Section 12: Journaling, 2PC

CS 162

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Contents

1 Vocabulary

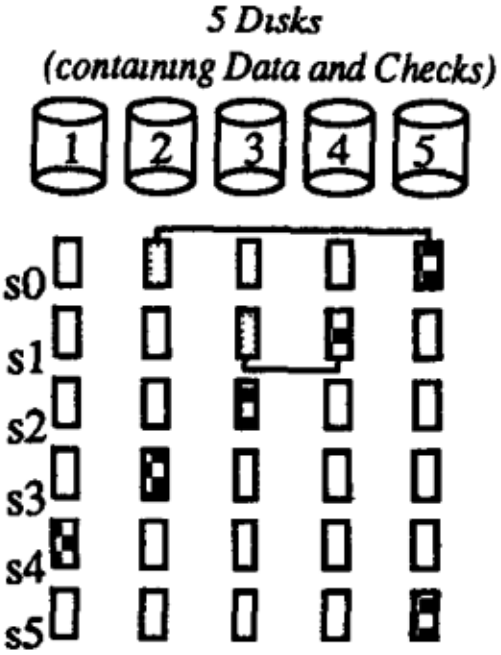
- **Fault Tolerance** The ability to preserve certain properties of a system in the face of failure of a component, machine, or data center. Typical properties include consistencies, availability, and persistence.
- **Transaction** - A transaction is a unit of work within a database management system. Each transaction is treated as an indivisible unit which executes independently from other transactions. The ACID properties are usually used to describe reliable transactions.
- **ACID** - An acronym standing for the four key properties of a reliable transaction.
  - *Atomicity* - The transaction must either occur in its entirety, or not at all.
  - *Consistency* - Transactions must take data from one consistent state to another, and cannot compromise data integrity or leave data in an intermediate state.
  - *Isolation* - Concurrent transactions should not interfere with each other; it should appear as if all transactions are serialized.
  - *Durability* - The effect of a committed transaction should persist despite crashes.
- **Idempotent** - An idempotent operation can be repeated without an effect after the first iteration.
- **Log** - An append only, sequential data structure.
- **Checkpoint** - Aka a snapshot. An operation which involves marshaling the system's state. A checkpoint should encapsulate all information about the state of the system without looking at previous updates.
- **Write Ahead Logging (WAL)** - A common design pattern for fault tolerance involves writing updates to a system's state to a log, followed by a commit message. When the system is started it loads an initial state (or snapshot), then applies the updates in the log which are followed by a commit message.
- **Serializable** - A property of transactions which requires that there exists an order in which multiple transactions can be run sequentially to produce the same result. Serializability implies isolation.
- **ARIES** - A logging/recovery algorithm which stands for: Algorithms for Recovery and Isolation Exploiting Semantics. ARIES is characterized by a 3 step algorithm: Analysis, Redo, then Undo. Upon recovery from failure, ARIES guarantees a system will remain in a consistent state.
- **Logging File System** - A logging file system (or journaling file system) is a file system in which all updates are performed via a transaction log ("journal") to ensure consistency in case the system crashes or loses power. Each file system transaction is written to an append-only redo log. Then, the transaction can be committed to disk. In the event of a crash, a file system recovery program can scan the journal and re-apply any transactions that may not have completed successfully. Each transaction must be idempotent, so the recovery program can safely re-apply them.
- **Metadata Logging** - A technique in which only metadata is written to the log rather than writing the entire update to the log. Modern file systems use this technique to avoid duplicating all file system updates.
- **EXT4** - A modern file system primarily used with Linux. It features an FFS style inode structure and metadata journaling.
- **Log Structured File System** - A file system backed entirely by a log.

- **RAID** - A system consisting of a Redundant Array of Inexpensive Disks invented by Patterson, Gibson, and Katz.

  The fundamental thesis of RAID is that in most common use cases, it is cheaper and more effective to redundantly store data on cheap disks, than to use/engineer high performance/durable disks.

- **RAID I** - Full disk replication. With RAID I two identical copies of all data is stored. If disk heads are not fully synchronized, this can decrease write performance, but increase read performance.

- **RAID V+** - Striping with error correction. In RAID V, 4 sequential block writes are placed on separate disks, then a 5th parity block is written by XORing the data blocks on the same stripe. RAID VI uses the EVENODD scheme to encode error correction. In general, Reed Solomon coding can be used for an arbitrary number of error correcting disks.



  Note: Due to the large size of disks in practice, RAID V is no longer used in practice, because it is too likely that a second disk will fail while the first is recovering. RAID VI is usually combined with other error recovery techniques in practice.

- **Eventual Consistency** - A weaker form of a consistency guarantee. If a system is eventually consistent, it will converge to a consistent state over time.

- **Failover** A fault tolerance procedure invoked when a component fails. Typically this involves switching over to, or promoting a secondary.

- **2PC** - Two Phase Commit (2PC) is an algorithm that coordinates transactions between one coordinator and many workers. Transactions that change the state of the worker are considered 2PC transactions and must be logged and tracked according to the 2PC algorithm. 2PC ensures atomicity and durability by ensuring that a write happens across ALL replicas or NONE of them. The replication factor indicates how many different workers a particular entry is copied among. The sequence of message passing is as follows:

```
for every worker replica and an ACTION from the coordinator,
origin [MESSAGE] -> dest :
---
COORDINATOR [VOTE-REQUEST(ACTION)] -> WORKER
WORKER [VOTE-ABORT/COMMIT] -> COORDINATOR
COORDINATOR [GLOBAL-COMMIT/ABORT] -> WORKER
WORKER [ACK] -> COORDINATOR
```

If at least one worker votes to abort, the coordinator sends a GLOBAL-ABORT. If all worker vote to commit, the coordinator sends GLOBAL-COMMIT. Whenever a coordinator receives a response from a worker, it may assume that the previous request has been recognized and committed to log and is therefore fault tolerant. (If the coordinator receives a VOTE, the coordinator can assume that the worker has logged the action it is voting on. If the coordinator receives an ACK for a GLOBAL-COMMIT, it can assume that action has been executed, saved, and logged such that it will remain consistent even if the worker dies and rebuilds.)

2 Logs and Journaling

You create two new files, F_1 and F_2, right before your laptop's battery dies. You plug in and reboot your computer, and the operating system finds the following sequence of log entries in the file system's journal.

1. Find free blocks x_1, x_2, ..., x_n to store the contents of F_1, and update the free map to mark these blocks as used.
2. Allocate a new inode for the file F_1, pointing to its data blocks.
3. Add a directory entry to F_1's parent directory referring to this inode.
4. *Commit*
5. Find free blocks y_1, y_2, ..., y_n to store the contents of F_2, and update the free map to mark these blocks as used.
6. Allocate a new inode for the file F_2, pointing to its data blocks.

What are the possible states of files F_1 and F_2 *on disk* at boot time?

Say the following entries are also found at the end of the log:

7. Add a directory entry to F_2's parent directory referring to F_2's inode.
8. *Commit*

How does this change the possible states of file F_2 on disk at boot time?

Say the log contained only entries (5) through (8) shown above. What are the possible states of file F_1 on disk at the time of the reboot?

What is the purpose of the *Commit* entries in the log?

When recovering from a system crash and applying the updates recorded in the journal, does the OS need to check if these updates were partially applied before the failure?

3 Two-Phase Commit

Quorum consensus is able to provide weak consistency. For this section, assume the DHT backs each node with multiple replicas. Further, assume that these machines use a two phase commit protocol to commit information in a strongly consistent manner.

1. 2PC requires a single coordinator and at least one worker. By default, all replicas can be workers. How should the coordinator be picked?

2. Briefly describe the messages that the **coordinator** will send and receive in response to a PUT. Also describe when and what would be logged.

3. Briefly describe the messages that a **worker** will send and receive.

4. Under the current model, multiple PUT queries could be sent to separate coordinator machines. Propose set of worker routines which can handle this. In particular, consider the case in which 2 coordinators receive PUT queries for **the same key but different values**. The state of the system should remain consistent.