, all detected crashes are crashes

Invariants

- All shared data structures are protected by locks.
- Deadlock does not occur
  - No instance of circular wait in acquiring mutex variables
- Any thread that holds the lock does not block
  - No thread does infinite wait

Invariants

- The number of ‘peer_receive’ threads will eventually be the same as the number of servers set 'alive' in peer_attributes
  - peer_receive thread updates peer_attributes
  - peer_receive thread cancelled when peer server is set ‘dead’
- No server joins the group when a two-phase commit that has been initiated by a server for serving client request is in effect.
  - peer_send does two-phase commit in a sequential order
  - Processing either client requests or server joining requests

Properties

- Client requests are eventually served if the mutexes are starvation free and at least one server is alive and no server crashes
  - peer_send does timed wait using ‘select’ call
  - client_receive does timed wait on condition variable
- When there is a perfect failure detector and there are no network failures, the state of the persistent store including current state and pending commits, will be the same in all servers that are alive
  - Pending commit – namespaces and objects locked
  - State of the store changes only after successful two-phase commit

Properties

- Consistency is guaranteed by the two-phase commit protocol. Operations on the persistent store are linearizable
  - Linearizability is a local property
  - Writes are in some sequential order, same in all servers
  - Operations performed after acquiring locks
  - Ties in acquiring locks are resolved based on IP address
  - Commit is done in the same order in every server
  - Sequence of writes same order in every server

Limitations

- Network partitions
  - ‘alive’ servers considered to be ‘dead’
  - Results in inconsistencies
- Denial of service attacks
  - Servers flooded with requests from clients
  - Impairs performance of the server
- Two-phase commit protocol may block
  - Server crashes at inopportune moments

Conclusions and Future work

- Conclusions
  - Persistent storage architecture designed and implemented
  - Proved properties
- Future work
  - Different Network Protocols
  - Different Consistency Models
  - Security Issues

Related work

- Ninja
- Nile
- Websphere
- Weblogic
- Local consistency (Ahamad et al)
- Linearizable objects (M.P. Herlihy and J. M. Wing)

Response time

List Namespaces	611 usec
	1542 usec
List Objects	1560 usec
	218 usec
Retrieve Object	601 usec (25 KB)
Create Namespace	46412 usec
	17388 usec
Clear Namespace	74148 usec
Delete Namespace	21686 usec
Store Object	55771 usec (25 KB)
	68872 usec (171 KB)
	63578 usec (25 KB)

Questions