Distributed Consistency with CRDTs

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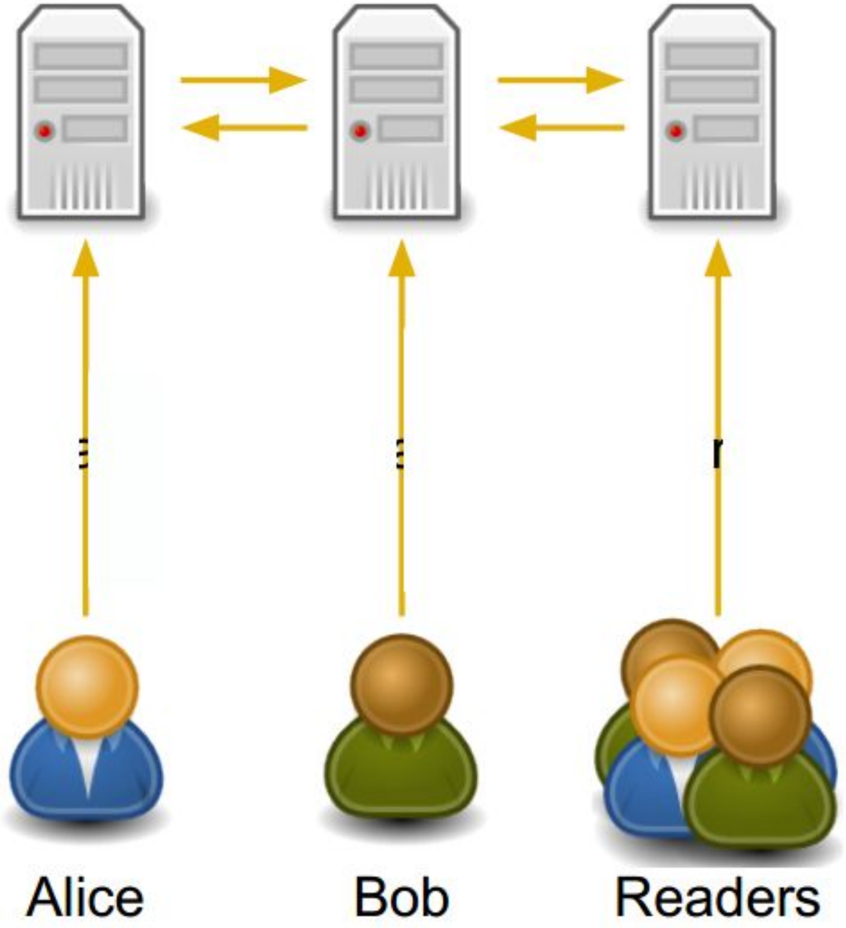
Conflict free

Replicated

Data-Types

Modified by many, but eventually consistent

Distributed Databases



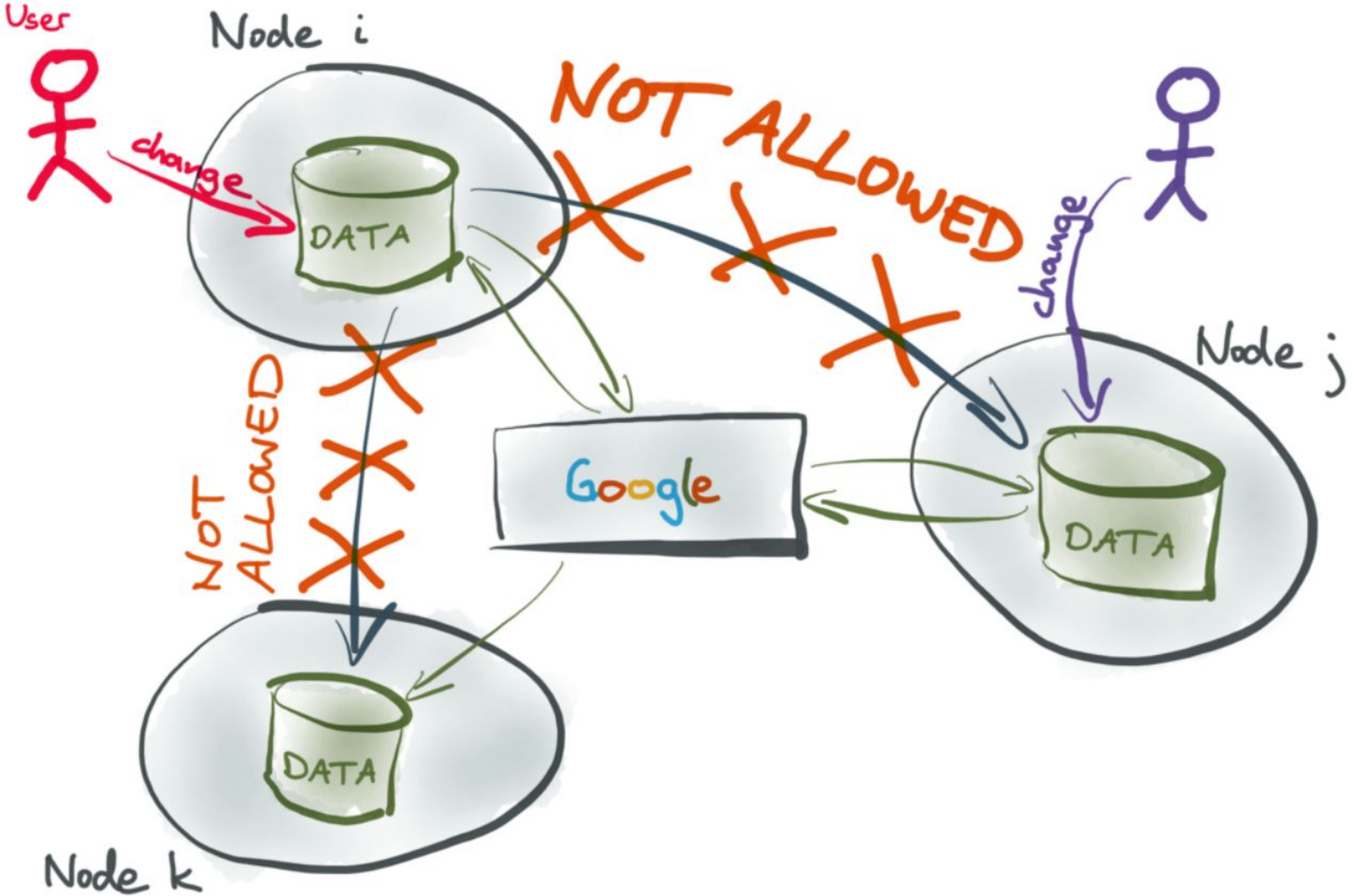
Modified by many, but eventually consistent

Collaborative Text Editors

OPERATIONAL TRANSFORMATION (OT)

- e.g. Google Docs,
  MS Office Online

OPERATIONAL TRANSFORMATION IN GOOGLE DOCS.



- So, *Operational Transformation* requires a server

- Can we do it *without a server*? YES

  https://peerpad.net/

CRDTs

What have people built?

- *Redis:* distributed, highly available and scalable in-memory database
- *Automerge*: A JSON-like data structure (a CRDT) that can be modified concurrently by different users, and merged again automatically.
- *Orbitdb*: Peer-to-Peer Databases for the Decentralized Web
- *Riak*: decentralized datastore
- *PeerPad*: is a real-time collaborative text editor
- *TomTom GPS* uses it for data synchronization
- *Teletype for atom*: collaborate on code in real time
- *Chat in League of Legends*
- *Cosmos DB* by Microsoft

And other things….

CRDTs are data types which provide *strong eventual consistency* among different *replicas* in a distributed system by requiring some properties from the *state* and/or the *operations* applied to modify it.

Strong Eventual Consistency

If two replicas have received the *same updates*, their state will be the *same*

State based CRDTs (*Convergent* CRDTs)

Operation based CRDTs (*Commutative* CRDTs)

Operation based CRDTs

Operations that modify states must be *commutative*

$A - 3$

$+ 4$

$A + 4$

$- 3$

✓

$A - 3$

$* 4$

$A * 4$

$- 3$

✗

Operation based CRDTs

Exactly once delivery semantics

Sum(A, 3) ✗

Max (A,3) ✓

State based CRDTs

In state-based CRDTs, the states in different replicas and different moments form a *monotonic join semilattice*.

JOIN SEMILATTICE YOU SAY!
TELL ME MORE ABOUT THAT
imgflip.com

- less than or equal to

  $a \leq b$ or $b \leq a$

- incomparable

  $a \parallel b$

- join

  $a \vee b$

- An *order* is a binary relation ≤ on a set S, written <S,≤>

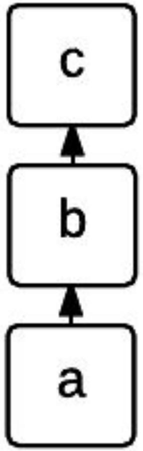
- examples

  less than or equal to 2 ≤ 4

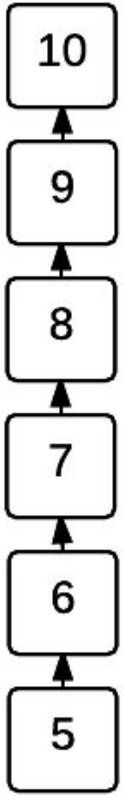
  descendent-of daughter ≤ mother

- *Total Order*

Comes-before order



Less Than or Equal To Order

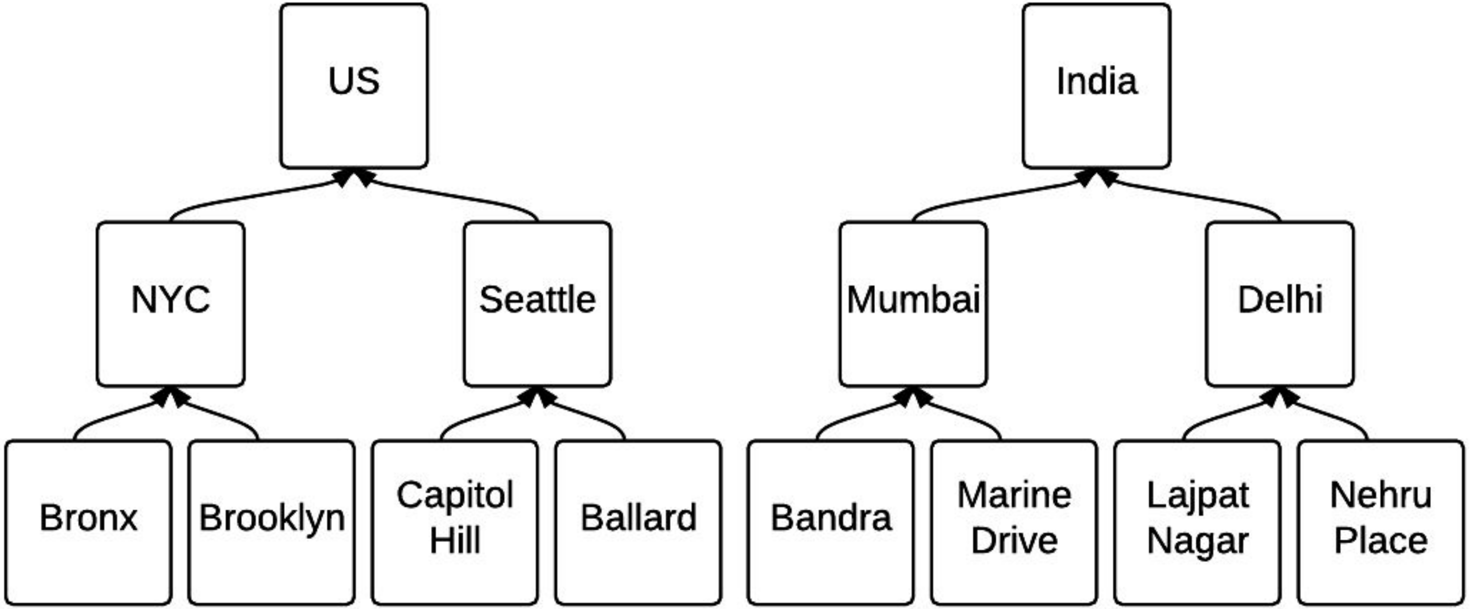


- *Partial Order*

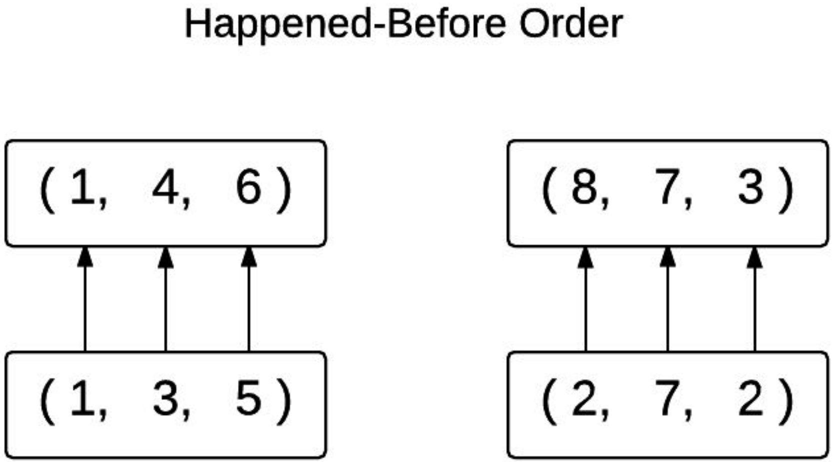
Seattle ≤ US and Brooklyn ≤ US

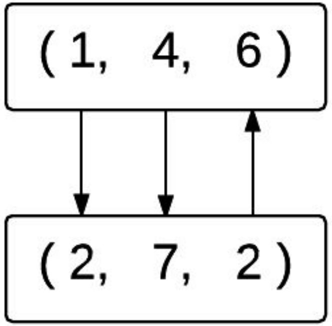
Seattle // NYC and Bronx // Mumbai

Located-in Order



- A *vector clock timestamp* is a collection of logical timestamps for all the nodes or processes we’re interested in.





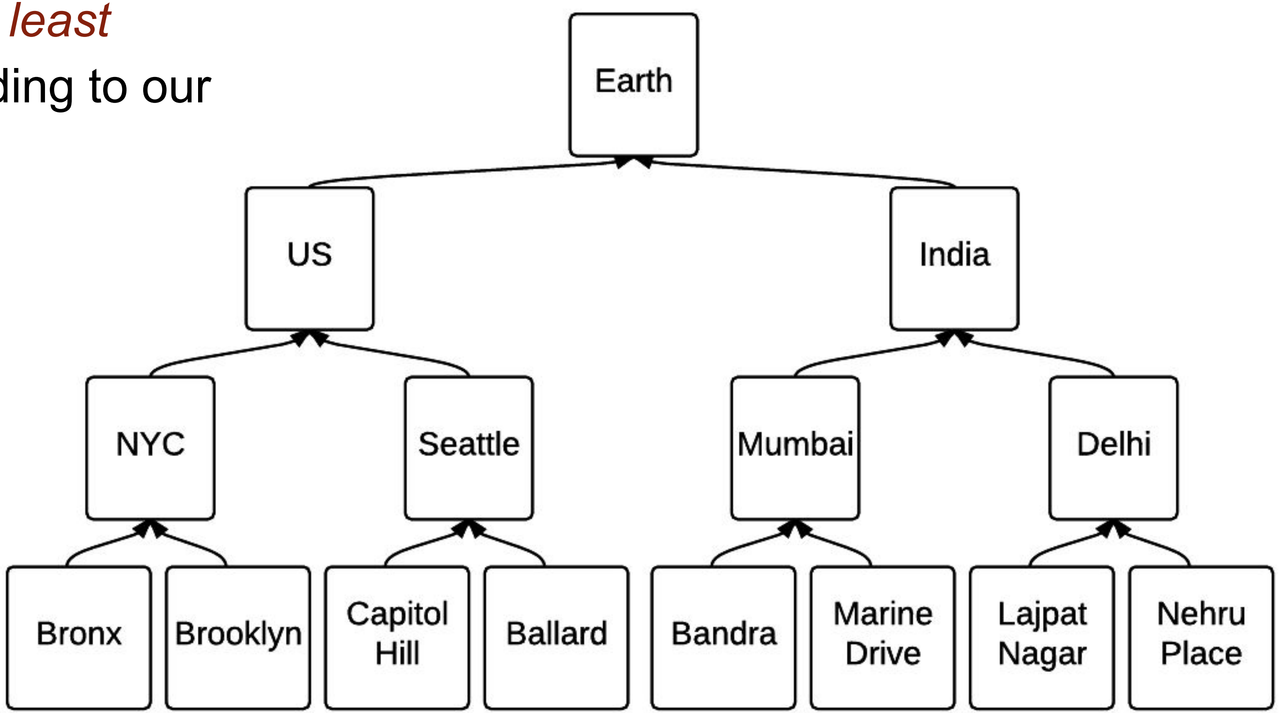
(1,3,5) ≤ (1,4,6)
(2,7,2) ≤ (8,7,3)

(1,4,6) // (2,7,2)

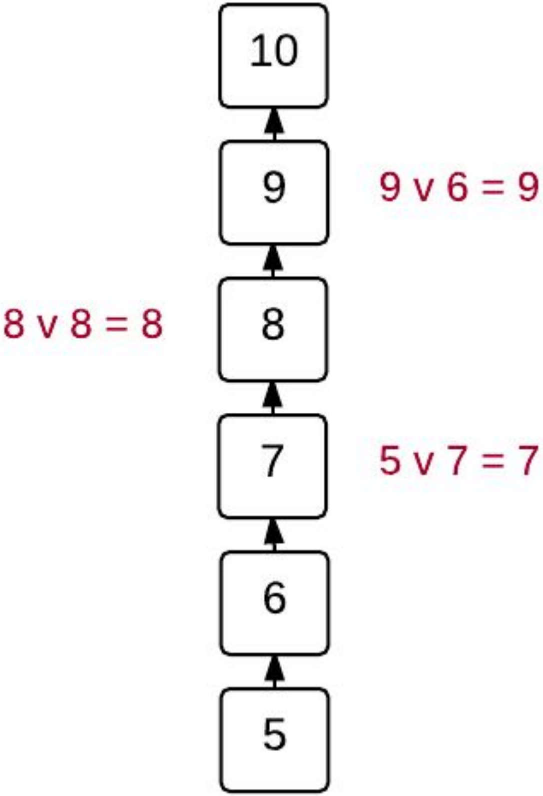
Join

For a set S, an order <S,≤>, and two elements a,b∈S, the *join* of a and b (written a⋁b) is a *least upper bound* of S according to our order <S,≤>

Upper Bound for Located-in Order



Less Than or Equal To Order



10

9

8

7

6

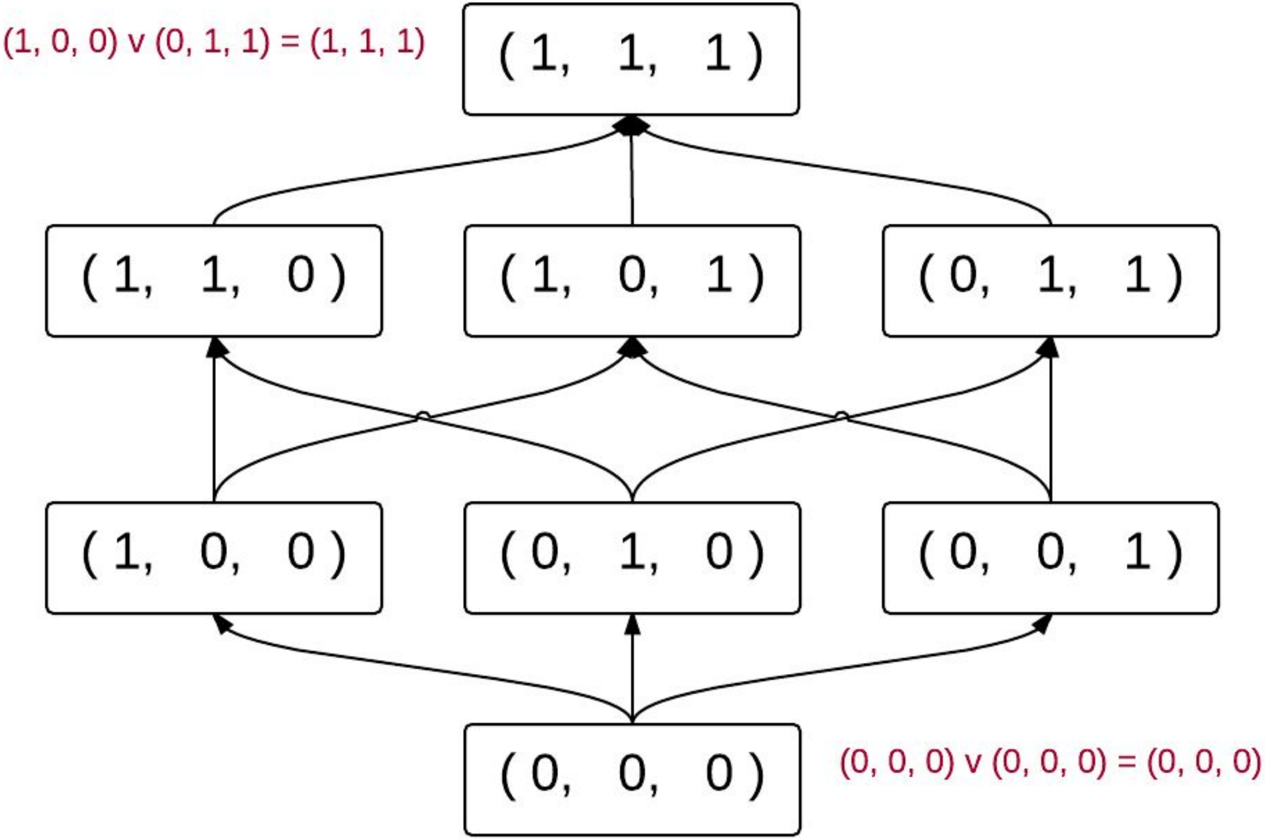
5

9 v 6 = 9

8 v 8 = 8

5 v 7 = 7

Happened-Before Order



(1, 0, 0) v (0, 1, 1) = (1, 1, 1)

(1, 1, 1)

(1, 1, 0)

(1, 0, 1)

(0, 1, 1)

(1, 0, 0)

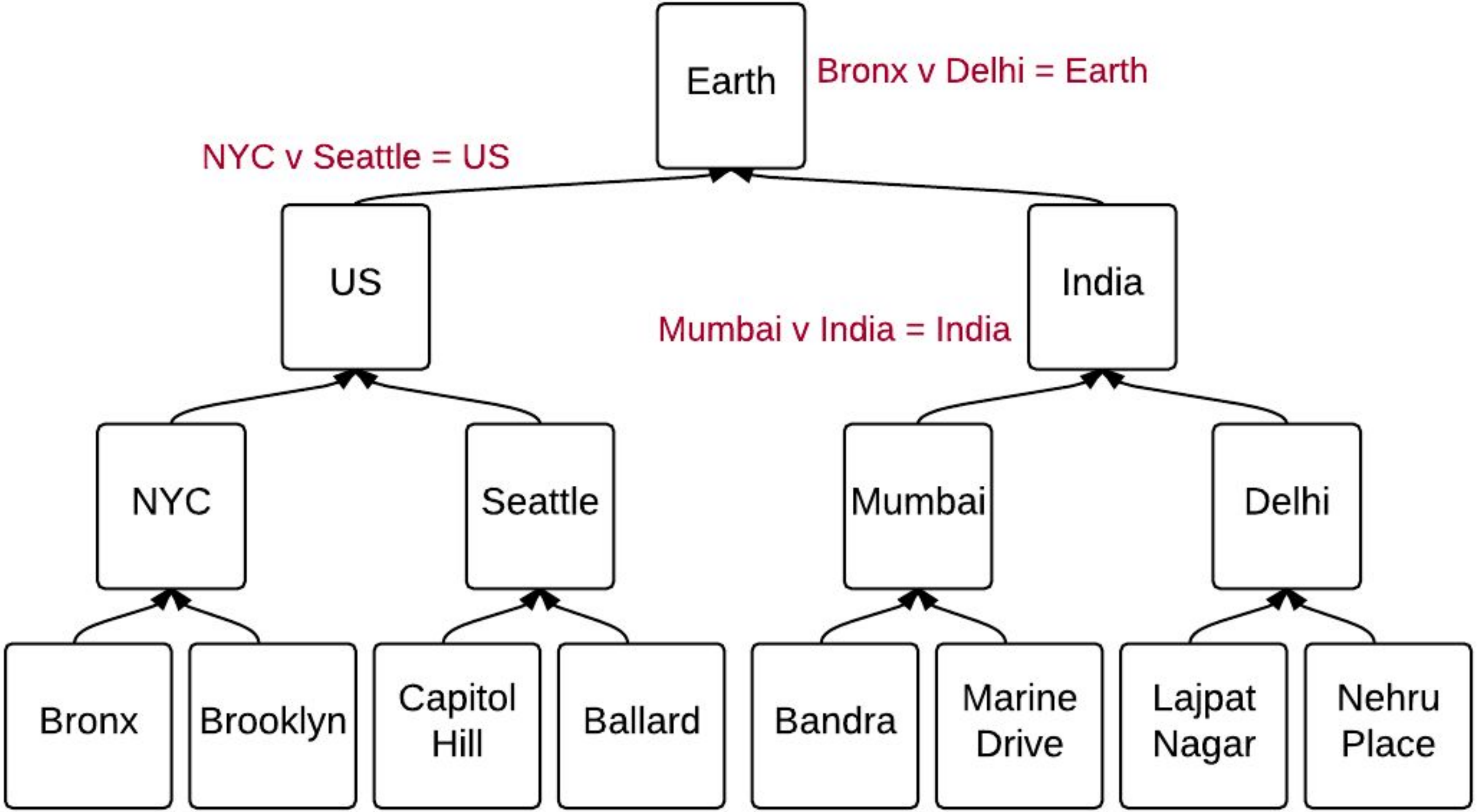
(0, 1, 0)

(0, 0, 1)

(0, 0, 0)

(0, 0, 0) v (0, 0, 0) = (0, 0, 0)

Located-in Order



Earth

Bronx v Delhi = Earth

NYC v Seattle = US

US

India

Mumbai v India = India

NYC

Seattle

Mumbai

Delhi

Bronx

Brooklyn

Capitol Hill

Ballard

Bandra

Marine Drive

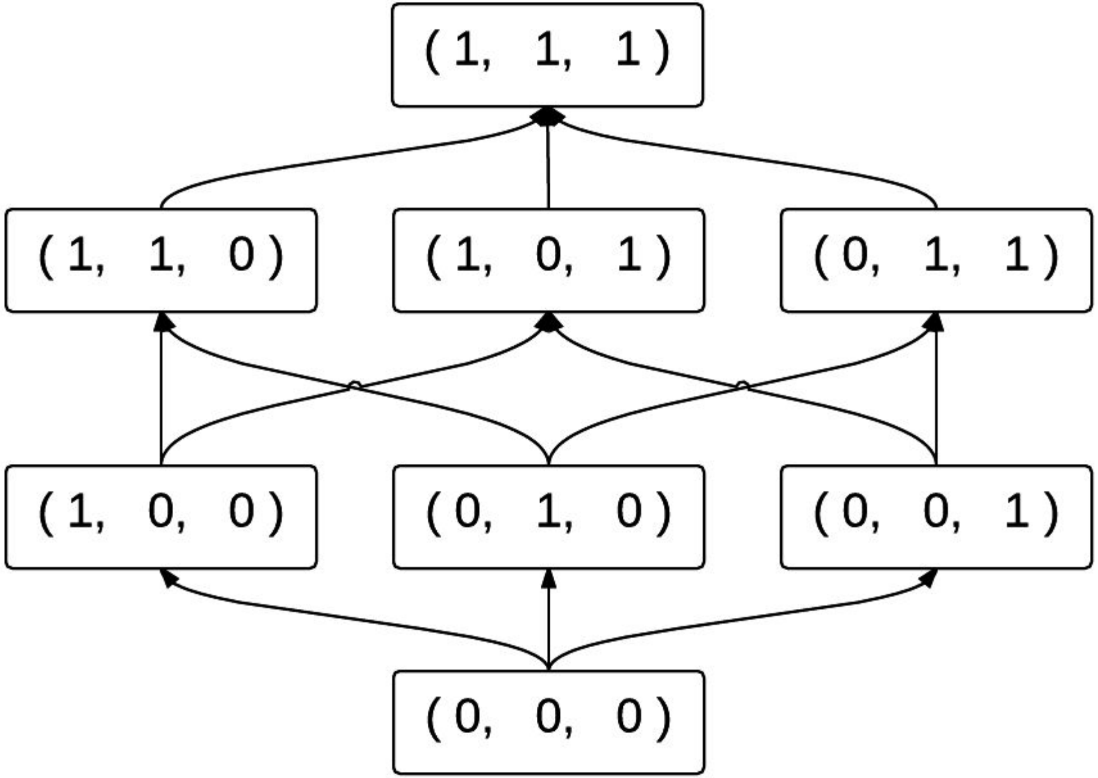
Lajpat Nagar

Nehru Place

- A *join semilattice* is an order <S,≤> for which there exists a join x∨y for any x,y∈S

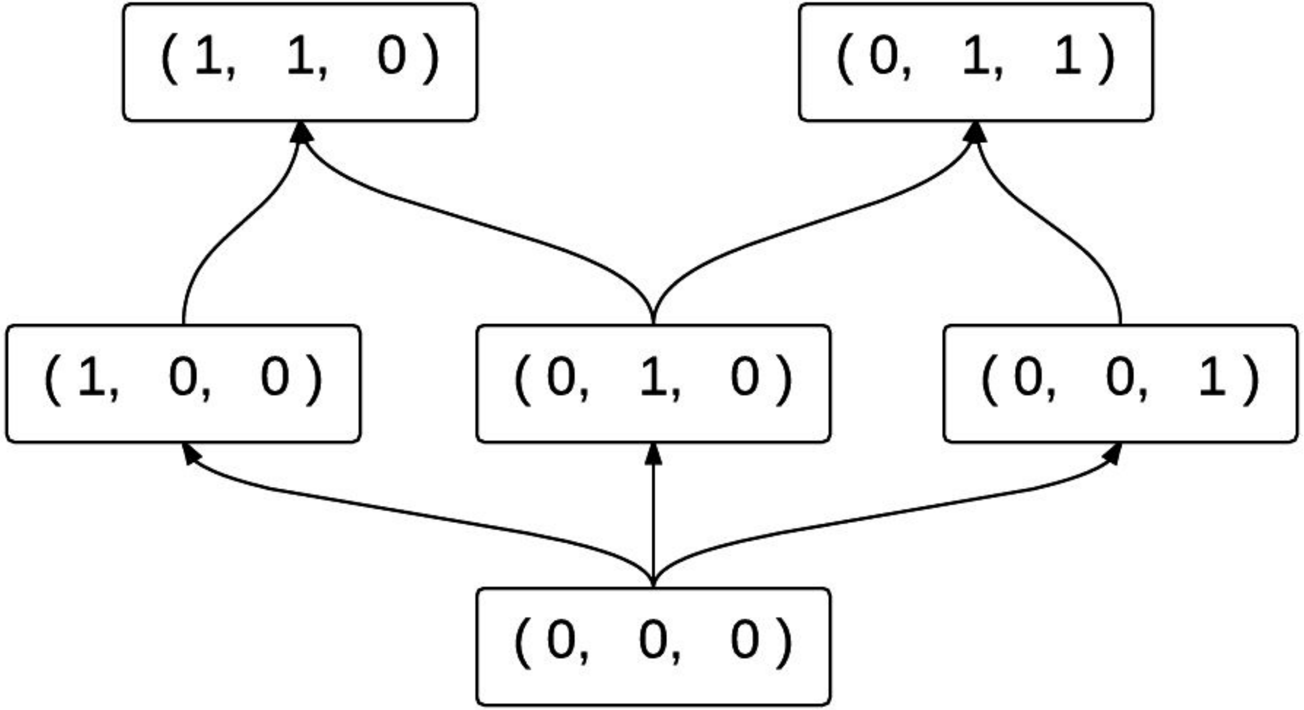
$$(0,0,0) \vee (0,0,1) = (0,0,1)$$
$$(1,0,0) \vee (0,1,1) = (1,1,1)$$
$$(1,0,1) \vee (1,0,1) = (1,0,1)$$
$$(0,1,0) \vee (0,0,1) = (0,1,1)$$

Happened-Before Order

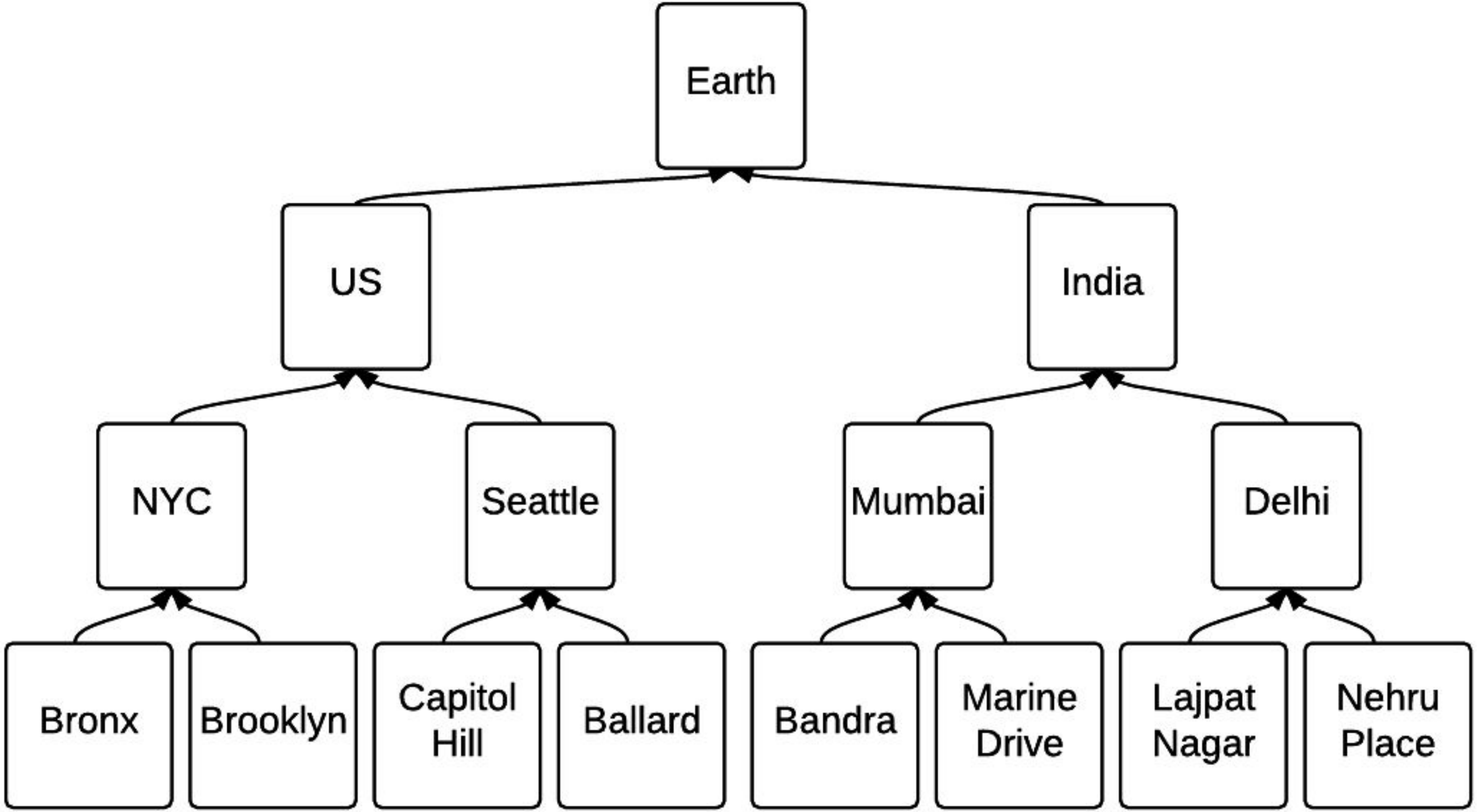


NOT A JOIN SEMI-LATTICE!

(1, 1, 0) v (0, 1, 1)
does not exist



Located-in Order



Earth

US

India

NYC

Seattle

Mumbai

Delhi

Bronx

Brooklyn

Capitol Hill

Ballard

Bandra

Marine Drive

Lajpat Nagar

Nehru Place

Joins obey three laws

- *Commutativity*: $a \vee b = b \vee a$
- *Associativity*: $(a \vee b) \vee c = a \vee (b \vee c)$
- *Idempotence*: $a \vee a = a$

- Joins tend to move *“upwards”*, so do merges of state-based CRDTs tend to converge on the *One True Value*

One True Value to Unite Them All

Convergent CRDTs

- *State* (elements of set)
- *merge()* function

$$merge(1,3) = 3$$
$$merge(9,5) = 9$$
$$merge(8,8) = 8$$

- *merge()* is max() here
- Can we use sum()?

$$merge((1,0,0),(0,1,1)) = (1,1,1)$$
$$merge((0,0,0),(2,0,2)) = (2,0,2)$$
$$merge((5,3,1),(1,9,2)) = (5,9,2)$$

$$merge(Seattle, Mumbai) = Earth$$
$$merge(Bronx, NYC) = NYC$$
$$merge(Mumbai, Delhi) = India$$

- *System*: set of available state at the moment

  [2, 5, 7]

- *Background set*: all integers
- *Value* of the System: upper bound of corresponding semilattice diagram (consistent value)

  Value([2,5,7])=7

- The *order of merges* doesn’t matter. This is guaranteed by the *associativity* and *commutativity* of joins.

- It doesn’t matter how many times we *repeat* a particular merge. This is guaranteed by the *idempotence* of joins.

Why do we care about this ?

Implementing a CvRDT

counter with a simple interface:

- *increment()*: increment the counter
- *value()*: gets the value of the counter

- 3 nodes X, Y, Z
- Set includes all integers
- merge() is max()

Imagine the following history:

- Start with 0 on all nodes
- Node 1 increments 3 times
- Node 2 increments 2 times
- Node 3 increments 1 time

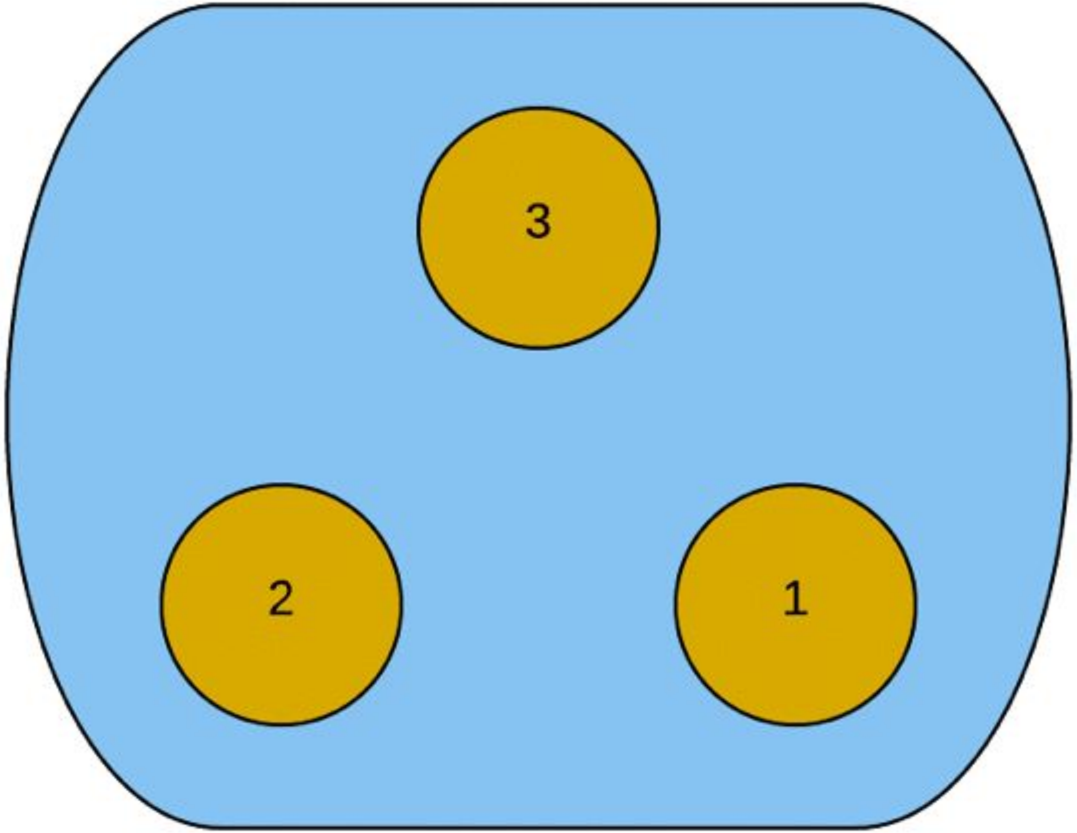
What should be the final result ?

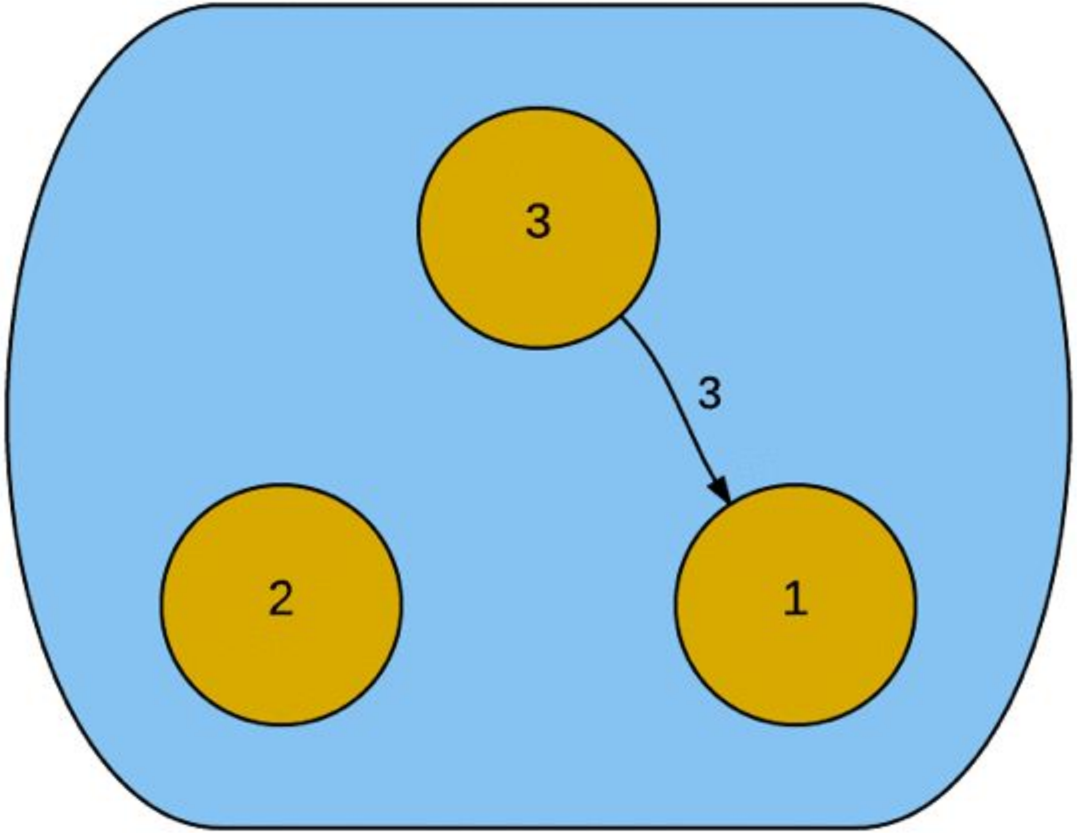
Imagine the following history:

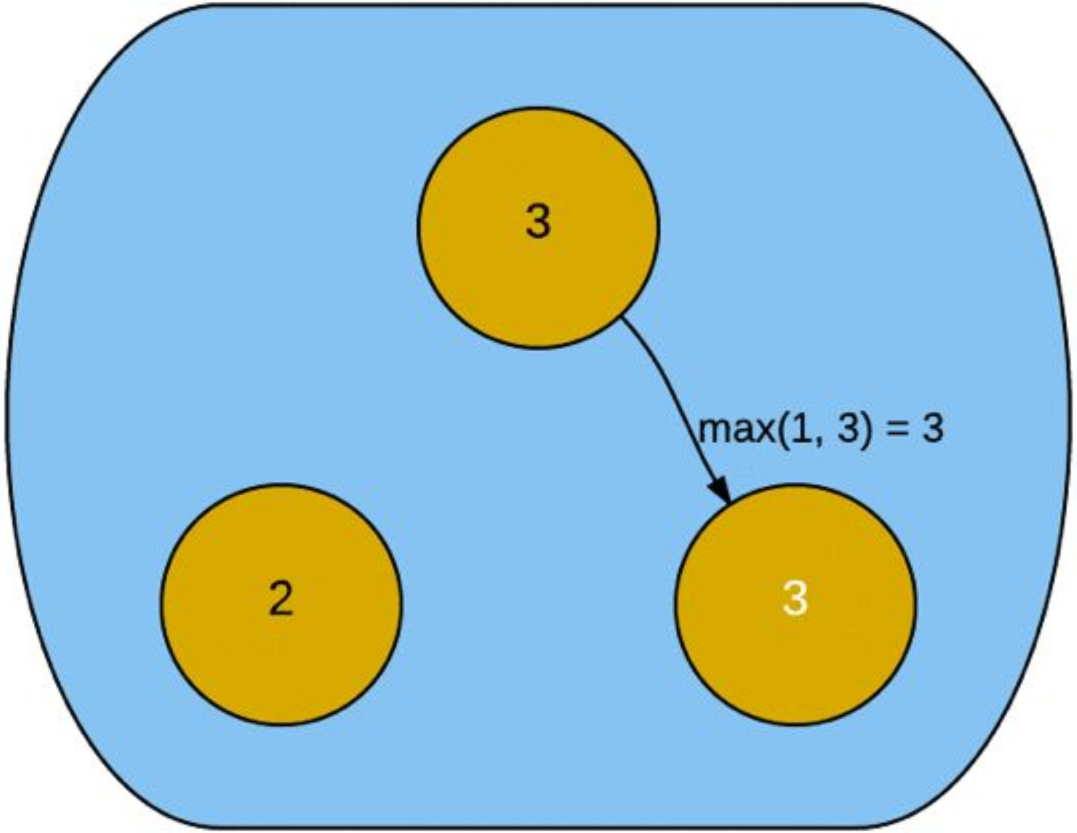
- Start with 0 on all nodes
- Node 1 increments 3 times
- Node 2 increments 2 times
- Node 3 increments 1 time

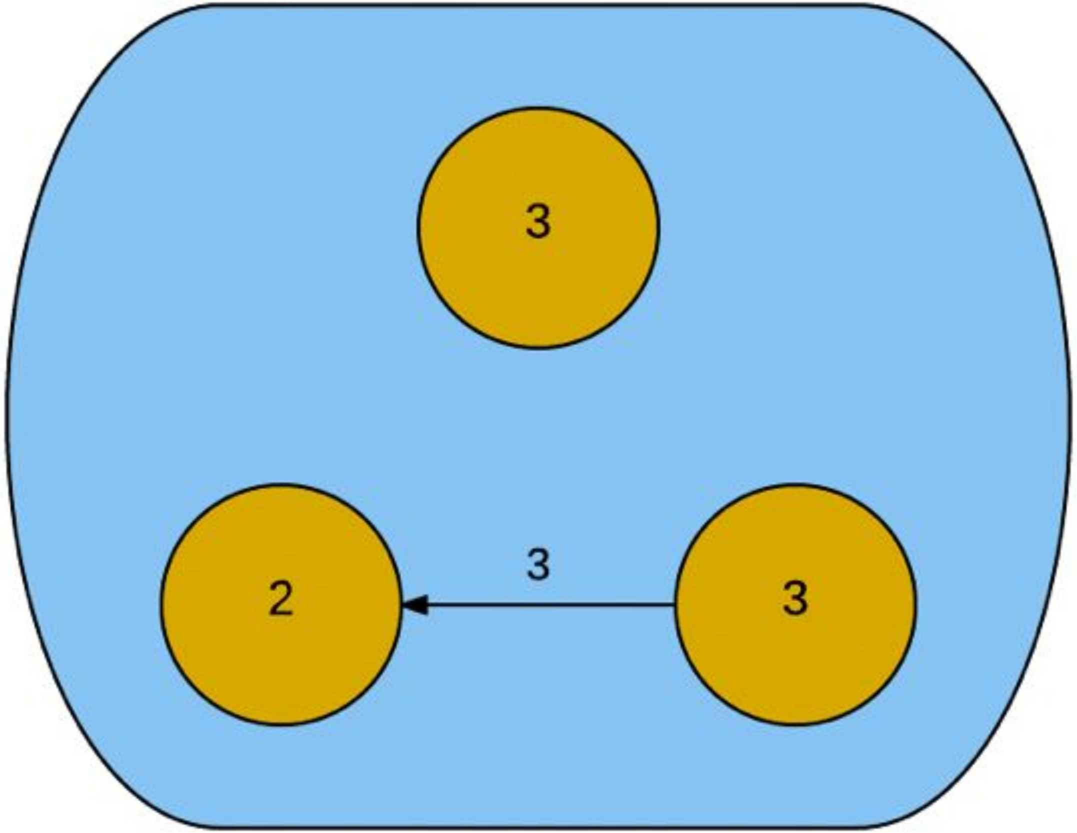
What should be the final result ?

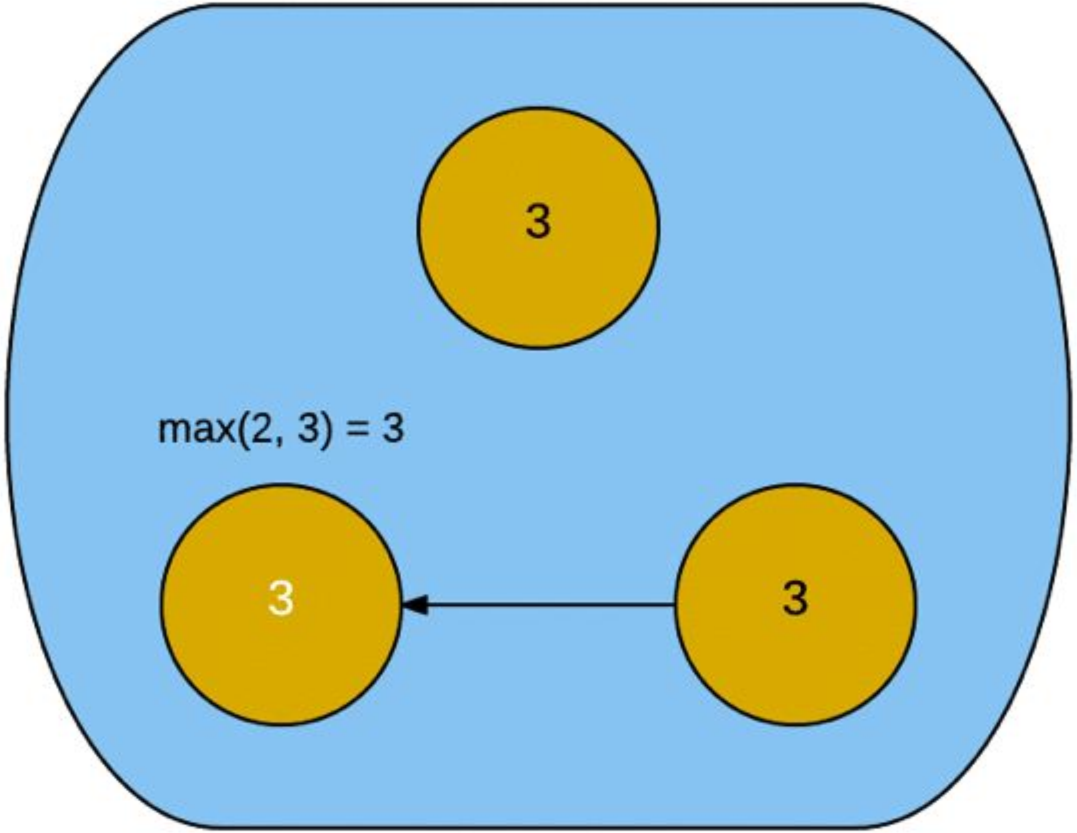
6


3
2
1


3
3
2
1


3
max(1, 3) = 3
2
3


3
2
3
3


3
max(2, 3) = 3
3
3

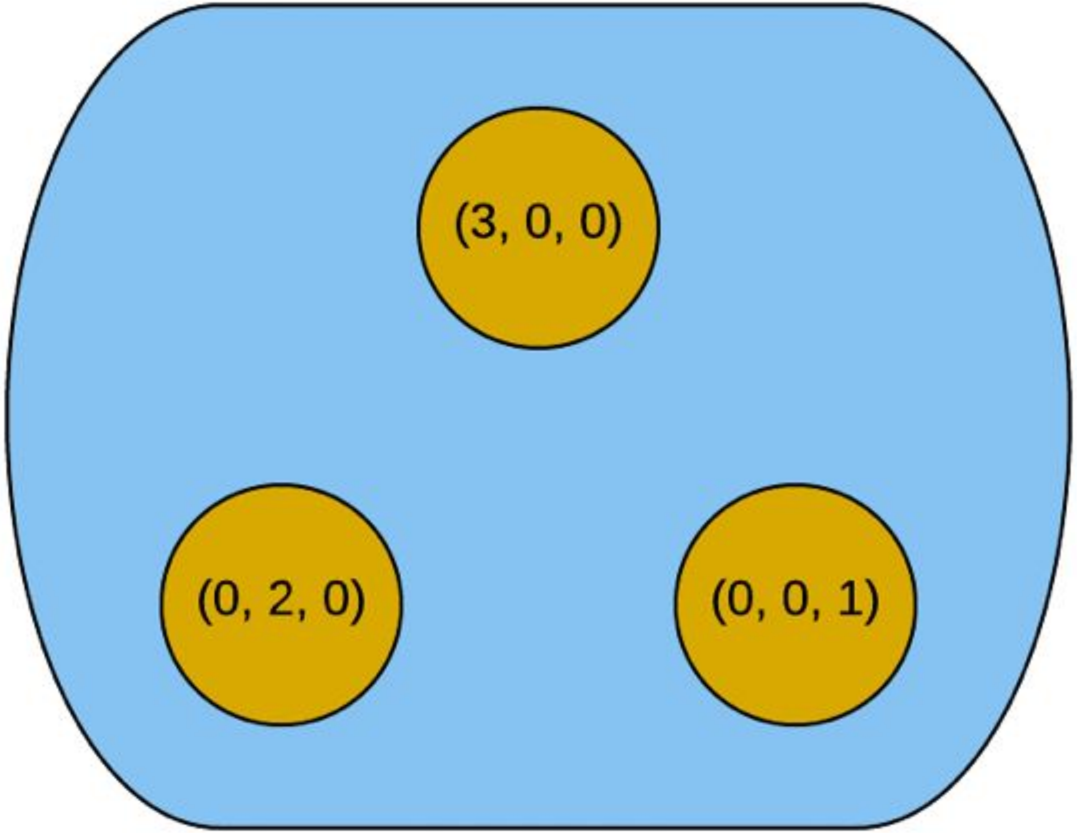
- Weren’t we supposed to get **6**?

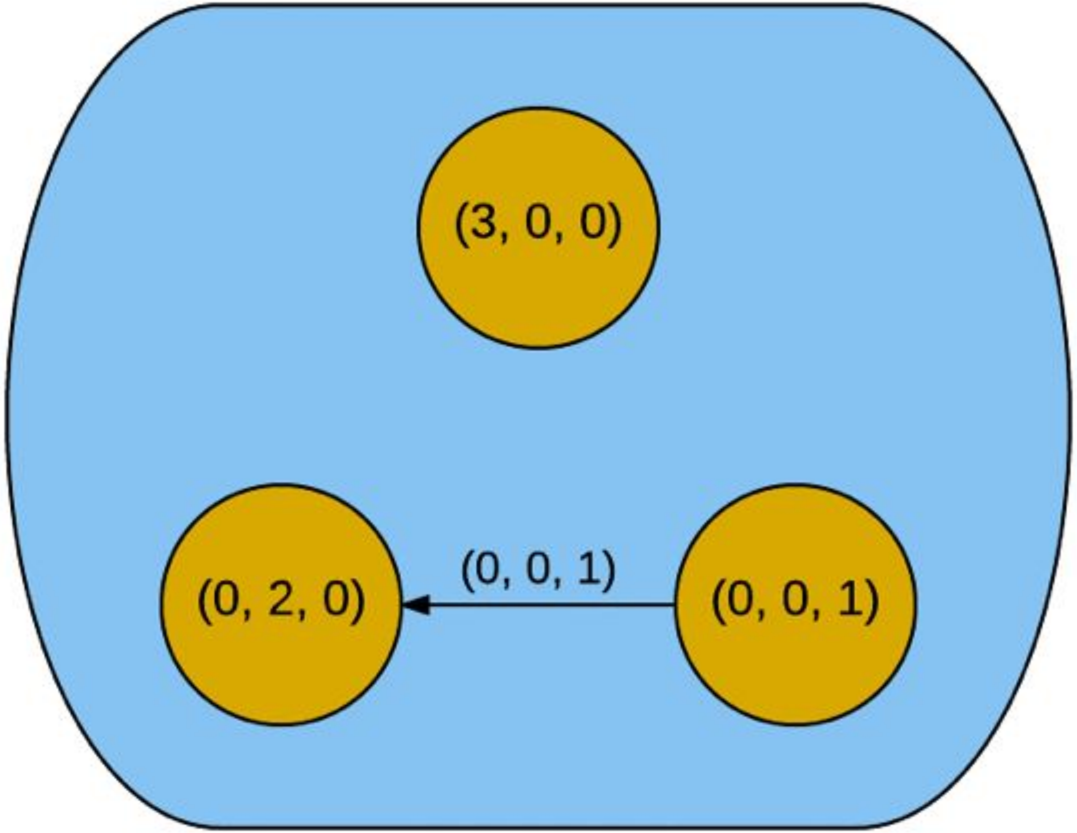
- Let’s use a better approach

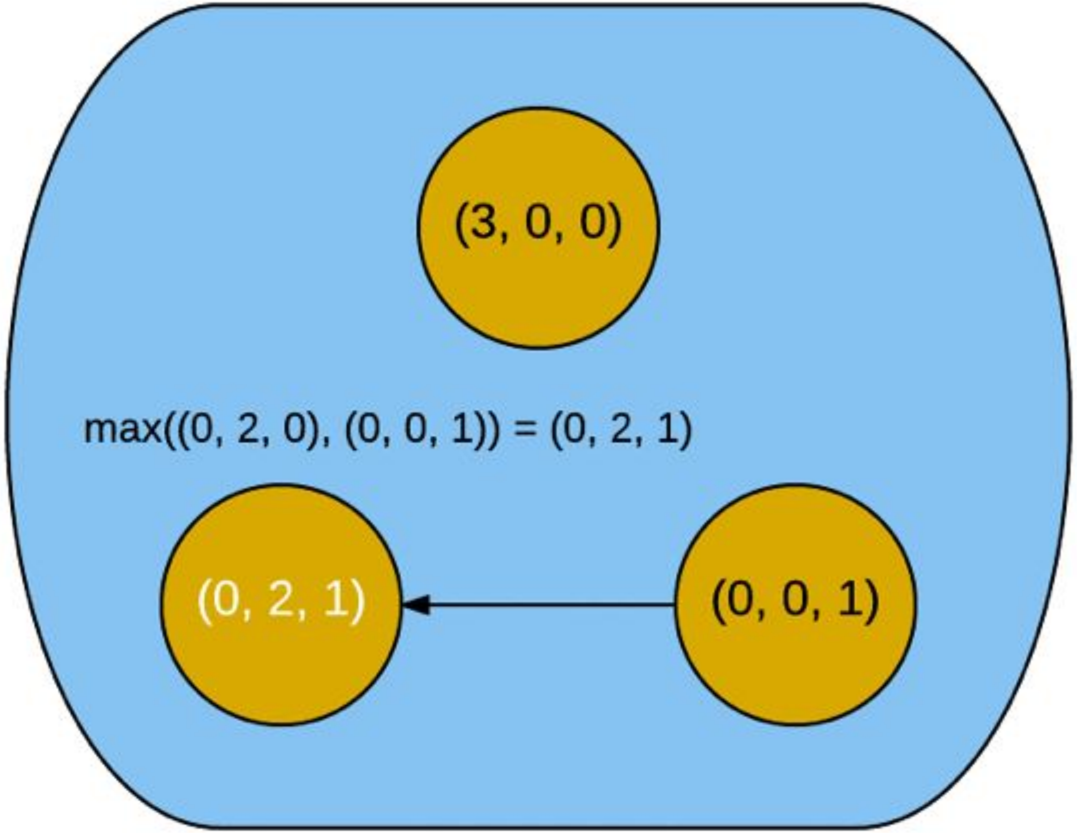
- Instead of *integers* use *vector of integers*
- *Value*: sum of all elements in the vectors

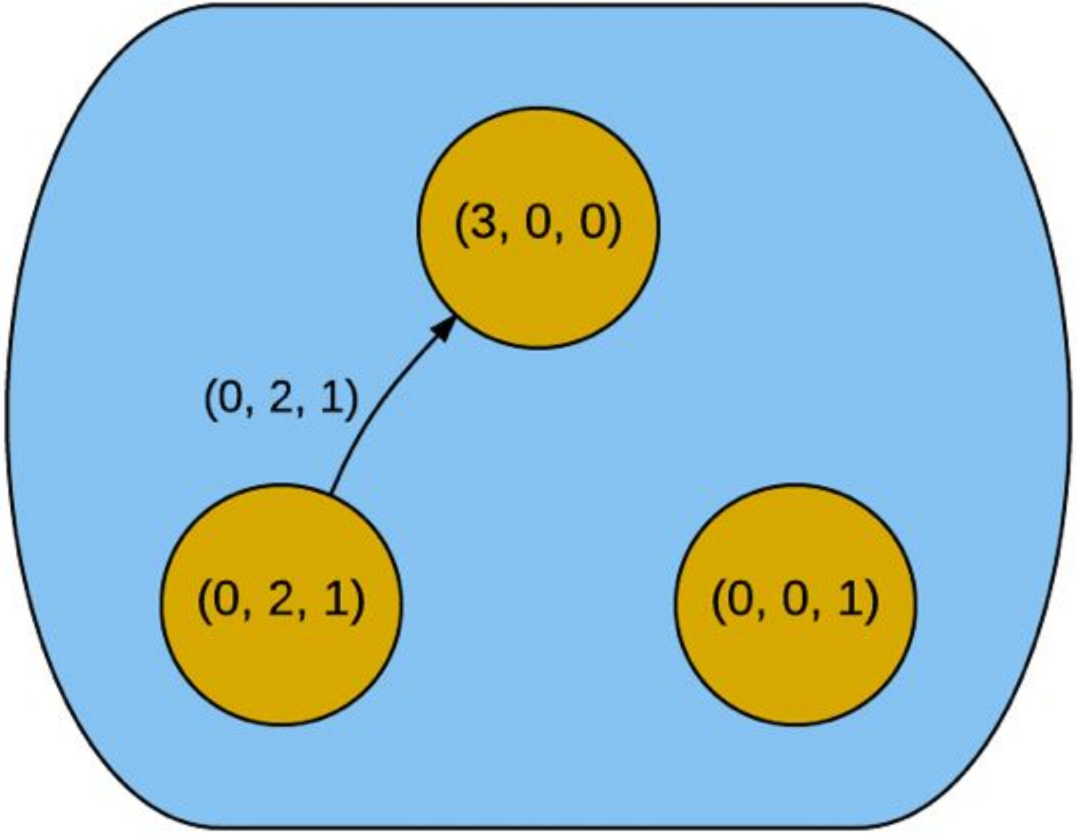
Last example becomes:

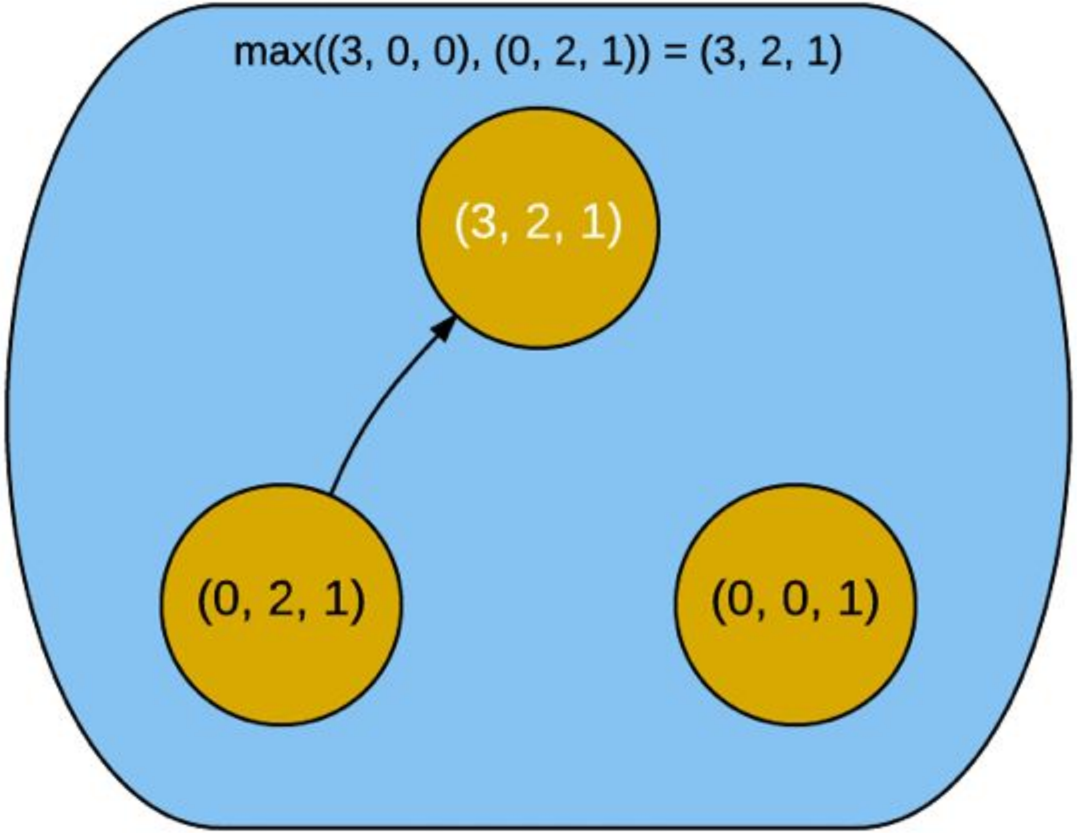
- X: (3, 0, 0)
- Y: (0, 2, 0)
- Z: (0, 0, 1)

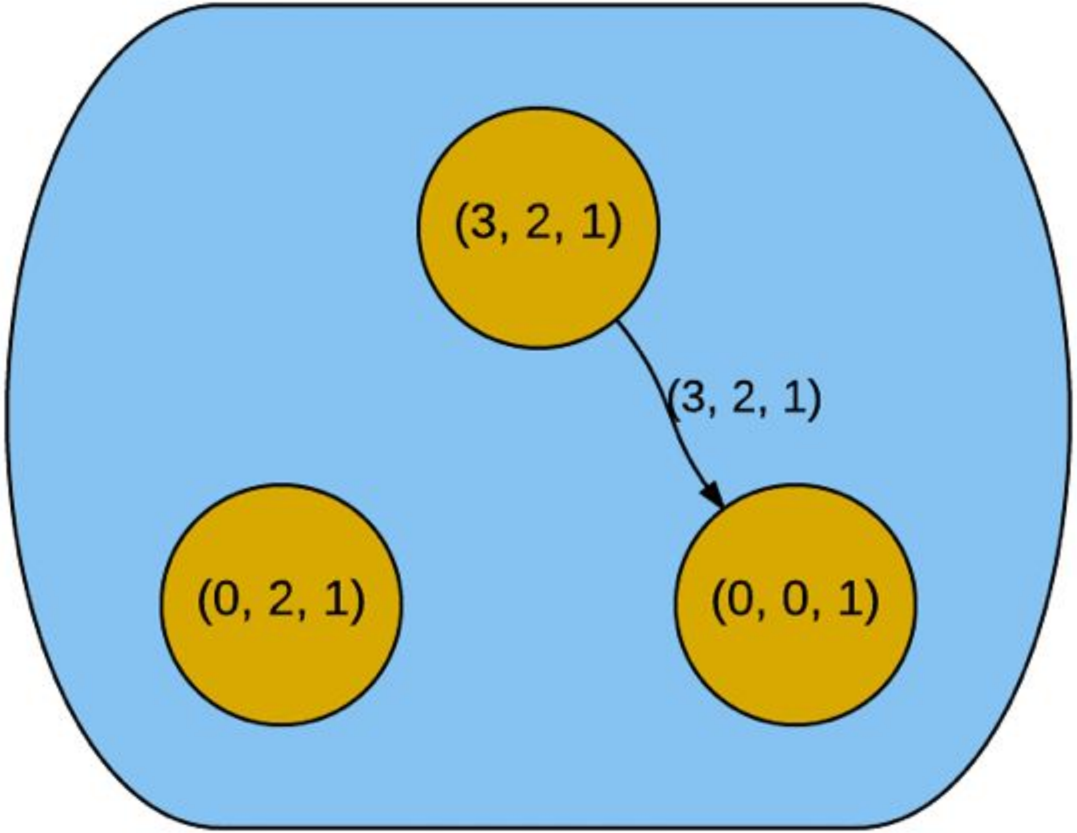

(3, 0, 0)
(0, 2, 0)
(0, 0, 1)

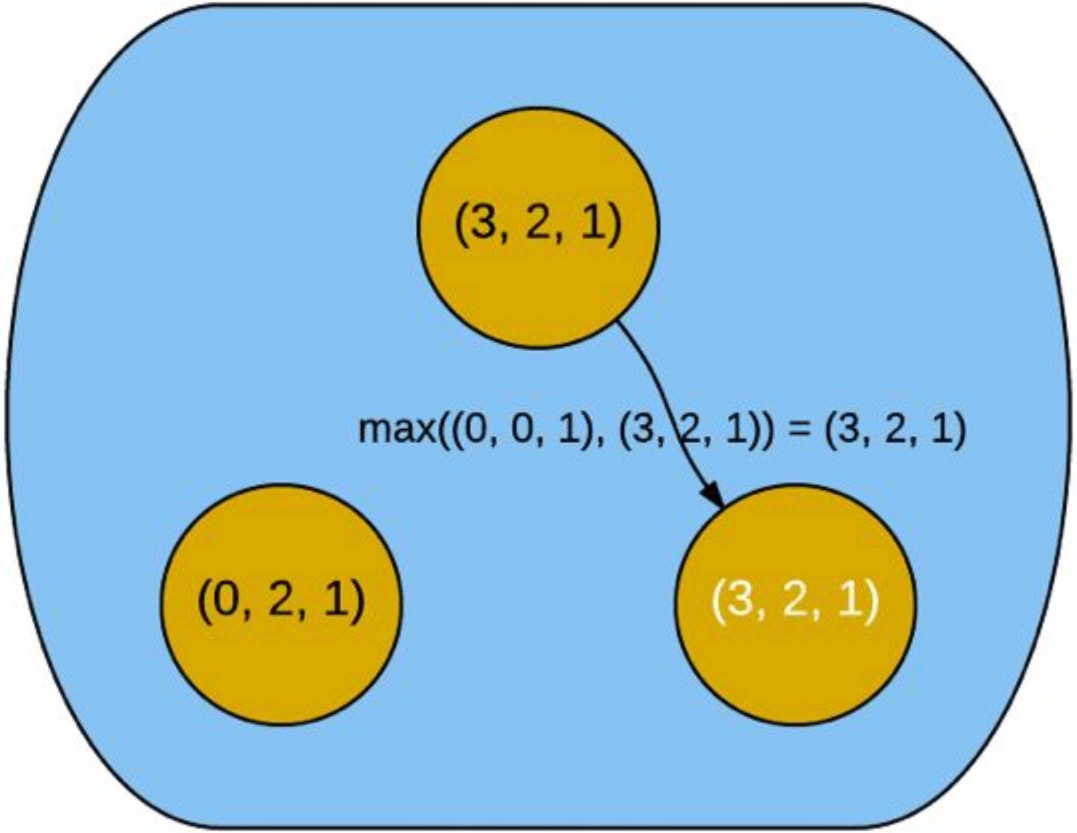

(3, 0, 0)
(0, 2, 0)
(0, 0, 1)
(0, 0, 1)

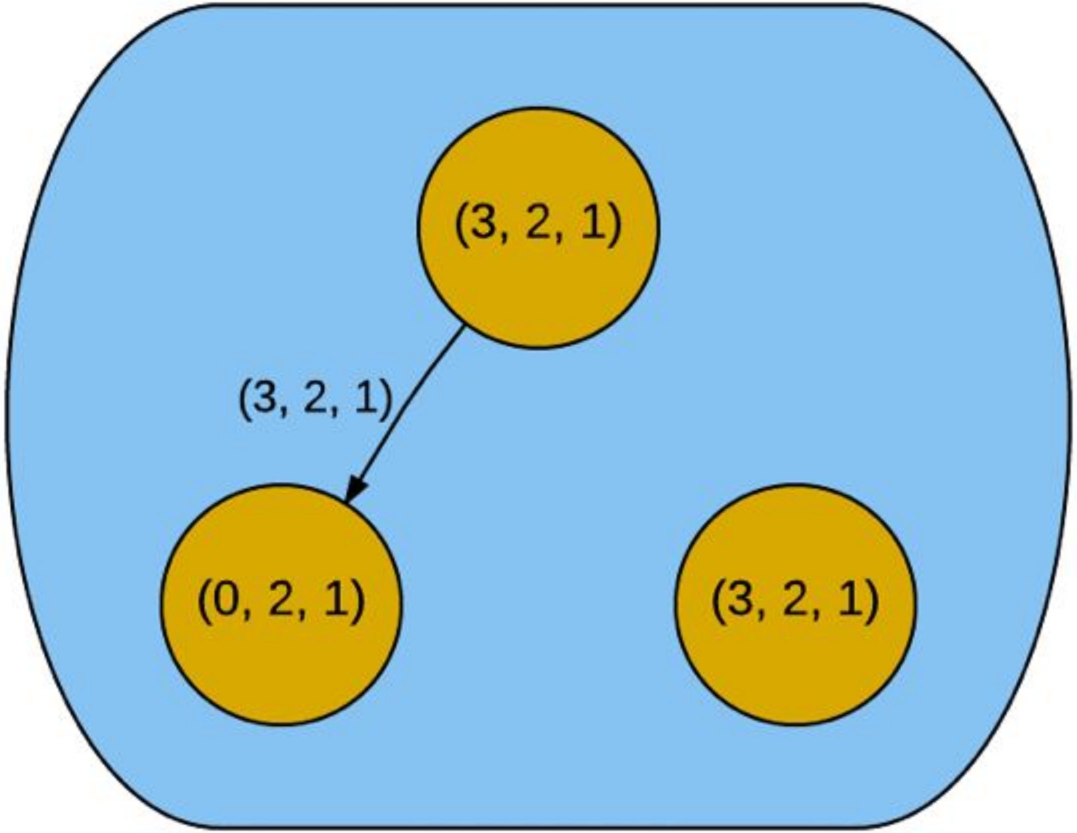

(3, 0, 0)
max((0, 2, 0), (0, 0, 1)) = (0, 2, 1)
(0, 2, 1)
(0, 0, 1)

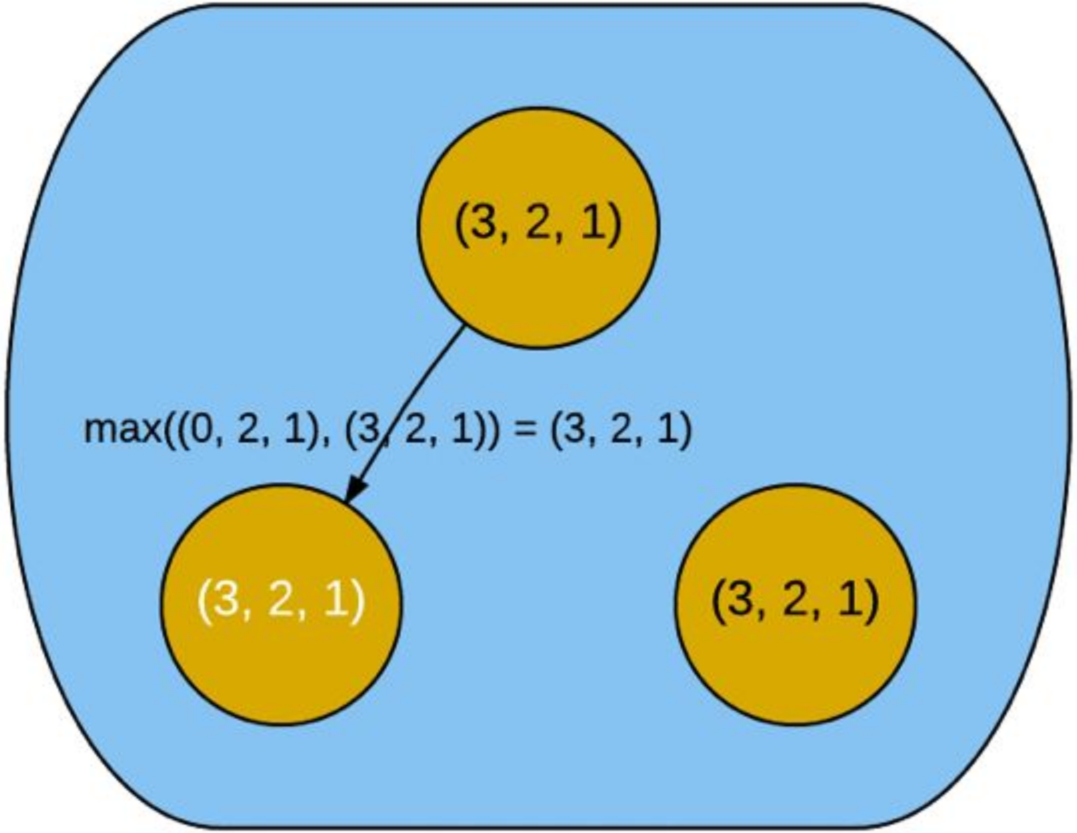

(3, 0, 0)
(0, 2, 1)
(0, 2, 1)
(0, 0, 1)


max((3, 0, 0), (0, 2, 1)) = (3, 2, 1)
(3, 2, 1)
(0, 2, 1)
(0, 0, 1)

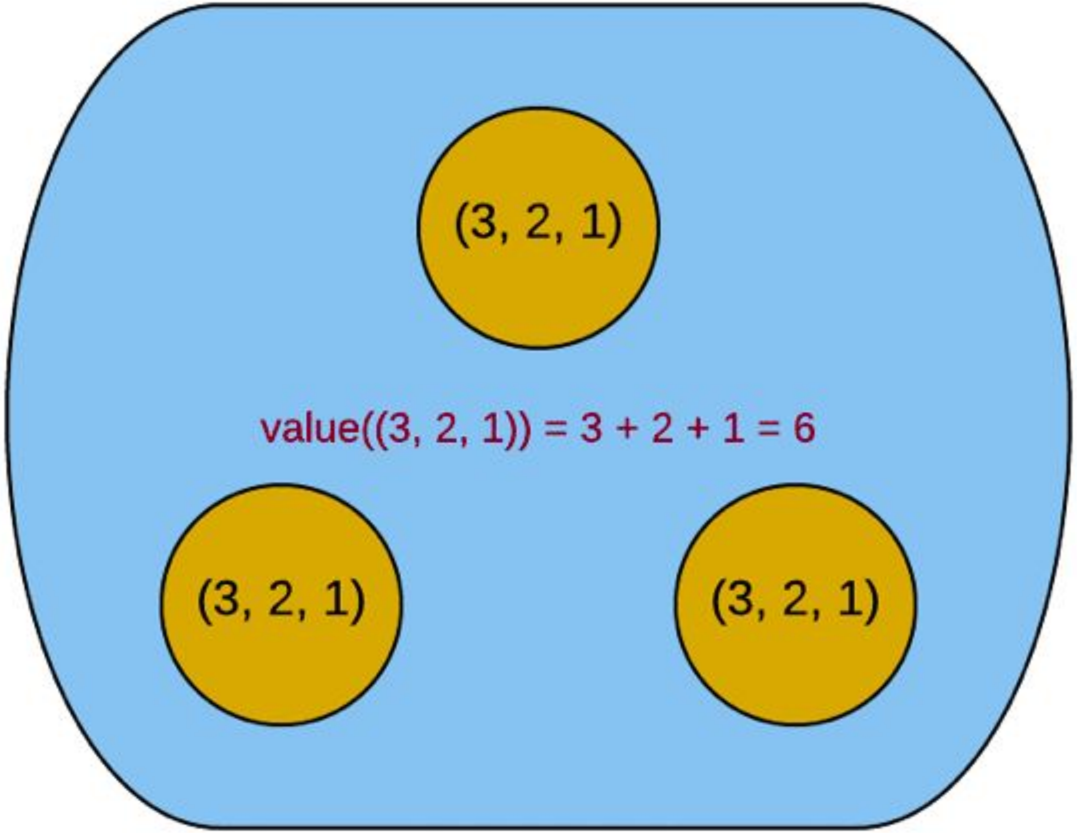

(3, 2, 1)
(3, 2, 1)
(0, 2, 1)
(0, 0, 1)


(3, 2, 1)
max((0, 0, 1), (3, 2, 1)) = (3, 2, 1)
(0, 2, 1)
(3, 2, 1)


(3, 2, 1)
(3, 2, 1)
(0, 2, 1)
(3, 2, 1)

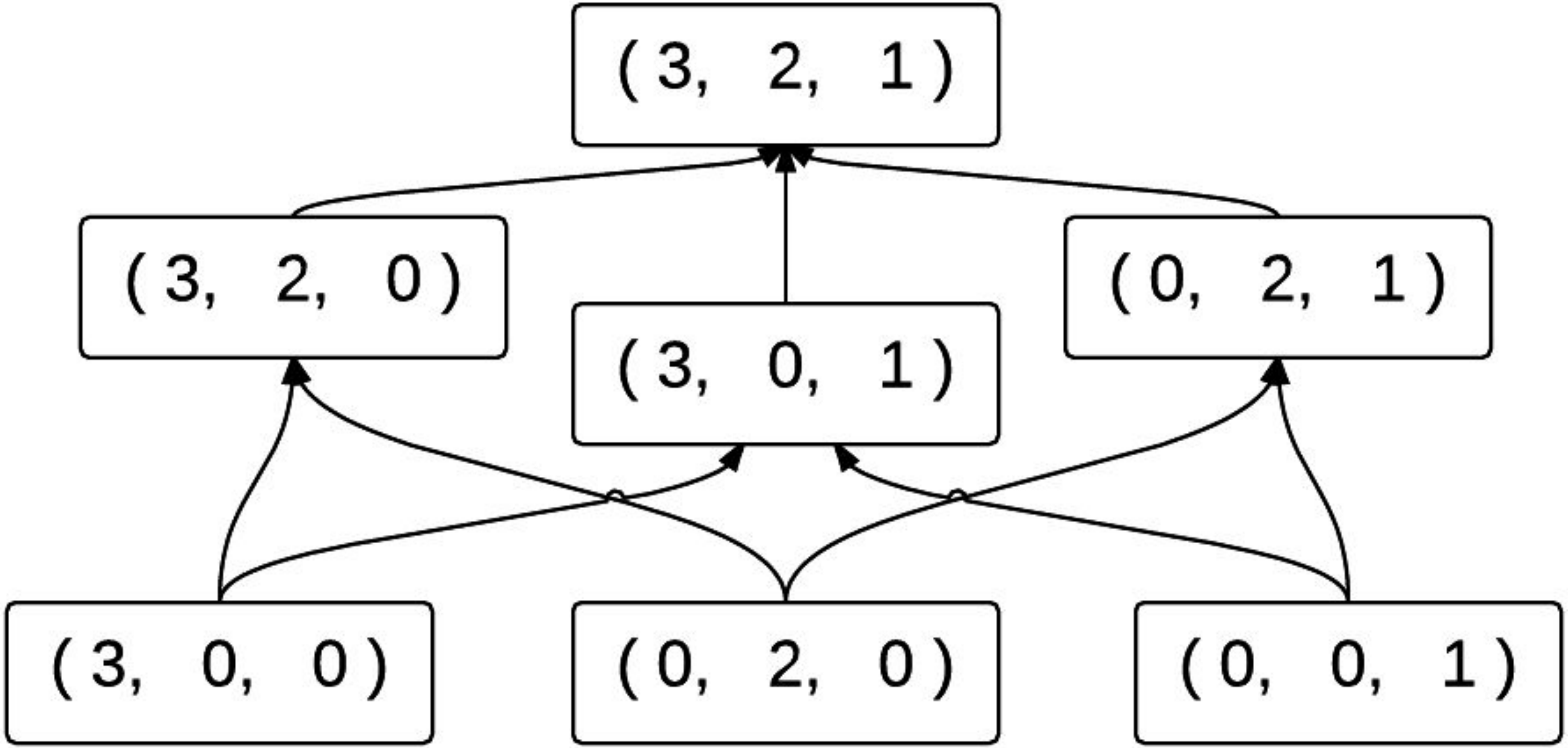


(3, 2, 1)
max((0, 2, 1), (3, 2, 1)) = (3, 2, 1)
(3, 2, 1)
(3, 2, 1)



(3, 2, 1)
value((3, 2, 1)) = 3 + 2 + 1 = 6
(3, 2, 1)
(3, 2, 1)

Semi-Lattice for Our System



- Create data-types that follow these *requirements*

References

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- "CRDTs Illustrated" by Arnout Engelen https://www.youtube.com/watch?v=9xFfOhasiOE
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- Paxos Simplified https://www.youtube.com/watch?v=SRsK-ZXTeZ0
- An extensive list of articles here https://github.com/ipfs/research-CRDT/
- https://en.wikipedia.org/wiki/Conflict-free_replicated_data_type