HY590.45
Modern Topics in Scalable Storage Systems

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Scalability requirements

- **Manageability**
  - Ability to self-configure, self-heal
  - System manager just adds or replaces machines

- **Availability**
  - Despite component failures, deliver good service to all users
  - Some users may be prevented from accessing some mail

- **Performance**
  - Single-node performance as good as single-node systems
  - Aggregate performance scale linearly with number of nodes
**Key principle and techniques behind Porcupine**

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Why E-Mail

• Need systems that can scale to billions messages/day

• Frequent writes present a challenge

• Weak consistency
Semantics of Internet E-Mail

- May arrive out of order
- May arrive more than once
- May reappear after being deleted
- SMTP, POP, IMAP
Mailbox management and storage

hash(“Bob”) = 13

"Alice" "Bob" "Chuck"

Alice:* {B} {A,B}
Bob:*
Chuck:* {A}

Chuck’s mbox fragment Bob’s mbox fragment(1)

Alice’s mbox fragment Bob’s mbox fragment(2)

Alice:*: Bob:*:
Chuck:*:

Node A

Node B

Variable size, contains message objects

Hard state

User map

User profile soft state

Mail map

Mailbox fragments

User profile database

/spool/13/bob
/spool/13/bob.idx
Mail delivery to “Bob”

1. DNS-RR selection.
2. “send mail to Bob”.
3. Who manages Bob? ⇒ A.
4. “Verify Bob”.
5. “OK, Bob has msgs on A and B.”
6. Pick the best node to store new msg ⇒ C.
7. “Store msg”.
8. Add C to Bob’s fragment list.
System architecture

Protocol handling

User lookup

Load balancing

Manage store (retrieve/update)

deliver mail

get/erase/update mail

Internet

Network sessions

Front-end modules

Middle-tier modules

Backend Modules
Replication properties

- Update anywhere / Retrieve from anywhere
- Eventual consistency (weaker than “single-copy”) 
- Total update
- Lock free
- Ordering by loosely synchronized clocks
Update protocol

What if
- Coordinator crashes
- Peer crashes
- Simultaneous update
- Network partitions

Coordinator

Delivery or Retrieval Agent

Peer

Update log

Timestamp, <user, msg ID>, Target-nodes, Remaining-nodes

5pm

6pm

network partition
Membership

- Coordinator
- A and B reply with the epoch IDs of the buckets they manage.
- A broadcasts the new membership and the user map, but B misses the packet.
- C recovers. A detects the recovery and starts TRM.
- A, B, and C reply with the epoch IDs of the buckets they manage.
- A broadcasts the new membership and the user map.

Nodes finally agree on the membership and the user map.
User profile, mail-map reconstruction

- Identify buckets with new manager assignments
  - Compare Epoch IDs

- Send relevant soft state to new managers
  - Update their mail map with mailbox fragments
  - Update their user profile soft state with user profiles

- Replica with highest IP does the transfer

- Hard state bucketed into directories for quick search
Mail-map consistency

- Mail-map pointers lead to valid fragments

- Valid fragments reachable from mail-map pointers

- Example: \{Bob, *\} : \{\{A, B\}, \{A, B, C\}, \{A, C\}\}
Mail-map consistency

(1) A node fails just after a message is stored in a new mailbox fragment on its disk, but before the corresponding mail map is updated. This case causes no problem because this copy of the message becomes non-retrievable after the node failure. The replication service (Section 4) ensures that another copy of the message is still available.

(2) A node fails just after the last message in a mailbox fragment on its disk is deleted, but before the corresponding mail map is updated. Each node periodically scans the mail maps it manages and removes all “dangling” links to nodes not in the membership. The links will be restored when the failed nodes rejoin the cluster.

(3) A node stores a message in a new mailbox fragment on its disk, but the corresponding user manager node fails before the mail map is updated. The message will be discovered by the disk scan algorithm that runs after membership reconfiguration and will be added to the mail map on a new user manager node.

(4) A node deletes the last message in a mailbox fragment on its disk, but the corresponding user manager node fails before the mail map is updated. The same argument as
Dynamic load balancing

- Decentralized
- Fine grained
- Support heterogeneous clusters
- Automatic; minimize manual tuning
- Maximize throughput
- Resolve tension between load and affinity
Load balancing information

• Load characterization
  – Whether or not disk is full
  – Number of pending RPC that are disk-bound

• Load dissemination
  – Piggybacked on RPCs
  – Exchanged on virtual ring
Affinity-based scheduling

- Prefer adding email to nodes that already have a fragment, unless too busy
  - Decreases number of inter-node RPCs
  - Increases sequentiality of disk accesses
  - Reduces mail-map memory requirements

- Define “spread”
  - Soft limit, can be exceeded
Scalability

![Graph showing Scalability](image)

- **Porcupine no replication**
- **Porcupine with replication, NVRAM**
- **Porcupine with replication**
- **Sendmail+popd**