Distributed Storage

EE379K - Architectures for Big Data Sciences
Dr. Sriram Vishwanath
Department of Electrical and Computer Engineering
The University of Texas at Austin
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Why Distributed Storage?

- Hard to store petabytes on a single machine
- Need to distribute data over many different machines
- This introduces some challenges

Real systems that use distributed storage codes

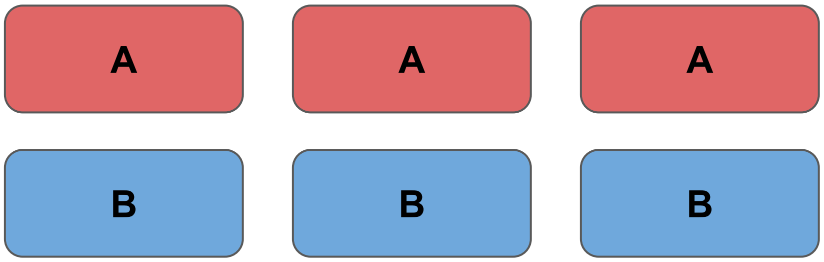
- Windows Azure, (Cheng et al. USENIX 2012) (LRC Code)
- Used in production in Microsoft
- CORE (Li et al. MSST 2013) (Regenerating EMSR Code)
- NCCloud (Hu et al. USENIX FAST 2012) (Regenerating Functional MSR)
- ClusterDFS (Pamies Juarez et al.) (SelfRepairing Codes)
- StorageCore (Esmaili et al.) (over Hadoop HDFS)
- HDFS Xorbas (Sathiamoorthy et al. VLDB 2013) (over Hadoop HDFS) (LRC code)
- Testing in Facebook clusters

Fault Tolerance

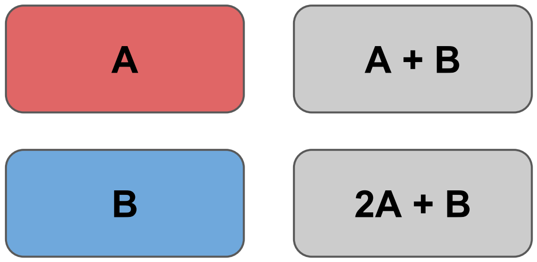
- Drives are not immune to failure
- High MTBF counteracted by large number of drives
    - Google datacenters house more than 1 million servers
    - Drive failures occur on the order of **minutes**
- How to prevent data loss when a drive fails?

Fault Tolerance: Solution

- Add redundancy to the system



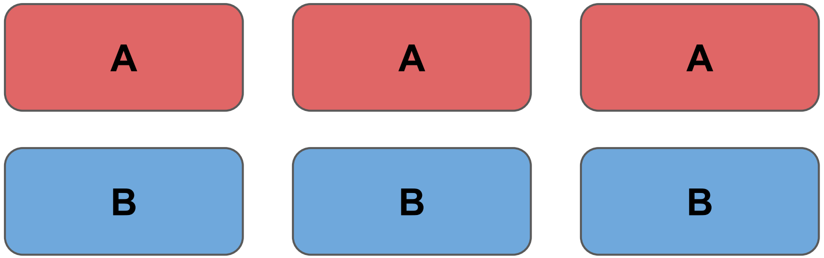
Triple Replication



(4, 2) Erasure Coding

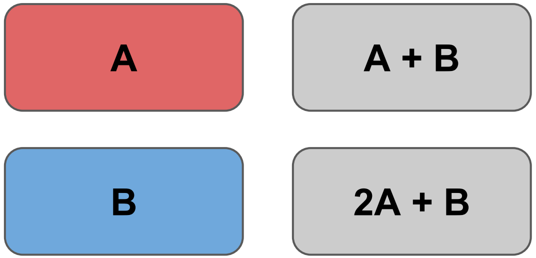
Fault Tolerance: Solution

- Add redundancy to the system



Triple Replication

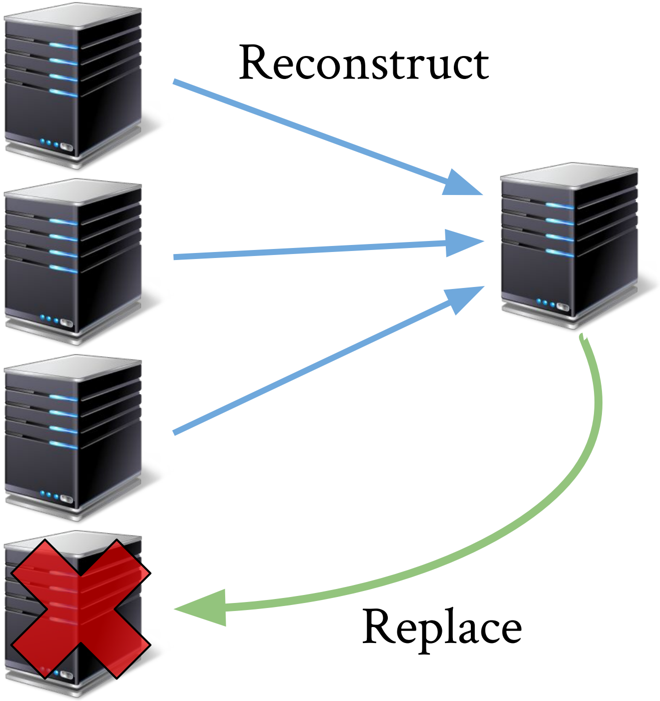
UNSUSTAINABLE



(4, 2) Erasure Coding

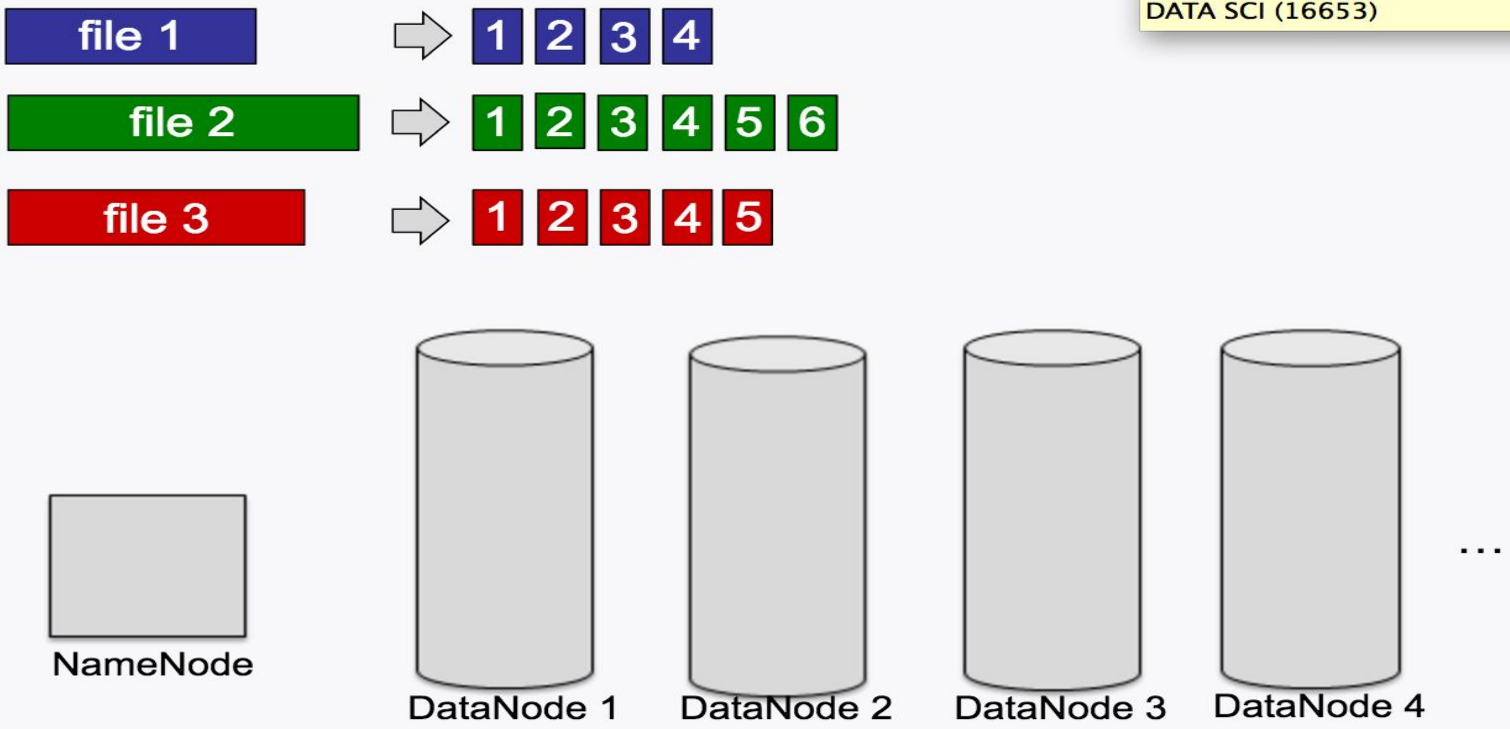
Node Repair

- On drive failure, node needs to be repaired

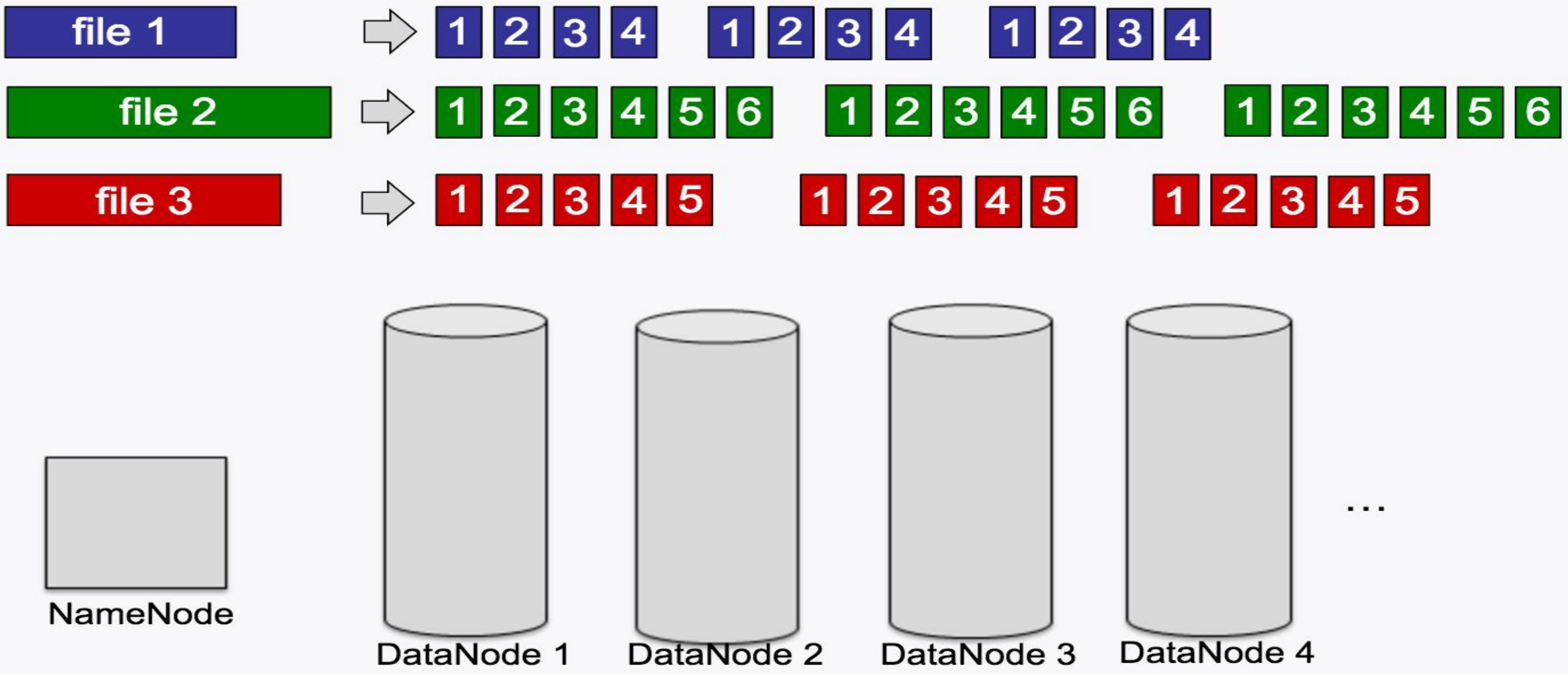


current hadoop architecture

Course Roster: Sp16 – ARCHITECTURE FOR BI
DATA SCI (16653)



current hadoop architecture



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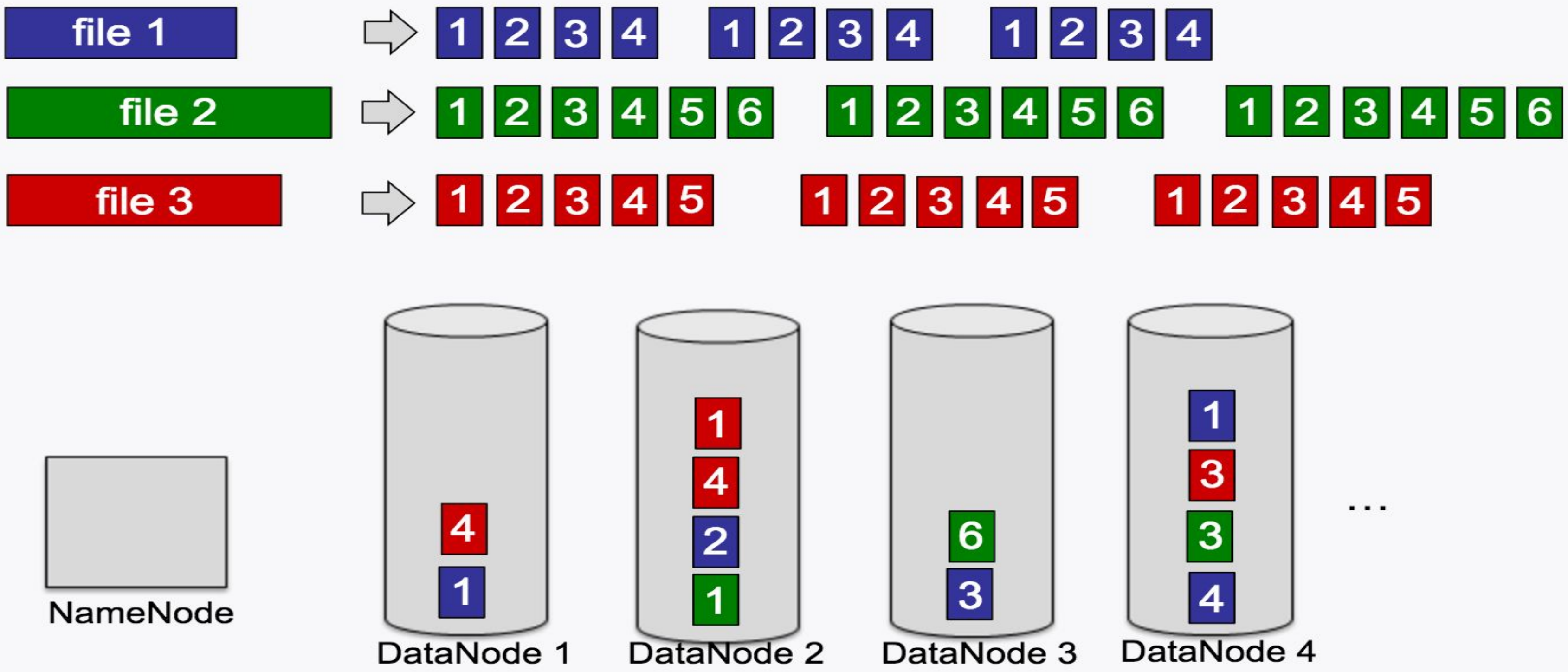

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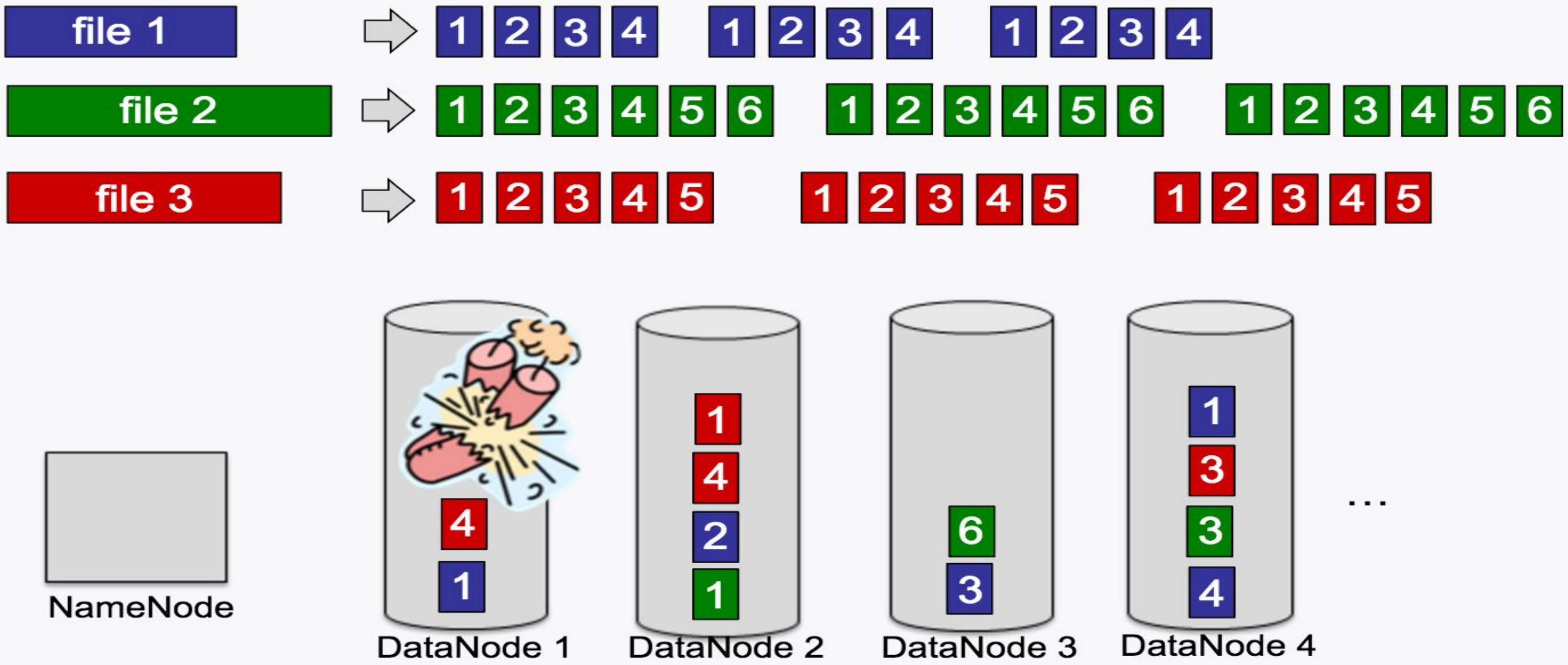
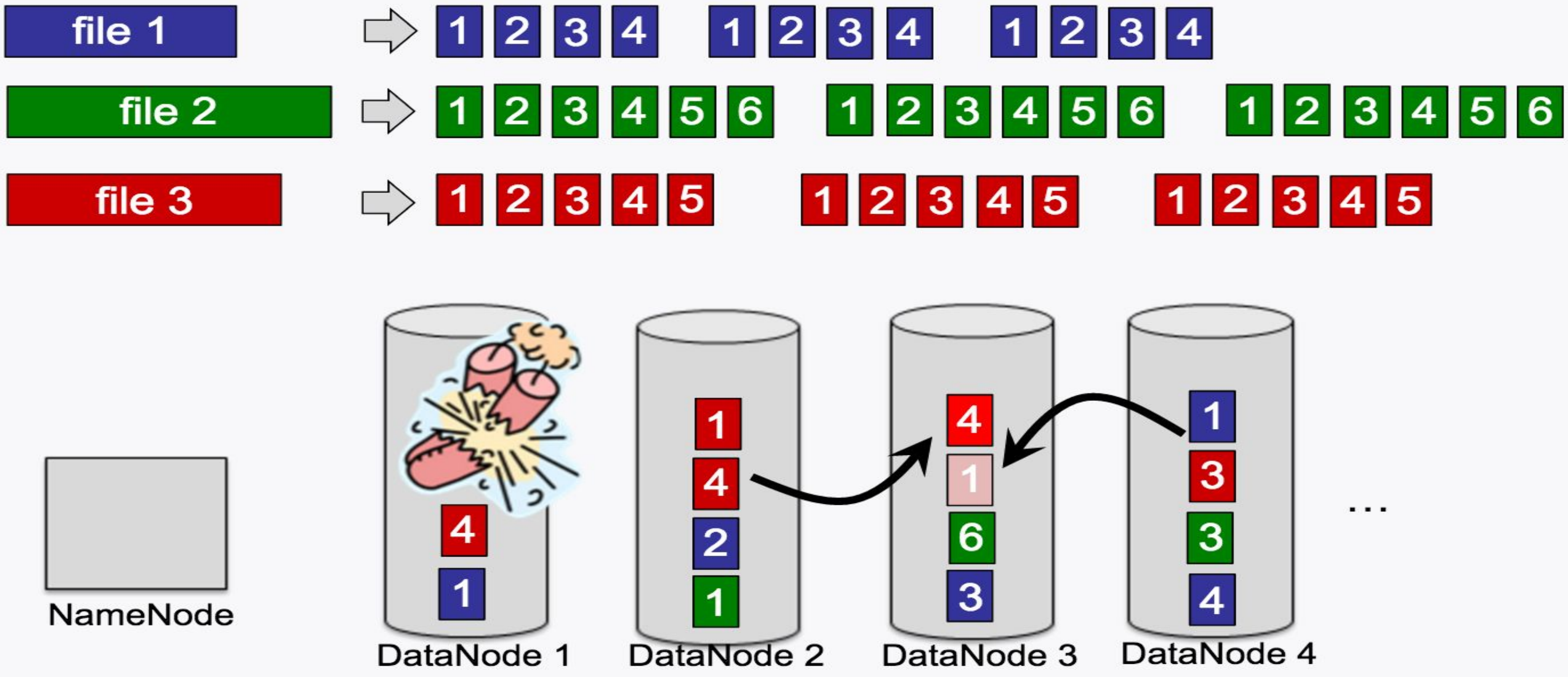
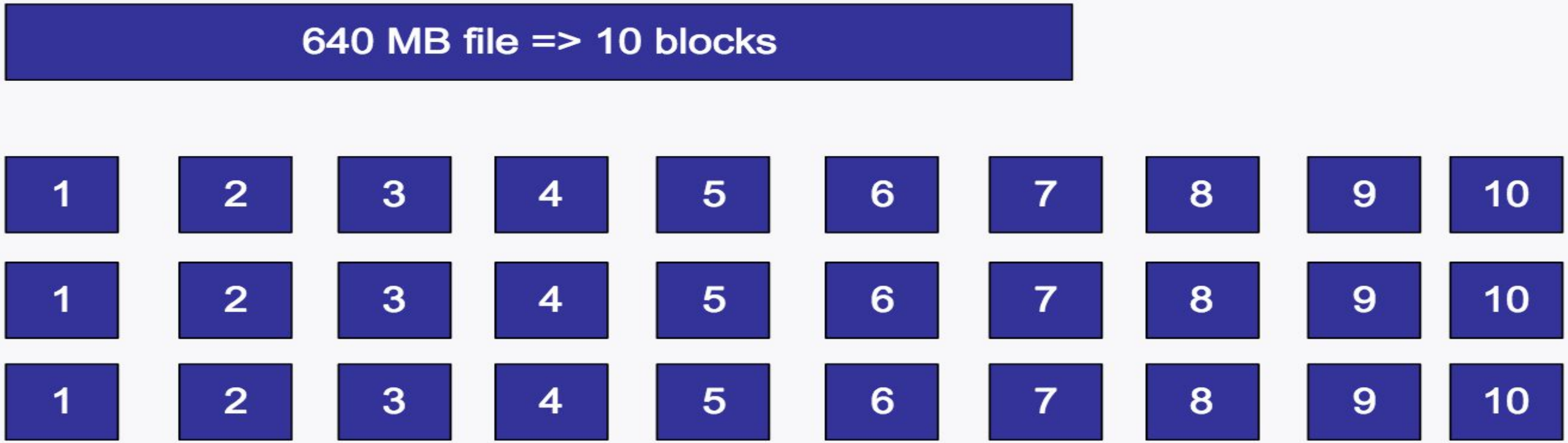


current hadoop architecture

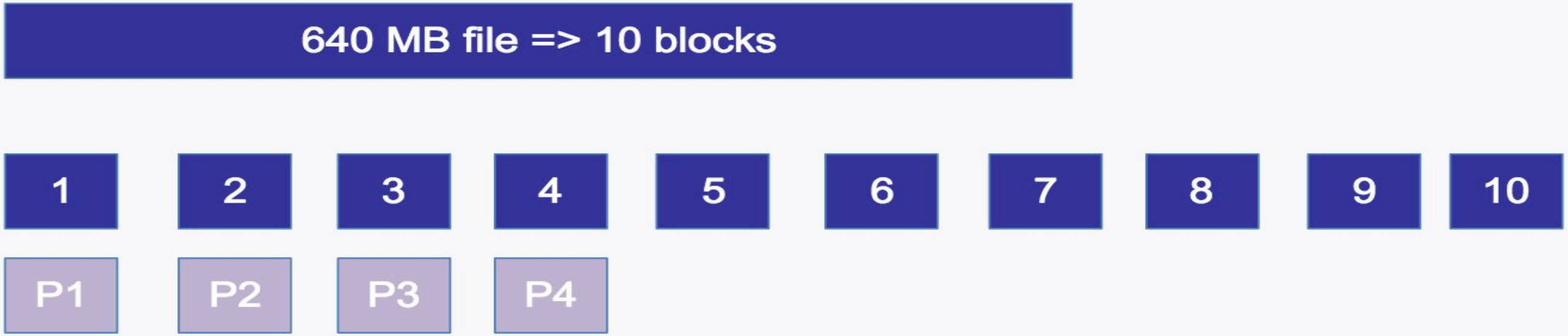


current default hadoop architecture

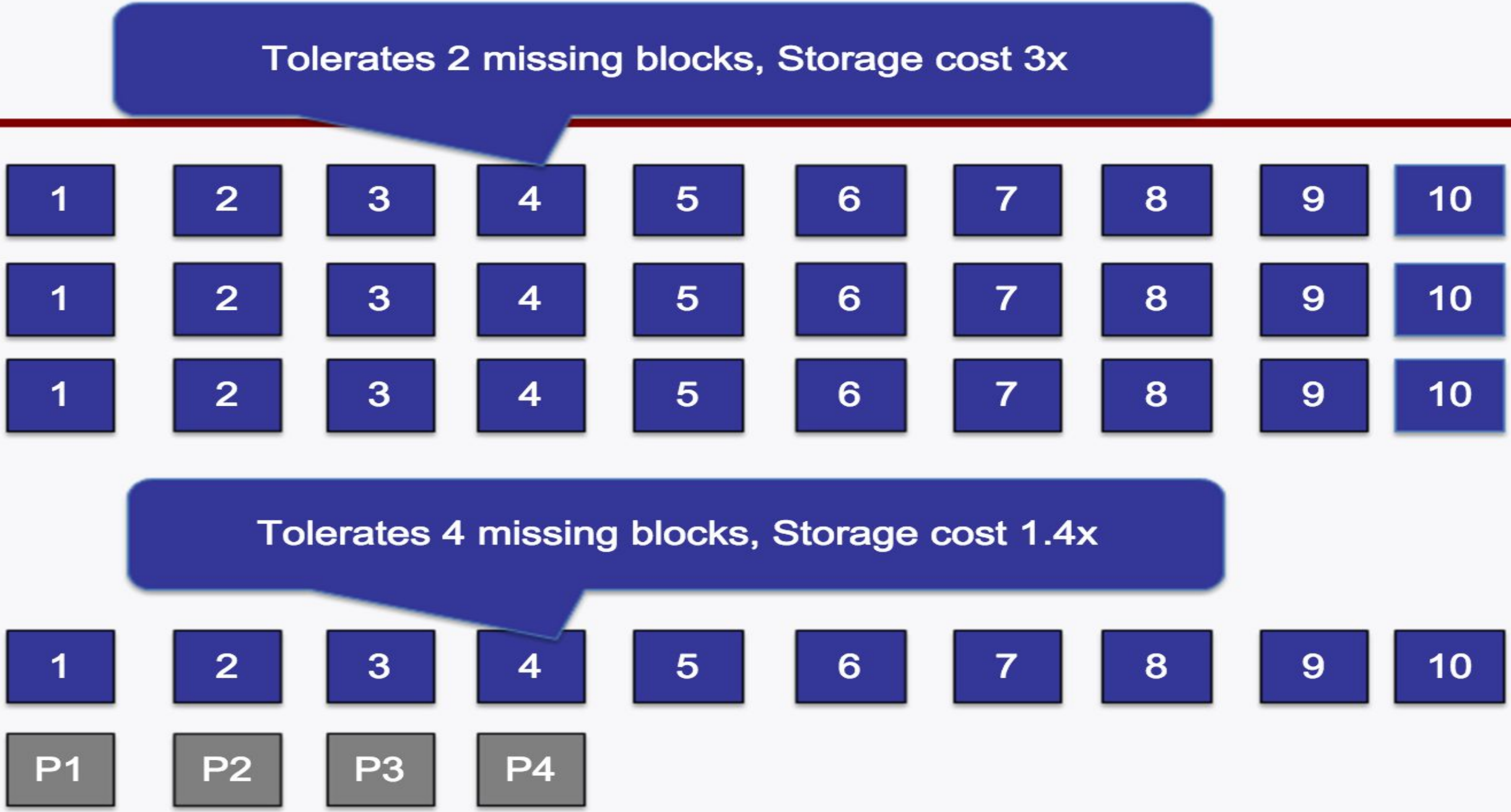


3x replication is HDFS current default.
Very large storage overhead.
Very costly for BIG data

facebook introduced Reed-Solomon (HDFS RAID)



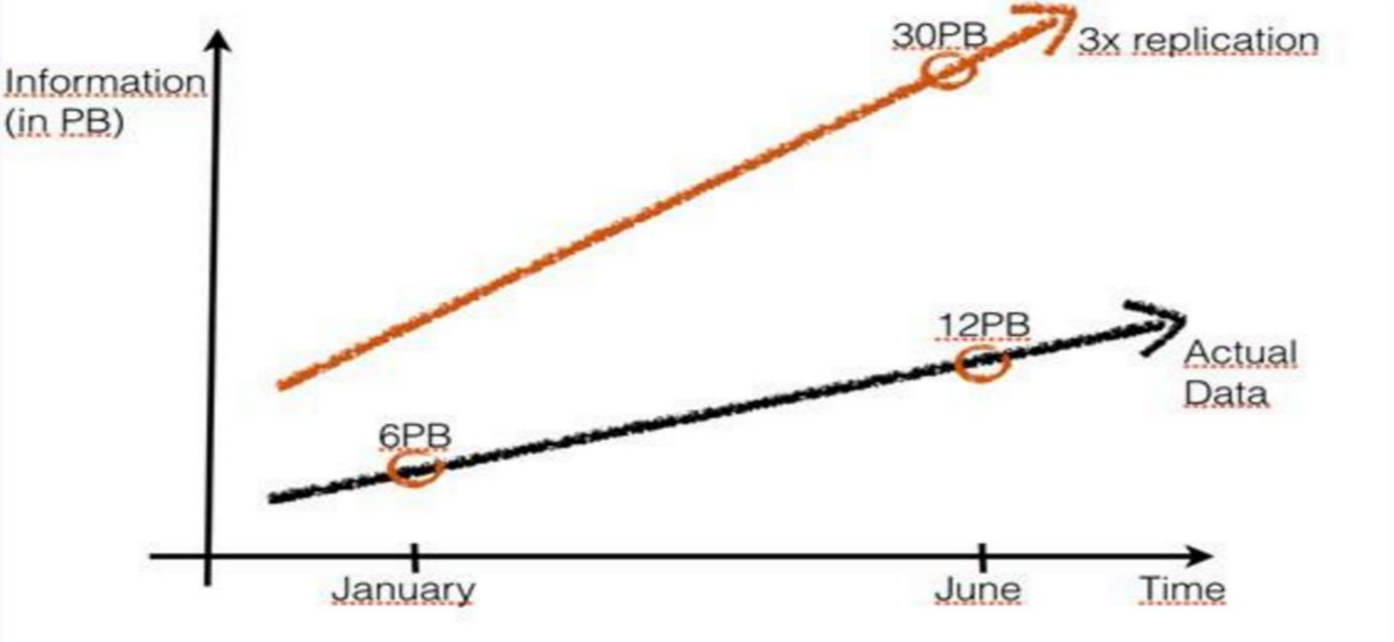
Older files are switched from 3-replication to (14,10) Reed Solomon.



HDFS RAID. Uses Reed-Solomon Erasure Codes

Diskreduce (B. Fan, W. Tantisiriroj, L. Xiao, G. Gibson)

erasure codes save space



Three repair metrics of interest

1. Number of bits **communicated** in the network during single node failures (Repair Bandwidth)

   Capacity known for two points only. My 3-year old conjecture for intermediate points was just disproved. [ISIT13]

2. The number of bits **read** from disks during single node repairs (Disk IO)

   Capacity unknown.
   Only known technique is bounding by Repair Bandwidth

3. The **number of nodes accessed** to repair a single node failure (Locality)

   Capacity known for some cases.
   Practical LRC codes known for some cases. [ISIT12, Usenix12, VLDB13]
   General constructions open

CAP Theorem

CAP Theorem: Introduction

- Three attributes used when describing distributed storage
- Consistency
- Availability
- Partition tolerance

CAP Theorem: Consistency

- A read is guaranteed to return the most recent write
- If data is replicated, any write **must** update all copies
- More copies implies more indirect writes
    - Requires communication bandwidth and time
    - Degrades performance

CAP Theorem: Availability

- A functioning node **eventually** will respond to your request

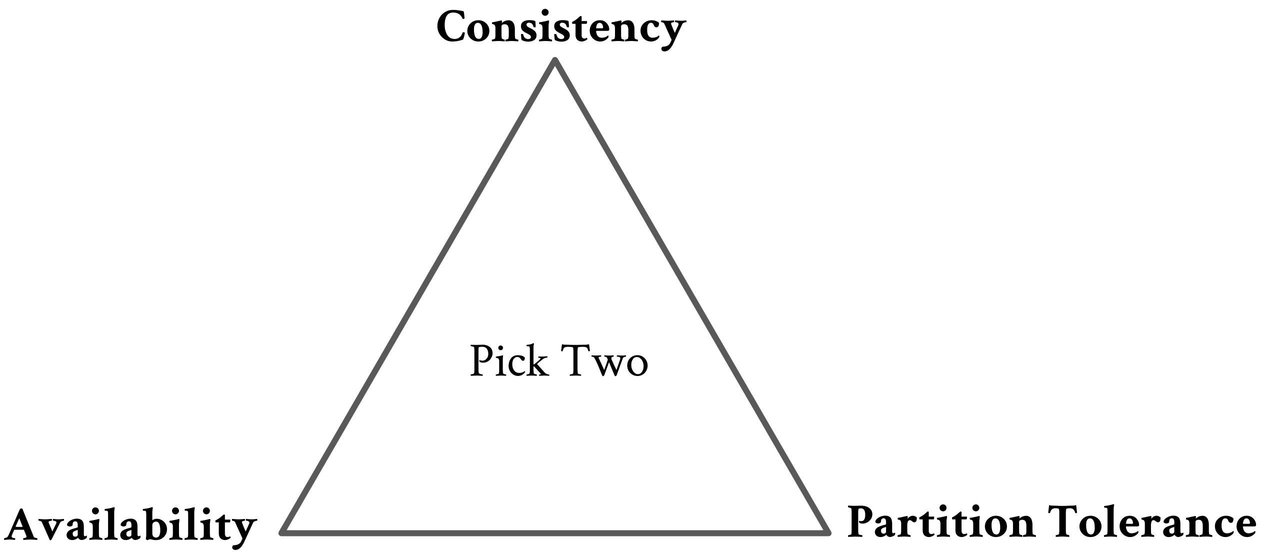
- Functioning nodes must not return errors or timeouts
  - Why would this happen?

CAP Theorem: Partition Tolerance

- System will function even if network becomes partitioned

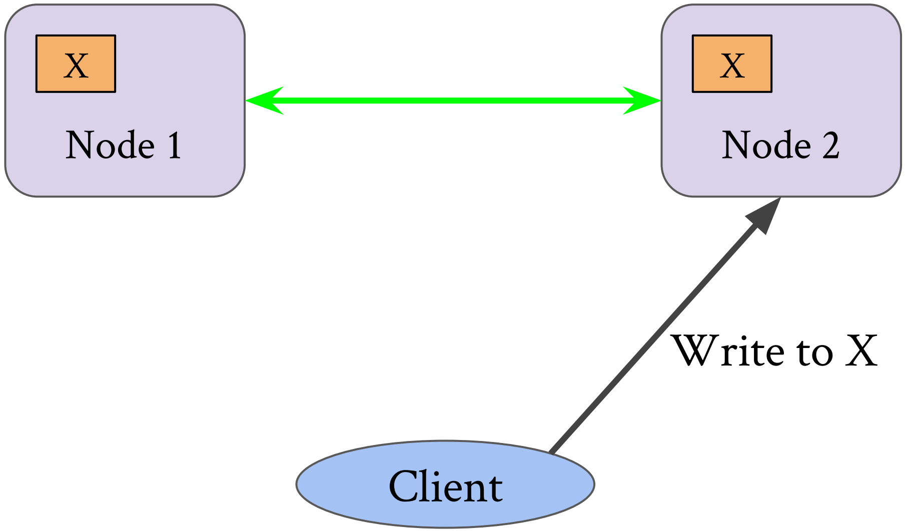
CAP Theorem

- CAP theorem asserts that you **cannot** have all three
- At best you can have two

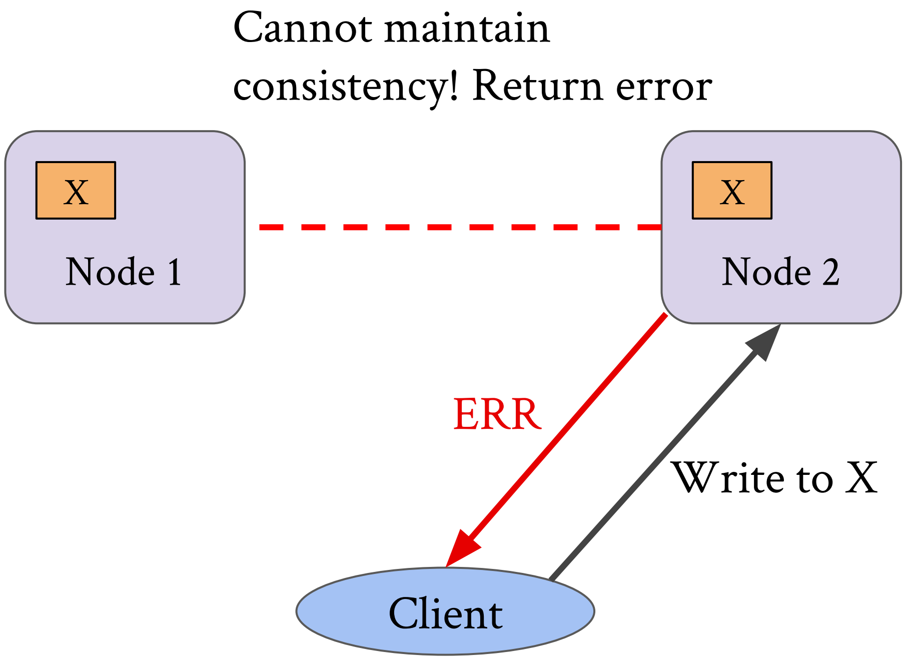


Consistency and Partition Tolerance

- System is consistent and partition tolerant, but not available

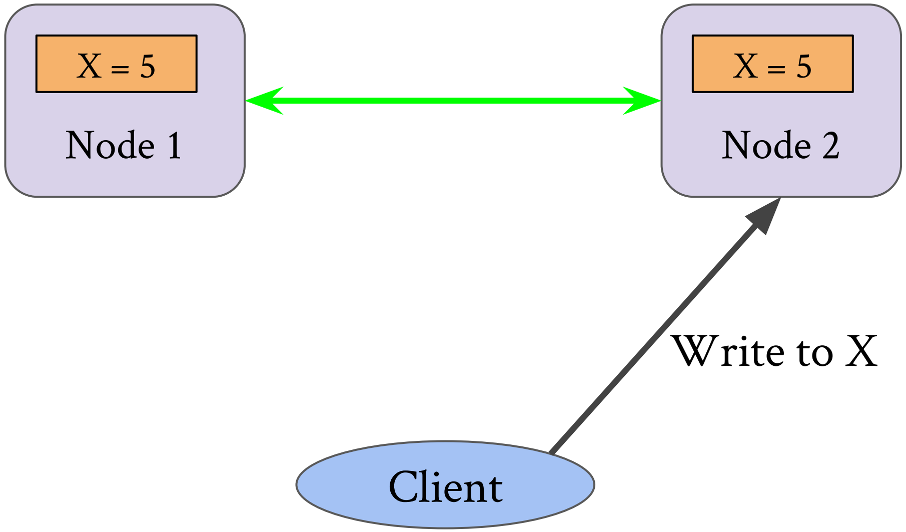


Consistency and Partition Tolerance

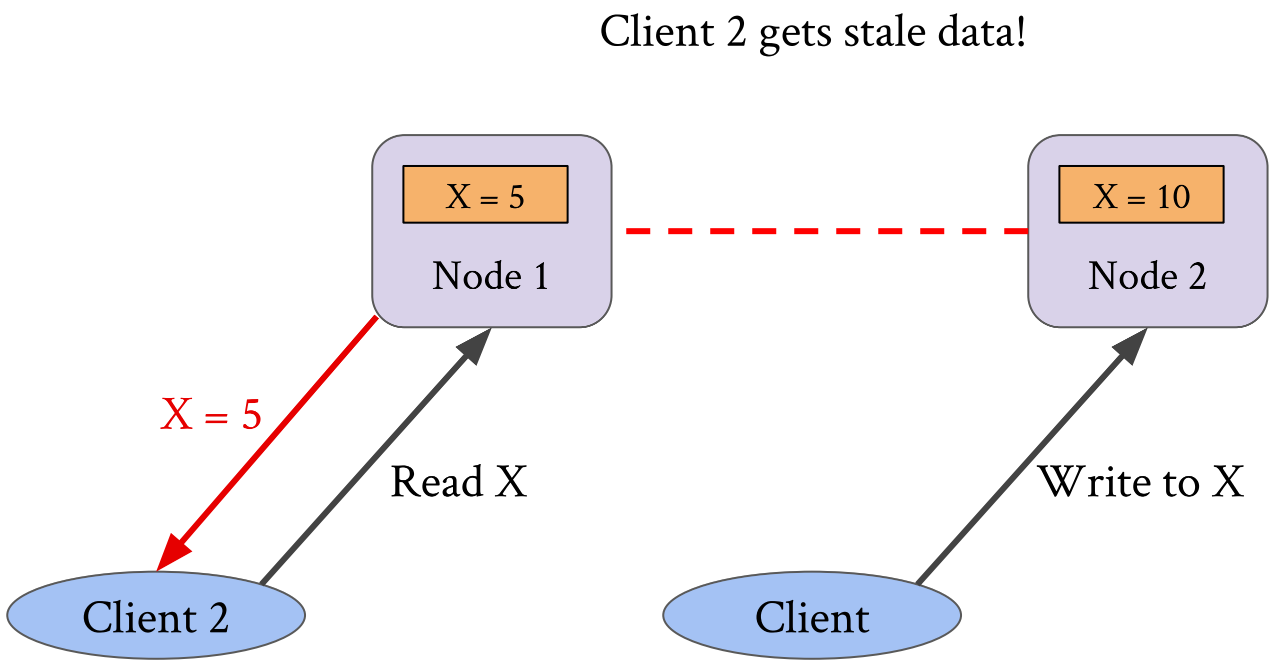


Availability and Partition Tolerance

- System is available and partition tolerant, but not consistent



Availability and Partition Tolerance



CAP Theorem: On Partition Tolerance

- In reality, distributed systems **must** be partition tolerant
- In any reasonably sized system, network failures **will** happen
- Your only choice is between consistency and availability
- Choose consistency when you require atomic operations
- Choose availability when system response is important

Replication/Coding and Consistency

Replication/Coding Dilemma

- All replicas must be kept consistent
  - Otherwise, what’s the point?
- Paradox:
  - Replicate data for better performance
  - Modifying one copy triggers a write to every other copy
  - Volume of writes uses bandwidth and reduces performance

Consistency Models

- A **consistency model** specifies when and how modifications are made to replicas
- Many different types:
  - Strict consistency
  - Sequential consistency
  - Causal consistency
  - Eventual consistency

Strict Consistency

- Strongest form of consistency
- Any execution is the same as if all reads and writes were executed in the wall-clock order that they were issued
- Pros: Reads always return the most recent value
- Cons: Poor performance. Why?

Eventual Consistency

- Weakest form of consistency
- Any read will **eventually** get the most recent value
    - “Eventually” could be a long time
- Pros: High performance. Why?
- Cons: Reads can get stale values

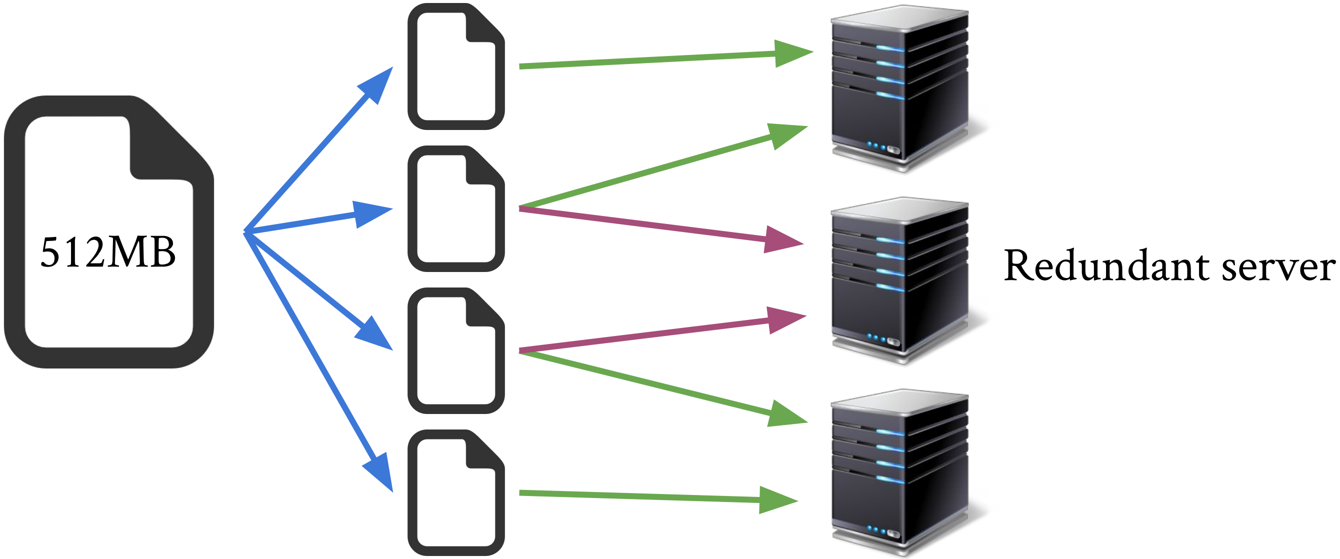
Hadoop Distributed File System (HDFS)

HDFS: Intro

- Hadoop is an open-source MapReduce framework by Apache
  - We will be using it for lab1
- HDFS is the file system used by Hadoop
- Designed to:
  - Store large data sets
  - Provide high reliability
  - Provide high bandwidth to user applications

HDFS Architecture: Blocks

- HDFS is a **block-structured** file system
  - Files are divided into 128MB blocks by default
  - Blocks are spread out and replicated across a cluster



HDFS Architecture: NameNodes and DataNodes

- Two node types: NameNode and DataNode
- NameNode - stores file **metadata**
  - Permissions, sizes, list of blocks
  - Considered the master
- DataNode - stores actual application data
  - Slave nodes
- All communication over TCP

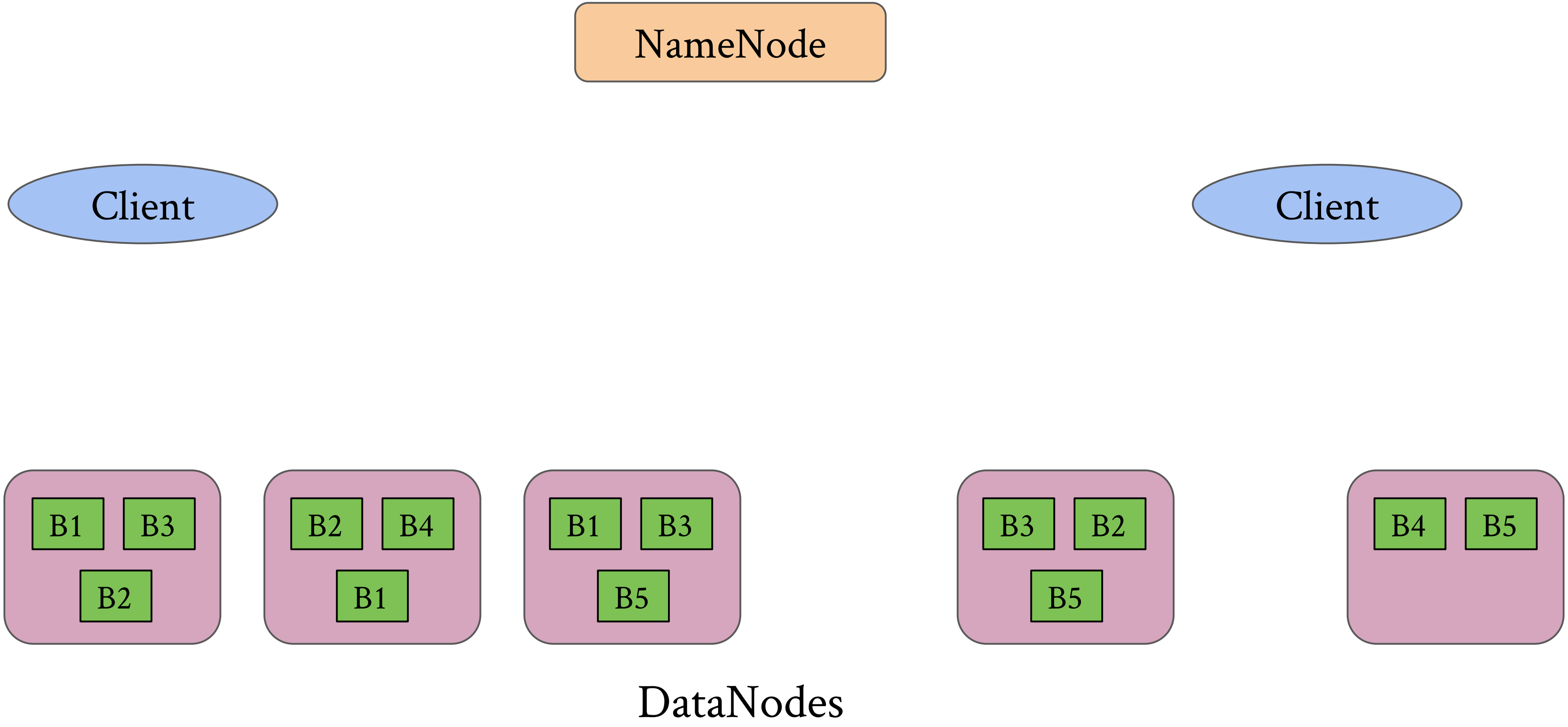
HDFS Architecture: NameNode Duties

- Only one NameNode
- Maintains the directory hierarchy
  - Handles open/close/rename requests
- Handles authentication
- Collects block reports from DataNodes
- Issues block commands to DataNodes

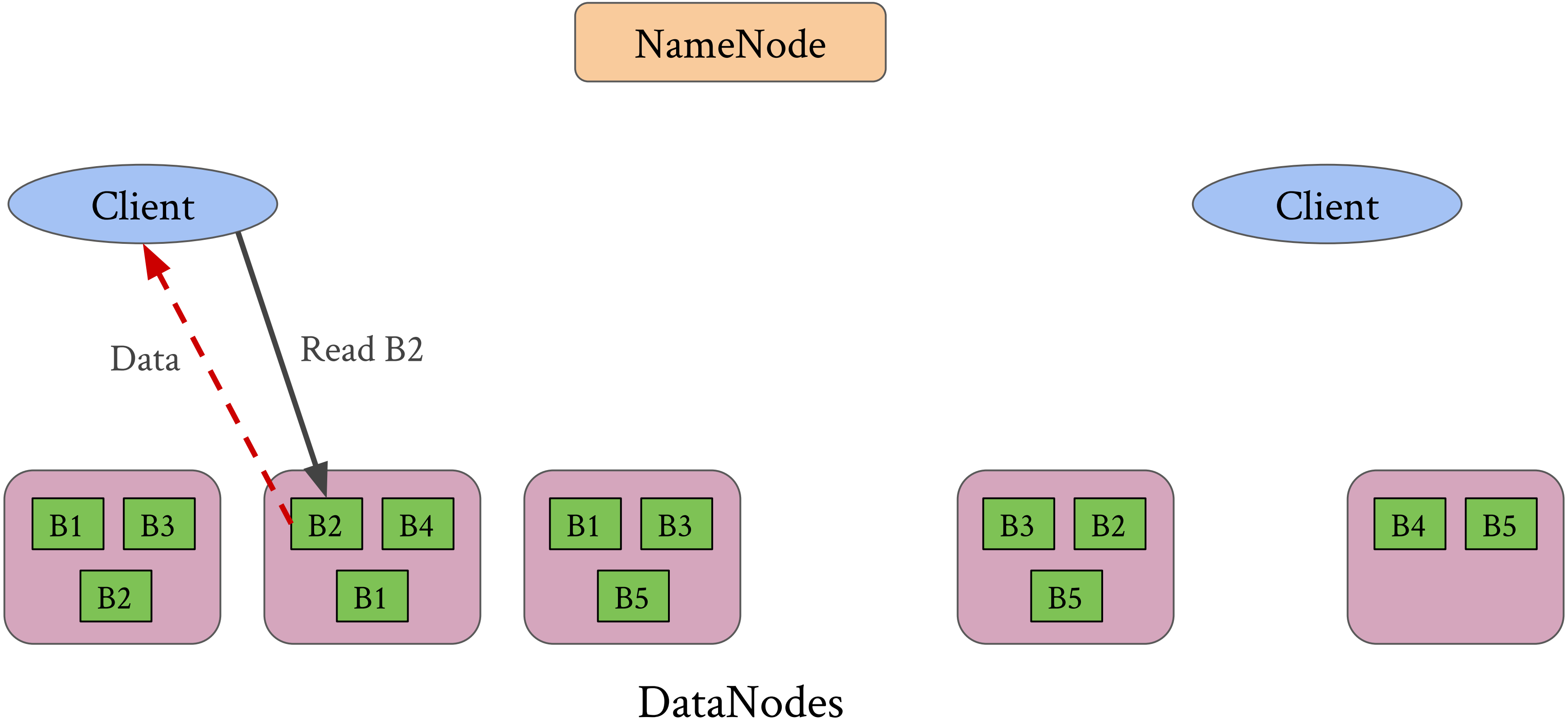
HDFS Architecture: DataNode Duties

- Many DataNodes
- Handle read/write requests from clients
- Perform block creation, deletion, and replication
  - Follow NameNodes orders
- Send block reports to NameNode

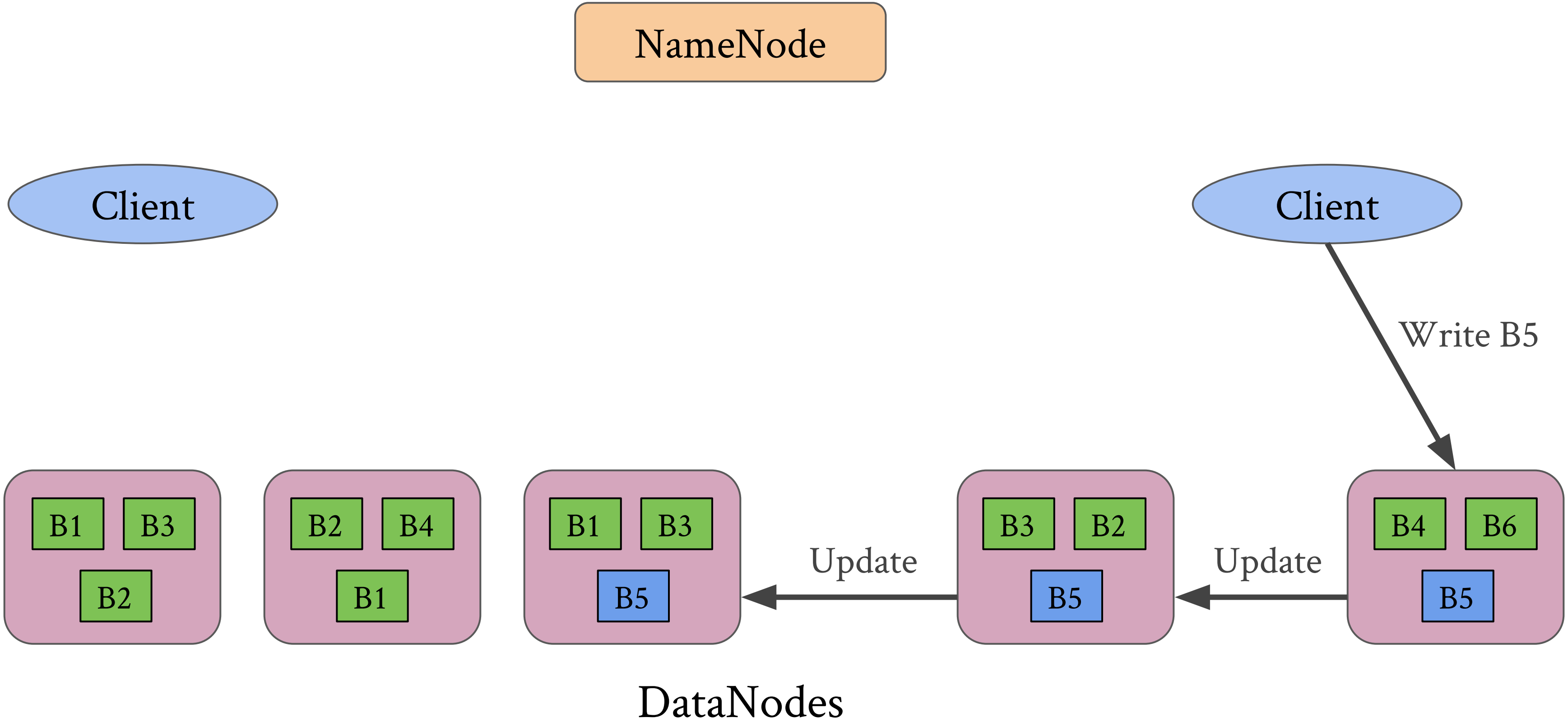
HDFS Architecture with replication



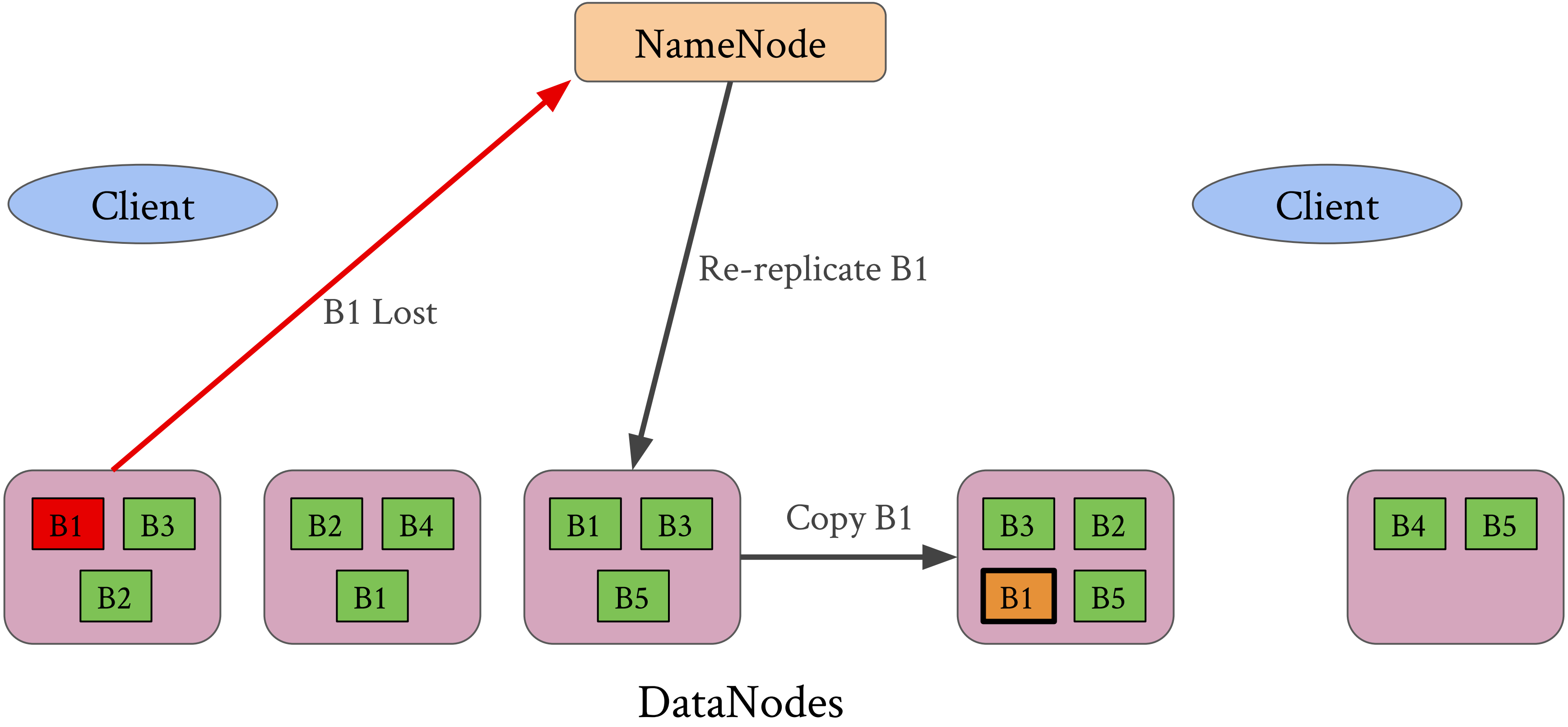
HDFS Architecture: Block Read



HDFS Architecture: Block Write



HDFS Architecture: Block Data Loss



Conclusion

Distributed data storage a challenge

- Fundamental limits in design: CAP theorem

Efficiency in storage through coding

Particular implementations:

HDFS, GFS and many others: HDFS used in assignment

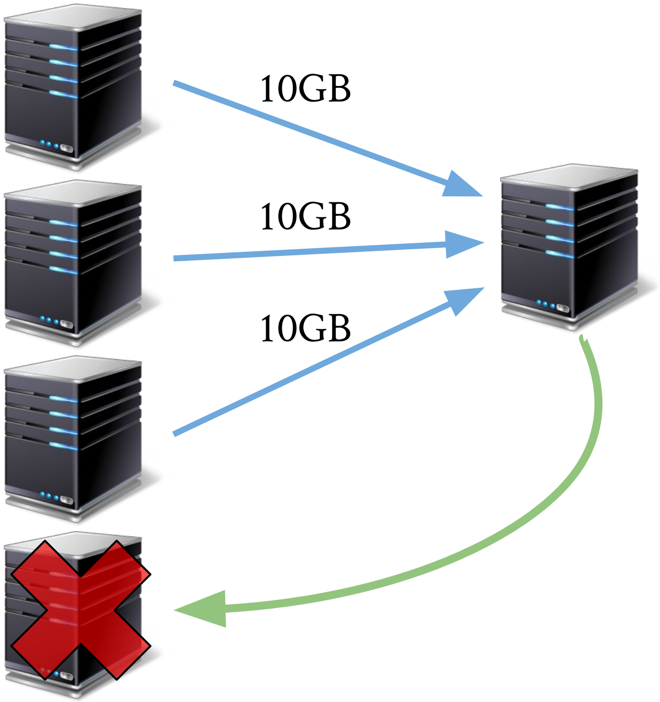
HDFS Architecture: Heartbeats

- Method of communication between NameNode and DataNodes

- DataNodes send heartbeats to NameNode
    - Signifies that DataNode is working correctly
    - Block replicas on the node are available

Node Repair: Repair Bandwidth

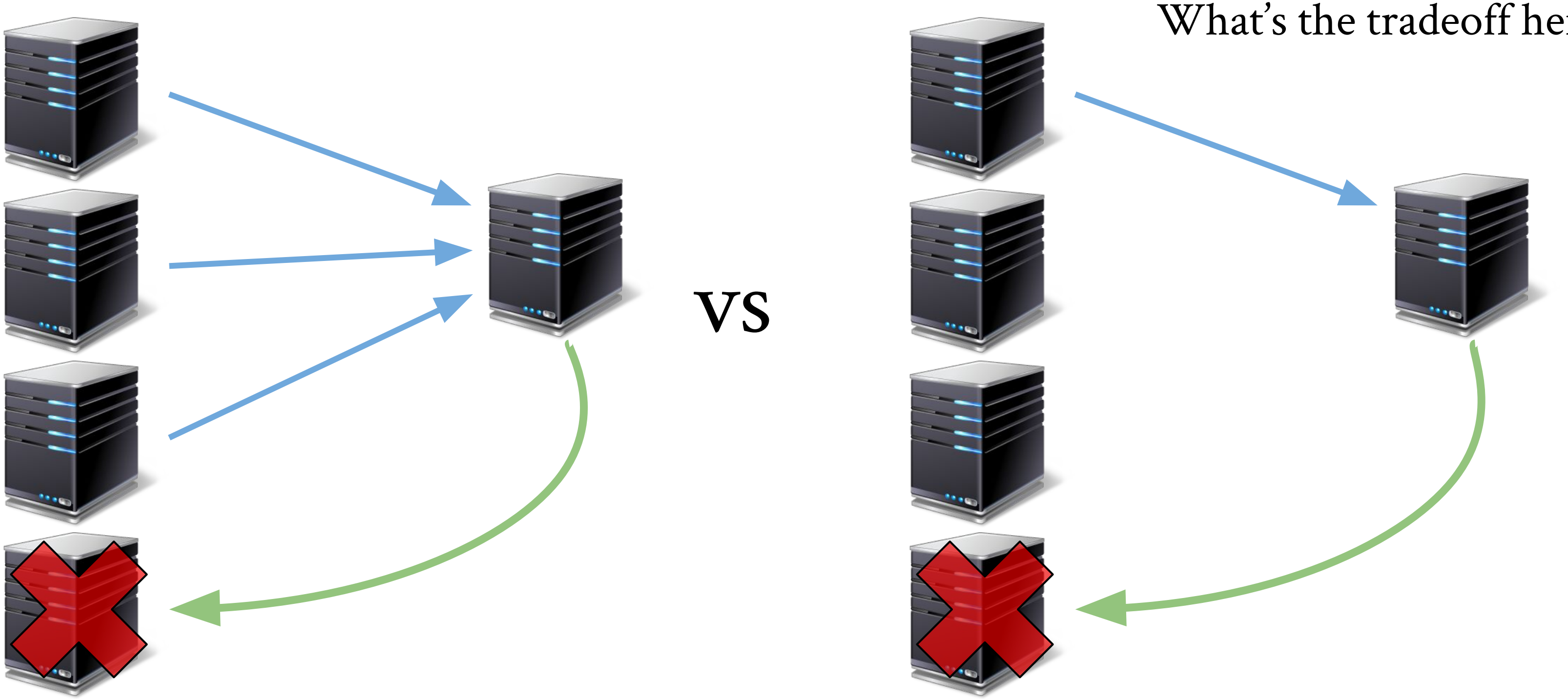
- How much data needs to be downloaded to reconstruct?



Node Repair: Locality

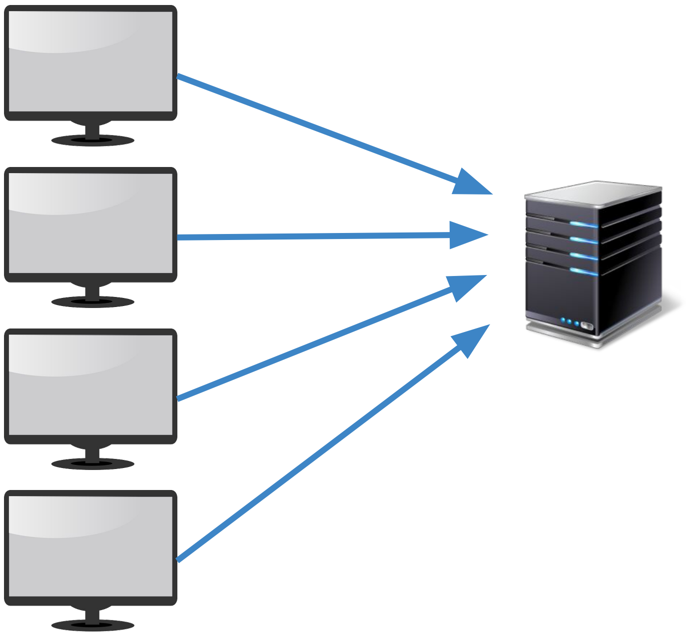
- Number of nodes accessed for a repair

What's the tradeoff here?



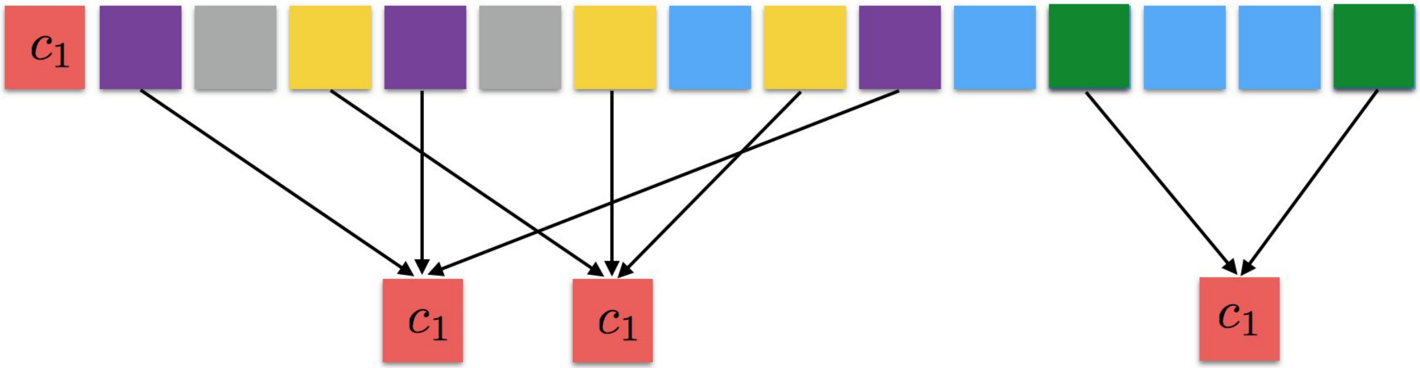
Parallel Access

- Support multiple users accessing the same data



Parallel Access

- 4 parallel read groups, locality less than 3



Parallel Access: Hot Data

- Hot data requires fast access by multiple concurrent users
  - Facebook photos
  - Google Maps
- CERN labels 13PB out of its 100PB dataset as hot data
- Replicate hot data on more machines
  - More machines $\Rightarrow$ more bandwidth

Security

- Prevent data snooping during regular operation and node repairs