Section 13: Networking, Distributed File Systems

CS 162

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Contents

1 Vocabulary

- **TCP** - Transmission Control Protocol (TCP) is a common L4 (transport layer) protocol that guarantees reliable in-order delivery. In-order delivery is accomplished through the use of sequence numbers attached to every data packet, and reliable delivery is accomplished through the use of ACKs (acknowledgements).
- **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.
- **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.
- **Checksum** - A mathematical function which maps a (typically large) input to a fixed size output. Checksums are meant to detect changes to the underlying data and should change if changes occur to the underlying data. Common checksum algorithms include CRC32, MD5, SHA-1, and SHA-256.
- **Replication** - Replication or duplication is a common technique for preserving data in the face of disk failure or corruption.

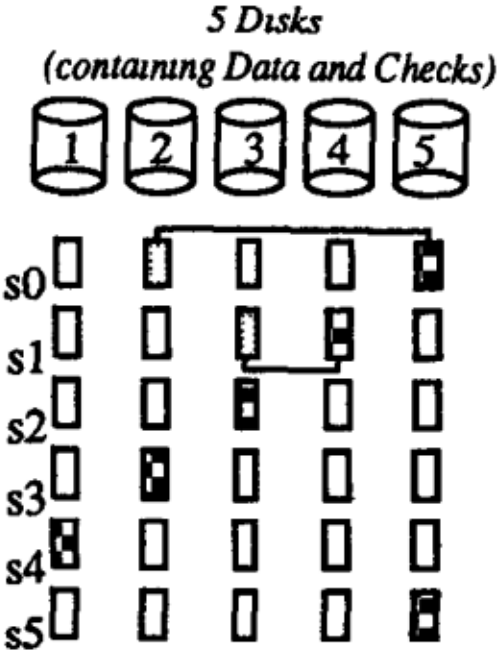
  If a disk fails, data can be read from the replica. If a sector is corrupted, it will be detected in the checksum. The data can then be read from another replica.

- **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.

- **Network File System (NFS)** - A distributed file system written by Sun. NFS is based on a stateless RPC protocol. Buffers are **write behind**. Few strong consistency guarantees on parallel writes. NFS is **eventually consistent**.

- **Andrew File System (AFS)** - A distributed file system written at CMU. Full files are buffered locally upon `open`. Buffers are **write back** and only flushed on `close`. File contents follow "last write wins" semantics.

2 Networking

1. (True/False) IPv4 can support up to 2^{64} different hosts.

2. (True/False) Port numbers are in the IP header.

3. (True/False) UDP has a built in abstraction for sending packets in an in order fashion.

4. (True/False) TCP provide a reliable and ordered byte stream abstraction to networking.

5. (True/False) TCP attempts to solve the congestion control problem by adjusting the sending window when packets are dropped.

6. In TCP, how do we achieve logically ordered packets despite the out of order delivery of the physical reality? What field of the TCP packet is used for this?

7. Describe how a client opens a TCP connection with the server. Elaborate on how the sequence number is initially chosen.

8. Describe the semantics of the acknowledgement field and also the window field in a TCP ack.

9. List the 5 layers specified in the TCP/IP model. Layering adds modularity to the internet and allows innovation to happen at all layers largely in parallel. What is the function of each layer?

10. The end to end principle is one of the most famed design principles in all of engineering. It argues that functionality should **only** be placed in the network if certain conditions are met. Otherwise, they should be implemented in the end hosts. These conditions are:

    – Only If Sufficient: Don't implement a function in the network unless it can be completely implemented at this level.
    – Only If Necessary: Don't implement anything in the network that can be implemented correctly by the hosts.
    – Only If Useful: If hosts can implement functionality correctly, implement it in the network only as a performance enhancement.

    Take for example the concept of reliability: making all efforts to ensure that a packet sent is not lost or corrupted and is indeed received by the other end. Using each of the three criteria, argue if reliability should be implemented in the network.

    (a) Only If Sufficient

    (b) Only If Necessary

    (c) Only If Useful

3 Distributed File Systems

Distributed file systems must provide the same access API as standard file systems. That access API quickly becomes non standard in the face of concurrent operations.

Compare the performance of AFS, NFS, EXT4, and EXT4 with the streaming api. Assume processes run on separate machines wherever it is applicable.

1. **open**

2. **write**

3. **read**

4. **close**

Now compare the behavior of AFS, NFS, EXT4, and EXT4 with the streaming api (with a large buffer). Assume processes run on separate machines wherever it is applicable and that buffers are only flushed when filled and upon close.

1. Process A and Process B write to a file simultaneously, then Process A closes the file, then Process B closes the file.

2. Process A increments an integer (using read and write), 1 second later, Process B increments the integer too. Both processes close the file.

3. Process A increments an integer (using read and write), 1 minute later, Process B increments the integer too. Both processes close the file.

4. Process A writes a large amount fo data, then Process B writes a large amount of data. Then Process B closes the file, then Process A closes the file.