Ίδρυμα Προώθησης Έρευνας

ΚΥΠΡΙΑΚΗ ΔΗΜΟΚΡΑΤΙΑ

ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ

Quorum Views: Client Side Tools for Atomic Distributed Register Implementations

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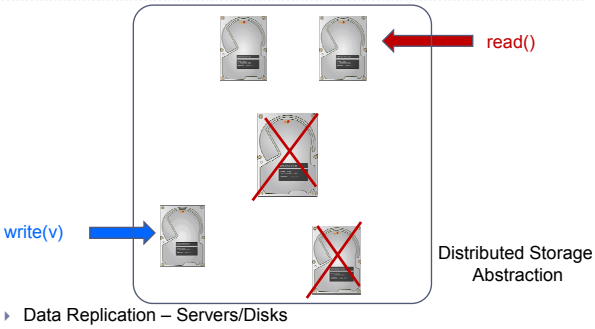
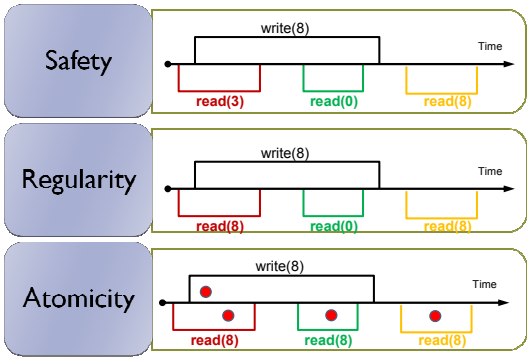
What is a Distributed Storage System?



- Data Replication – Servers/Disks
  - Survivability and Availability
- Read/Write operations
- Consistency Semantics

Consistency Semantics [Lamport86]



Complexity Measure-Operation Latency

- Consistent Register Implementations
  - **Message-Passing, Asynchronous** model
  - Access **multiple replicas** per operation
  - Perform **multiple accesses** per operation

Operation Latency is measured in
Communication Rounds (round-trips)

Fastness of Atomic Implementations

Traditional SWMR
- Single round writes
- Two round reads
  - Phase 1: Obtain latest value
  - Phase 2: Propagate latest value
    - Folklore belief: "Reads must Write"

SWMR Fast
- Single round (***fast***) writes and reads
  - Bounded readers: $R<(S/f)-2$ where S servers & f failures
  - Impossible in MWMR model

SWMR Semifast
- Fast writes
- Only a single complete 2-round (***slow***) read per write
  - Unbounded readers
  - Bounded Virtual Nodes: $V<(S/f)-2$
  - Impossible in the MWMR model

Quorum Systems

- Quorum System:
  A collection of sets with non-empty pairwise intersections
- Numerous results exploit quorums for
  - MWMR and Dynamic Atomic Memory Implementations
  - "Slow" operations
    - Some achieve fast reads when a write is confirmed [DGLSW03, CGGMS05]
- Refined Quorum Systems - Guerraoui and Vukolic [PODC2007]
  - Introduce Fast Operations in Quorum-Based systems
  - Rely on operation timeout

Question

Can we obtain Fast/Semifast Implementations in a general quorum-based framework?

First the Bad News

- Quorum-Based Fast Implementations are not Fault-Tolerant
  - Possible iff there exists a common intersection among all the quorums
  - A single failure in the common intersection collapses the Quorum system.
- Quorum-Based Semifast Implementations are not Fault-Tolerant
  - One of the properties of the semifast definition is violated if no common intersection exists among all the quorums.
    - A single complete "slow" read operation is not enough for every write operation

Now the Good News

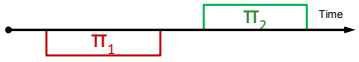
- Trade speed for efficiency and fault-tolerance
  - Allow multiple "slow" reads per write operation but maintain the fast behavior when possible
- To do so, we introduce **Quorum Views**

Model: Definitions

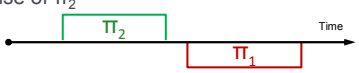
- Asynchronous, Message-Passing model
  - Process sets: writers W, readers R, servers S (replica hosts)
  - Reliable Communication Channels
  - Well Formedness
- Environments:
  - SWMR: $|W|=1, |R|\geq 1$
  - MWMR: $|W|\geq 1, |R|\geq 1$
- Failures:
  - Crash Failures
- Correctness: Atomicity (safety), Termination (liveness)
- Order write operations
  - SWMR: <timestamp, value> pairs
  - MWMR: <tag, value> pairs

Definition: Operation Relations

- Precedence Relations for two operations π_1, π_2:
  - π_1 precedes π_2 if the response of π_1 happens before the invocation of π_2

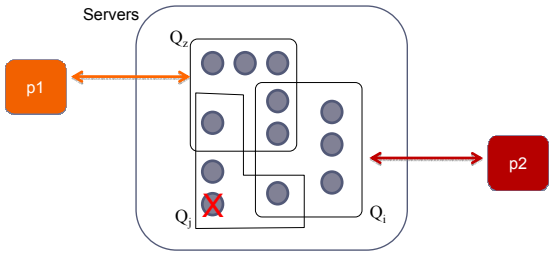


  - π_1 succeeds π_2 if the invocation of π_1 happens after the response of π_2



  - π_1 is concurrent with π_2 if π_1 neither precedes nor succeeds π_2

Definition: Quorum systems



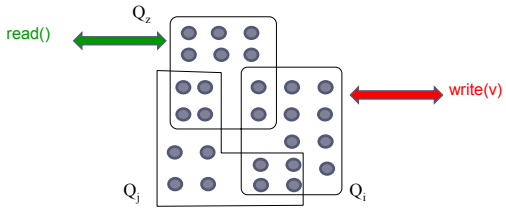
- Q_i, Q_j, Q_z are **quorums**
- **Quorum System** is the set $\{Q_i, Q_j, Q_z\}$
  - Property: every pair of quorums intersects
- Every R/W operation communicates with a single quorum
- Faulty Quorum: Contains a faulty process

Definition: Fastness

- A process p performs a communication round during an operation π if:
  - p sends a message m to a set of servers for π
  - Any server that receives m replies to p
  - Once p receives responses from a single quorum completes π or proceeds to a next communication round
- Fast Operation
  - Completes at the end of its first round
- Fast Implementation
  - All operations are fast
- Communication scheme
  - Message delivery: Servers to Clients
  - No server to server or client to client communicaiton

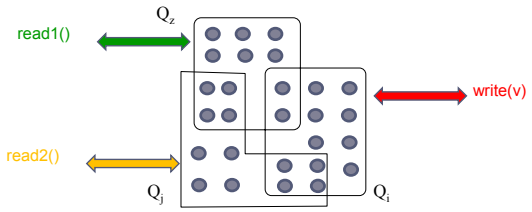
Non-Robust Fast Implementations: Proof Sketch

- Execution a:
  - Complete write(v) => Q_i
  - Complete read() => Q_z
    - read() returns v to preserve atomicity



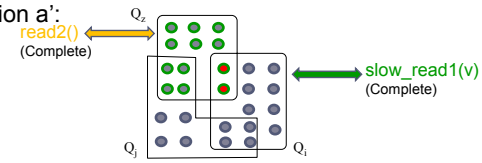
Not Robust Fast Implementations (Proof Sketch)

- Execution b:
  - Incomplete write(v) => $Q_i \cap Q_z$
  - Complete read1() => Q_z
    - read1() cannot distinguish between executions a and b, thus returns v
  - Complete read2() => Q_j
    - read2() returns an older value since does not observe v

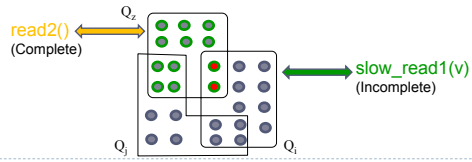


Not Robust SemiFast Implementations (Proof Sketch)

Execution a':



Execution b':



Tool: Quorum Views

Idea:

- Try to determine the state of the write operation based on the distribution of the latest value in the replied quorum.
- Write State in the First Round of Read Operation

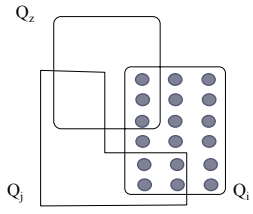
  Determinable => Read is Fast

  Undeterminable => Read is Slow

Determinable Write - Qview(1)

- All members of a quorum contain maxTs

$$[qView(1)] : \forall s \in Q_i : s.ts = \max TS$$

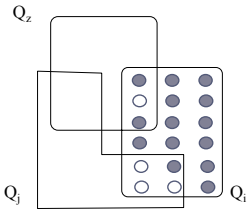


(Potentially) Write Completed

Determinable Write - Qview(2)

- Every intersection contains a member with ts<maxTs

$$[qView(2)]: \forall j \neq i, \exists A \subseteq Q_i \cap Q_j \; s.t. \; A \neq \emptyset \text{ and } \forall s \in A : s.ts < \max TS$$

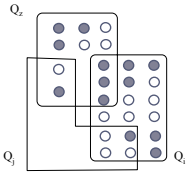


(Definitely) Write <maxTag,v> Incomplete

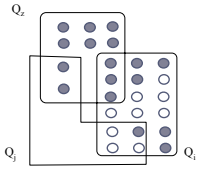
Undeterminable Write - Qview(3)

- There is intersection with all its members with ts=maxTs

$$[qView(3)]: \exists s \in Q_i \; s.t. s.ts < \max Ts \;\; and \;\; \exists j \neq i \; s.t. \forall s \in Q_i \cap Q_j : s.ts = \max TS$$



qV(3) and Incomplete Write



qV(3) and Complete Write

Undeterminable => second Com. Round

Algorithm:SLIQ

Write Protocol: one round

- P1:Writer increments ts and propagates the <ts,v> to a quorum

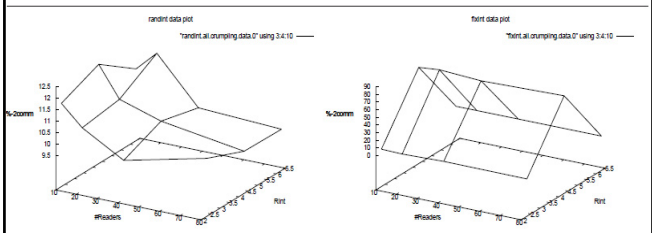
Read Protocol: one or two rounds

- P1: send read requests and wait for replies from a quorum Q
  - $QView_Q(1)$ – **Fast** and return maxTS
  - $QView_Q(2)$ – **Fast** and return maxTS-1
  - $QView_Q(3)$ – **Slow** proceed to P2 and return maxTS
- P2: propagate <maxTS,v> to a quorum and return <maxTS,v>

Server Protocol: passive role

- Receive requests, update local timestamp and return <ts,v>

SLIQ: Simulation Results



Setting a: Stochastic simulations Setting b: Fixed interval simulations

Fig. 3. Simple runs using Crumbling Walls

Follow-Up Question

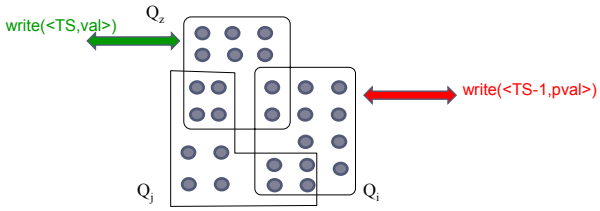
Can Quorum Views be used to obtain fast operations in the MWMR environment?

Tagging the values

- TAG : <timestamp, wid> pair
  - tag1 > tag2 if either:
    - tag1.timestamp > tag2.timestamp, or
    - tag1.timestamp = tag2.timestamp AND tag1.wid > tag2.wid
- Why wid is necessary?
  - Separate writes with the same timestamp

Why be fast in Qview(2) in SWMR?

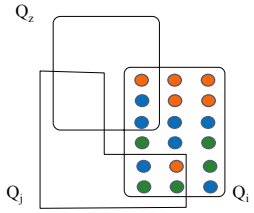
- Single writer
  - If it writes <TS, val> => it completed writing <TS-1, pval>



Any read operation will observe either QView1 or QView3 for <TS-1,pval>

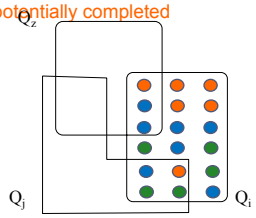
What happens in MWMR?

- MWMR environment
  - Concurrent writes
  - Multiple concurrent values
- For values <tag1,v1> , <tag2, v2>, <tag3,v3>
  - Let tag1 < tag2 < tag3



Idea: Uncover the Past

- Discover the latest potentially completed write
- For values <tag1,v1> , <tag2, v2>, <tag3,v3>:
  - <tag3,v3> not completed (servers possibly contained <tag2, v2>)
  - <tag2, v2> not completed (servers possibly contained <tag1,v1>)
  - <tag1,v1> potentially completed



Algorithm: CWFR

Traditional Write Protocol: two rounds

- P1: Query a single quorum for the latest tag
- P2: Increment the max tag, send <newtag, v> quorum

Read Protocol: one or two rounds

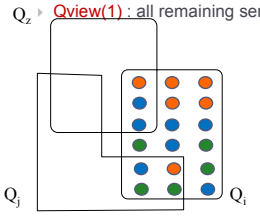
- Iterate to discover smallest completed write
- P1: receive replies from a quorum Q
  - $QView_Q(1)$ – Fast: return maxTag of current iteration
  - $QView_Q(2)$ – remove servers with maxTag and re-evaluate
  - $QView_Q(3)$ – Slow: propagate and return $maxTag_Q$

Server Protocol: passive role

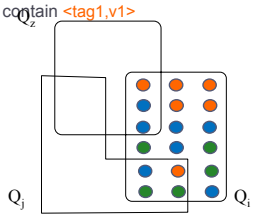
- Receive requests, update local timestamp and return <tag,v>

Read Iteration: Discard Incomplete Tags

- For values <tag1,v1> , <tag2, v2>, <tag3,v3>:
  - <tag3,v3> not completed: remove servers that contain <tag3,v3>
  - <tag2, v2> not completed: remove servers that contain <tag2, v2>
  - <tag1,v1> potentially completed in Q_i
    - Qview(1) : all remaining servers contain <tag1,v1>



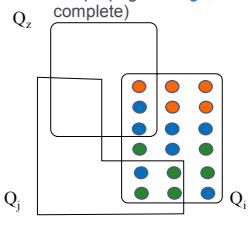
Server Removal



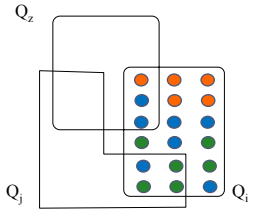
Past Prediction

Read Iteration: Discard Incomplete Tags

- For values <tag1,v1> , <tag2, v2>, <tag3,v3>:
  - <tag3,v3> not completed: remove servers that contain <tag3,v3>
  - <tag2, v2> potentially completed in Q_j
    - Qview(3) : an intersection of the remaining servers contains <tag2, v2>
    - P2: propagate <tag3,v3> to a complete quorum (help <tag3,v3> to complete)



Server Removal



Past Prediction

CWFR: Empirical Results

- In progress experimentation on Planetlab
  - Planetary scale real-time environments
- Measure the percentage of ‘‘slow’’ reads
- Get the average of operation latency
- Compare with classic 2 round aproaches

Closing Remarks