PARTITIONING IN LARGE DATA SYSTEMS
(IF IT IS NOT DYNAMIC, WHAT’S THE POINT?)

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alberto.lerner@gmail.com
Data partitioning as a way to scale

If only one could “stretch” a single server indefinitely as one grew...
Which server holds a given key?

The system can maintain metadata on participant nodes and on partitioning. A client (library) can lookup metadata.
A partition’s size changed? Repartition as it goes

From the metadata perspective, the system can adjust a partitioning boundaries.
If need be, system can accept new nodes

Again (and quite simplistically) adding a node would mean adjusting the system metadata.
Rebalances as it goes as well

The system may reassign load from one node to another.
Recap: dynamic partitioning primitives

What’s hard about implementing these primitives in practice?

• **Locate** a given key
• **Split** a partition
• **Add** a node
• **Migrate** a partition
• **Merge partitions**
• **Subtract** a node

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<th>Keys</th>
<th>Node</th>
<th>Address</th>
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<td>P1</td>
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Metadata
1. **Partition** system data across nodes on the system
   - Changes should be made in the responsible node
   - No node has global information

2. **Replicate** (not necessarily fully) system data on all system nodes
   - Whenever a change is made, propagate across the system
   - All nodes have a view of global information, even if sometimes not a current one

For one, metadata **must not** be a single point of failure!

Let’s look at alternative strategies to implement dynamic partitioning from the *metadata perspective*. 

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### Metadata

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• We’ll assume a simple **key-value** data model. (In practice, models can be more sophisticated.) And we’ll try to make the fewest possible assumptions about the **underlying storage** layout. (Of course, partitioning the data has its challenges too.)

• For our purposes here, let’s assume that there is a completely orthogonal **data replication scheme** for fault tolerance. (Orthogonal?! Yeah, right.)

• We won’t go into **crash recovery** nor into **fault detection**

**What the talk is *not* about**

But, please, let’s fill a whiteboard on any of these offline!
Idea: the partition table is ... a table!

But only the system can update it. Table read is public, though.
The partition table can be... partitioned

Lookup’s complexity is logarithmic.
Is split a local operation?

From the metadata perspective, probably not.
Load Balancing

Pull load information from all the nodes. Migrate partitions if necessary. Do it again periodically.
A missing piece?

Where does a client start looking for system data? How does the load balancer know about the nodes in the system? How does a node join the system?
Was that a central point of failure?

No. The information is kept in several places that agree on values using a distributed consensus algorithm.
Paxos

Solves the distributed consensus problems in scenarios involving crashes, omissions, and restarts. Depicted here is a very well behaved instance. Under faults, each phase may involve several rounds of messages.
**Liveness**

Any node can be a proposer. In fact, this guarantees liveness, in case a previous leader crashes or gets disconnected.
**Correctness**

Once a majority of nodes locks in a value, that value is propagated through later proposals.
Replicated State Machines

Use a Paxos instance to decide on the next operation (or on the next instance leader). Having a leader across instances speeds things up.
Distributed Lock Manager

Wraps a Paxos layer with a file system interface, complete with locks, sequencers, and watchers. Now, can you solve the group membership problem?
And back to the big picture

Sync point: we’ve seen key location, partition split, partition migration, and node addition under the first partitioning scheme. What could be a motivation for another scheme?
**Consistent Hashing**

Nodes’ tokens and user data’s keys are hashed and placed on a ring representing the hash space. A key belongs to the first clock-wise node. That is, *partitioning is implicit.*
Finger tables

Each node knows the addresses (and hashes) of increasingly distant nodes in the ring, in particular, it’s successor.
Routing in DHT’s

Efficient schemes are known that route requests in $O(\log n)$. Replicating a “complete” finger table would bring that to $O(1)$ but...
How does a client go about finding a key?

Logic of key location can be pushed to clients. Or the client can ask a node to redirect requests.
Adding a new node

Impact only on “following” node, which has to transfer some of its keys to the new arrival.
Adding a node

Node announces itself to successor. The latter offers to transfers the relevant keys.

1) hello, I’m ‘token C’ and here’s my address
2) transfer “brown” keys
Group membership through gossip

Each node contacts a random node periodically and they reconcile their system data. Eventually all nodes learn about incoming and outgoing nodes.
Even partitioning through virtual nodes

One may assign $T$ tokens per node to assure even key distribution. Now, what if we wanted to keep the same partition number and just throw one more server?
Equal-sized partitions

Use $Q$ partitions regardless of number of servers. Now, can $Q$ vary?
• Does a uniform **key distribution** guarantee uniform **load distribution**?

• How about the ability to issue **sequential scans**? Is it lost for the sake of load balancing?

• How likely replication system data would keep scaling?

**Load balancing, questions**

Adopters have reported positive answers to all the above.
Are they really that different?

Ultimately, yes. And both are successfully deployed.
References

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