Scalable Web Architectures(SWA)

COMP 599 - Graduate Seminar, Fall 2018

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Roadmap

1. The landscape of SWA
   - Why I switched my topic
   - Why bother studying SWA?
2. Vertical & Horizontal scaling
3. Beyond single node deployment
   - Replication
   - Sharding/Partitions
4. Some strategies to scale up high-traffic web systems
   - Using Caches
   - Proxies
   - Indexes
   - Load Balancers
   - Queues
   - Naive Hashing
   - Consistent Hashing
5. References
6. Thats it

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- Availability
- Partial Tolerance
- Consistency
- scalability
- Maintenance

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Vertical & Horizontal scaling

Horizontal

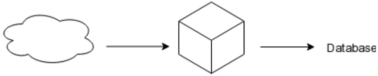
- ability to redirect request to another nodes (in short, resiliency) *
- load balancing
- network calls RPC/REST
- data consistency issues
- system scales proportional to variable data sets *

Vertical

- has a single point of failure
- N/A
- inter-process communication (IPC) *
- consistent *
- hardware limit

Beyond single node deployment

Imagine a simple image upload service using a central server



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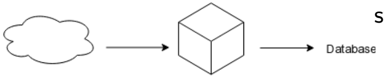

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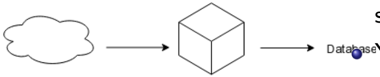

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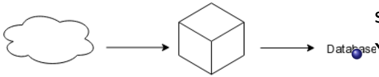

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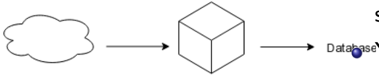

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- low-latency request-response

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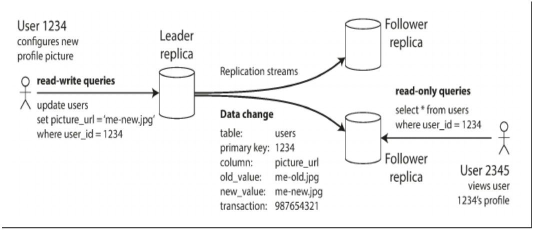
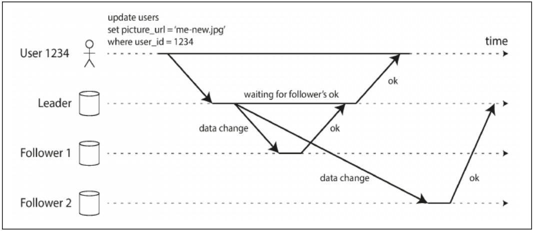
1. Single-leader based replication
2. Multi-leader replication
3. Leaderless replication

Single-Leader based replication



- Also called master-slave replication
- Considering synchronous/asynchronous config in databases.
- Using synchronous configuration is bad
- Async configuration is widely used in production deployments.

leader follower copying strategy



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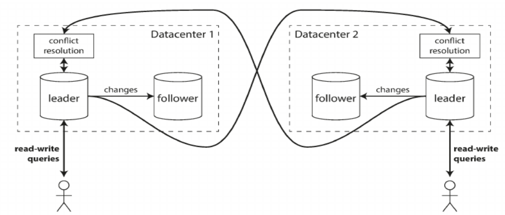
- Leader failure
  - one of its followers takes the leader
  - clients need to be reconfigured to send writes to new leader
  - other followers need to start consuming data changes from new leader.
  - old leader joins back as normal follower

Multi-leader based replication



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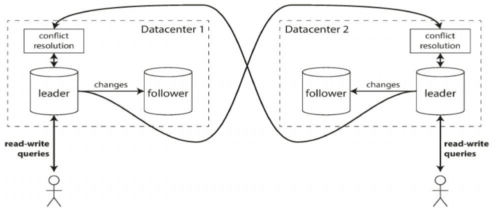

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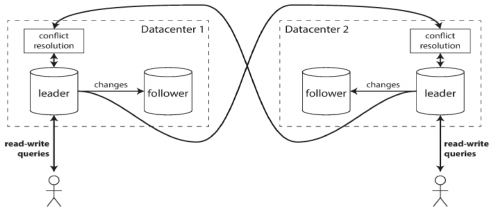

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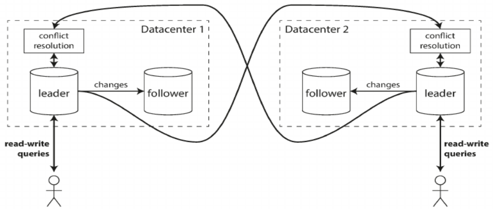

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- mostly used in multi-data center operations

Conflict resolution problem

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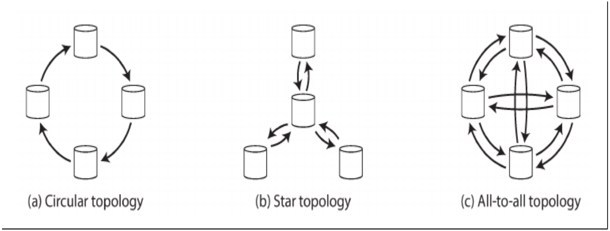
- In worst case, you have to deal with concurrent writes
- There is some research on conflict resolving
  - Conflict-free replicated data types
  - Mergeable persistent data structures
  - Operation transformation

Multi-leader topologies

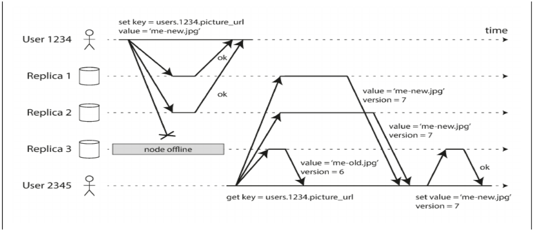


(a) Circular topology

(b) Star topology

(c) All-to-all topology

Leaderless replication



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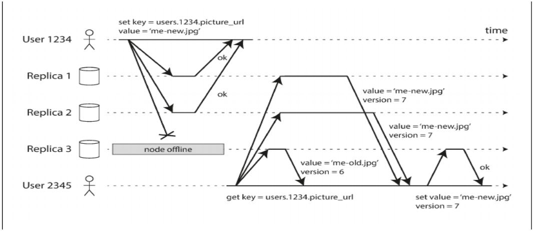

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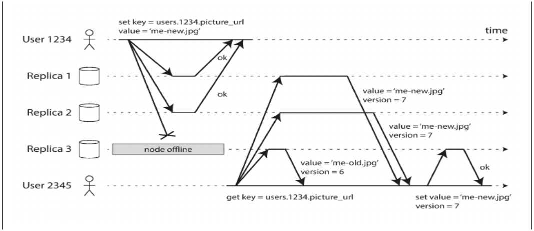

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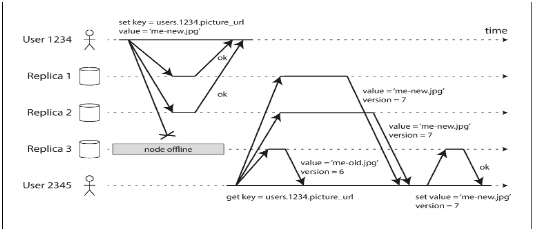

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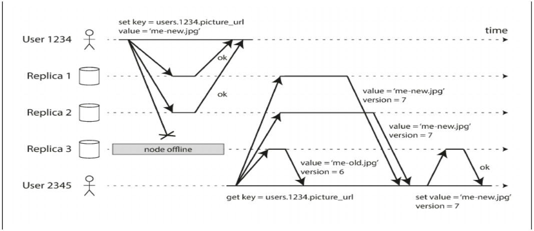

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- Amazon's DynamoDB is built using this concept
- examples include Cassandra, Riak

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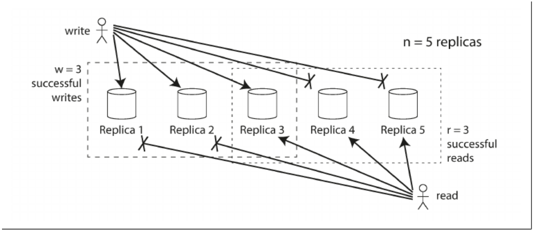
- **Anti-entropy process**
  - does reconcilation in background process
  - writes are copied in unordered way

Quorums for reading and writing

Write processed on 2 out of 3 replicas. What if only 1 of 3 replicas accepted write ? How far can we push ?



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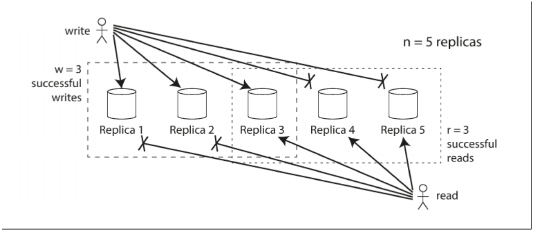

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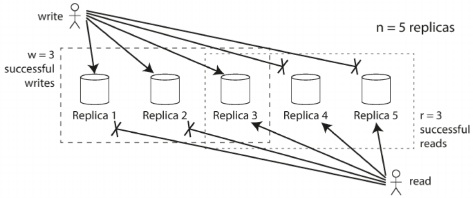

Corollary

$w + r > n$

- If w $<$ n, we can still process writes if a node is missing
- If r $<$ n, we can still process reads if a node is missing
- n $=$ 3, w $=$ 2, r $=$ 2, we can tolerate 1 unavailable node
- n $=$ 5, w $=$ 3, r $=$ 3, we can tolerate 2 unavailable nodes

Sharding/Partitioning

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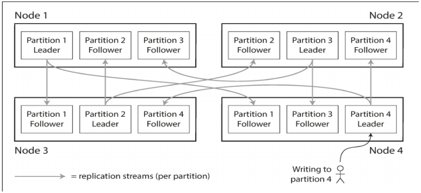
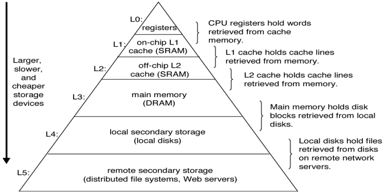
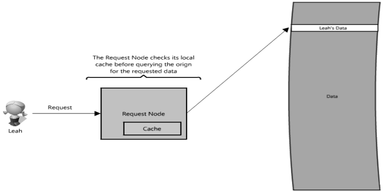


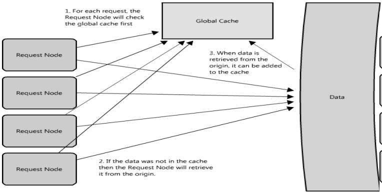
Using Caches

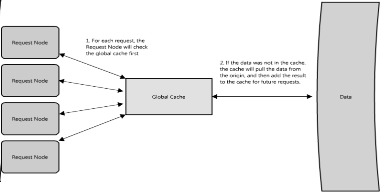

L0:
registers
CPU registers hold words retrieved from cache memory.
L1:
on-chip L1 cache (SRAM)
L1 cache holds cache lines retrieved from memory.
L2:
off-chip L2 cache (SRAM)
L2 cache holds cache lines retrieved from memory.
L3:
main memory (DRAM)
Main memory holds disk blocks retrieved from local disks.
L4:
local secondary storage (local disks)
Local disks hold files retrieved from disks on remote network servers.
L5:
remote secondary storage (distributed file systems, Web servers)
Larger, slower, and cheaper storage devices


The Request Node checks its local cache before querying the orign for the requested data
Leah
Request
Request Node
Cache
Leah's Data
Data

- any serious app will deploy a cache server
- usually placed in front of original data source
- algorithms like LRU(online algorithms) are widely used
- problem - If your system design uses load balancer, you will need to overcome high cache misses

Overcoming cache misses


1. For each request, the Request Node will check the global cache first
Global Cache
3. When data is retrieved from the origin, it can be added to the cache
Request Node
Request Node
Request Node
Request Node
Data
2. If the data was not in the cache then the Request Node will retrieve it from the origin.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Request Node
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Global Cache
2. If the data was not in the cache, the cache will pull the data from the origin, and then add the result to the cache for future requests.
Data

figure 1

figure 2

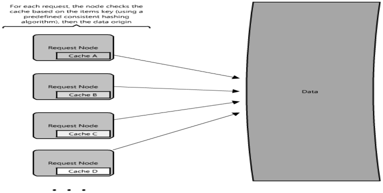
For each request, the node checks the cache based on the items key (using a predefined consistent hashing algorithm), then the data origin
Request Node
Cache A
Request Node
Cache B
Request Node
Cache C
Request Node
Cache D
. . .
Data

figure 3

1st figure handles eviction and data retrieval on its own

2nd figure application handles eviction

3rd figure each cache holds a portion of cached data

3rd figure uses consistent hashing to lookup data across nodes

Proxies

basic role is to receive requests from client and relay them to next node in line.

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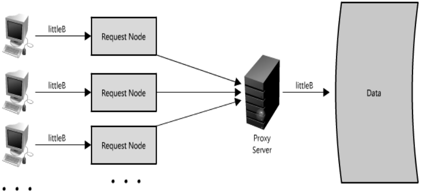

figure 1

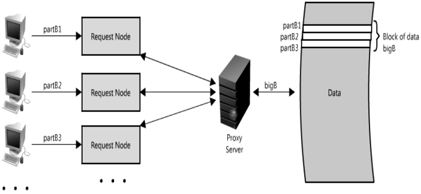

figure 2

1st figure collapse similar requests into a single request

2nd figure collapse requests for data that is spatially close together

Indexes

A very common, popular and important technique used to speedup data access

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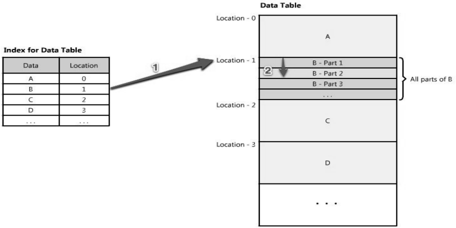
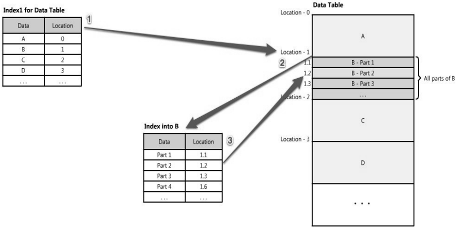


Index for Data Table

Data	Location
A	0
B	1
C	2
D	3
...	...



Index1 for Data Table

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C	2
D	3
...	...

Index into B

Data	Location
Part 1	1.1
Part 2	1.2
Part 3	1.3
Part 4	1.6
...	...

- the trick is to index your database based on users data access patterns
- In return for faster data access they do add write overhead and requiring updating indexes on each write

Load Balancers

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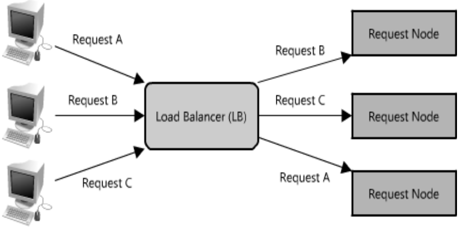

Algorithms used -

- round robin
- just pick a random node
- selecting a node on a criteria - CPU, memory

Queues

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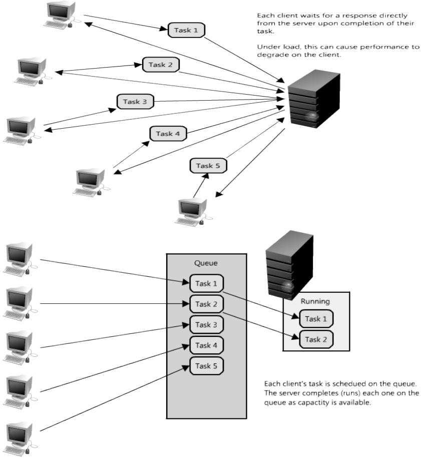


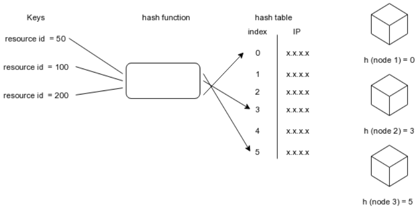
Each client waits for a response directly from the server upon completion of their task.

Under load, this can cause performance to degrade on the client.

Each client's task is scheduled on the queue. The server completes (runs) each one on the queue as capactity is available.

- work in async manner
- client is given acknowledgement that request is served
- tasks range from as simple as write to a data store to as complex as extracting pdf from text

Naive Hashing



index	IP
0	x.x.x.x
1	x.x.x.x
2	x.x.x.x
3	x.x.x.x
4	x.x.x.x
5	x.x.x.x

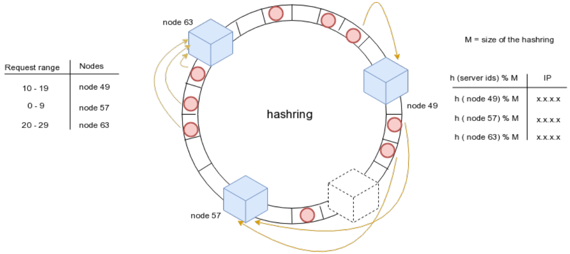
General hashing

some assumptions -

- no. of nodes serving request never change
- repeated request can be served using cache
- requires rehashing every single key, caches get obselete.

Consistent Hashing

Incoming requests and serving nodes are placed onto a virtual ring structure called *hashring*



Request range	Nodes
10 - 19	node 49
0 - 9	node 57
20 - 29	node 63

h (server ids) % M	IP
h (node 49) % M	x.x.x.x
h (node 57) % M	x.x.x.x
h (node 63) % M	x.x.x.x

Consistent Hashing

Graphic By: Rihan Pereira

- placement of server nodes is not fixed on the ring, instead are placed at random locations
- each server owns a range of hashring
- No worries on adding new servers or server disruptions
- only rehashing of affected portion of requests is required

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Thank you! Questions ?