Bayou / Chord

Feb 29th, 2024

[Adapted from Andrew Or and Ion Stoica's original slides]

Context on Bayou: Disconnected Nodes [Stoica]

Early days: nodes always on when not crashed

- Network bandwidth always plentiful.
- Never needed to work on a disconnected node

Now: nodes detach then reconnect elsewhere

- Even when attached, bandwidth is variable
- Reconnection elsewhere means often talking to different replica
- Work done on detached nodes

Bayou

- ”[R]eplicated, [eventually] consistent storage system designed for … portable machines with less-than-ideal network connectivity.”

- System developed at PARC in the mid-90’s

- First coherent attempt to fully address the problem of disconnected operation

Bayou

What is it?

- Weakly consistent, replicated storage system

Goals:

- Maximize availability, *support offline collaboration*
- Minimize network communication
- Agree on all values (eventually)

Bayou Update Protocol: Review from Class

- Client sends update to a server
- Updates uniquely identified by:
    <Commit Sequence Number (CSN), Local Timestamp, Node ID>

- Updates are either committed or tentative
    CSNs increase monotonically
    Tentative updates have commit-stamp = ∞

- Only Primary server can commit updates
    Allocates CSN in monotonically increasing order
    CSN is different from time-stamp

Anti-Entropy Exchange

- Each server keeps a version vector:
  - R.V[X] is the latest timestamp from server X that server R has seen
- When two servers connect, exchanging the version vectors allows them to identify the missing updates
- These updates are exchanged in the order of the logs, so that if the connection is dropped the crucial monotonicity property still holds
  - If a server X has an update accepted by server Y, server X has all previous updates accepted by that server

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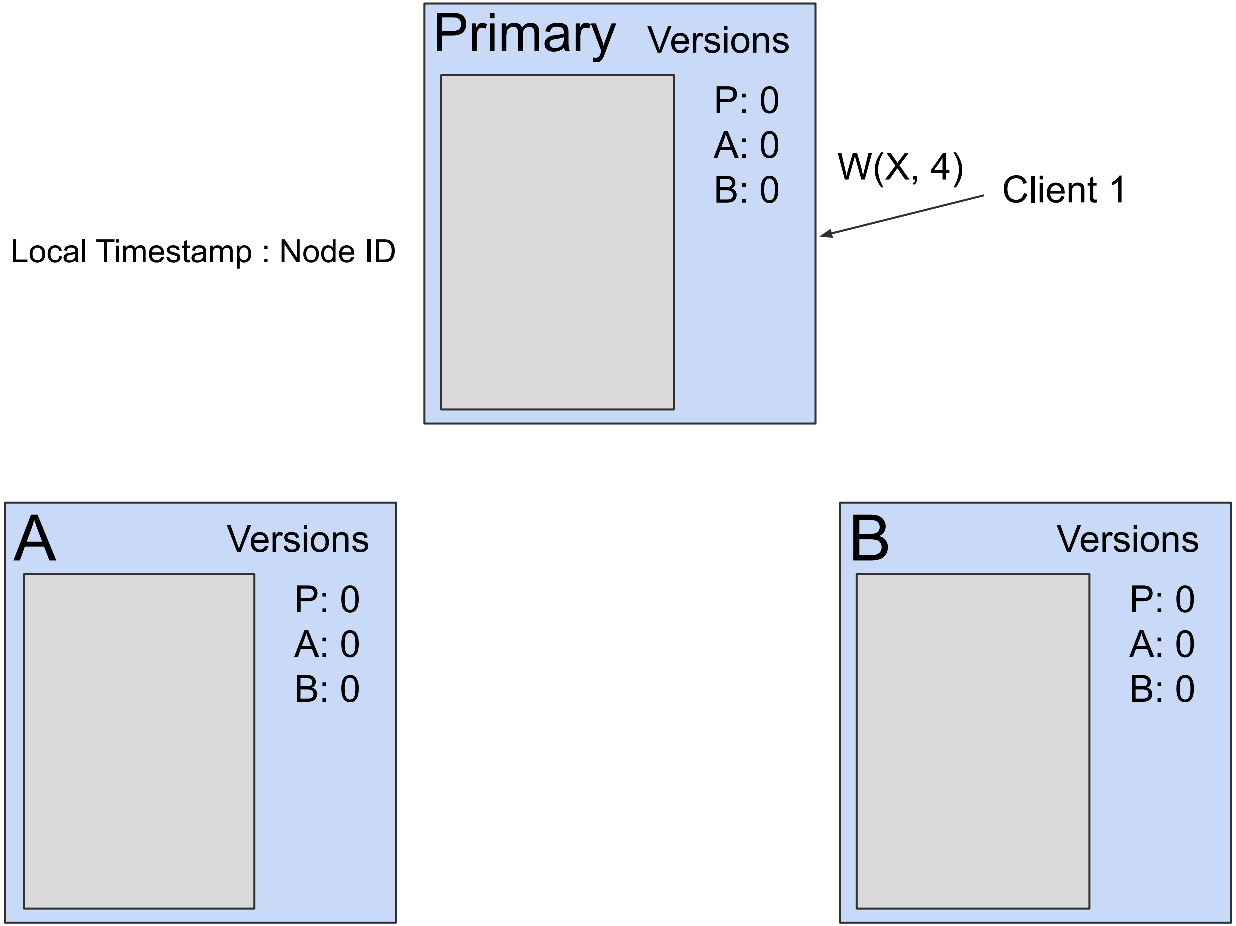
Source: Berkeley CS 268 Lecture 20 Slide Deck

Bayou Writes

value1 : value2 : value3 denotes
Commit Sequence Number (CSN) : Local Timestamp : Node ID



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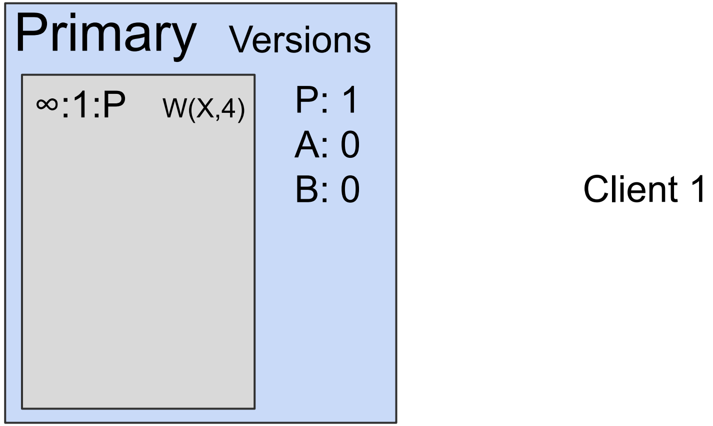

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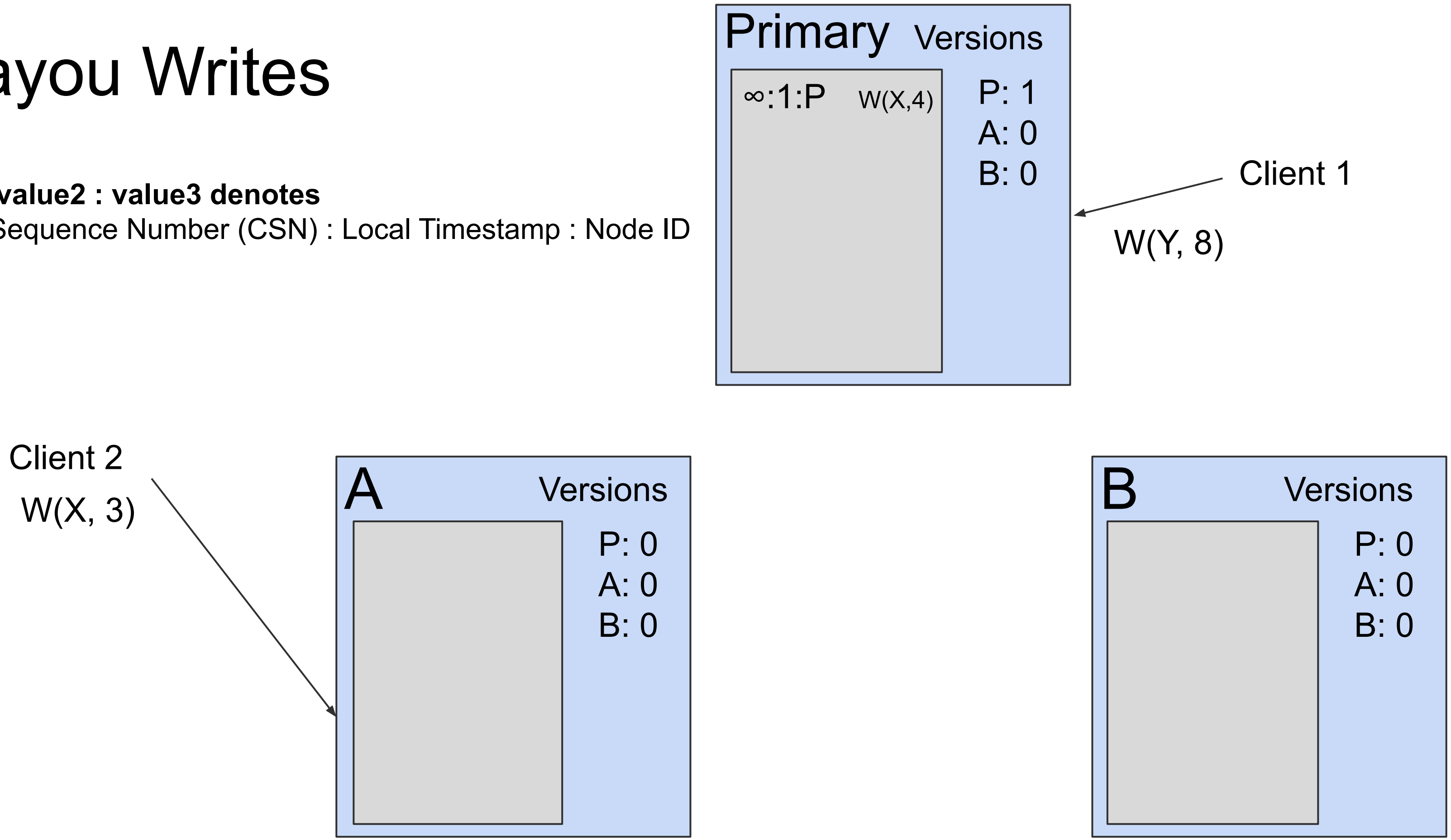

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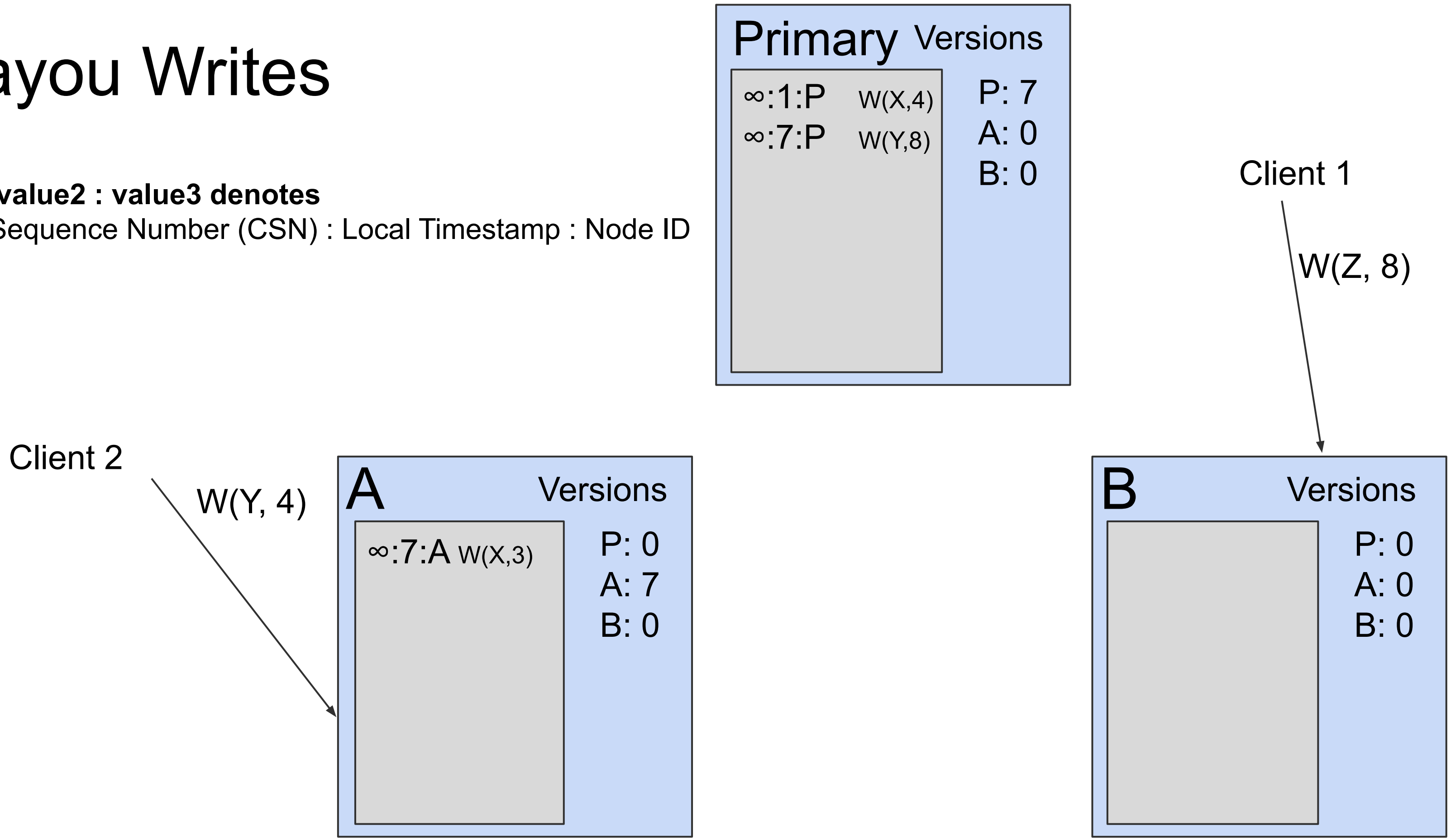

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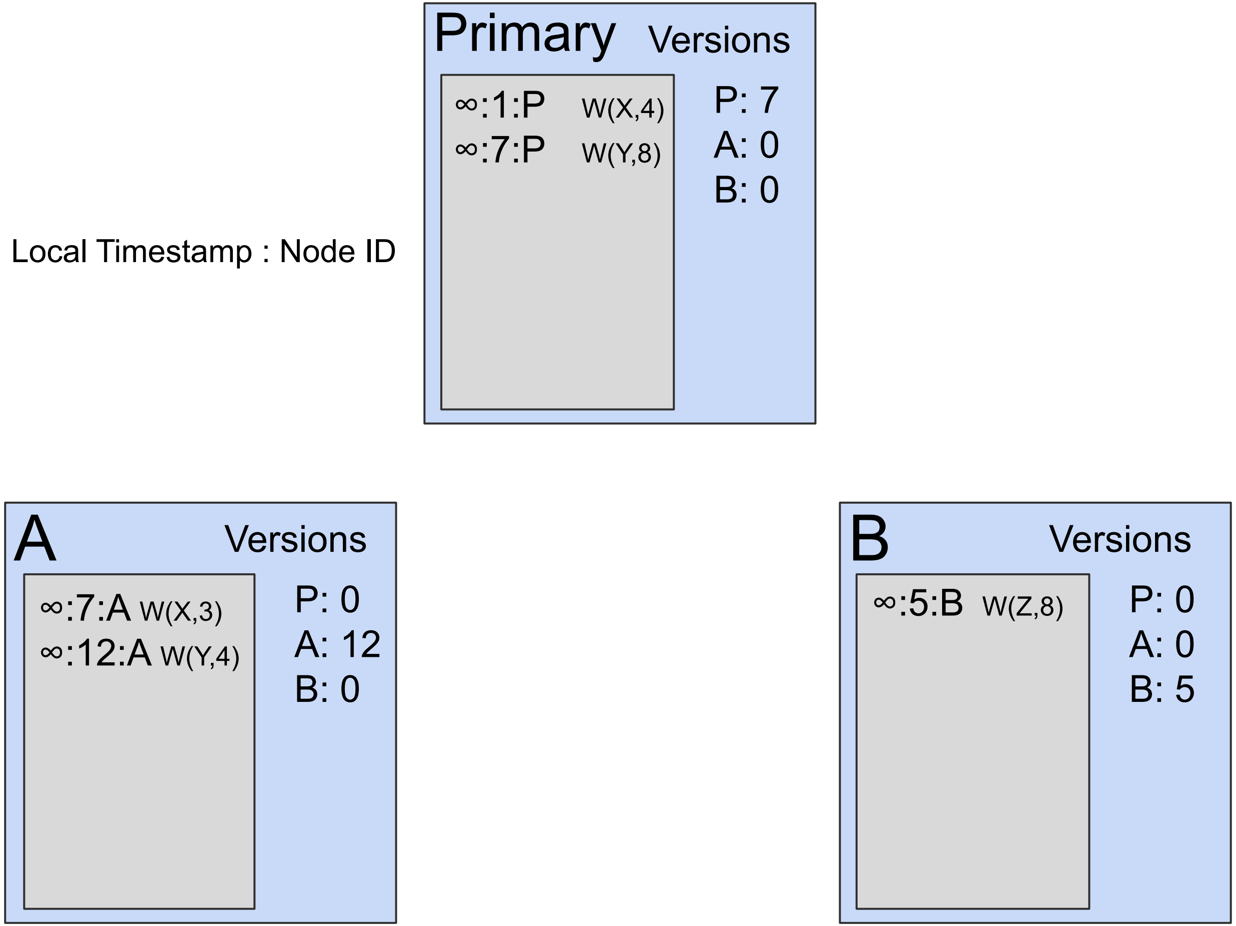
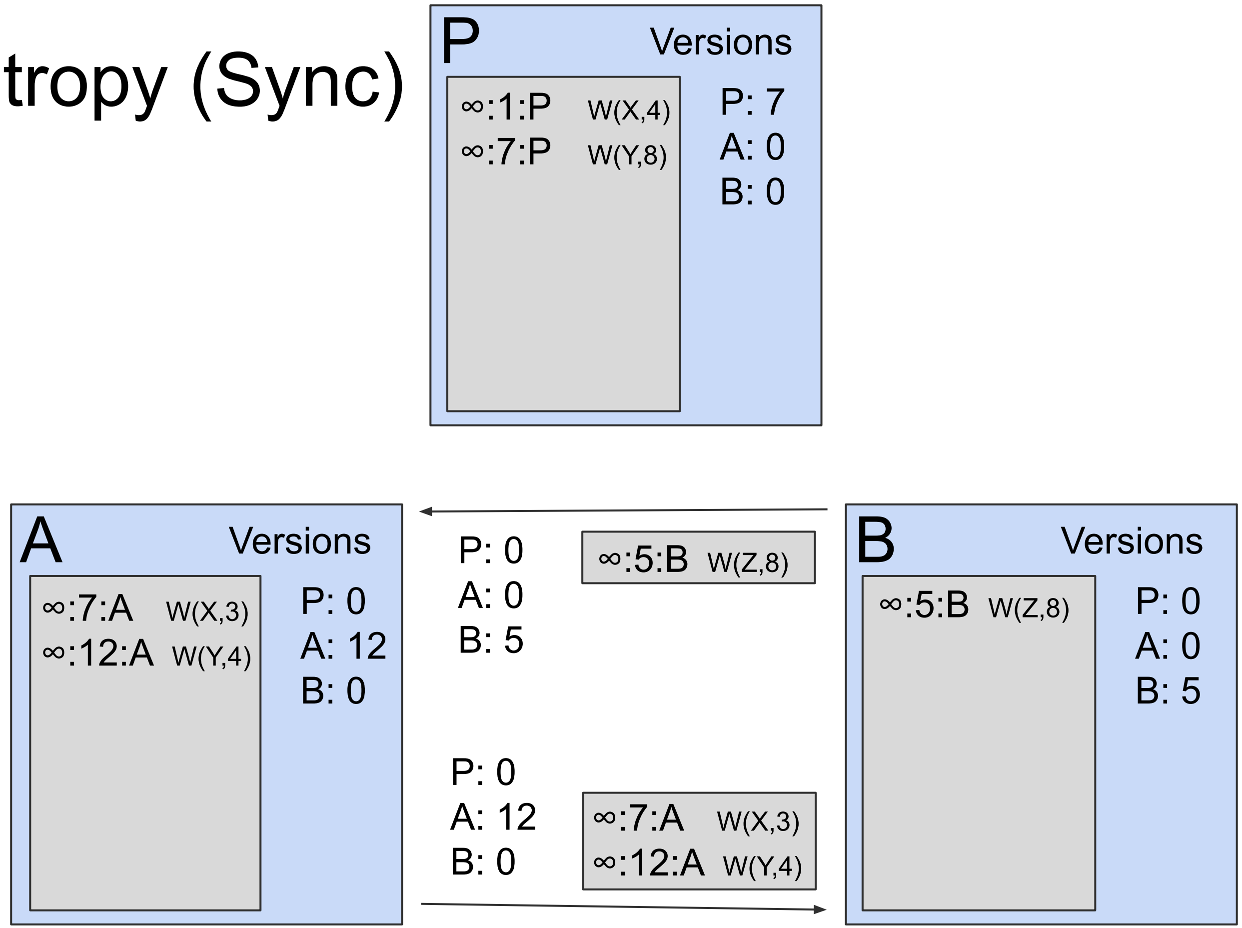


Bayou Anti-Entropy (Sync)

Anti-entropy Session
A & B



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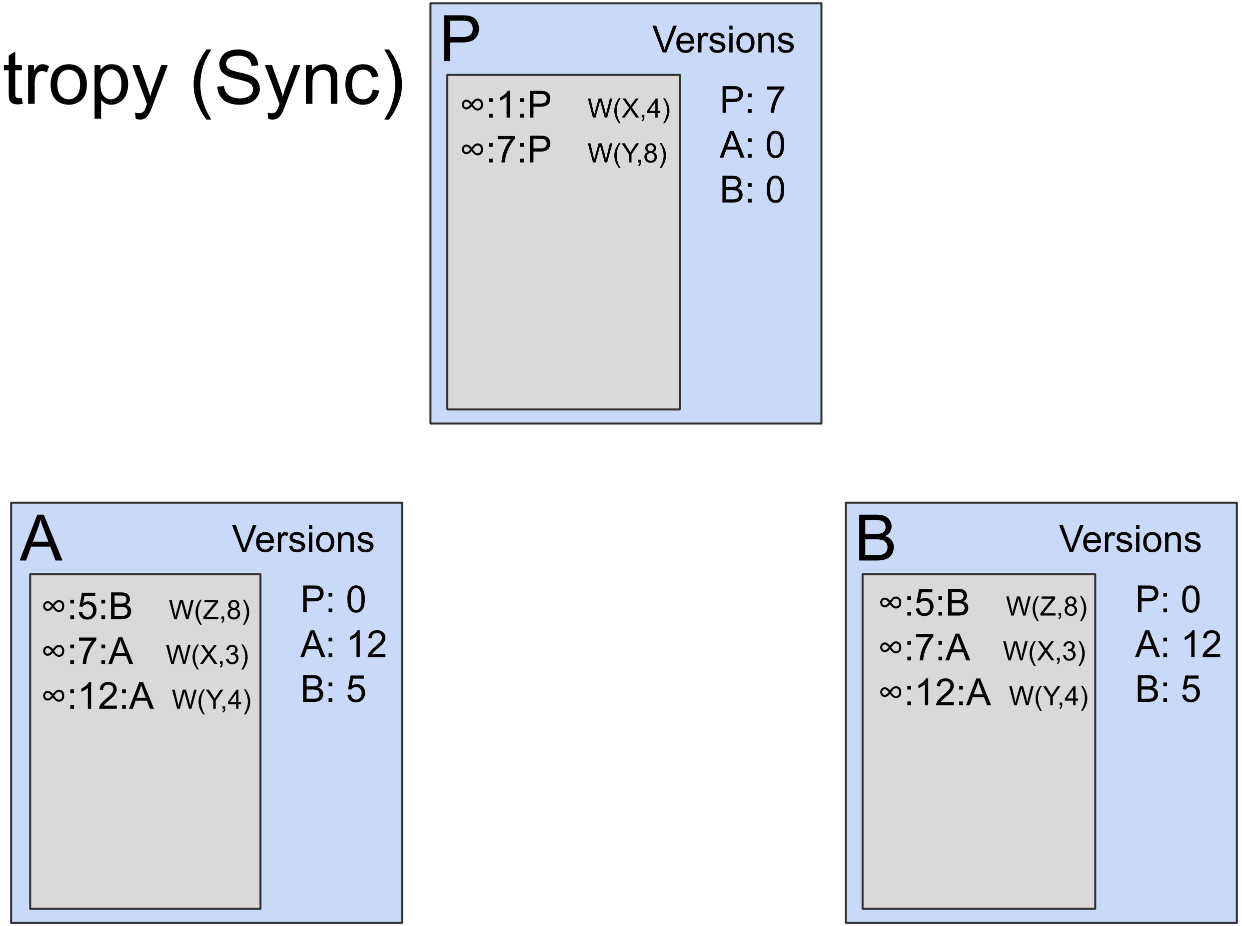
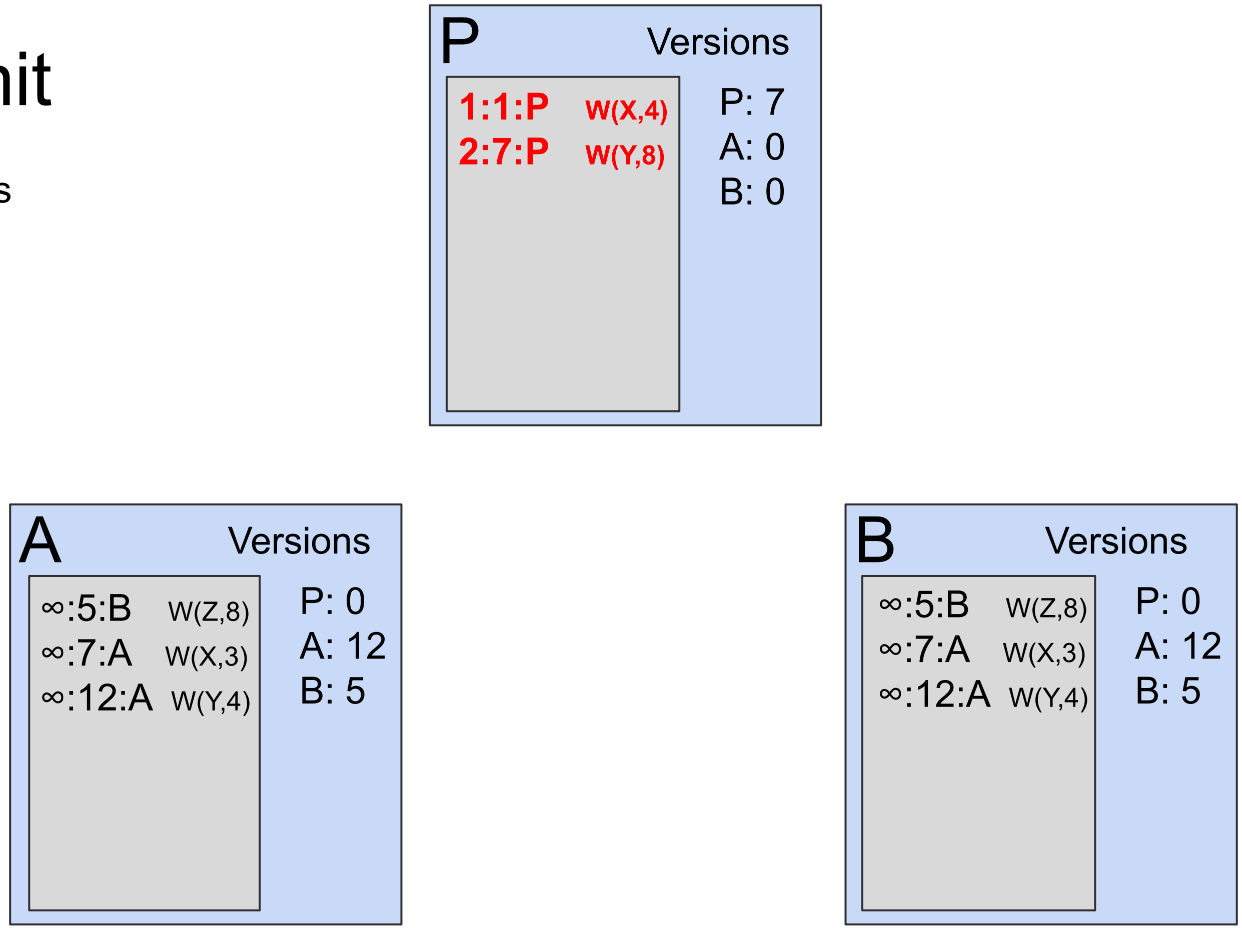


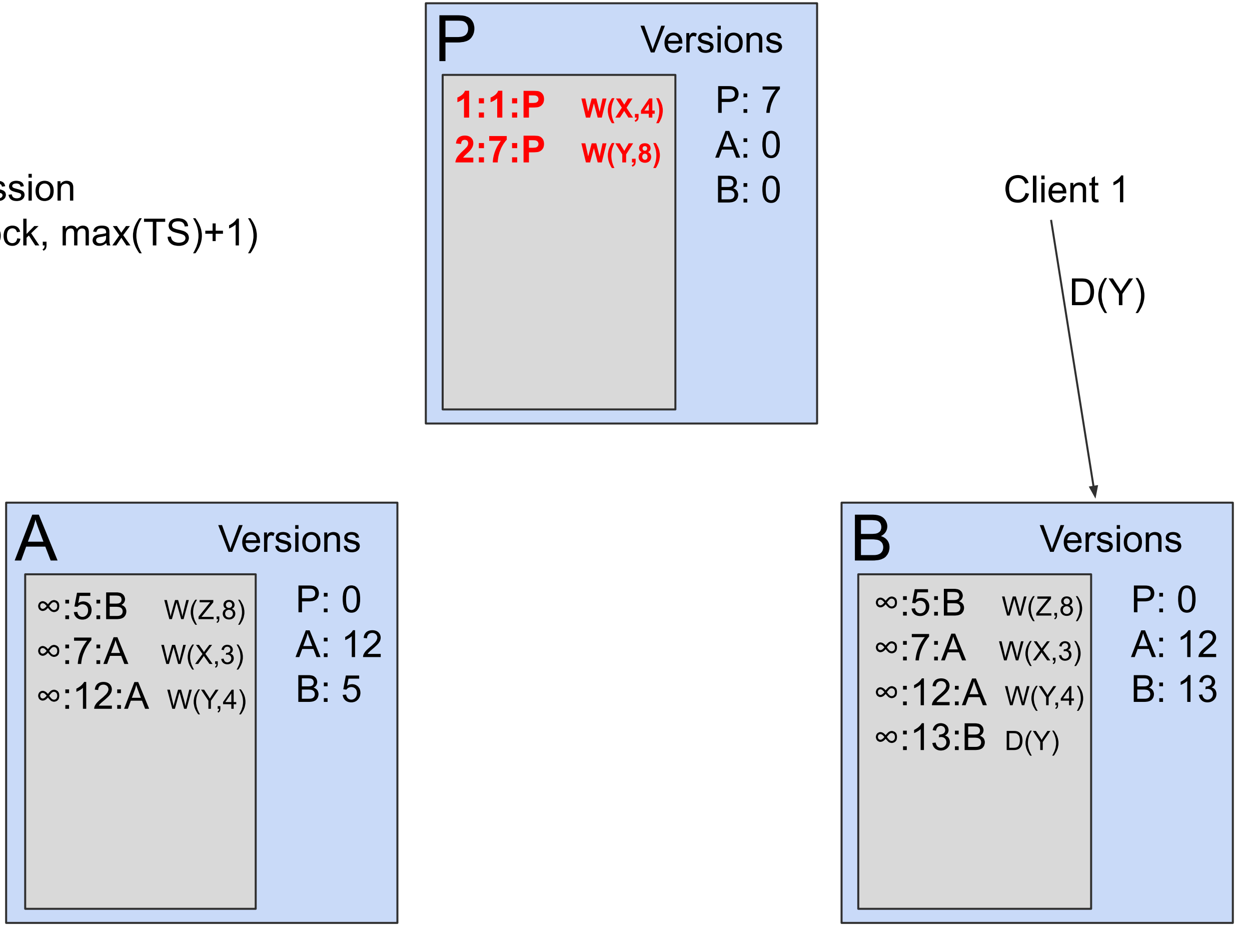
Bayou Commit

Primary commits its entries



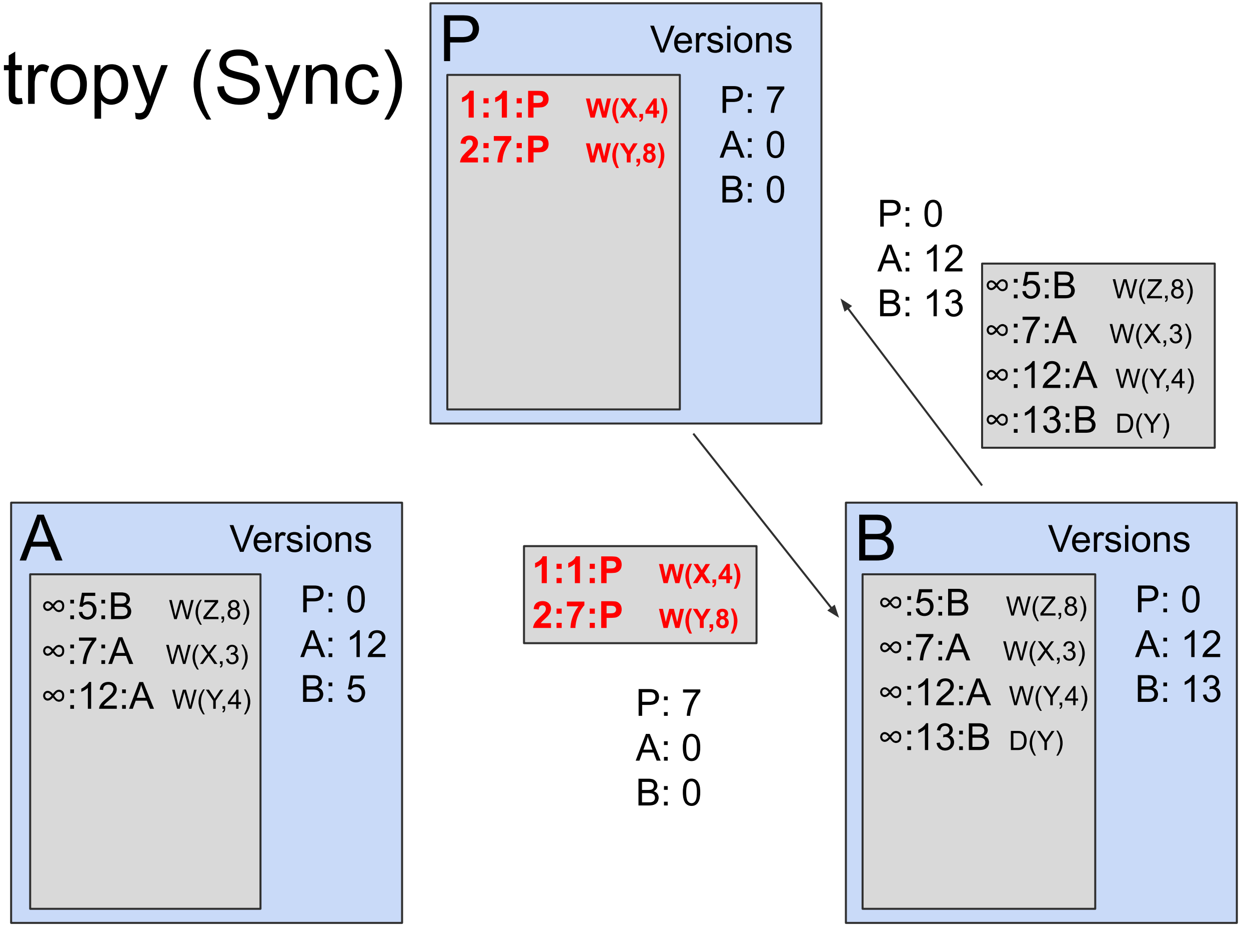
Bayou Write

Write after anti-entropy session
Write timestamp = max(clock, max(TS)+1)



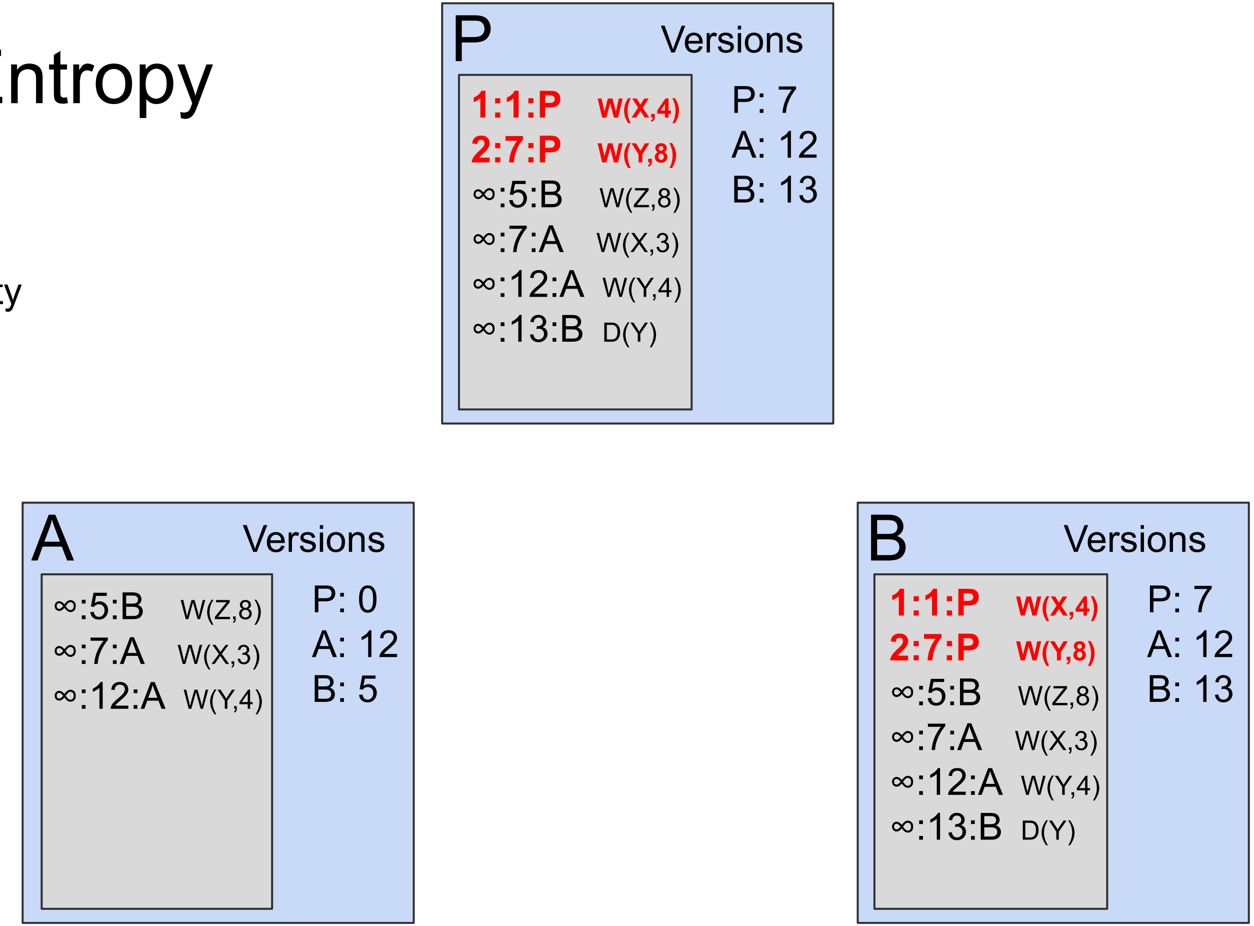
Bayou Anti-Entropy (Sync)

Anti-entropy Session
P & B



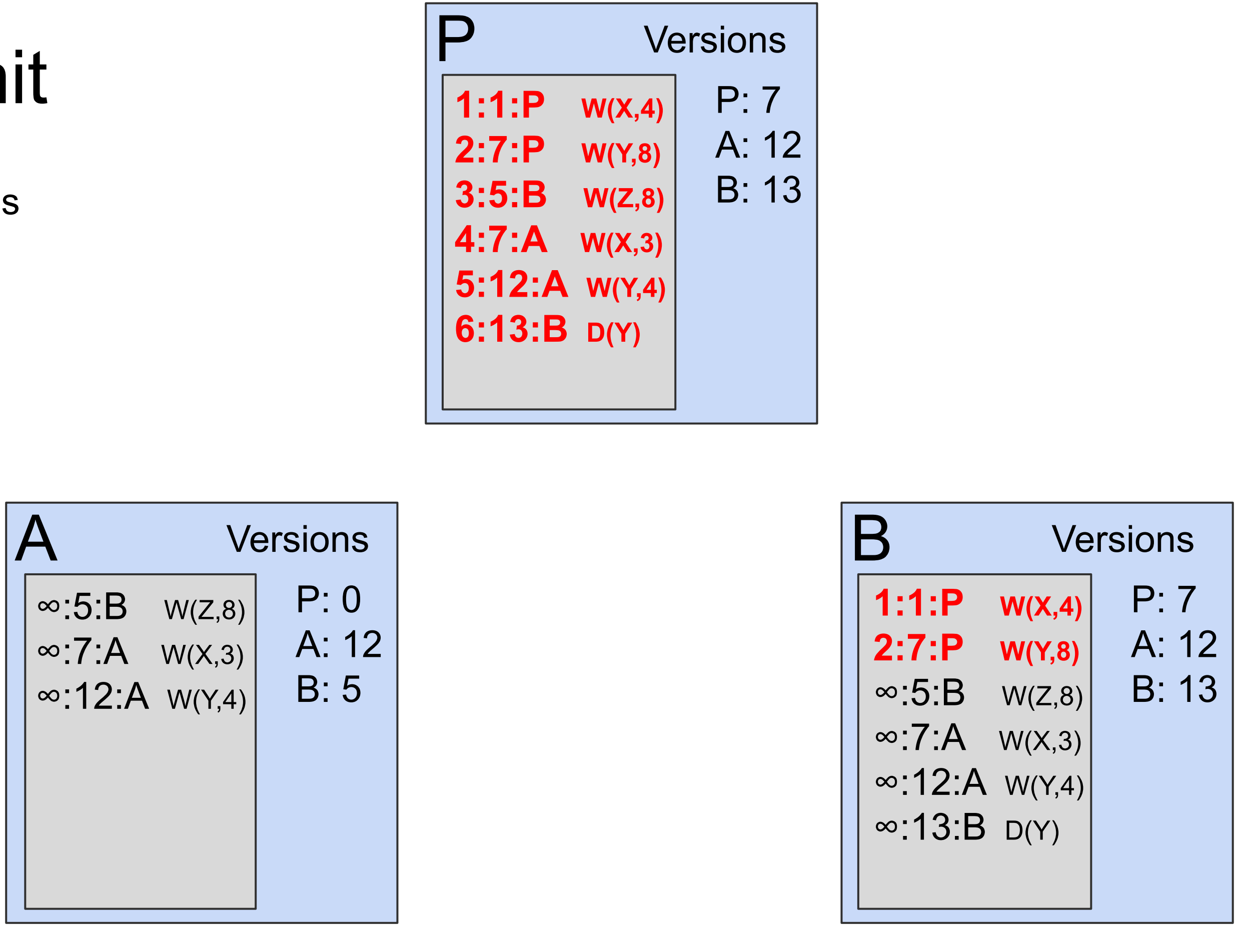
Bayou Anti-Entropy

Anti-entropy Session
P & B
Primary respects causality



Bayou Commit

Primary commits Its entries



Bayou

After a number of commits and anti-entropy sessions (without further writes), all nodes converge on same state.

P

Versions

1:1:P W(X,4)
2:7:P W(Y,8)
3:5:B W(Z,8)
4:7:A W(X,3)
5:12:A W(Y,4)
6:13:B D(Y)

P: 7
A: 12
B: 13

A

Versions

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B

Versions

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2:7:P W(Y,8)
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Bayou (review from class)

1. Eventual consistency: if updates stop, all replicas eventually the same view.
2. Update functions for automatic app-driven conflict resolution.
3. Ordered update log is the real truth, not the DB.
4. Use Lamport clocks: eventual consistency that respects causality.

Context for Chord: Key Value Stores

Amazon:
- Key: customerID
- Value: customer profile (e.g., buying history, credit card, ..)

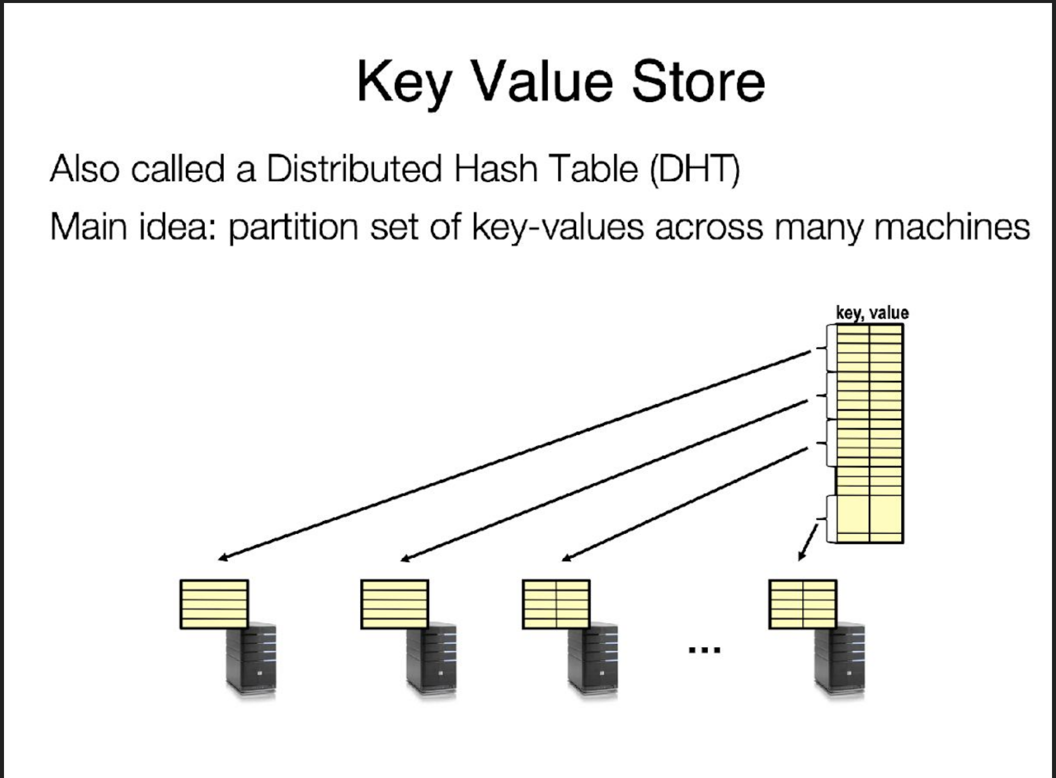
Facebook, Twitter:
- Key: UserID
- Value: user profile (e.g., posting history, photos, friends, …)

iCloud/iTunes:
- Key: Movie/song name
- Value: Movie, Song

Distributed file systems
- Key: Block ID
- Value: Block

Credit: Ion Stoica's slide deck

Context for Chord: Key Value Stores



Credit: Ion Stoica’s slide deck

Chord

- Chord: “a distributed lookup protocol” for a peer-to-peer distributed hash table [Stoica ‘01]
- *Consistent hashing* for partitioning key space + lookup

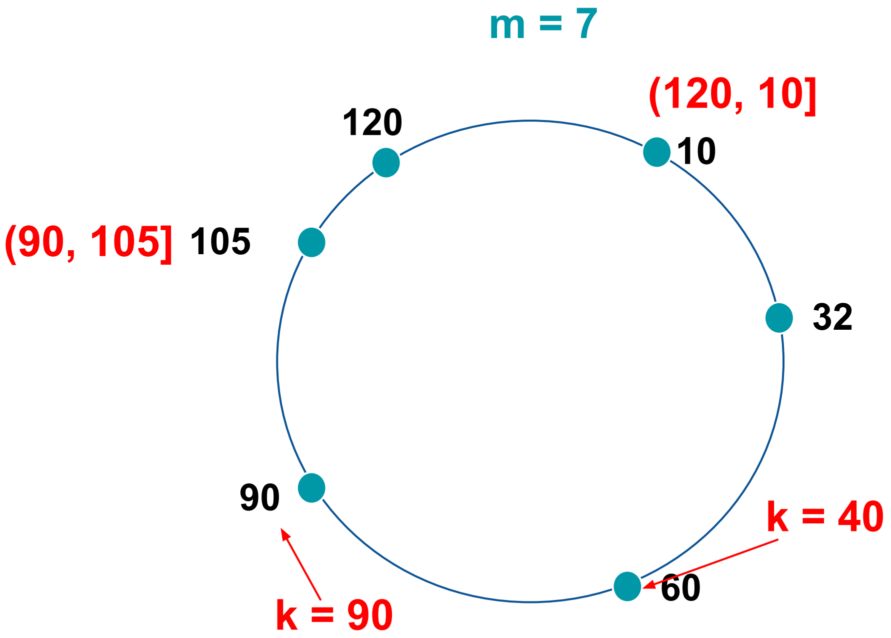
Identifiers in Chord

- Key identifier = SHA1(key) mod 2^m
- Node identifier = SHA1(IP address) mod 2^m
- Both are uniformly distributed in the same identifier space
- The identifier length, m, must be large enough to make the probability of two nodes or keys hashing to the same identifier negligible (e.g. m = 160)

How do we map key IDs to node IDs?

Consistent Hashing

- A node owns the preceding key range, including its own identifier.
- Key k is stored at its successor node, the first node whose identifiers is equal to or greater than the identifier of key k.

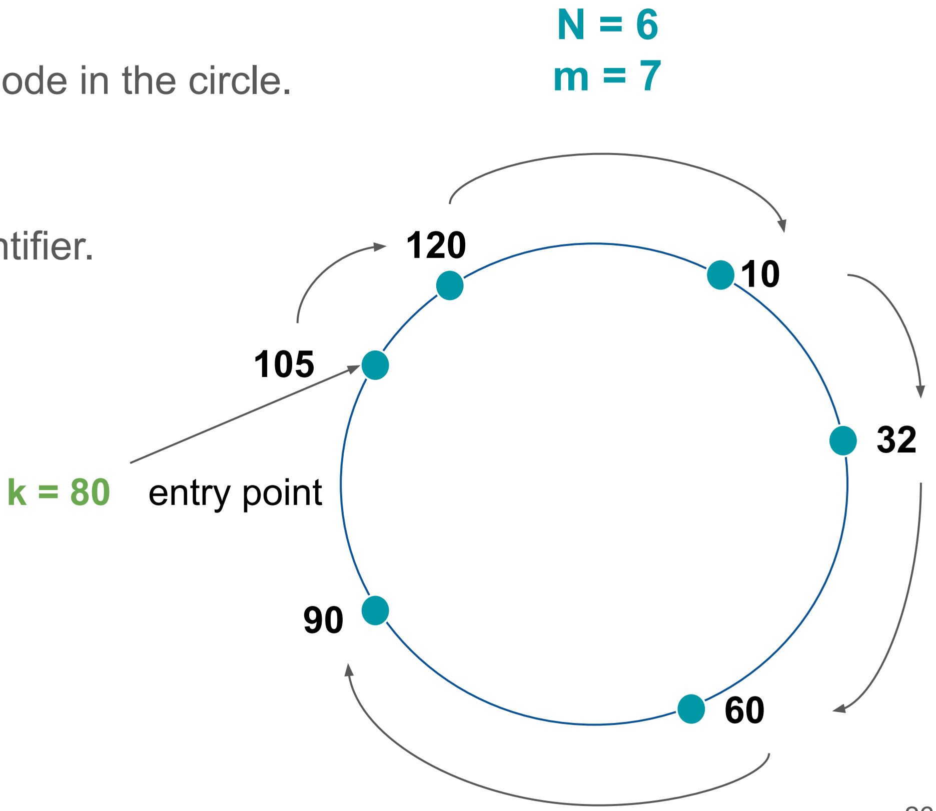


Basic Lookups

- Each node only remembers its successor node in the circle.
- Lookups in clockwise direction.
- Assume N nodes and K keys.
- m is the number of bits in the node/key identifier.

What is the lookup time?

O(N) hops



Finger Table Notations

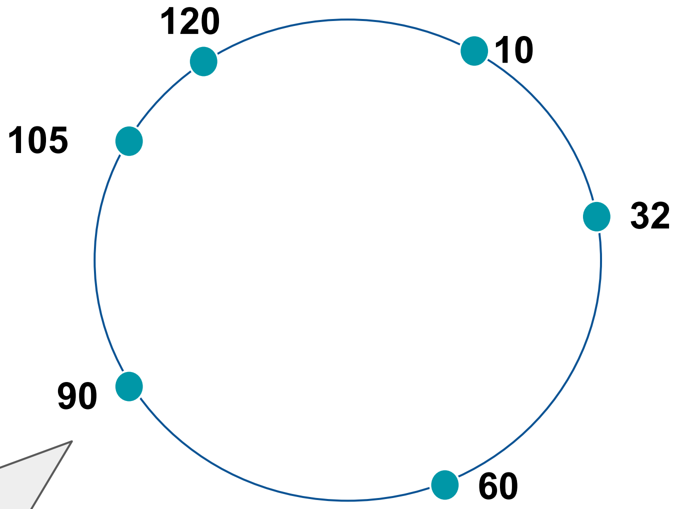
- Each node maintains additional routing information (e.g., finger tables) to accelerate lookups.
- A finger table contains m entries

n is the identifier of the node

Notation	Definition
$finger[k].start$	$(n + 2^{k-1}) \bmod 2^m, 1 \leq k \leq m$
$.interval$	$[finger[k].start, finger[k+1].start)$
$.node$	first node $\geq n.finger[k].start$

m = 7

	start	interval	node
k = 1	91	[91, 92)	105
k = 2	92	[92, 94)	105
k = 3	94	[94, 98)	105
k = 4	98	[98, 106)	105
k = 5	106	[106, 122)	120
k = 6	122	[122, 26)	10
k = 7	26	[26, 91)	32



Finger Table of Node 10

- A finger table contains m entries

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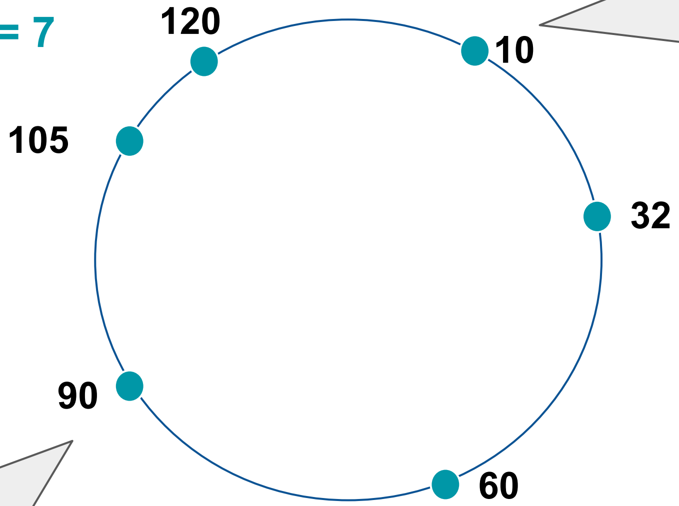
N = 6
m = 7



start	interval	node
11	[11, 12)	32
12	[12, 14)	32
14	[14, 18)	32
18	[18, 26)	32
26	[26, 42)	60
42	[42, 74)	60
74	[74, 11)	90

start	interval	node
91	[91, 92)	105
92	[92, 94)	105
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Route k = 15

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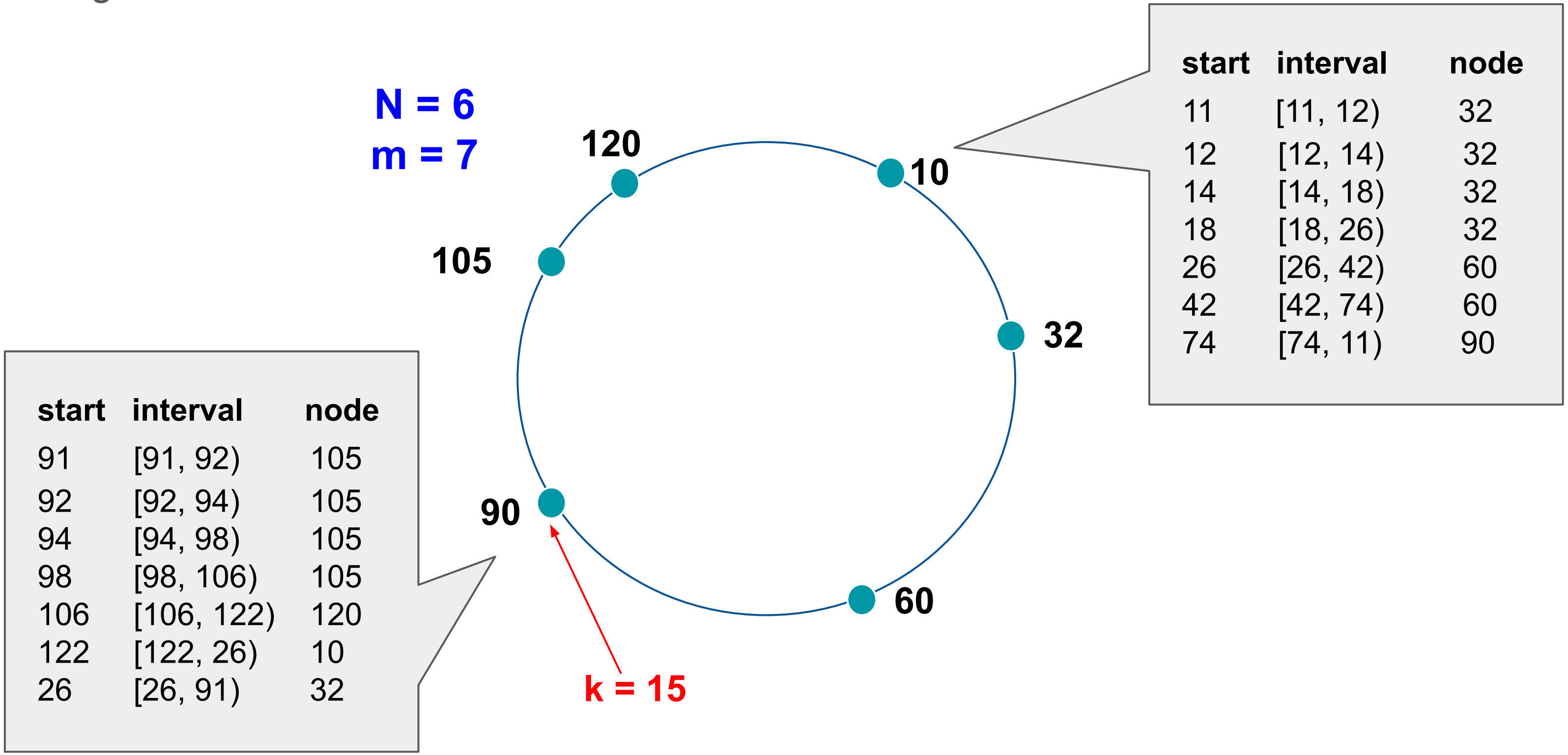

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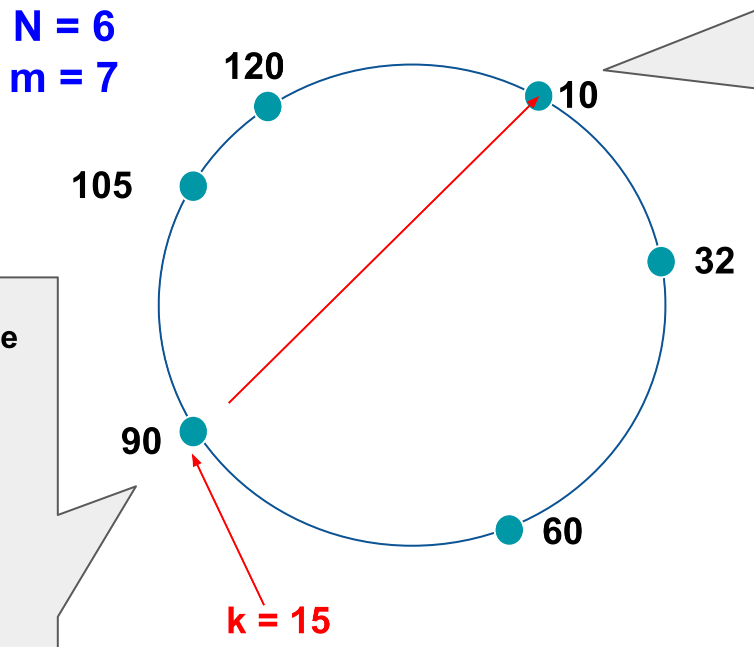

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.*interval*	[*finger*[*k*].*start*, *finger*[*k* + 1].*start*)
.*node*	first node $\geq$ *n*.*finger*[*k*].*start*

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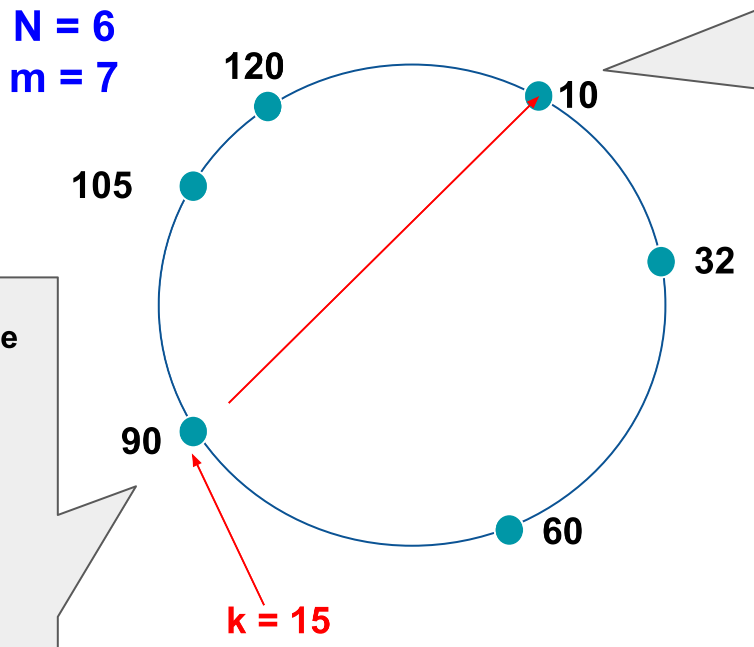

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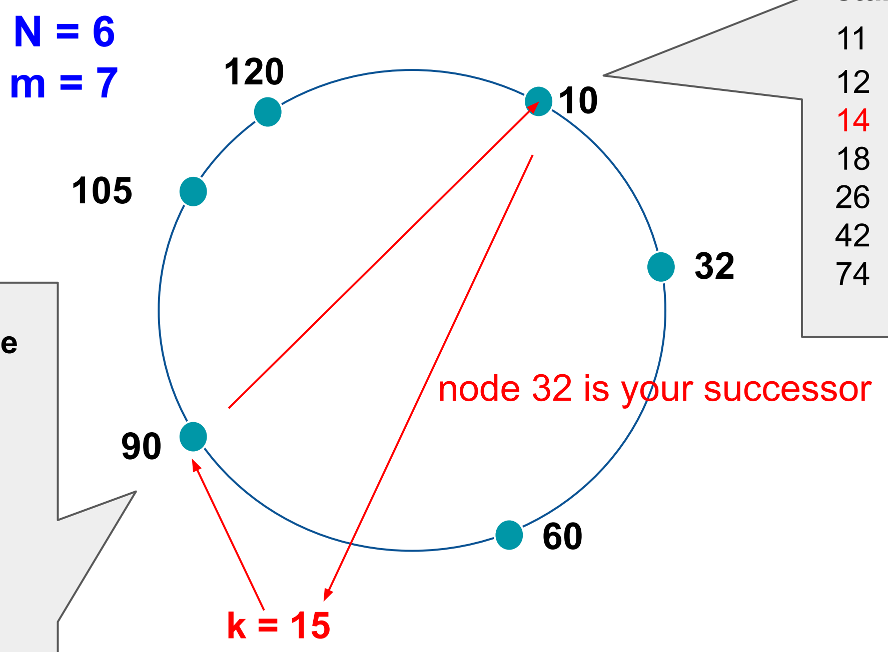

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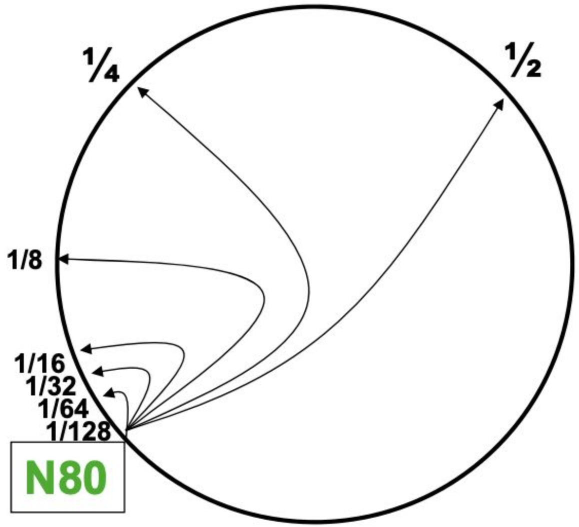
Summary: Finger Table

- Each node maintains additional routing information (e.g., finger tables) to accelerate lookups.This information is not essential for correctness, as long as the successor information is correct.
- A finger table contains m entries
- We tradeoff space for better lookup performance

What is the lookup time?

O(logN) hops



Credit: UC Berkeley CS 262a Fall 2023 slide deck.