Distributed Consensus

an introduction

Tony Astolfi, June 2020


How do we build reliable systems from unreliable components?


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Partial Failure


How do we build single coherent state from many divergent states?


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Asynchrony

Goals

- Use Case for Consensus
- Problem Definition and (De-)Composition
- Trade-off Analysis
- Common Protocol Mechanics
- Rules of Thumb & Advice
- Resources for Further Learning

Consensus Protocols

Crucial Building Block for Distributed Systems

- Broadly Used
  - Hadoop Ecosystem
    - ZooKeeper
    - Apache Cassandra, Kudu
  - Kubernetes
    - etcd
  - Cloud
    - Google Spanner
    - Amazon Elastic File System (EFS)

Consensus Protocols

Many Riffs on a Common Theme

- Viewstamped Replication [1988, 2012]
- Paxos [1990/1998, 2001, 2007]
- ZAB (ZooKeeper Atomic Broadcast) [2007, 2011]
- RAFT [2014]
- NO-Paxos [2016]
- Parallel RAFT [2018]
- Generalized Consensus [2019]

Out of Scope
(caveat…)

- Weak consistency for greater:
  - scale/availability/throughput/etc. (Redis, BigTable)
- Big Data, sharding/slicing: data/problem too big for single machine
  - Consensus is often *part* of the solution (Cassandra, Spanner)
- “Byzantine” or untrusted consensus
  - Blockchains, cryptocurrency, etc. (Bitcoin, Ethereum)

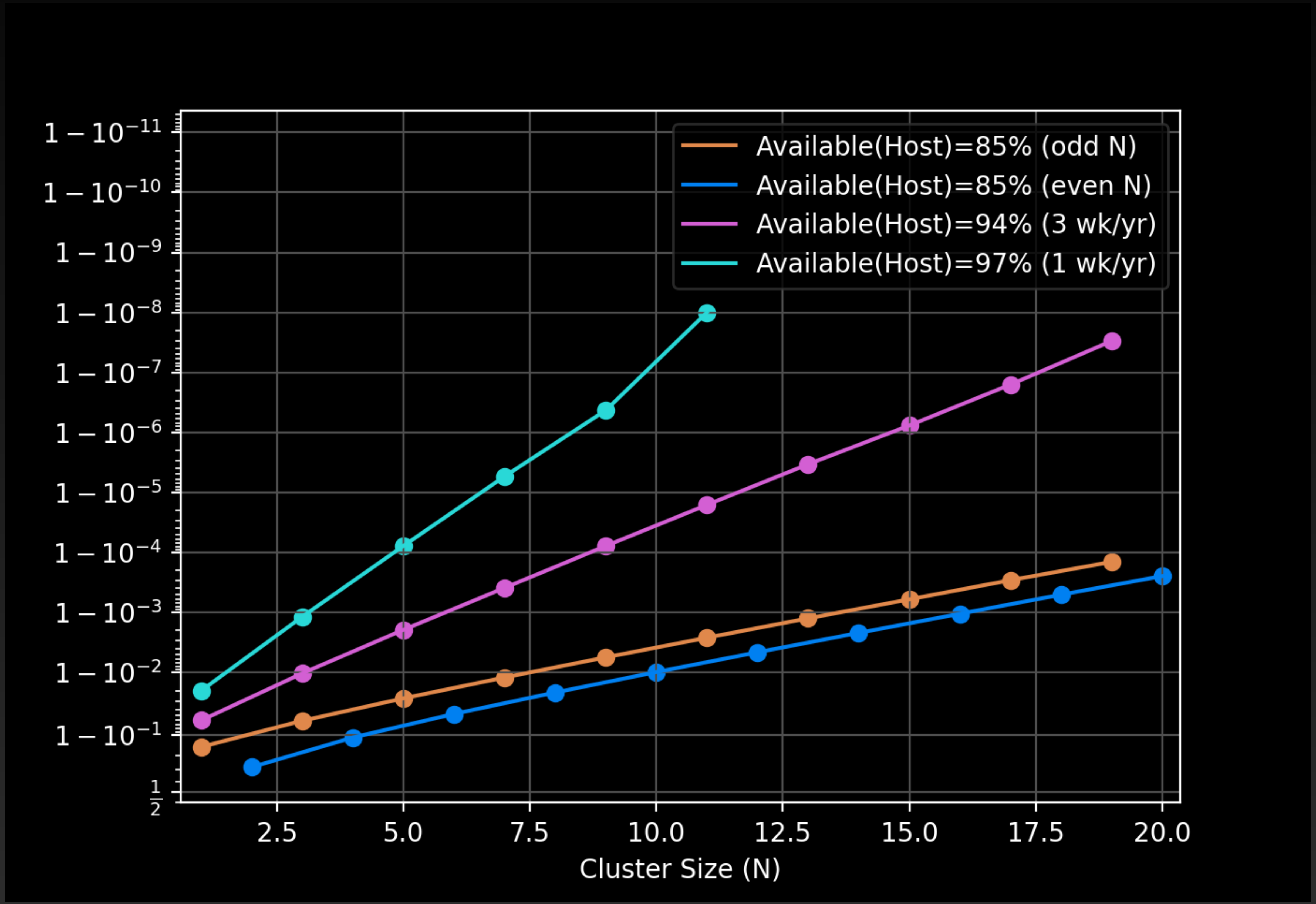
Why Consensus?

Strong Consistency & Fault Tolerance

Preserve: Single-Node Simplicity

Add: Reliability ($N = 2F + 1$)

Reliability Amplification



- Exponential improvement as a function of cluster size
- When host downtime is 1wk/yr & N=9, cluster is down less than 14s/yr!

Problem Definition

What is the consensus problem?

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$$X = ?$$

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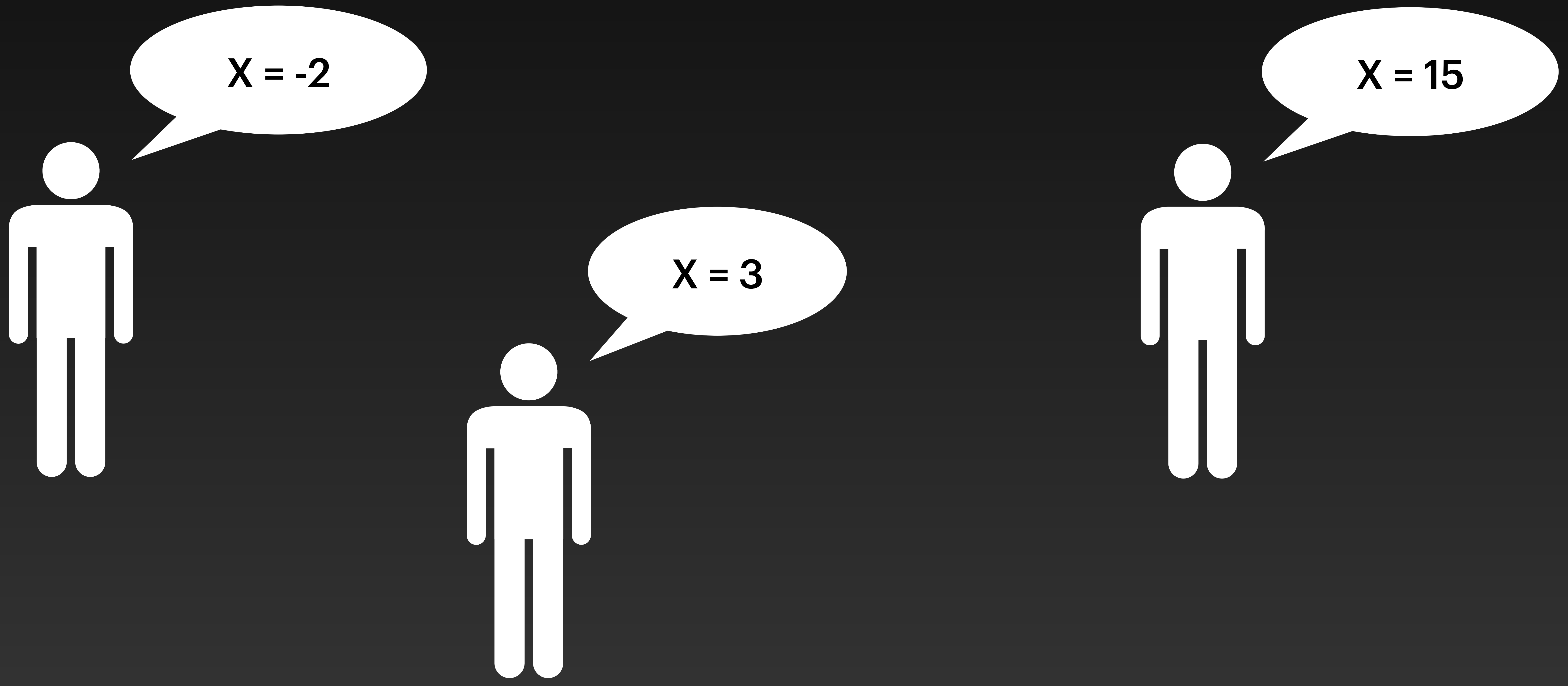

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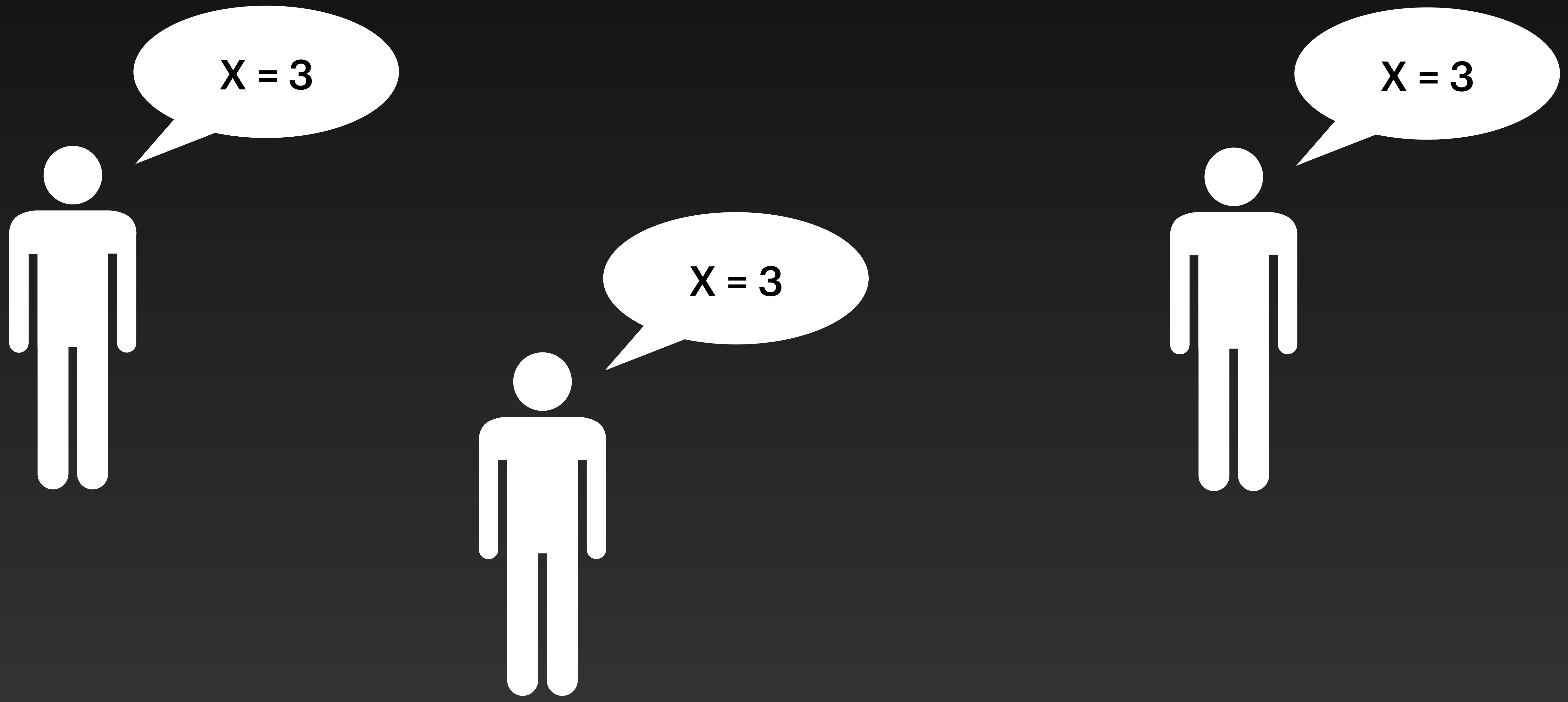

Requirements

- **Non-Triviality:** Any decided value must be proposed as input
- **Consistency:** The decided value is agreed upon and immutable
- **Liveness:** Some decision is eventually made

How do we go from “the value of X as a service” to something useful?

Replicated State Machine Model

State Machine Design Principles

State Machine Design Principles

“Design graphs, not graph algorithms” - Skiena

State Machine Design Principles

"Design state machines, not consensus algorithms"

- MUST be deterministic!
- Trim the log!
  - Snapshot + deltas
  - Write snapshots incrementally or in the background
  - Log-structured or append-only data structures
- Write-ahead-log (WAL) techniques
  - Group commands by declaring *intent*
  - Commit at the end

On a Good Day…

On a Bad Day…

This is complicated!
Why Study Consensus?

- Know what the design-tradeoffs might be so you can pick the right dependency to take. (What “lunches” aren’t free?)
- Know how to configure the system (avoid even N, cluster sizing)
- Know how to build proper monitoring (failure margin, leader elections)
- *Build vs Buy should be a choice!*

Is it a good deal?

Cost/Benefit Trade-offs

Cost	Benefit
Latency: 3-4 delays	Better Latency Distribution
Single-Node Bottleneck	Simplicity for Apps
Operational Complexity: Config, Leader Elections	No Planned Outages for Upgrades/Maintenance
Resources: N x Single Host	(very) High Availability

More Resources

- Integrating into larger systems
  - Google Chubby *(inspiration for "Paxos-as-a-Service:" ZooKeeper, etcd, ...)*
  - Google Spanner *(consensus within database shards, atomic clocks for transactions)*
  - Eris *(NOPaxos successor; another approach to cross-cluster transactions)*
  - Tapir *(high level: consistent transactions, low level: inconsistent log replication)*
- Alternative/Complimentary
  - Google File System (GFS) *(small, consistent metadata + big inconsistent data)*
  - Amazon Dynamo *(weak consistency model, consistent hashing & gossip)*
  - Tango/Corfu *(Shared-Log-as-a-Service; replicated state machine model w/o consensus)*

Thank you!

(Questions, please!)

Levels of Build/Buy

- Level 0: No Consensus (high-availability or consistency: pick one)
- Level 1: Depend on a System that depends on Consensus
- Level 2: Depend on a Consensus-as-a-Service system (ZK, etcd, ...)
- Level 3: Depend on an existing implementation (design state machines...)
- Level 4: Implement an existing protocol (RAFT)
- Level 5: Invent a new protocol (dangerous & hard, but worth it at scale)

Live Reconfiguration

Change cluster membership without interrupting service

- Key Idea: Make membership part of the state machine
    - Protocol must be aware
    - Membership commands require quorum in new and old configs
- Use Cases:
    - Scale up/down
    - Replace unhealthy machine
    - Re-balance load/resources

END OF DECK