Spanner: Google's Globally-Distributed Database

Department of Computer Science and Engineering
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Courtesy

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Paper Information

- **Paper title:** Spanner: Google's Globally-Distributed Database
- **Authors:** Corbett JC, Dean J, Epstein M, Fikes A, Frost C, Furman JJ, Ghemawat S, Gubarev A, Heiser C, Hochschild P, Hsieh W, Kanthak S, Kogan E, Li H, Lloyd A, Melnik S, Mwaura D, Nagle D, Quinlan S, Rao R, Rolig L, Saito Y, Szymaniak M, Taylor C, Wang R, Woodford D
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Motivation

- Google's advertising backend: **F1**
  - originally based on MySQL
  - sharded manually
  - data too large for MySQL
- Stored some data to external BigTable:
  - difficult to use for applications with complex, evolving schema
  - no cross-row transaction

Spanner came up with solutions to all these and much more

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Features

- Globally distributed
- Scalable - *"Spanner is designed to scale up to millions of machines across hundreds of datacenters and trillions of database rows."*
- Cross-datacenter replication of data
- Semi-relational
- Multiversioned

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- External consistency of distributed transactions
  - $T(e_{1commit}) < T(e_{2start}) \implies s_1 < s_2$
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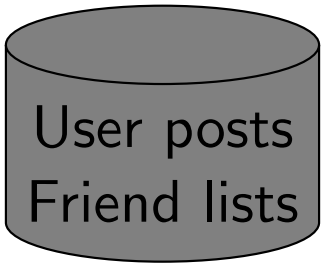

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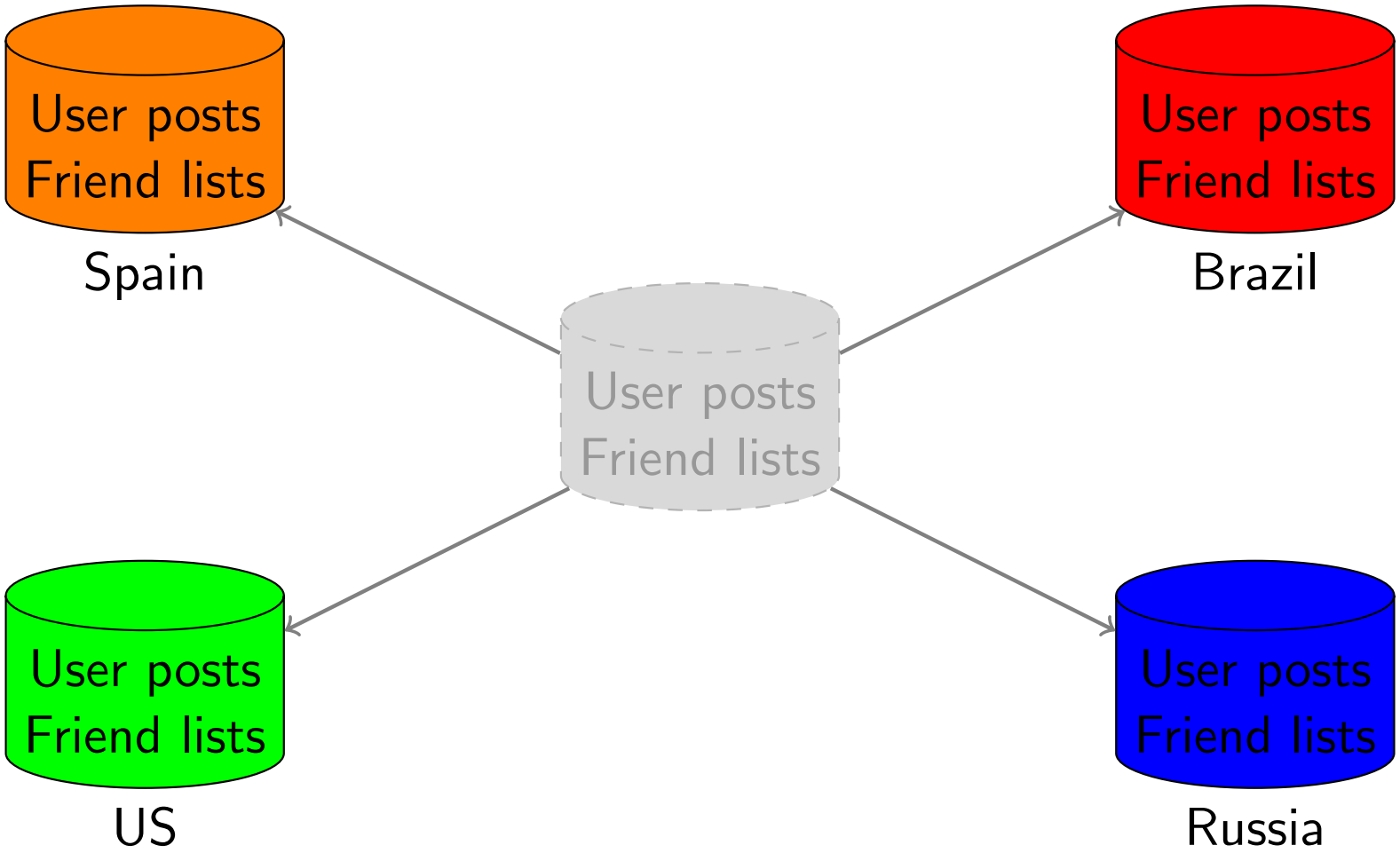

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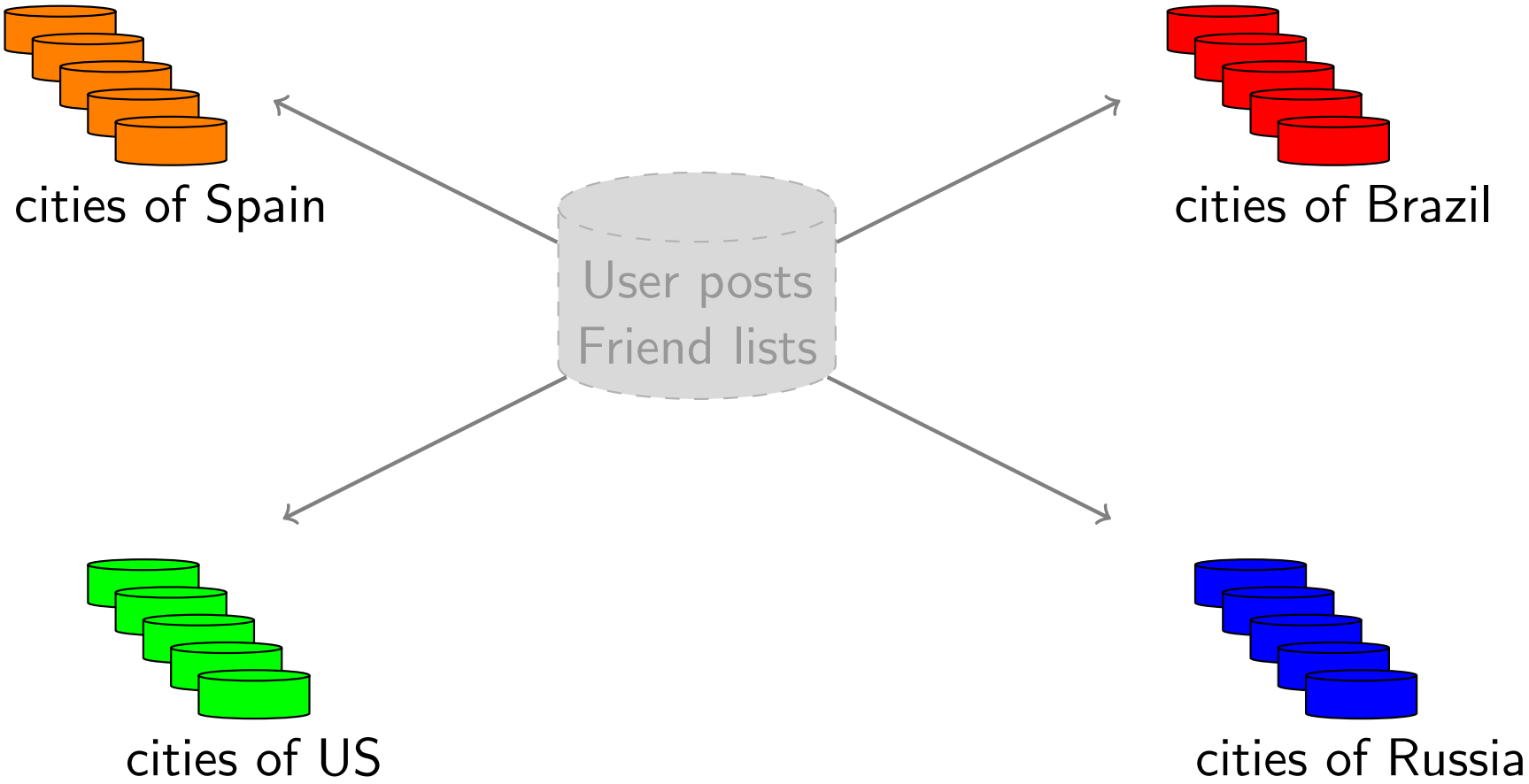
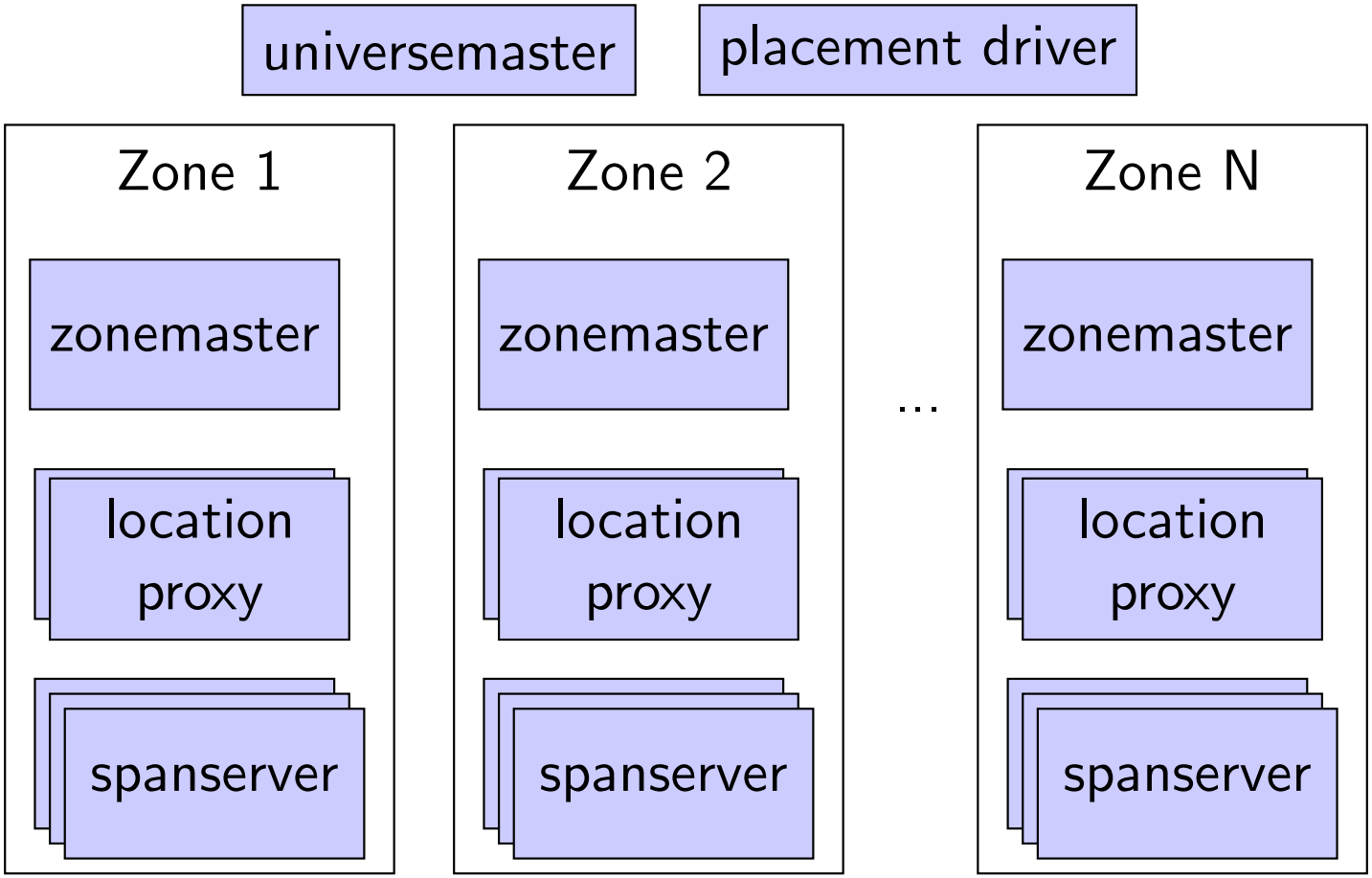
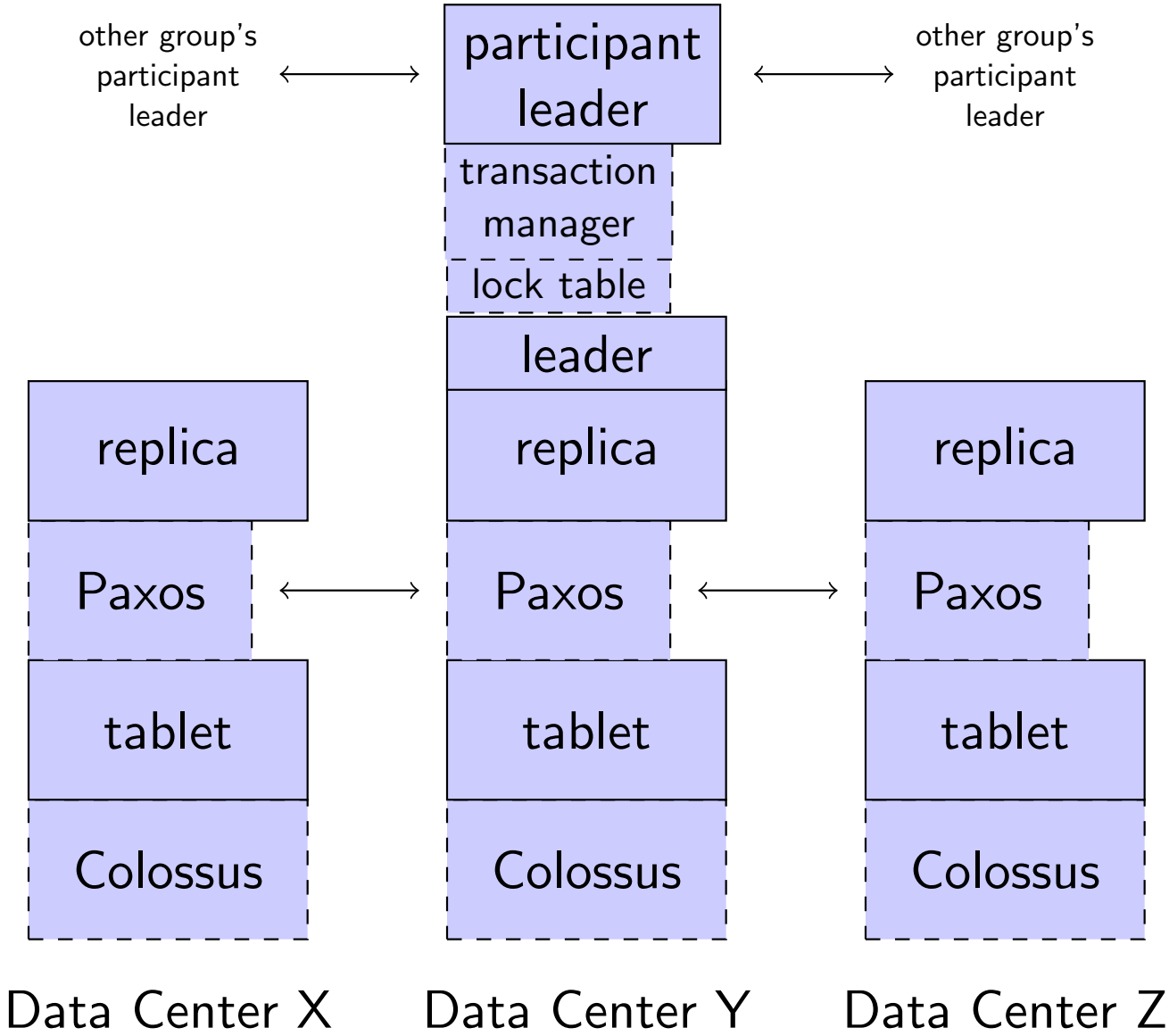


Spanner Server Organization



Spanserver Software Stack



Data Model

- (key:string, timestamp:int64) $\rightarrow$ string
- Directory:
  - set of contiguous keys that share a common prefix
  - unit of data placement and movement
  - might be reduced to fragments

Read Transactions

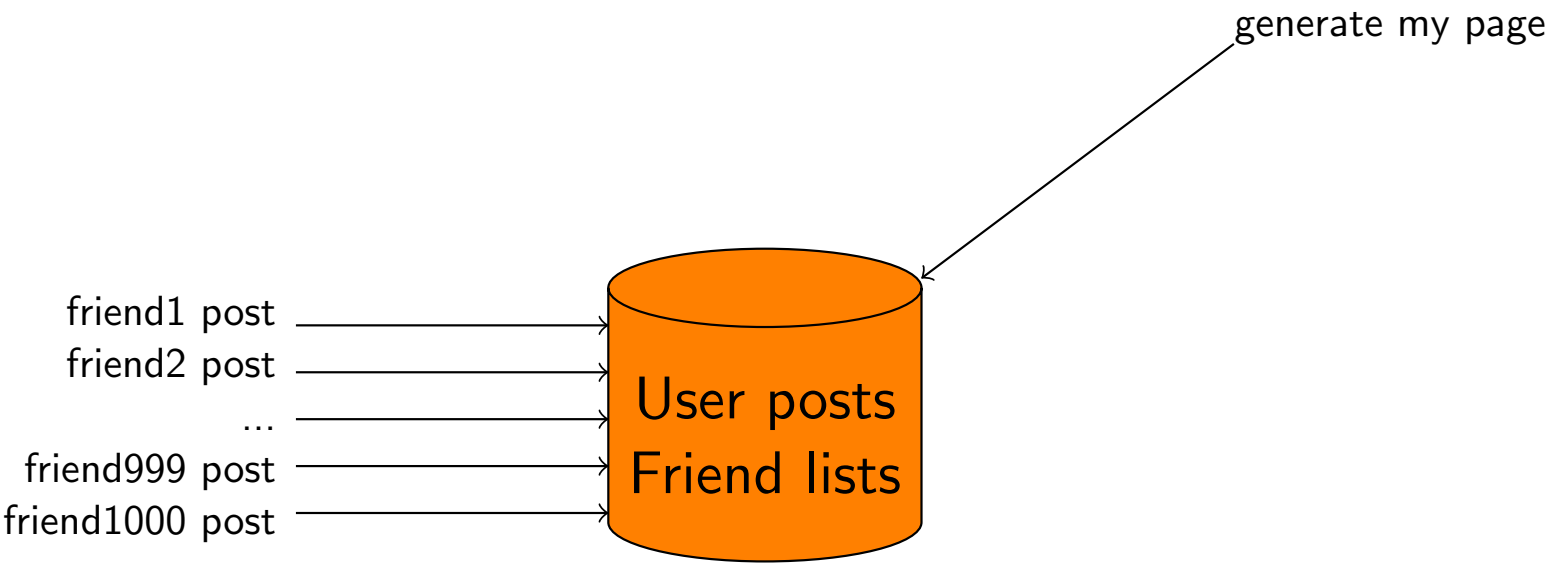
Why consistency matters?

- Generate a page of friends' recent posts
  - Consistent view of friend list and their posts

Why Consistency Matters

1. Remove untrustworthy person X as friend
2. Post P: "My government is repressive"

Single Machine



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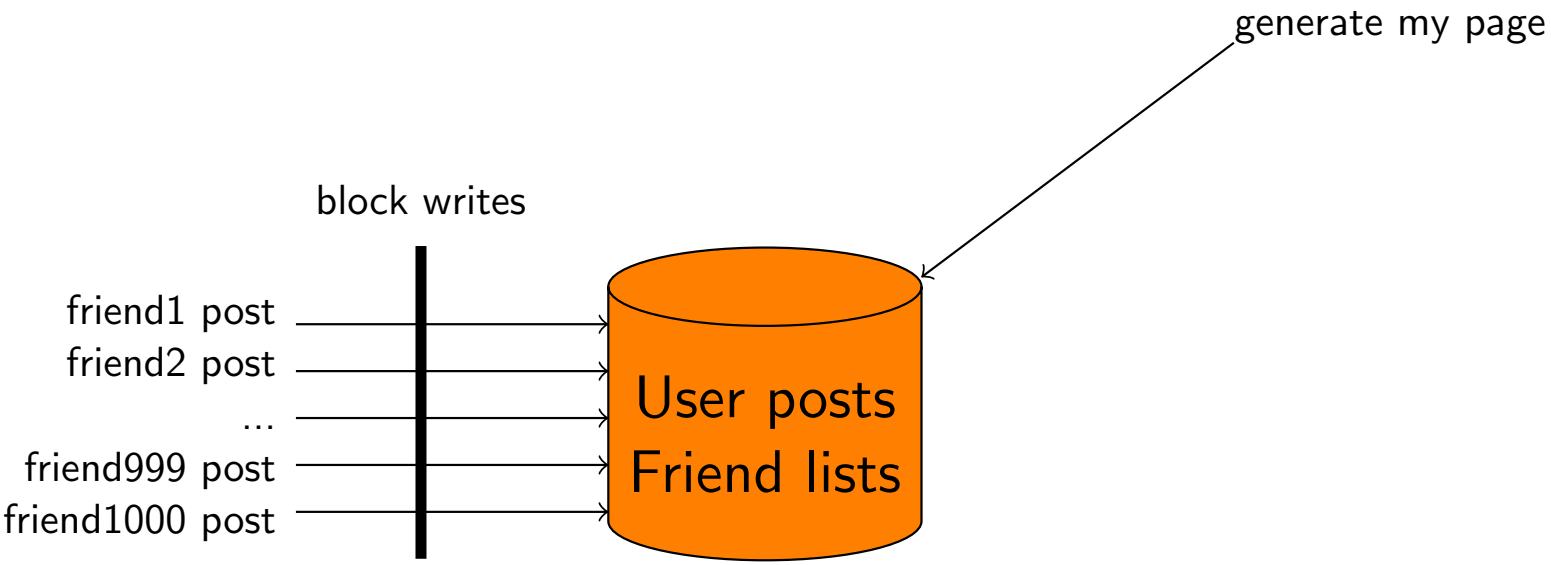

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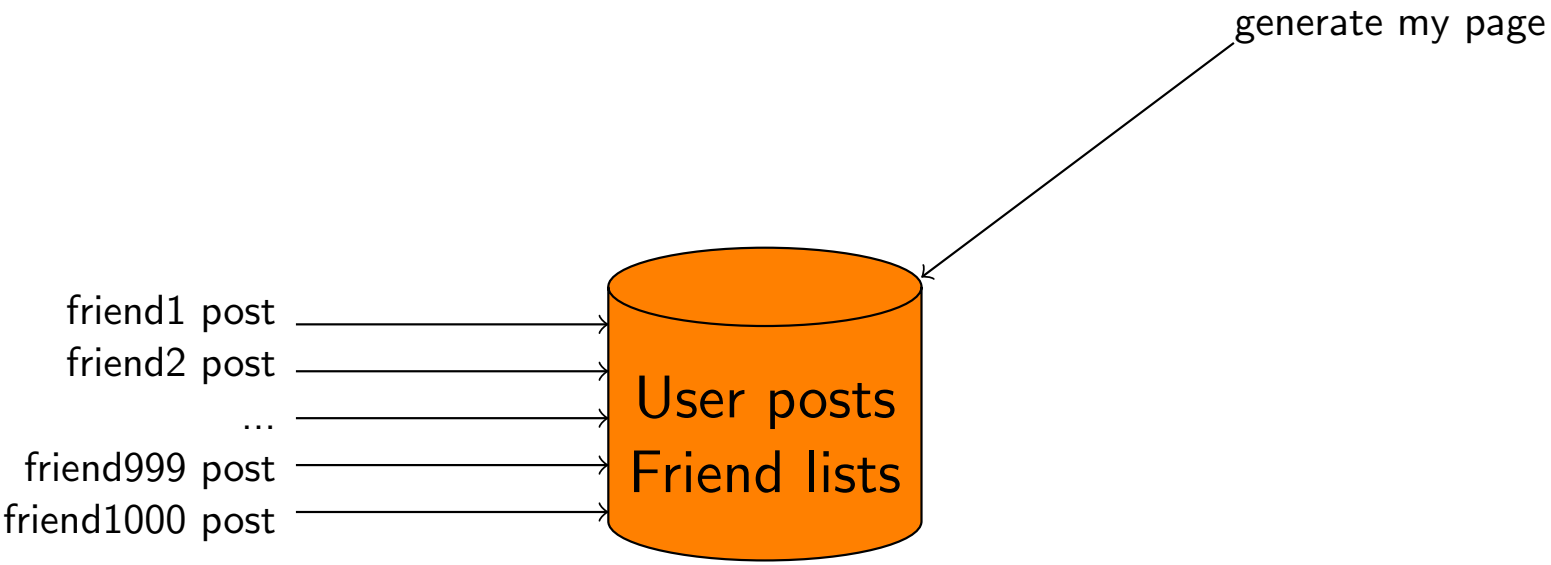

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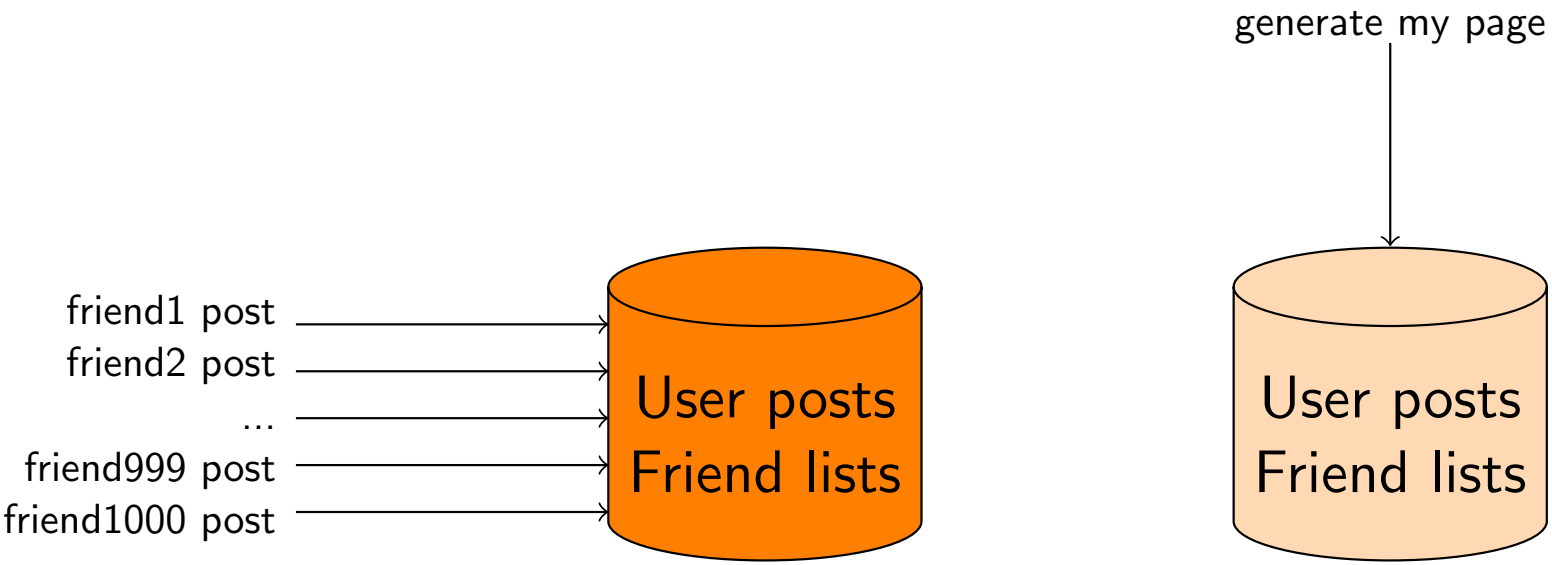

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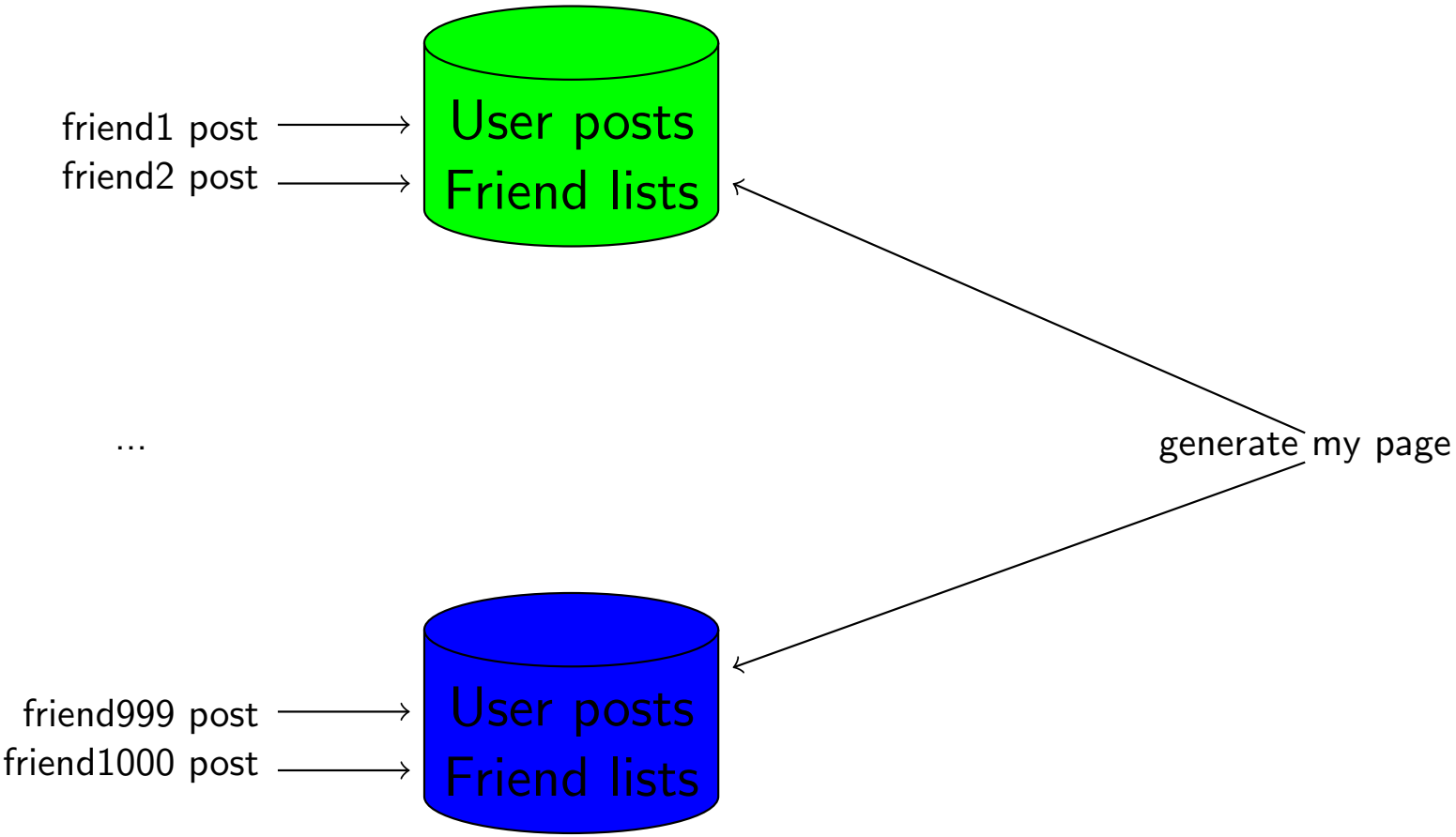

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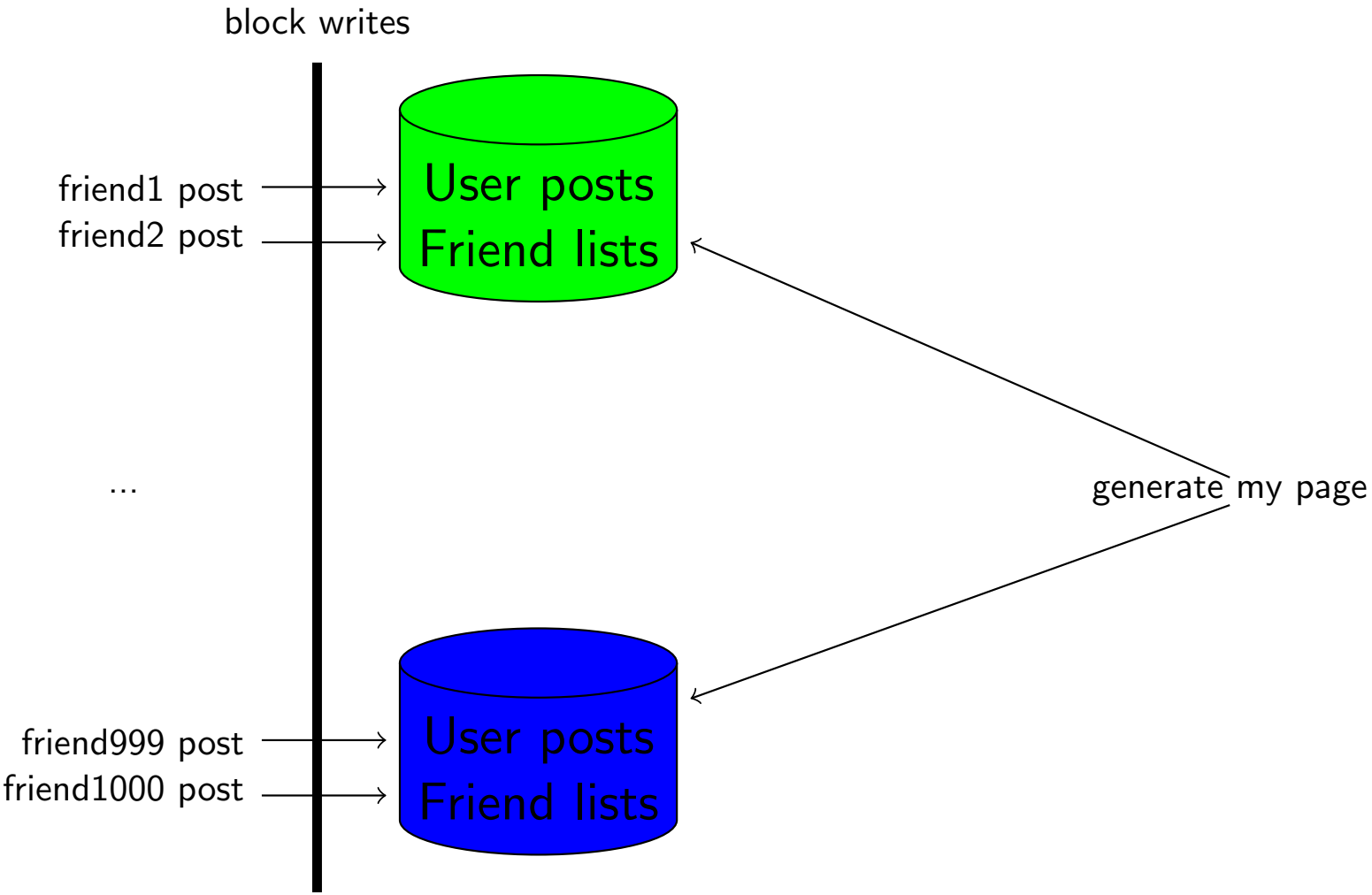

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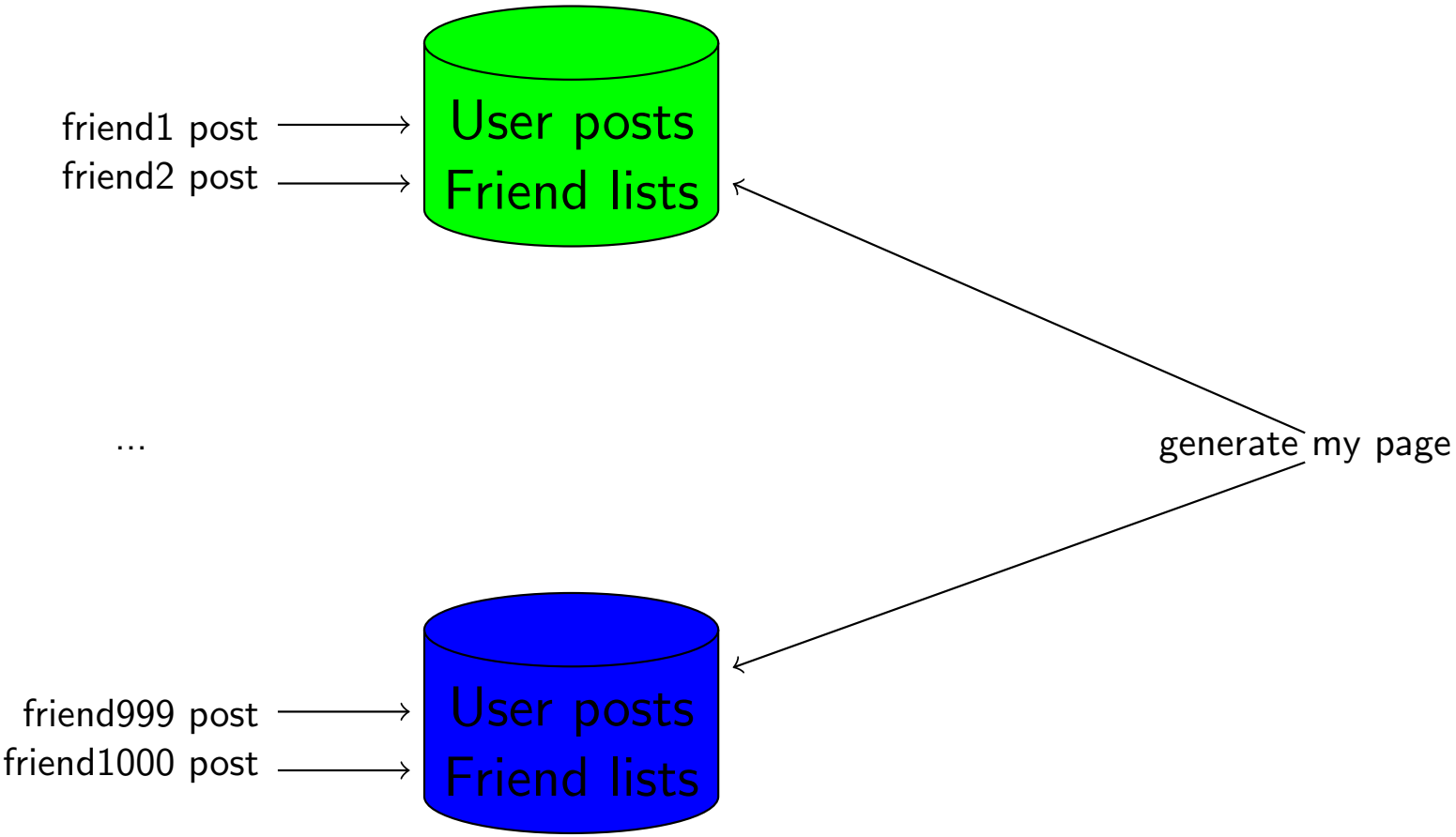

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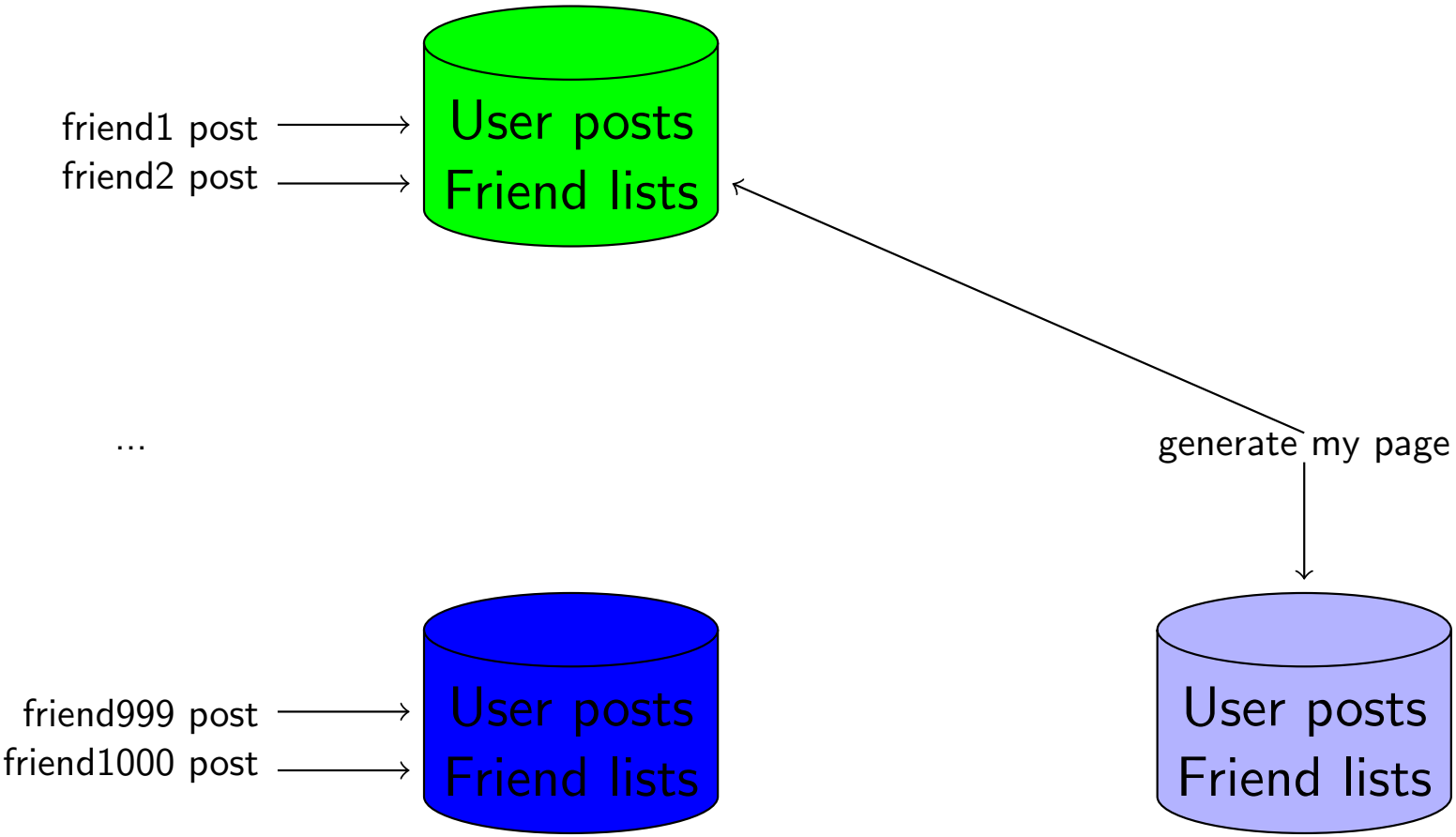

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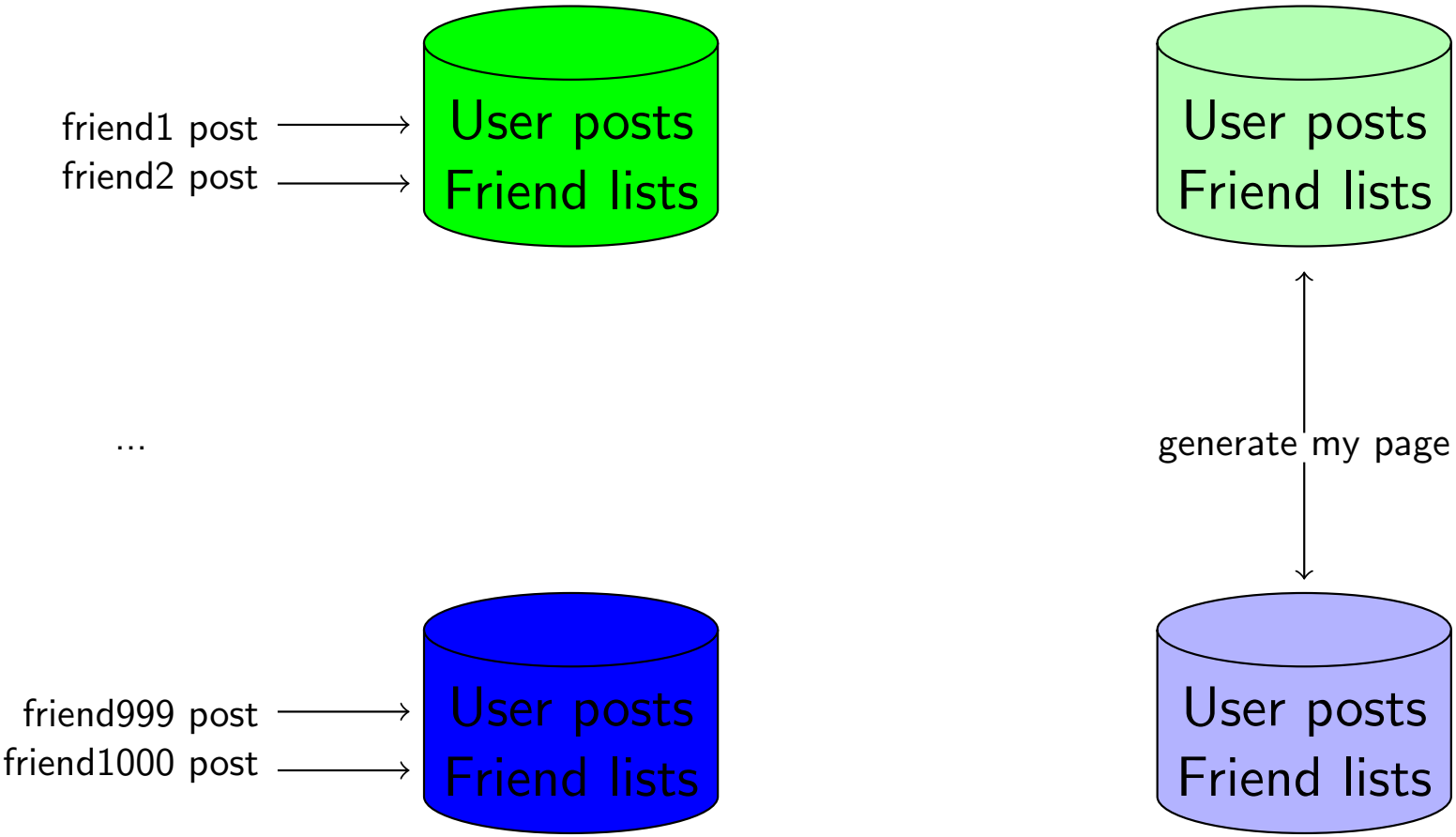

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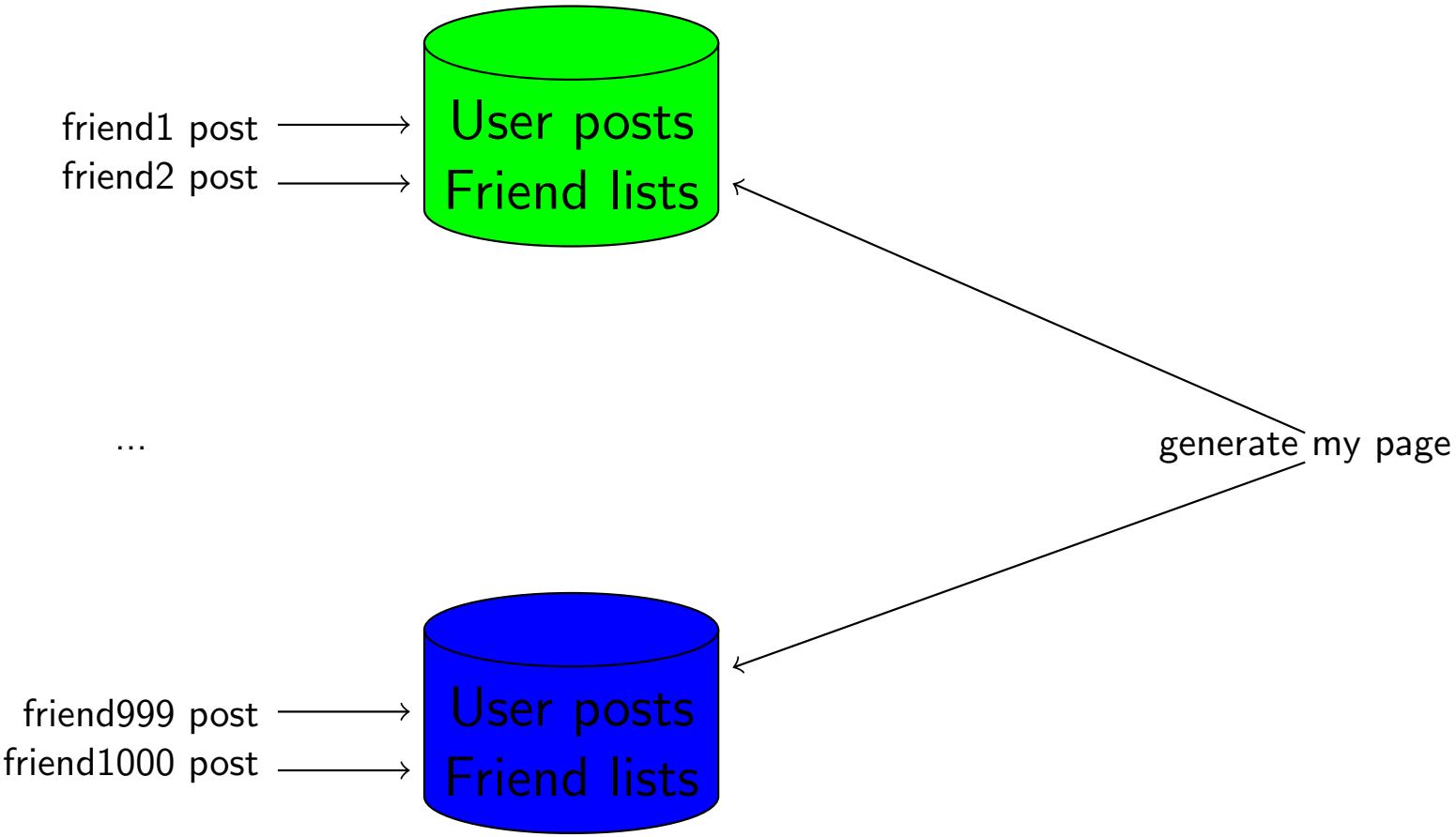

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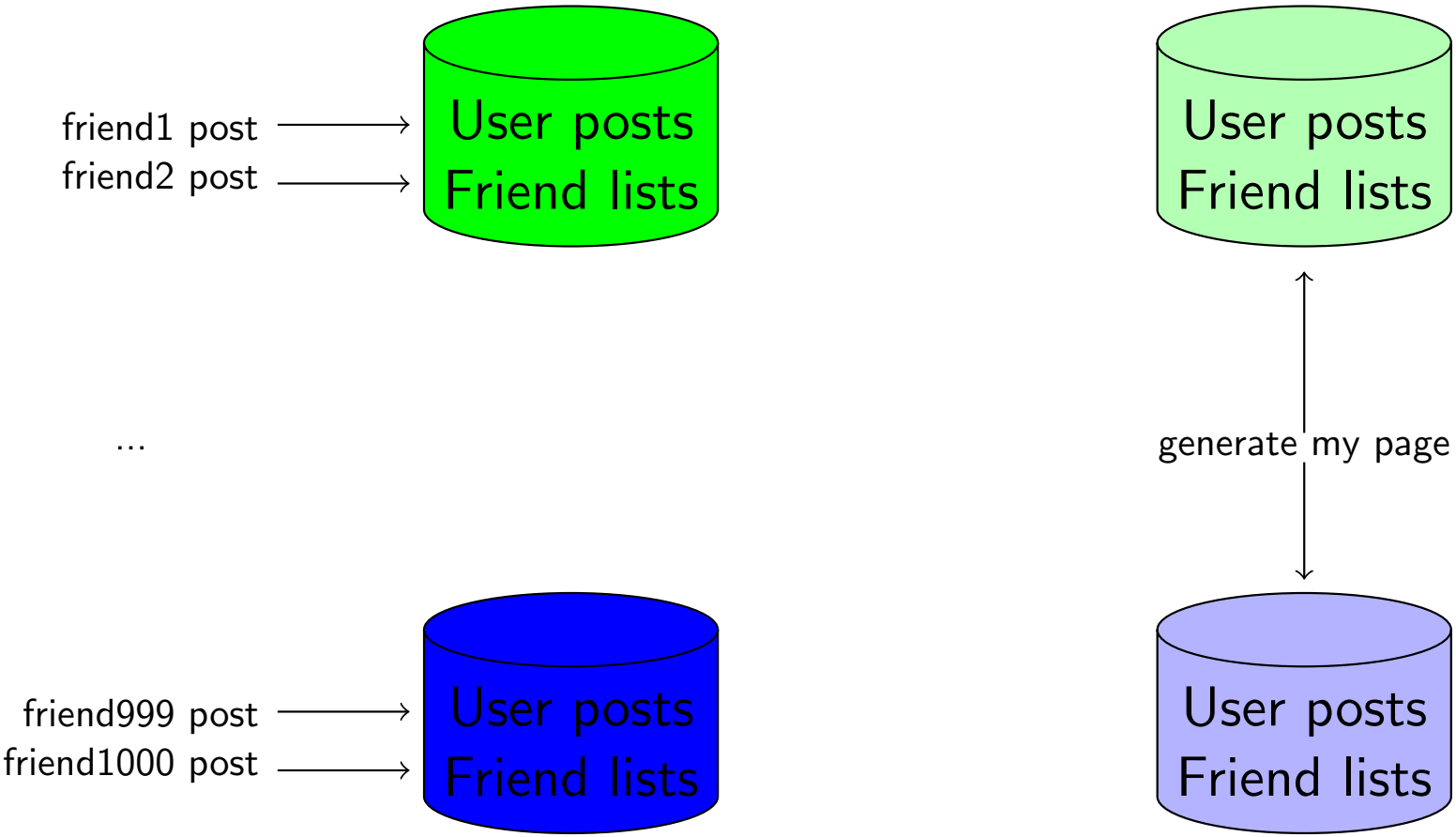
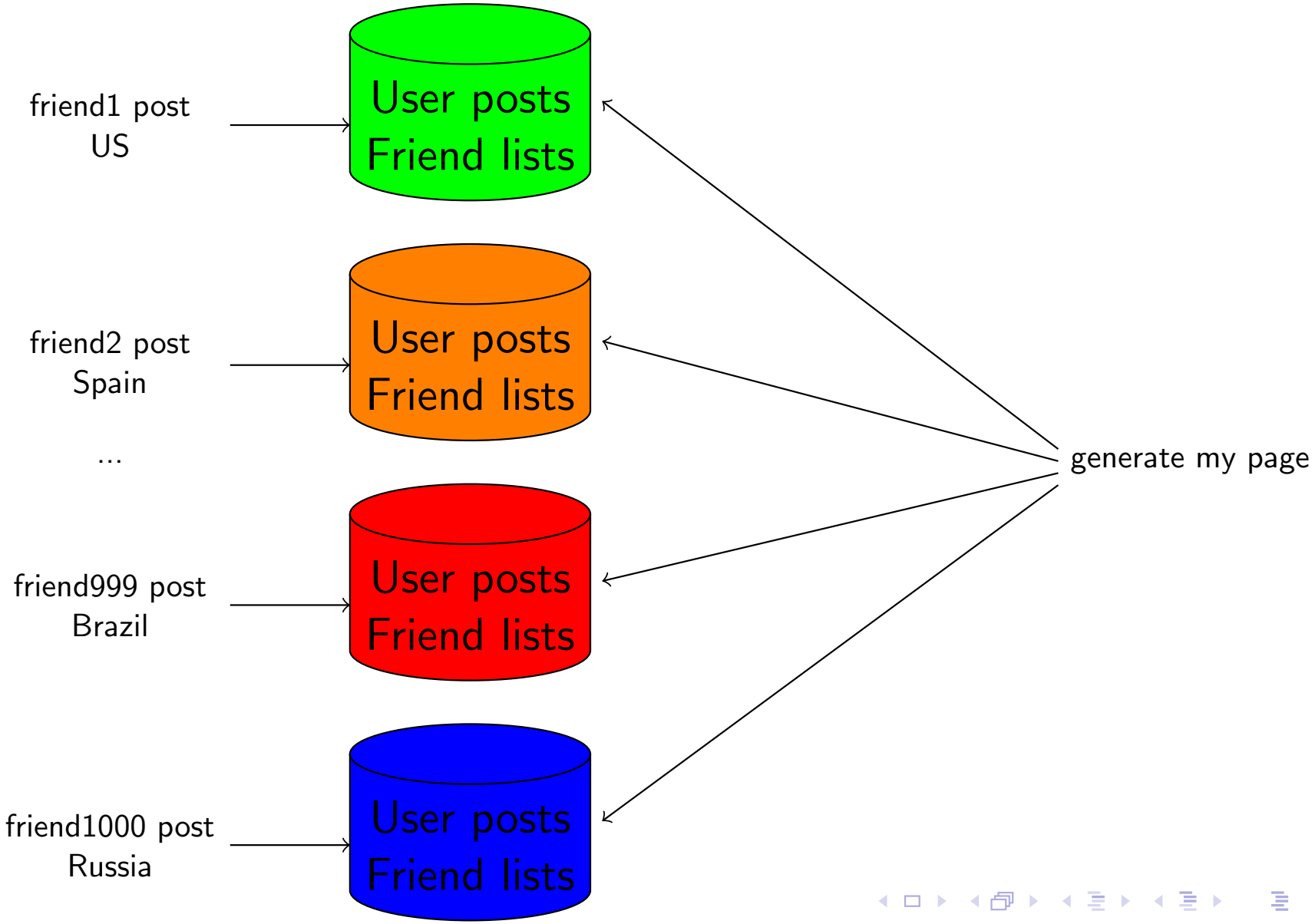


Multiple Datacenters



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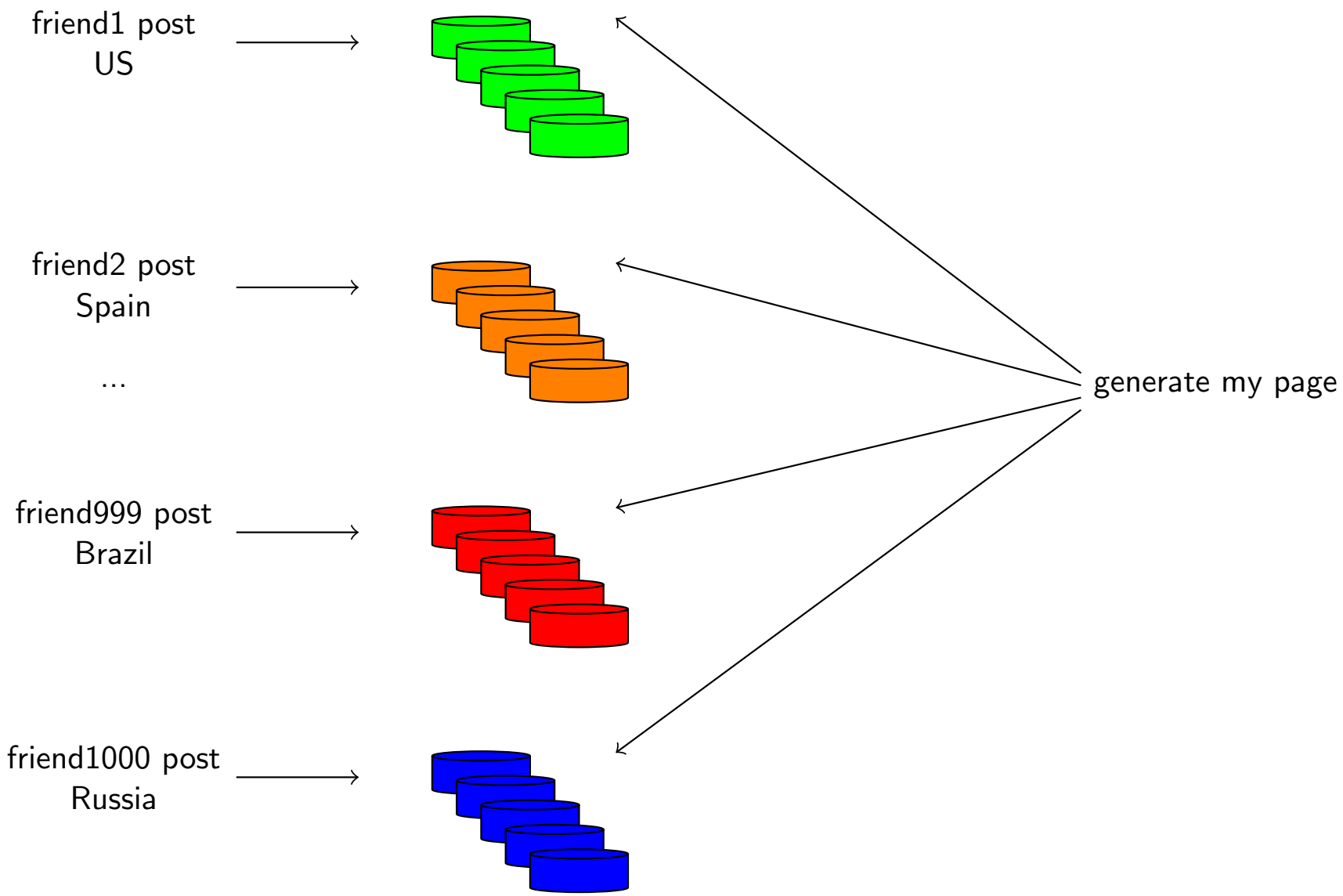

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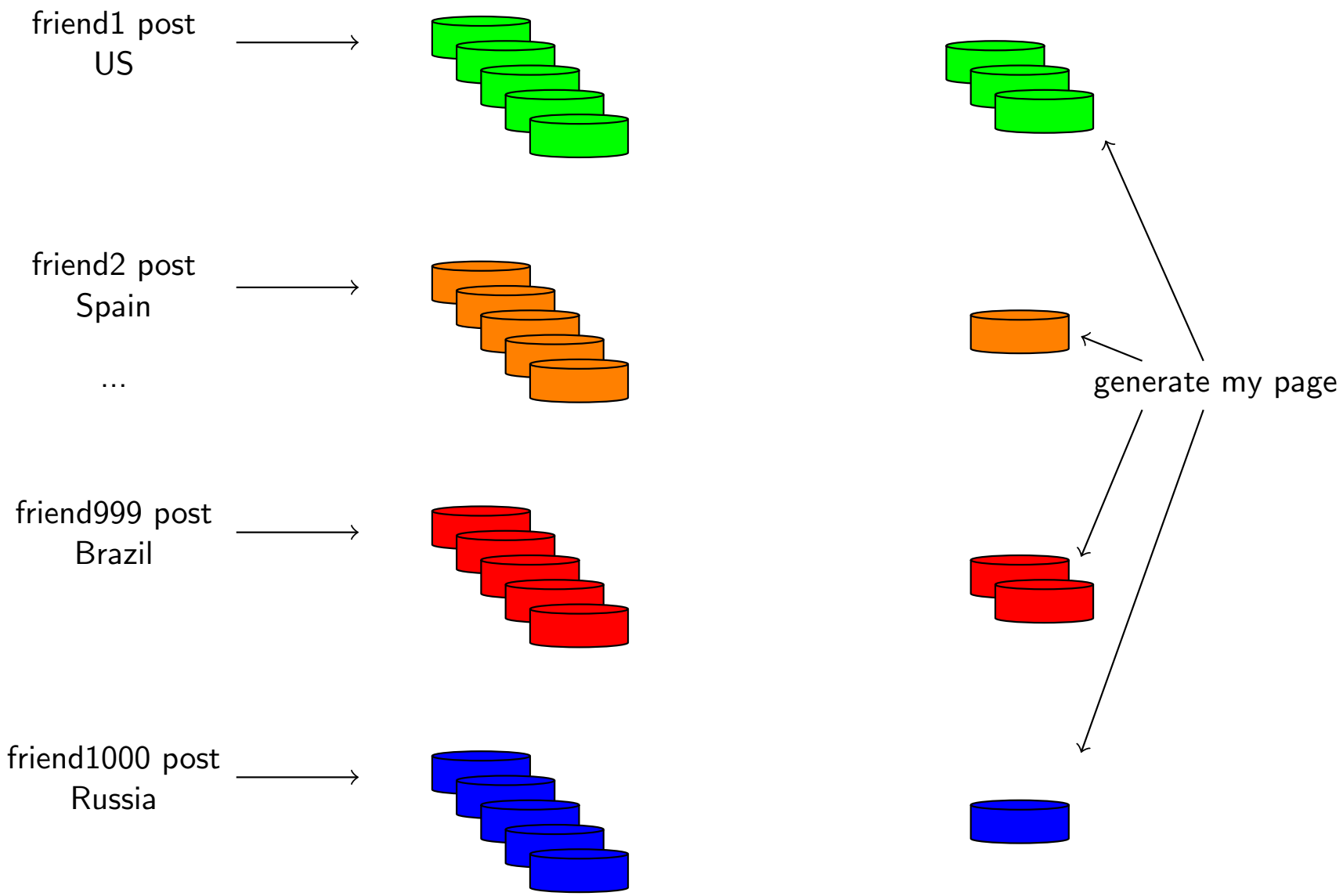

Version Management

- Transactions that write use strict 2PL
  - Each transaction T is assigned a timestamp s
  - Data written by T is timestamped with s

time	<8	8	15
my friends	[X]	[ ]	
my posts			[P]
X's friends	[me]	[ ]	

Synchronizing Snapshots

global wall-clock time

==

external consistency:
commit order respects global wall-time order

==

timestamp order respects global wall-time order
given
timestamp order == commit order

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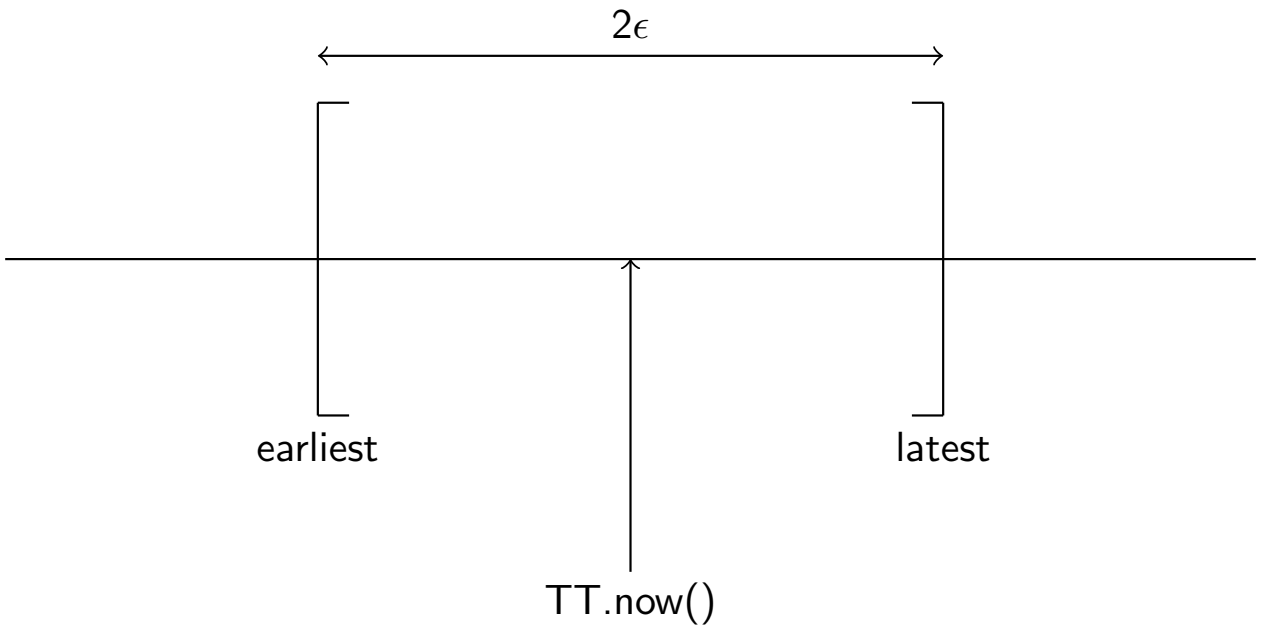
TrueTime

- Represents time as a TTinterval
- GPS and atomic clocks
- Marzullo's algorithm
- Slowly increasing time uncertainty ϵ (sawtooth function of time)

Known unknowns are better than unknown unknowns

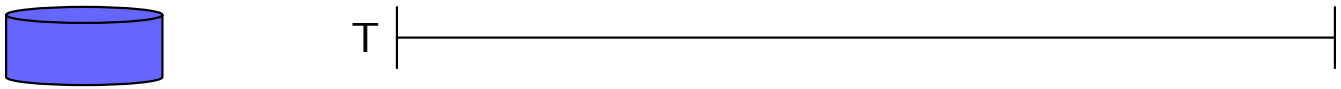
TT.Now()

- "global wall-clock time" with bounded uncertainty



Timestamps and Global Clock

- Strict two phase locking for write transactions
- Assign timestamp while locks are held



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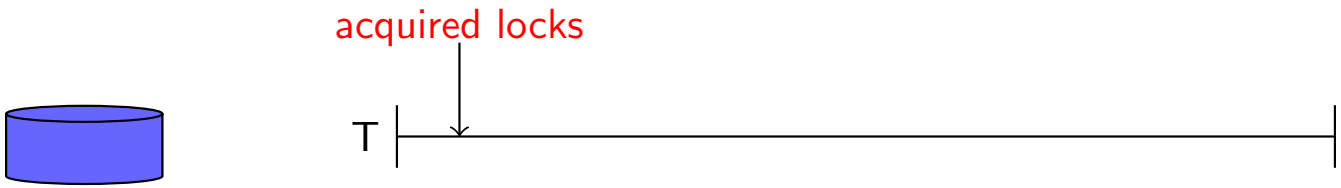

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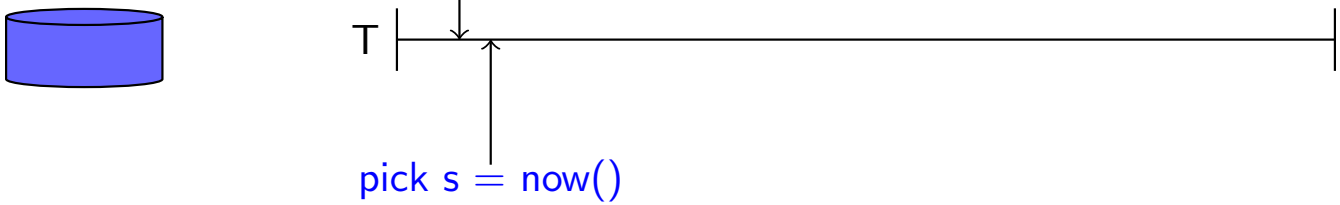

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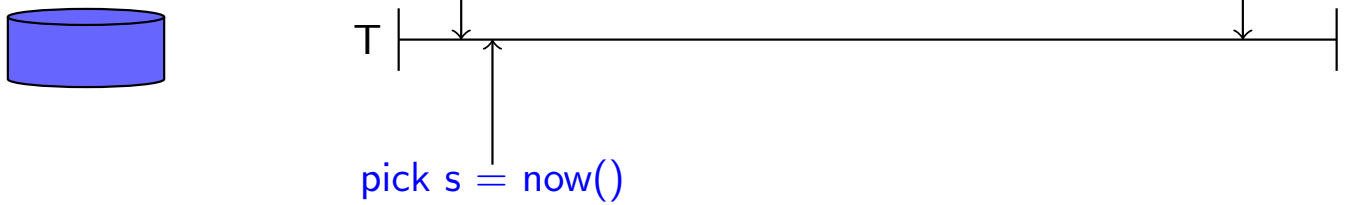

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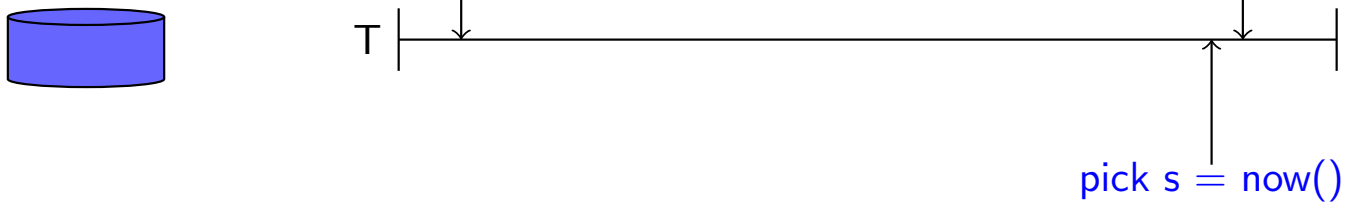
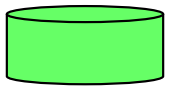
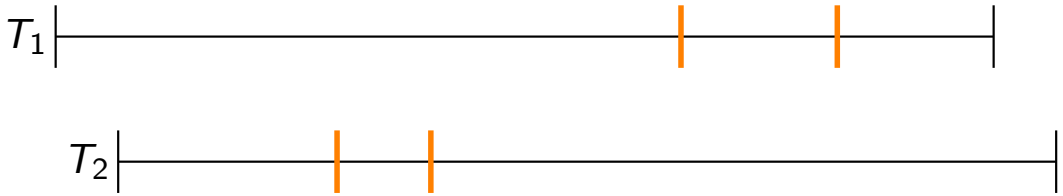


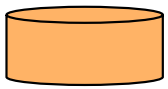
Timestamp Invariants

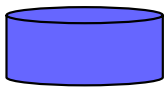
- timestamp order == commit order



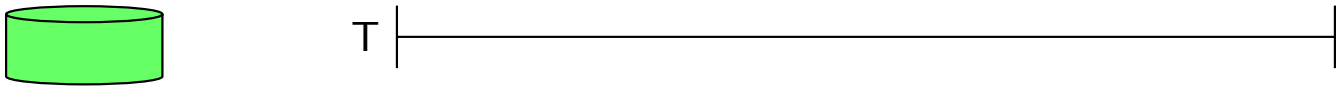


- timestamp order respects global wall-time order





Timestamps and TrueTime



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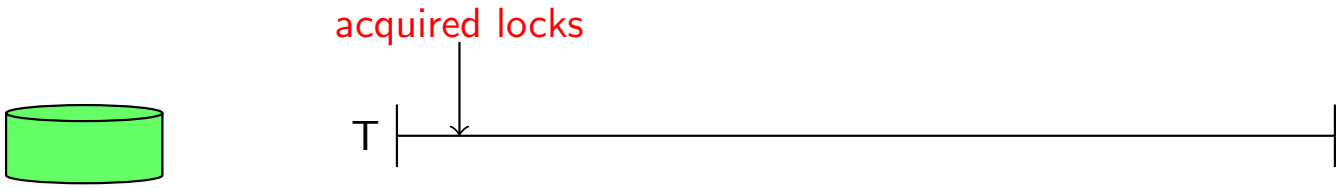

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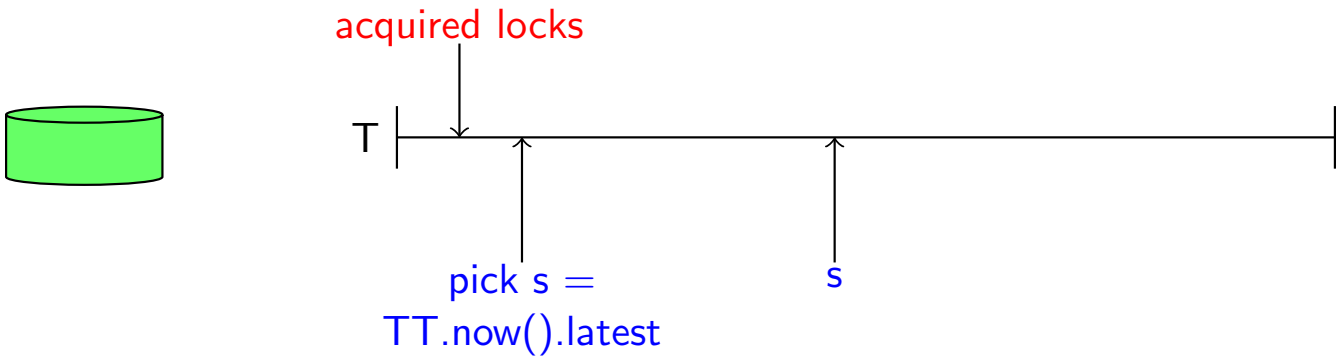

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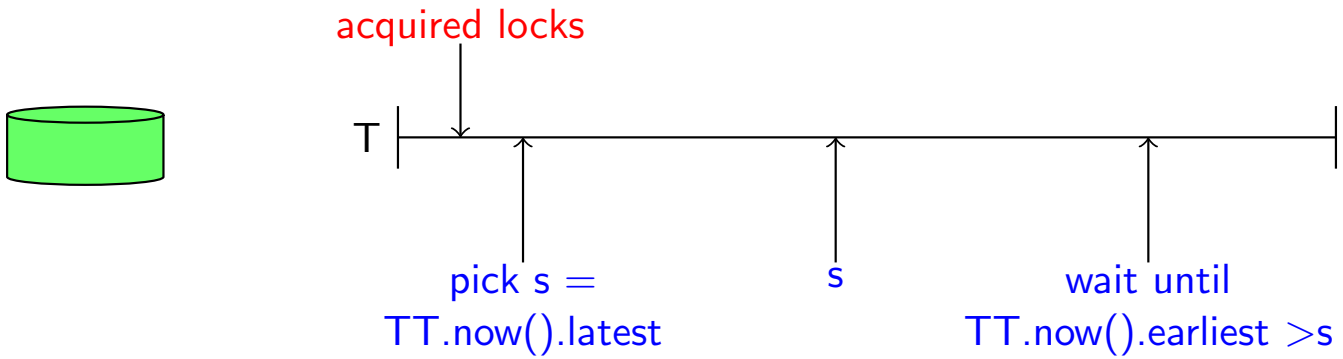

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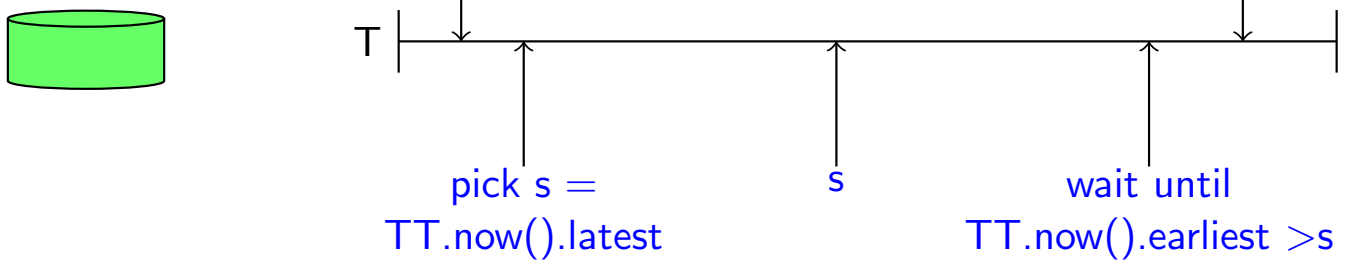
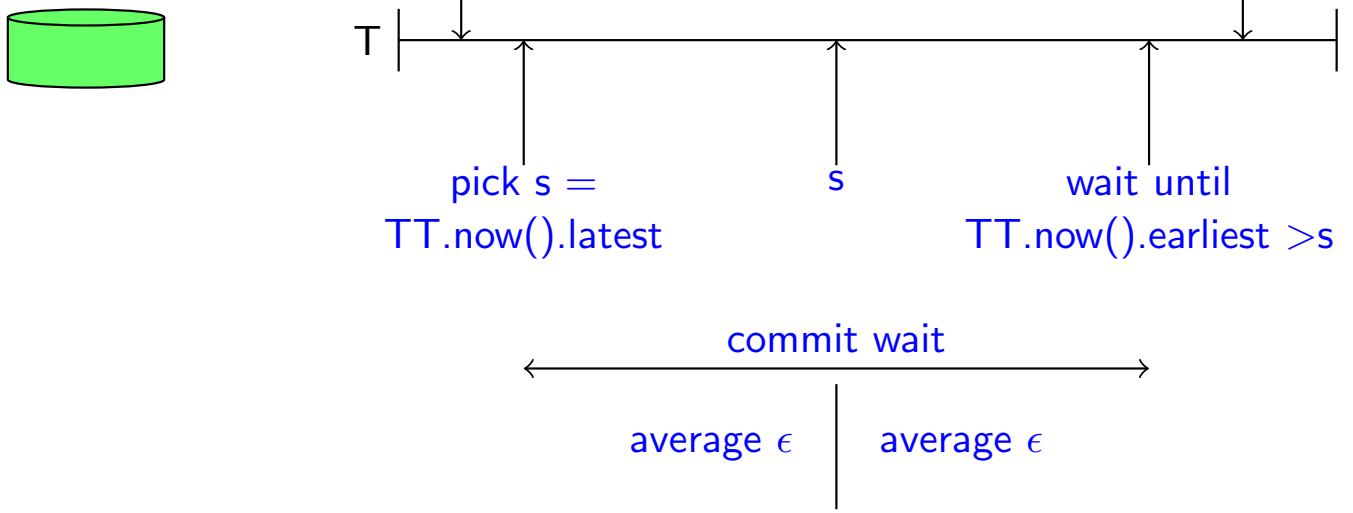
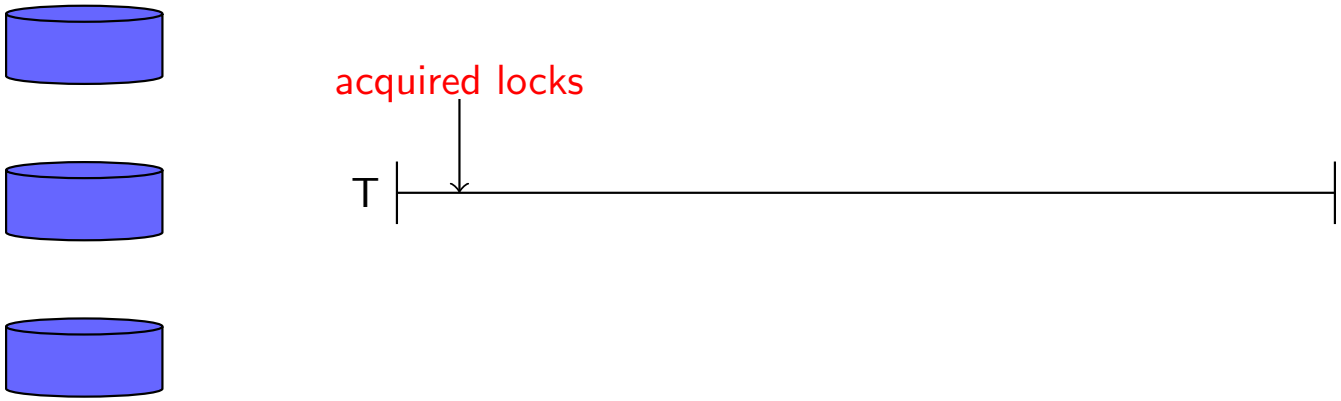


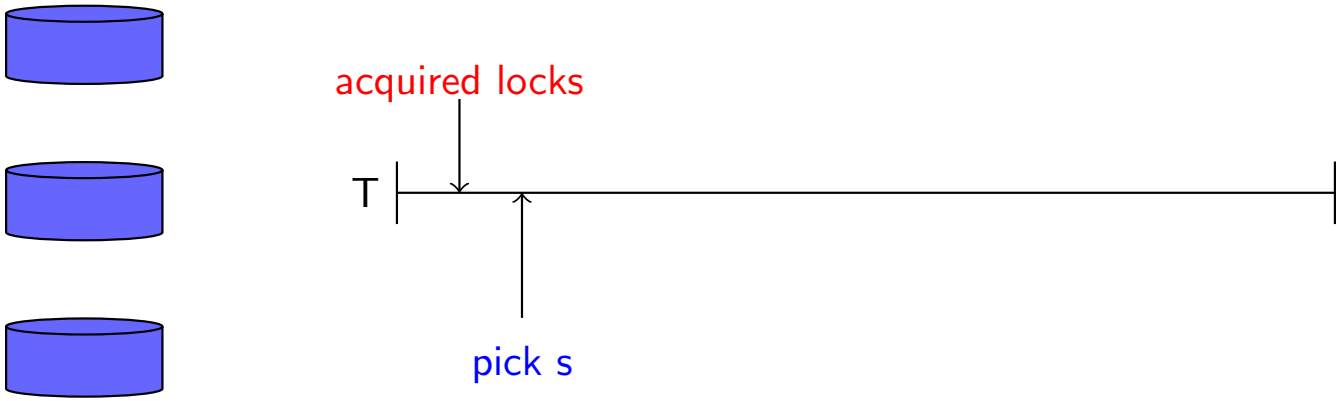
Timestamps and TrueTime *(Cntd.)*



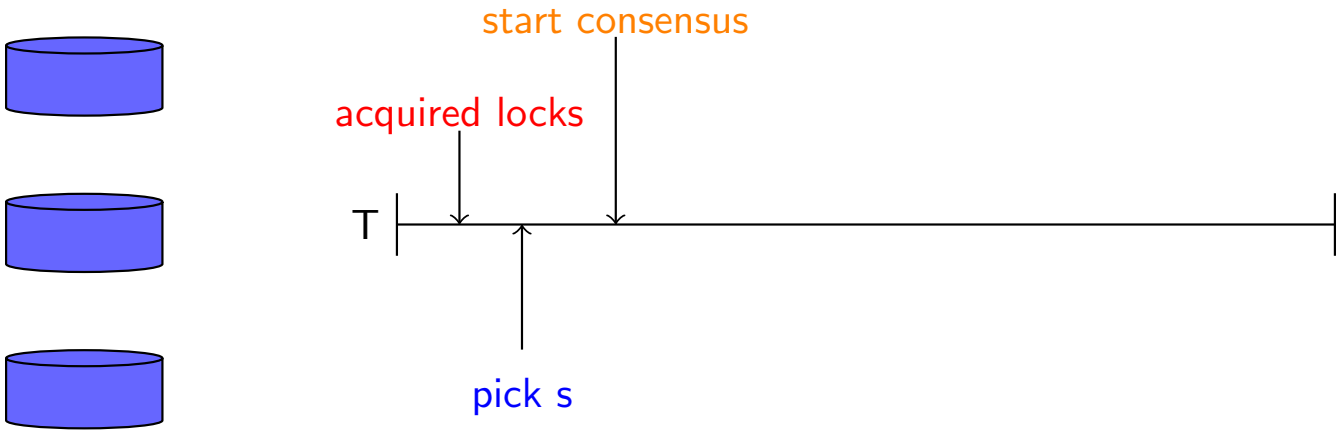
Commit Wait and Replication



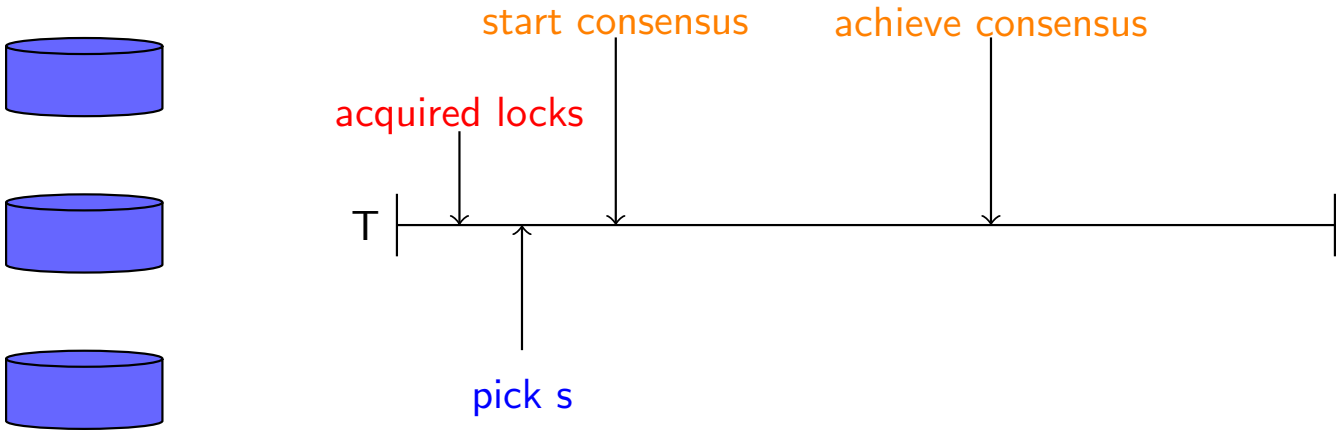
Commit Wait and Replication *(Cntd.)*



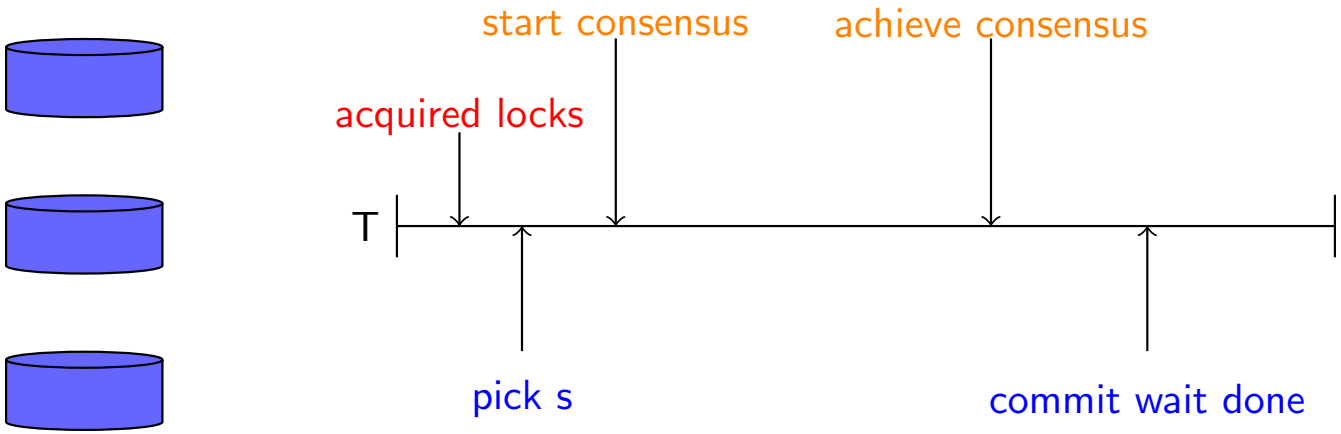
Commit Wait and Replication *(Cntd.)*



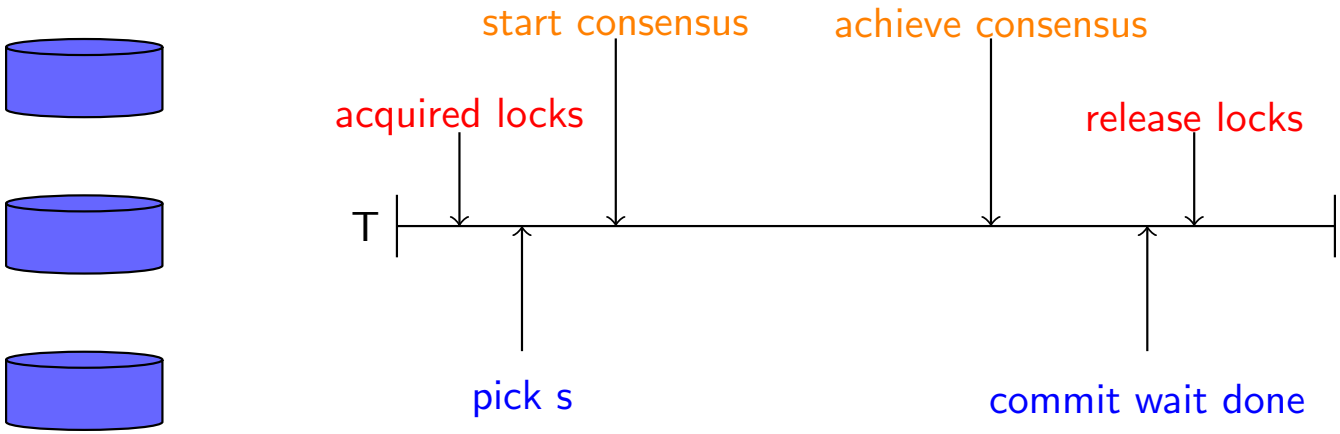
Commit Wait and Replication *(Cntd.)*



Commit Wait and Replication *(Cntd.)*



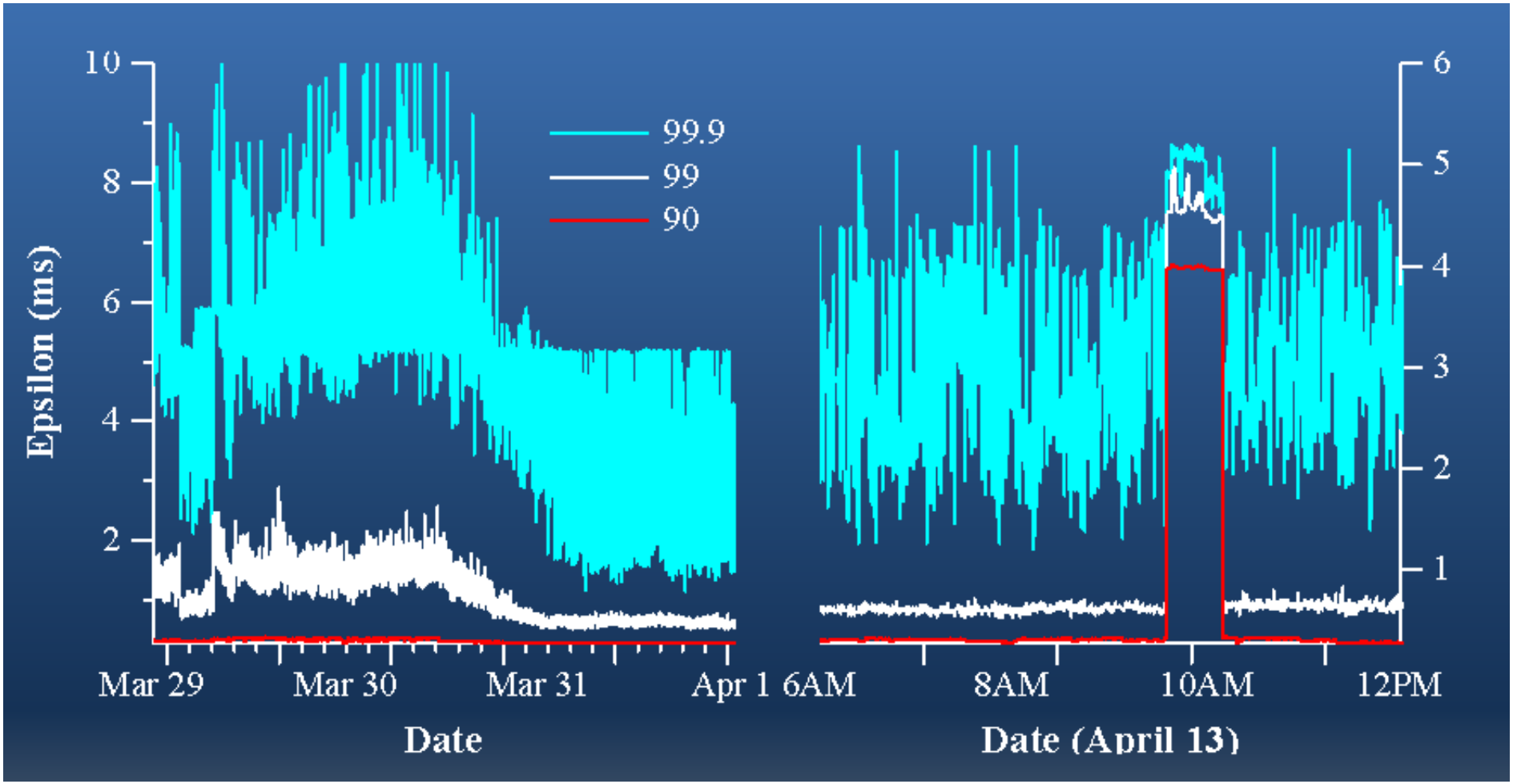
Commit Wait and Replication *(Cntd.)*



What if a Clock goes Rogue

- Timestamp assignment would violate external consistency
- Empirically unlikely based on 1 year of data
  - bad CPUs 6 times more likely than bad clocks

Network-Induced Uncertainty



What's in the Literature

- External consistency/linearizability
- Distributed database
- Concurrency control
- Replication
- Time (NTP, Marzullo)

Future Work

- Improving TrueTime
  - lower ϵ $<1ms$
- Building out database features
  - finish implementing basic features
  - efficiently support rich query patterns

Questions?