Quorum

CSE 486/586: Distributed Systems

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Quorum

We saw quorum for atomic commitment in Raft.

There are other uses for quorum, including:

- Transaction commitment
- Read-write ordering
- Mutual exclusion

They're all related in mechanism and protocol.

Different uses have different rules for quorum.

Transaction Commitment

Transactions are a sequence of operations that:

- Are typically related in some way
- Must either all succeed or all fail
- Failed operations have no effect

Quorum can be used to commit transactions.

…Raft could be used for this, but there are more efficient protocols.

(We'll talk more about transactions later.)

Read/Write Ordering

Quorum can be used to order reads and writes such that:

- Before some time t, all reads are before a given write
- After time t, all reads are after a given write

This is a form of serializability.

(We'll talk more about serializability later.)

Mutual Exclusion

Quorum can be used to ensure exclusive access.

This is also essentially a commit:

- The committed value is the current lock holder.

This can provide mutual exclusion in the face of failure.

Maekawa's Algorithm

Maekawa proposed an efficient algorithm for mutual exclusion. [2]

It requires only $O(\sqrt{n})$ messages to be exchanged for n hosts!

It does this by carefully selecting the hosts to contact.

As n grows, this is considerably easier than Ricart and Agrawala. [3]

Permission Subsets

All processes in the algorithm are divided into subsets.

Every process p_i, $1 \leq i \leq n$, belongs primarily to some subset S_i.

For every process p_i and p_j, $1 \leq i, j \leq n$, $S_i \cap S_j \neq \varnothing$.

This means that p_i is also in other subsets!

A process must receive permission from its entire subset to enter the critical section.

Set Sizes

There are K members of each subset S_i.

Every process p_i is a member of D subsets.

If $K = n$ and $D = 1$, the algorithm is Ricart and Agrawala.

Choosing Subsets

Subsets are chosen carefully.

The paper describes the selection scheme:

> *The problem of finding a set of S_i's that satisfies these conditions is equivalent to finding a finite projective plane of N points.*

For now, let's assume the sets can be created.

Acquiring the Lock

Lock acquisition *similar to* Ricart and Agrawala:

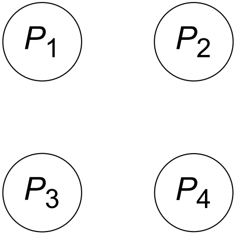
- Every node keeps a timestamp
- The node sends a timestamped request to all other nodes in its subset
- Eventually it receives K replies and enters its critical section

Lock release is likewise similar:

- The node sends a release to all other nodes in its subset

Example

Consider the subsets in four nodes:



Example

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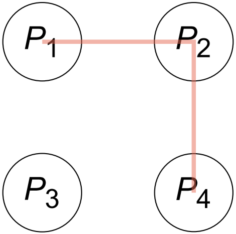

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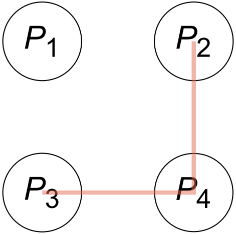

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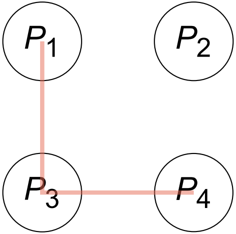

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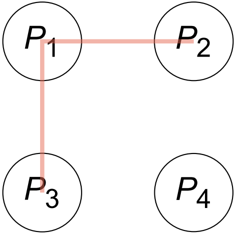
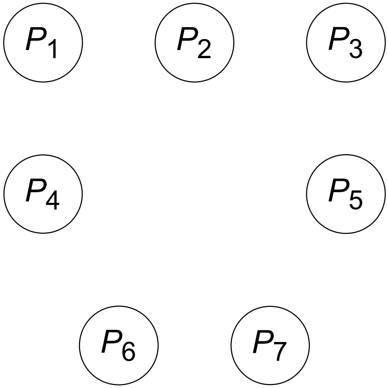


Example 2

Seven nodes gets more complicated:



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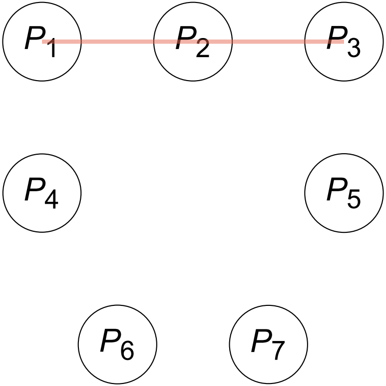

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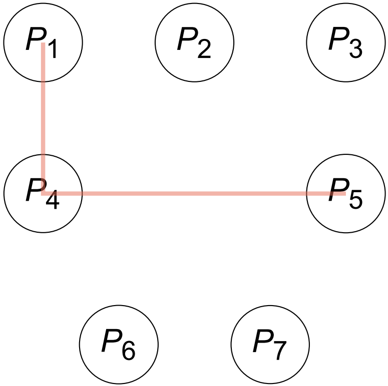

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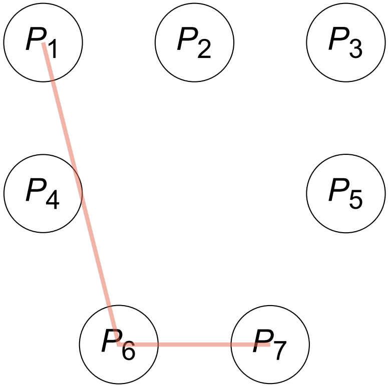

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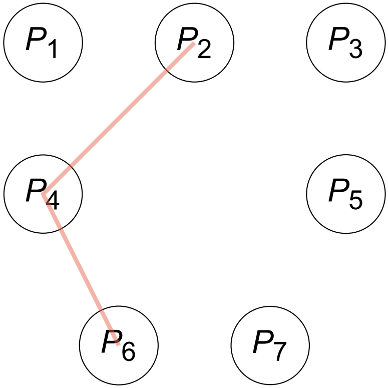

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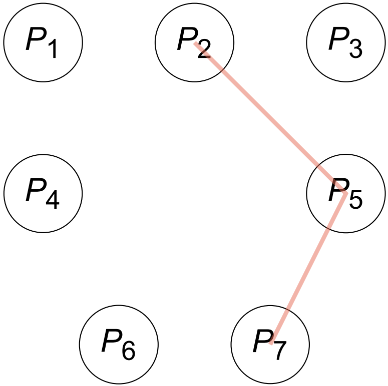

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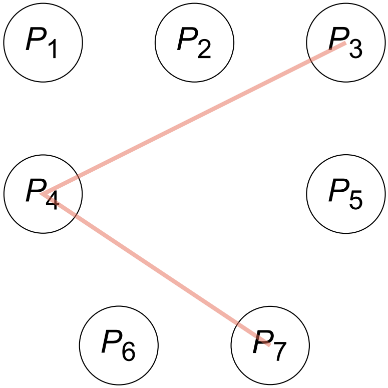

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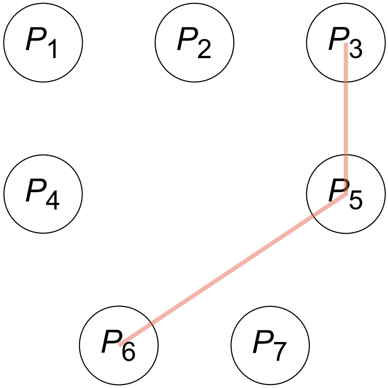

Deadlock

Consider three processes: p_1, p_2, p_3.

Three subsets: (p_1, p_2), (p_2, p_3), (p_3, p_1).

Now consider that each process locks at the same time.

Every subset has one locking process, and is waiting on another.

This is deadlock!

Relinquishment

Maekawa must modify Ricart and Agrawala to prevent deadlock.

Instead of witholding a response, processes send a FAILED message.

Processes waiting to lock keep track of FAILED messages.

If a process becomes aware of two processes requesting its permission to lock, it sends an INQUIRE message to the process with the lower-priority lock.

If that processs received any FAILED message, it relinquishes.

(There are more complications.)

Observations

This is safe because every quorum overlaps.

If any quorum holds the lock, no other quorum can complete.

This depends on perfect subset selection.

There may be several possible solutions for any set of processes!

Process membership and subsets are static configurations.

Properties

Safety: Similar to Ricart & Agrawala

Liveness:

- Deadlock for any quorum with a failed process
- Special tools to prevent deadlock otherwise

Fairness: Complicated (because of relinquishment), but pretty good

Synchronization Delay: One-way message delay

Throughput: Complicated, but faster than Ricart and Agrawala

Message Complexity: Complicated ($O(\sqrt{n})$)

Summary

- Quorum can solve many problems
- Different quorums have different uses
- Maekawa's mutual exclusion uses quorum for mutexes
- Mutexes can be solved with relatively few members in a quorum

References I

Required Readings

[1] Ajay D. Kshemkalyani and Mukesh Singhal. *Distributed Computing: Principles, Algorithms, and Systems*. Chapter 9: 9.7, 9.8. Cambridge University Press, 2008. ISBN: 978-0-521-18984-2.

Optional Readings

[2] Mamoru Maekawa. "A $\sqrt{N}$ Algorithm for Mutual Exclusion in Decentralized Systems". In: 3.2 (May 1985), pp. 145–159. DOI: 10.1145/214438.214445. URL: https://search.lib.buffalo.edu/permalink/01SUNY_BUF/12pkqkt/cdi_crossref_primary_10_1145_214438_214445.

References II

[3] Glenn Ricart and Ashok Agrawala. "An optimal algorithm for mutual exclusion in computer networks". In: 24.1 (Jan. 1981). Ed. by R. Stockton Gaines, pp. 9–17. DOI: 10.1145/358527.358537. URL: https://search.lib.buffalo.edu/permalink/01SUNY_BUF/12pkqkt/cdi_crossref_primary_10_1145_358527_358537.

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