Dynamo

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Logistics notes

Wednesday 5/24: Bitcoin (with special guest Tom)

Friday 5/26: Verification, testing, correctness

Monday 5/29: Memorial Day

Wednesday 5/31: More correctness

Friday 6/2: Wrapup

Dynamo motivation

Fast, available writes

- Shopping cart: always enable purchases!

CAP theorem: can’t have strict consistency

- Paxos: must communicate with a quorum

Performance: strict consistency = “single” copy

- Updates serialized to single copy

- Or, single copy moves

Dynamo motivation

Dynamo goals

- Expose “as much consistency as possible”
- Good latency, 99.9% of the time
- Easy scalability

Dynamo consistency

Eventual consistency

- Can have stale reads
- Can have multiple “latest” versions
- Reads can return multiple values

Not sequential consistency

- Can’t “defriend and dis”

External interface

get : *key* -> ([*value*], *context*)

- Exposes inconsistency: can return multiple values
- *context* is opaque to user (more on it in a bit!)

put : (*key*, *value, context*) -> *void*

- Caller passes context from previous get

Example: add to cart

```
(carts, context) = get("cart-" + uid)
cart = merge(carts)
cart = add(cart, item)
put("cart-" + uid, cart, context)
```

Resolving conflicts in application

Applications can choose how to handle inconsistency:

- Shopping cart: take union of cart versions
- User sessions: take most recent session
- High score list: take maximum score

Default: highest timestamp wins

Context used to record causal relationships between gets and puts

- Once inconsistency resolved, should stay resolved
- Implemented using vector clocks

Dynamo's vector clocks

Each object associated with a vector clock

- e.g., [(node1, 0), (node2, 1)]

Each write has a coordinator, and is replicated to multiple other nodes

- More on this later

Vector clock returned as context with get

- Merge of all returned objects' clocks

Used to detect inconsistencies on write

Dynamo's vector clocks

Client sends clock with put (as context)

Coordinator increments its own index in clock, then replicates across nodes

Nodes keep objects with conflicting vector clocks

- These are then returned on subsequent gets

If clock(v1) < clock(v2), node deletes v1

node1

“1” @ [(node1, 0)]

node2

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

client

node1

“1” @ [(node1, 0)]

get()

node2

client

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

node1

“1” @ [(node1, 0)]

node2

client

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

node1

“1” @ [(node1, 0)]

node2

client

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

node1

“1” @ [(node1, 0)]

[1], [(node1, 0)]

node2

client

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

node1

“1” @ [(node1, 0)]

node2

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

client

node1

“1” @ [(node1, 0)]

put(“2”, [(node1, 0)])

node2

client

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

node1

```
“1” @ [(node1, 0)]

“2” @ [(node1, 1)]
```

node2

client

```
“1” @ [(node1, 0)]
```

node3

```
“1” @ [(node1, 0)]
```

node1

“2” @ [(node1, 1)]

node2

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

client

node1

“2” @ [(node1, 1)]

node2

client

“1” @ [(node1, 0)]

node3

“1” @ [(node1, 0)]

node1

“2” @ [(node1, 1)]

node2

client

“2” @ [(node1, 1)]

node3

“1” @ [(node1, 0)]

node1

“2” @ [(node1, 1)]

OK

node2

client

“2” @ [(node1, 1)]

node3

“1” @ [(node1, 0)]

node1

“2” @ [(node1, 1)]

node2

client

“2” @ [(node1, 1)]

node3

“1” @ [(node1, 0)]

node1

“2” @ [(node1, 1)]

node2

“2” @ [(node1, 1)]

client

put(“3”, [(node1, 0)])

node3

“1” @ [(node1, 0)]

node1

“2” @ [(node1, 1)]

node2

client

“2” @ [(node1, 1)]

node3

“3” @ [(node1, 0), (node3, 0)]

node1

```
“2” @ [(node1, 1)]
```

node2

client

```
“2” @ [(node1, 1)]
“3” @ [(node1, 0), (node3, 0)]
```

node3

```
“3” @ [(node1, 0), (node3, 0)]
```

node1

“2” @ [(node1, 1)]

node2

“2” @ [(node1, 1)]

“3” @ [(node1, 0), (node3, 0)]

client

OK

node3

“3” @ [(node1, 0), (node3, 0)]

node1

```
“2” @ [(node1, 1)]
```

node2

client

```
“2” @ [(node1, 1)]
“3” @ [(node1, 0), (node3, 0)]
```

node3

```
“3” @ [(node1, 0), (node3, 0)]
```

node1

“2” @ [(node1, 1)]

get()

node2

client

“2” @ [(node1, 1)]

“3” @ [(node1, 0), (node3, 0)]

node3

“3” @ [(node1, 0), (node3, 0)]

node1

“2” @ [(node1, 1)]

node2

client

“2” @ [(node1, 1)]

“3” @ [(node1, 0), (node3, 0)]

node3

“3” @ [(node1, 0), (node3, 0)]

node1

“2” @ [(node1, 1)]

node2

client

“2” @ [(node1, 1)]

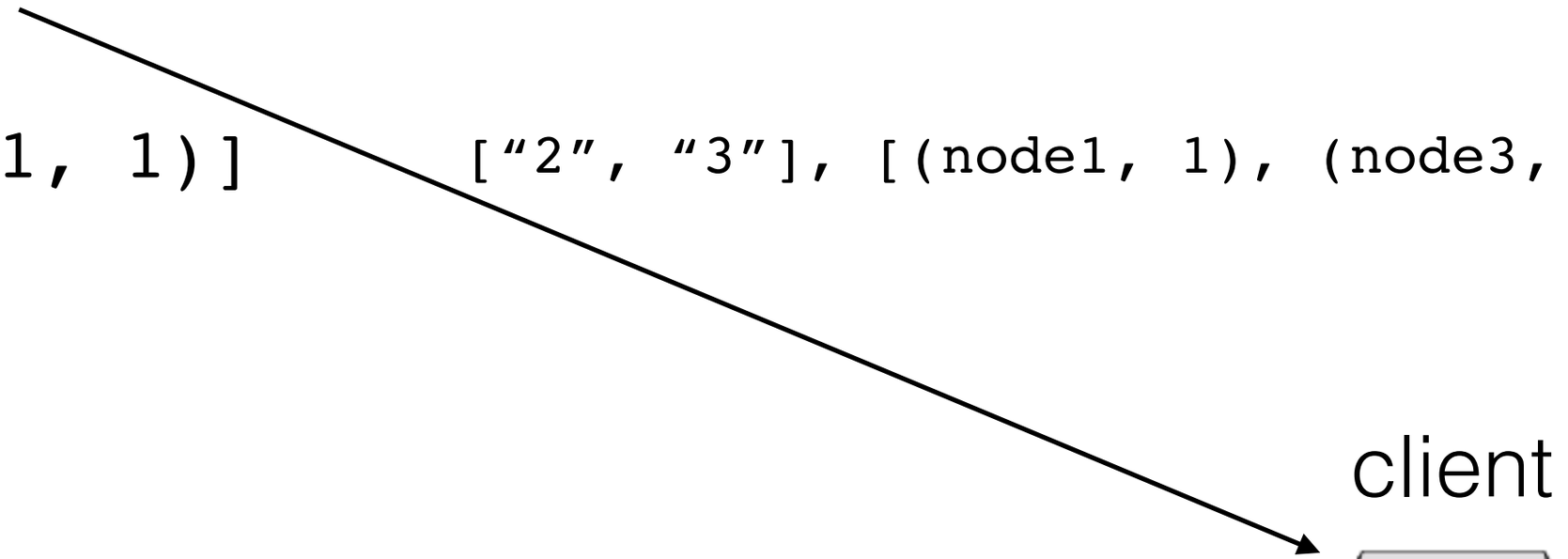
“3” @ [(node1, 0), (node3, 0)]

node3

“3” @ [(node1, 0), (node3, 0)]

node1

“2” @ [(node1, 1)]



[“2”, “3”], [(node1, 1), (node3, 0)]

node2

client

“2” @ [(node1, 1)]

“3” @ [(node1, 0), (node3, 0)]

node3

“3” @ [(node1, 0), (node3, 0)]

node1

“2” @ [(node1, 1)]

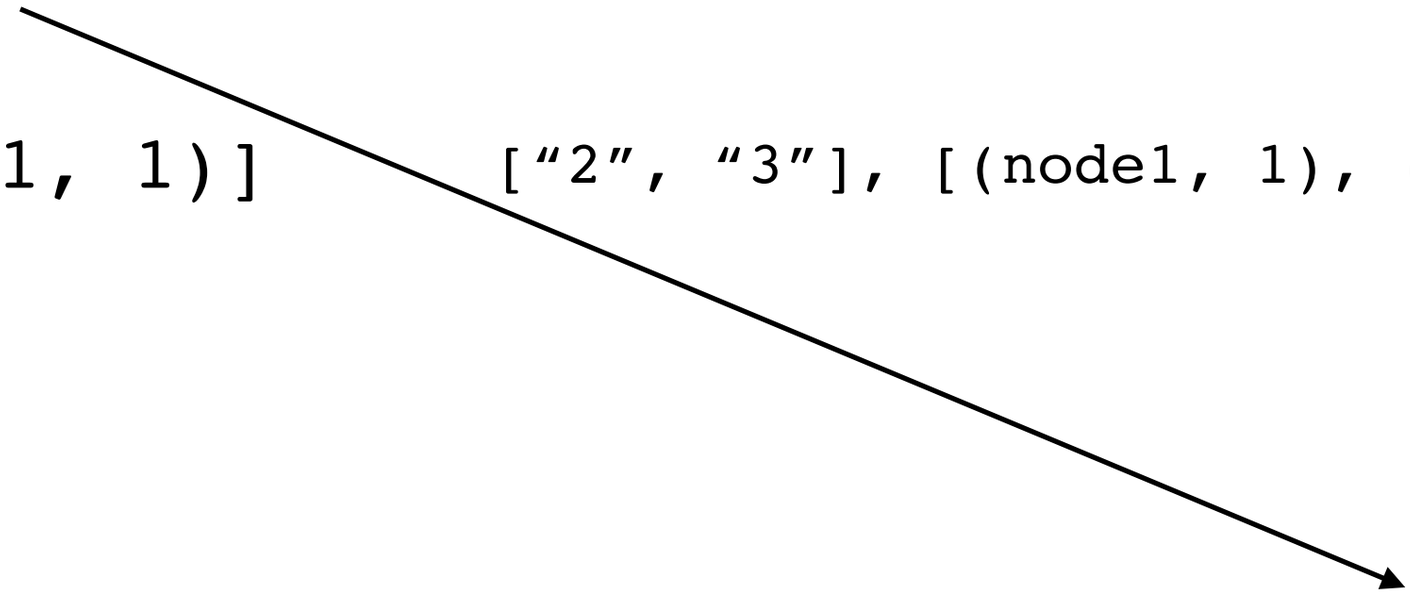
node2

“2” @ [(node1, 1)]

“3” @ [(node1, 0), (node3, 0)]

node3

“3” @ [(node1, 0), (node3, 0)]



[“2”, “3”], [(node1, 1), (node3, 0)]

client

client must now run merge!

node1

“2” @ [(node1, 1)]

put(“3”, [(node1, 1), (node3, 0)])

node2

client

“2” @ [(node1, 1)]

“3” @ [(node1, 0), (node3, 0)]

node3

“3” @ [(node1, 0), (node3, 0)]

node1

```
“3” @ [(node1, 2), (node3, 0)]
```


node2

client

```
“2” @ [(node1, 1)]
“3” @ [(node1, 0), (node3, 0)]
```

node3

```
“3” @ [(node1, 0), (node3, 0)]
```

node1

```
“3” @ [(node1, 2), (node3, 0)]
```

node2

client

“3” @ [(node1, 2), (node3, 0)]

node3

```
“3” @ [(node1, 0), (node3, 0)]
```

node1

“3” @ [(node1, 2), (node3, 0)]

node2

client

“3” @ [(node1, 2), (node3, 0)]

node3

“3” @ [(node1, 0), (node3, 0)]

node1

```
“3” @ [(node1, 2), (node3, 0)]
```

node2

client

“3” @ [(node1, 2), (node3, 0)]

node3

“3” @ [(node1, 2), (node3, 0)]

Where does each key live?

Goals:

- Balance load, even as servers join and leave
- Replicate across data centers
- Encourage put/get to see each other
- Avoid conflicting versions

Solution: consistent hashing

Recap: consistent hashing

Node ids hashed to many pseudorandom points on a circle

Keys hashed onto circle, assigned to “next” node

Idea used widely:

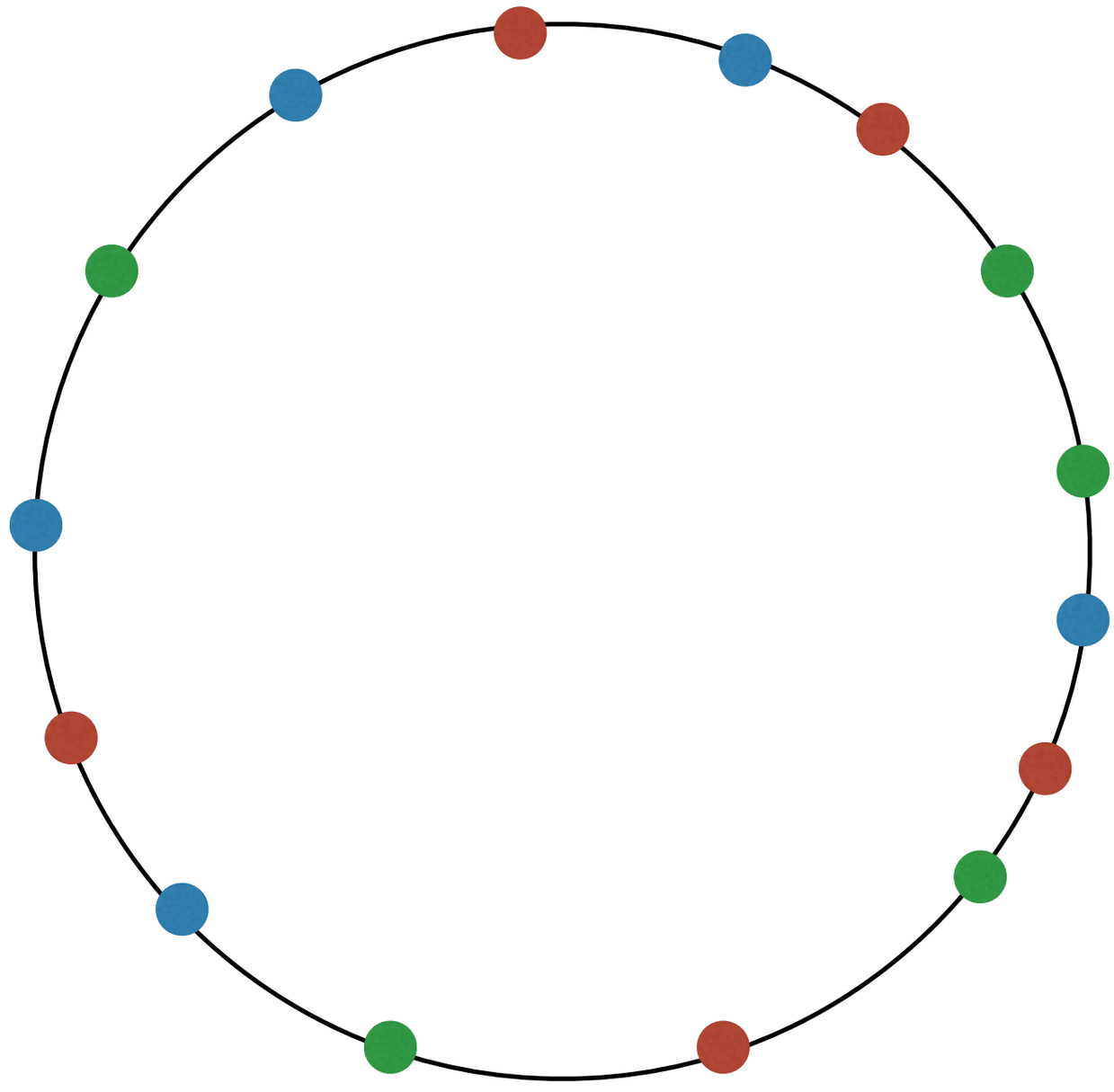
- Developed for Akamai CDN
- Used in Chord distributed hash table
- Used in Dynamo distributed DB

Consistent hashing

Cache 1

Cache 2

Cache 3



Consistent hashing in Dynamo

Each key has a “preference list”—next nodes around the circle

- Skip duplicate virtual nodes

- Ensure list spans data centers

Slightly more complex:

- Dynamo ensures keys evenly distributed

- Nodes choose “tokens” (positions in ring) when joining the system

- Tokens used to route requests

- Each token = equal fraction of the keyspace

Replication in Dynamo

Three parameters: N, R, W

- N: number of nodes each key replicated on
- R: number of nodes participating in each read
- W: number of nodes participating in each write

Data replicated onto first N live nodes in pref list

- But respond to the client after contacting W

Reads see values from R nodes

Common config: (3, 2, 2)

Sloppy quorum

Never block waiting for unreachable nodes

- Try next node in list!

Want get to see most recent put (as often as possible)

Quorum: R + W > N

- Don’t wait for all N

- R and W will (usually) overlap

Nodes ping each other

- Each has independent opinion of up/down

“Sloppy” quorum—nodes can disagree about which nodes are running

Replication in Dynamo

Coordinator (or client) sends each request (put or get) to first N reachable nodes in pref list

- Wait for R replies (for read) or W replies (for write)

Normal operation: gets see all recent versions

Failures/delays:

- Writes still complete quickly

- Reads eventually see

Ensuring eventual consistency

What if puts end up far away from first N?

- Could happen if some nodes temporarily unreachable
  - Server remembers “hint” about proper location
  - Once reachability restored, forwards data

Nodes periodically sync whole DB

- Fast comparisons using Merkle trees

Dynamo deployments

~100 nodes each

One for each service (parameters global)

How to extend to multiple apps?

Different apps use different (N, R, W)

- Pretty fast, pretty durable: (3, 2, 2)
- Many reads, few writes: (3, 1, 3) or (N, 1, N)
- (3, 3, 3)?
- (3, 1, 1)?

Dynamo results

Average *much* faster than 99.9%

- But, 99.9% acceptable

Inconsistencies rare in practice

- Allow inconsistency, but minimize it

Discussion

Why is symmetry valuable? Do seeds break it?

Dynamo and SOA

- What about malicious/buggy clients?

Issues with hot keys?

Transactions and strict consistency

- Why were transactions implemented at Google and not at Amazon?

- Do Amazon's programmers not want strict consistency?