GFS and HDFS

DS 5110/CS 5501: Big Data Systems

Spring 2024

Lecture 4a

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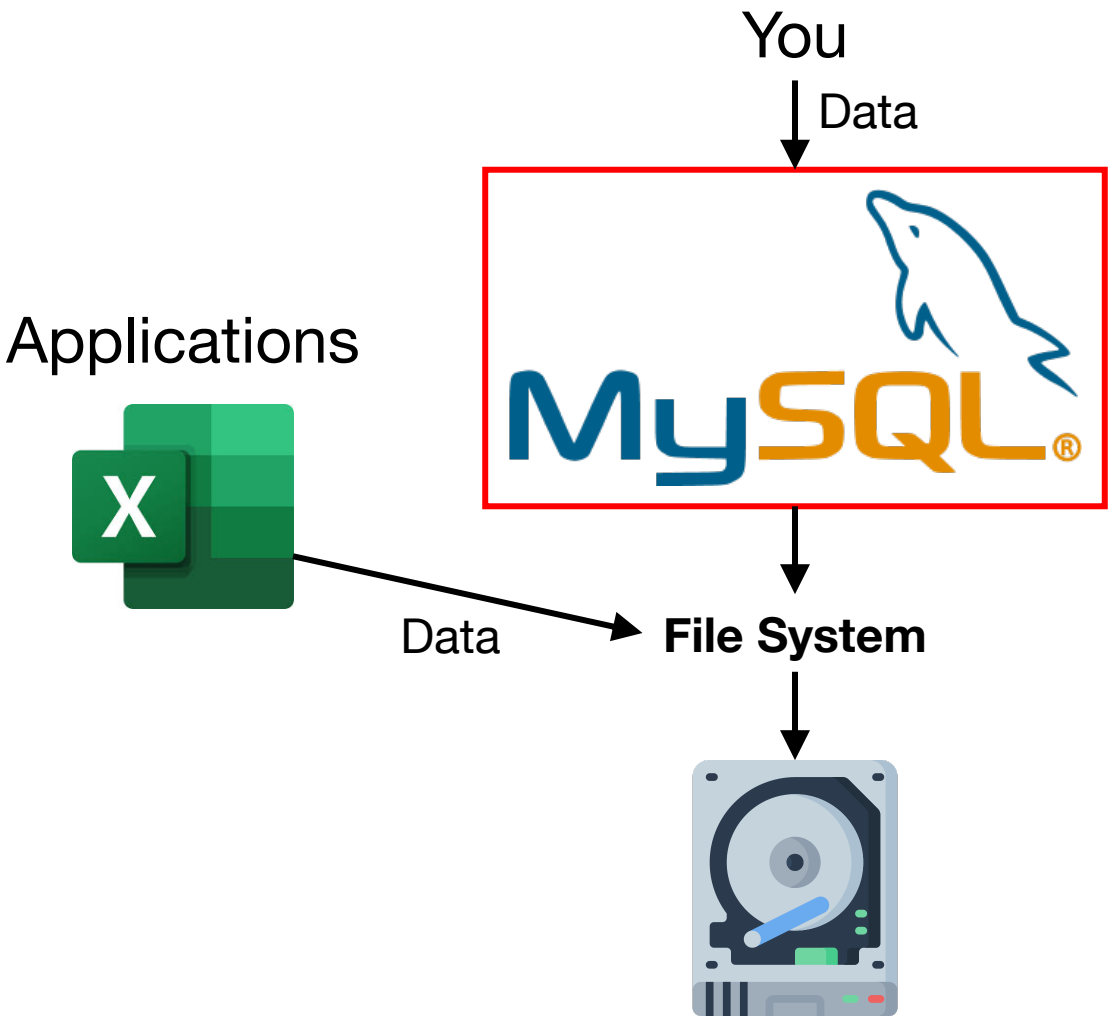
Some material taken/derived from:

- Wisconsin CS 320 by Tyler Caraza-Harter.

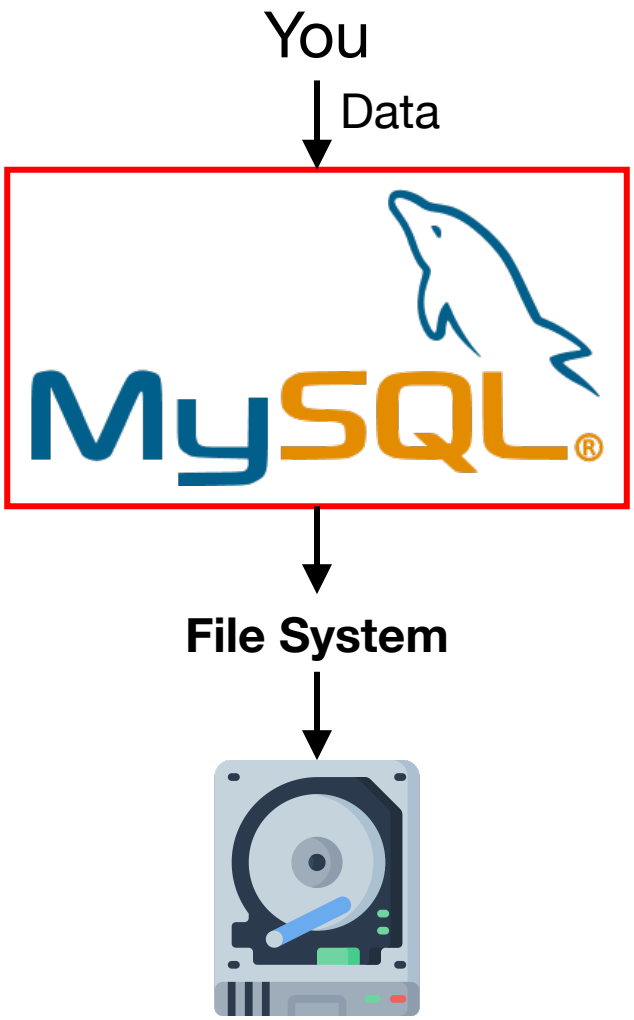
Learning objectives

- Describe the design of GFS (HDFS)
- Understand partitioning, replication, and the motivation of each technique
- Identify the role that clients, NameNode, DataNodes play for HDFS reads and writes

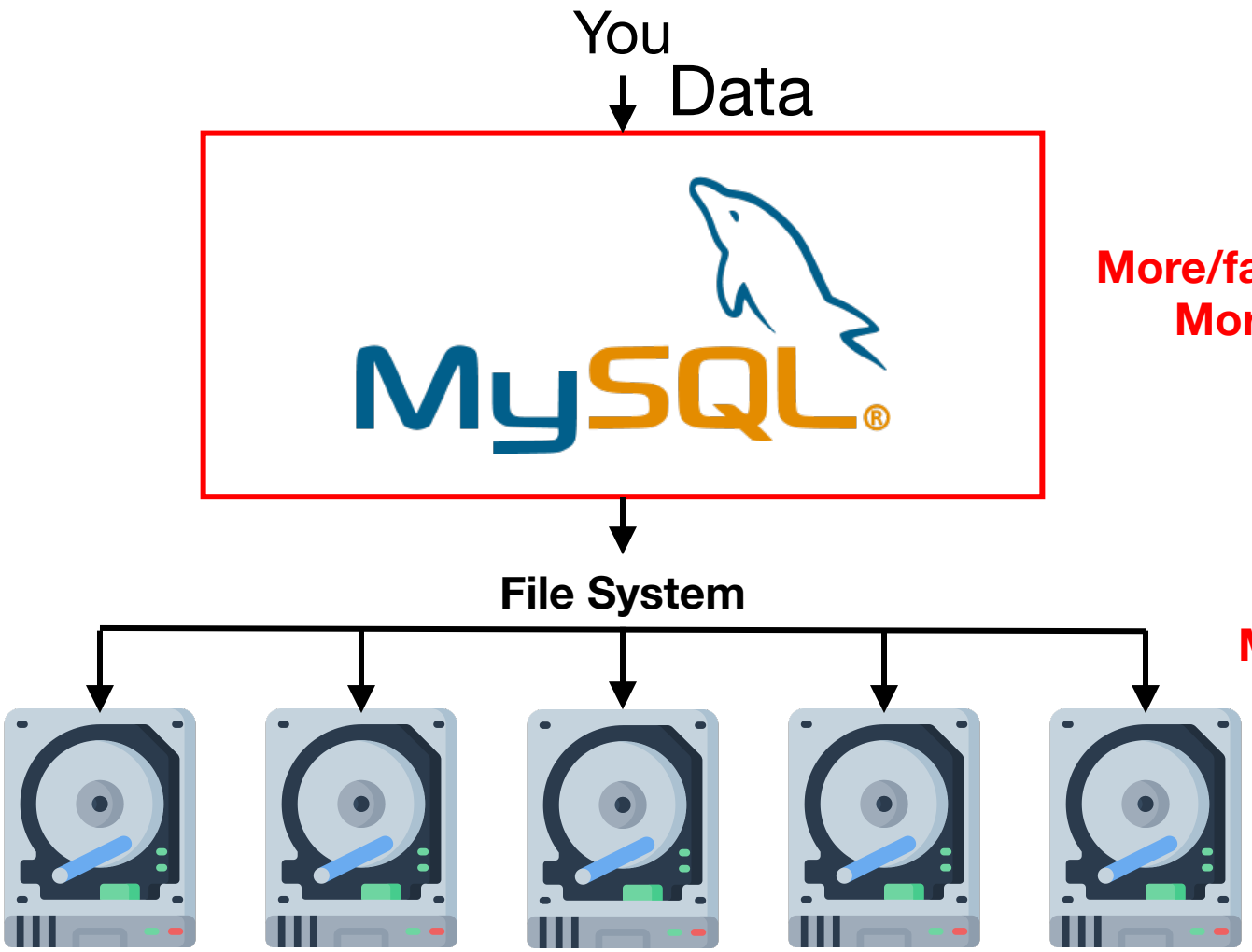
Design: Storage systems are generally built as a composition of layered subsystems



Problem: What if your data is too big?



Problem 1: What if your data is too big?
Option 1: Scale up (buy better hardware)

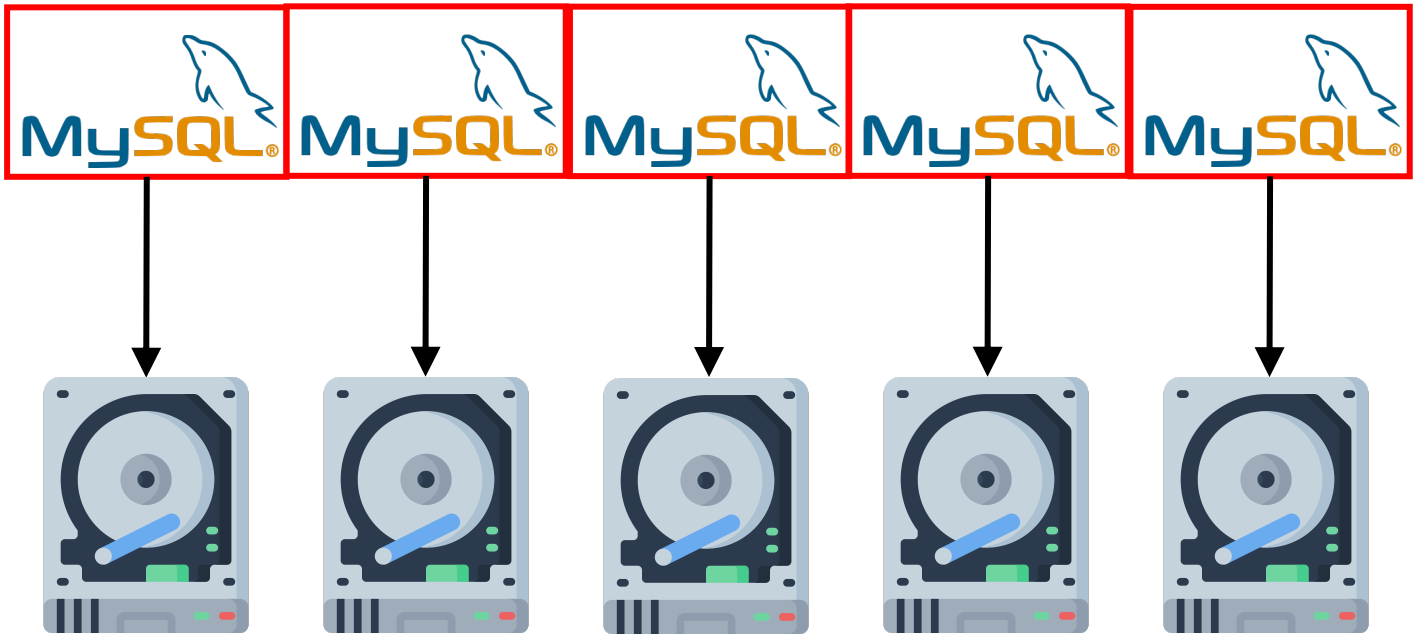


More/faster CPUs
More RAM

More disks

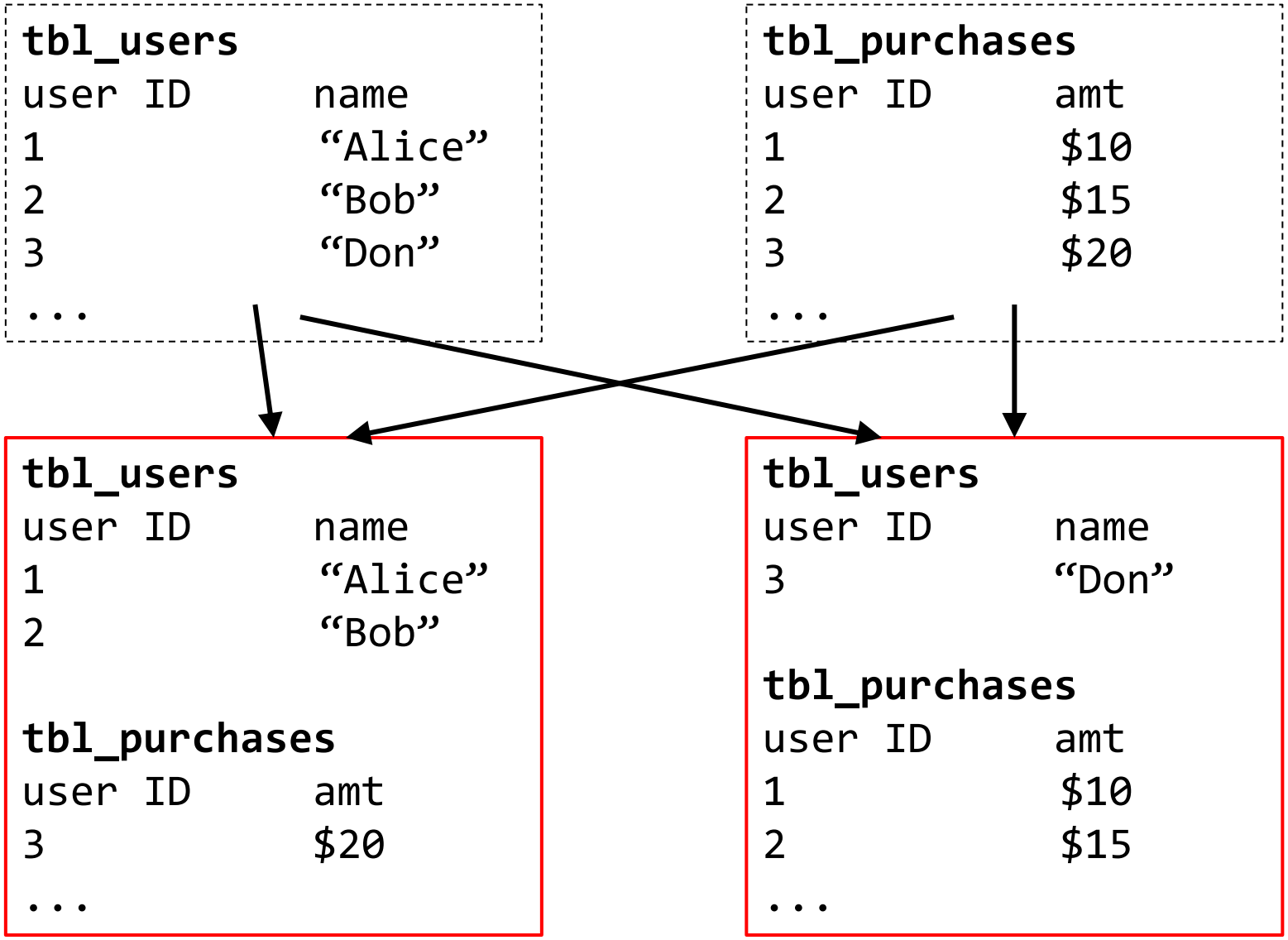
Problem 1: What if your data is too big?
Option 2: Scale out (more machines)

Where does the data actually go?



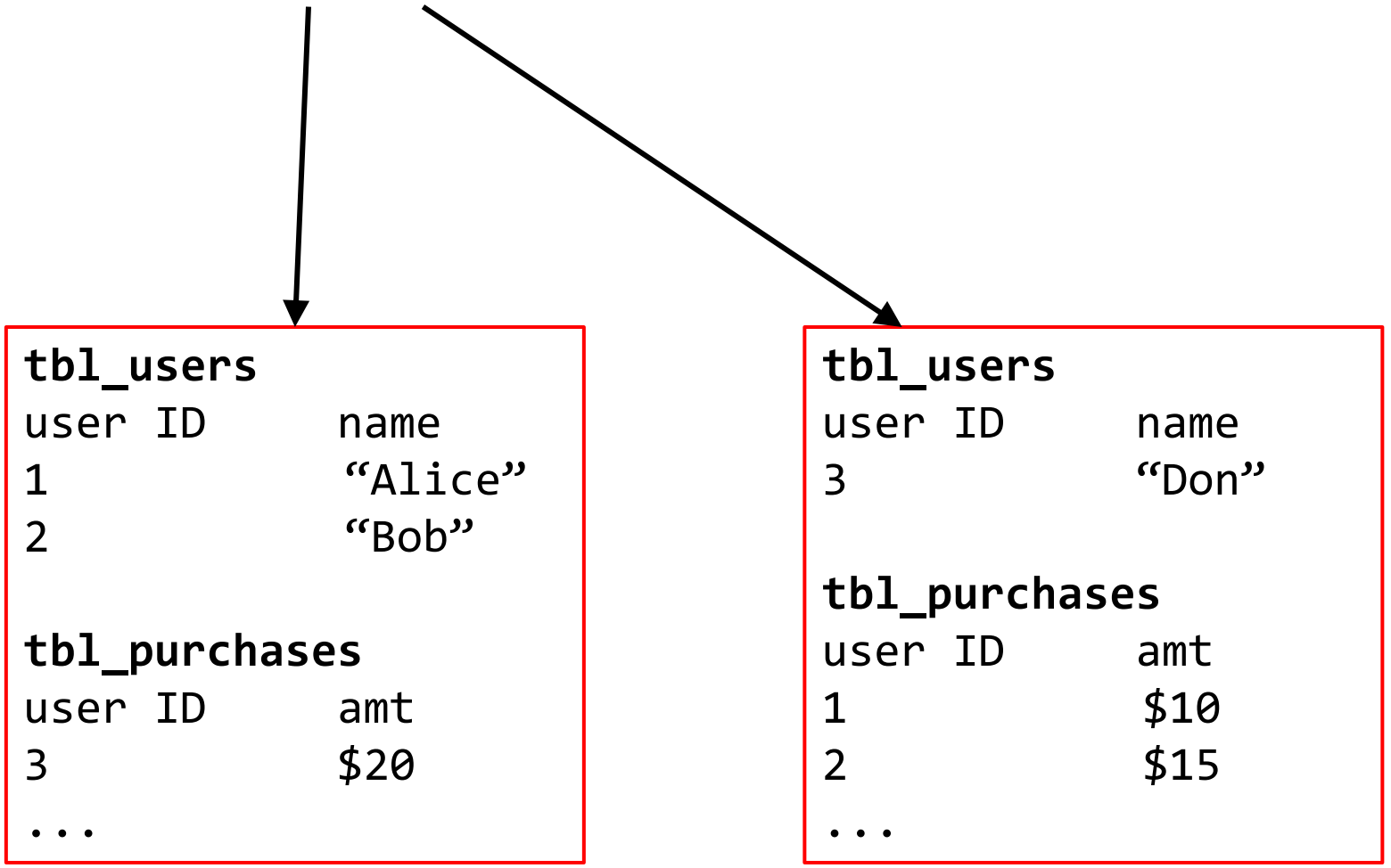
…1000 more…

Approach: Partition the data



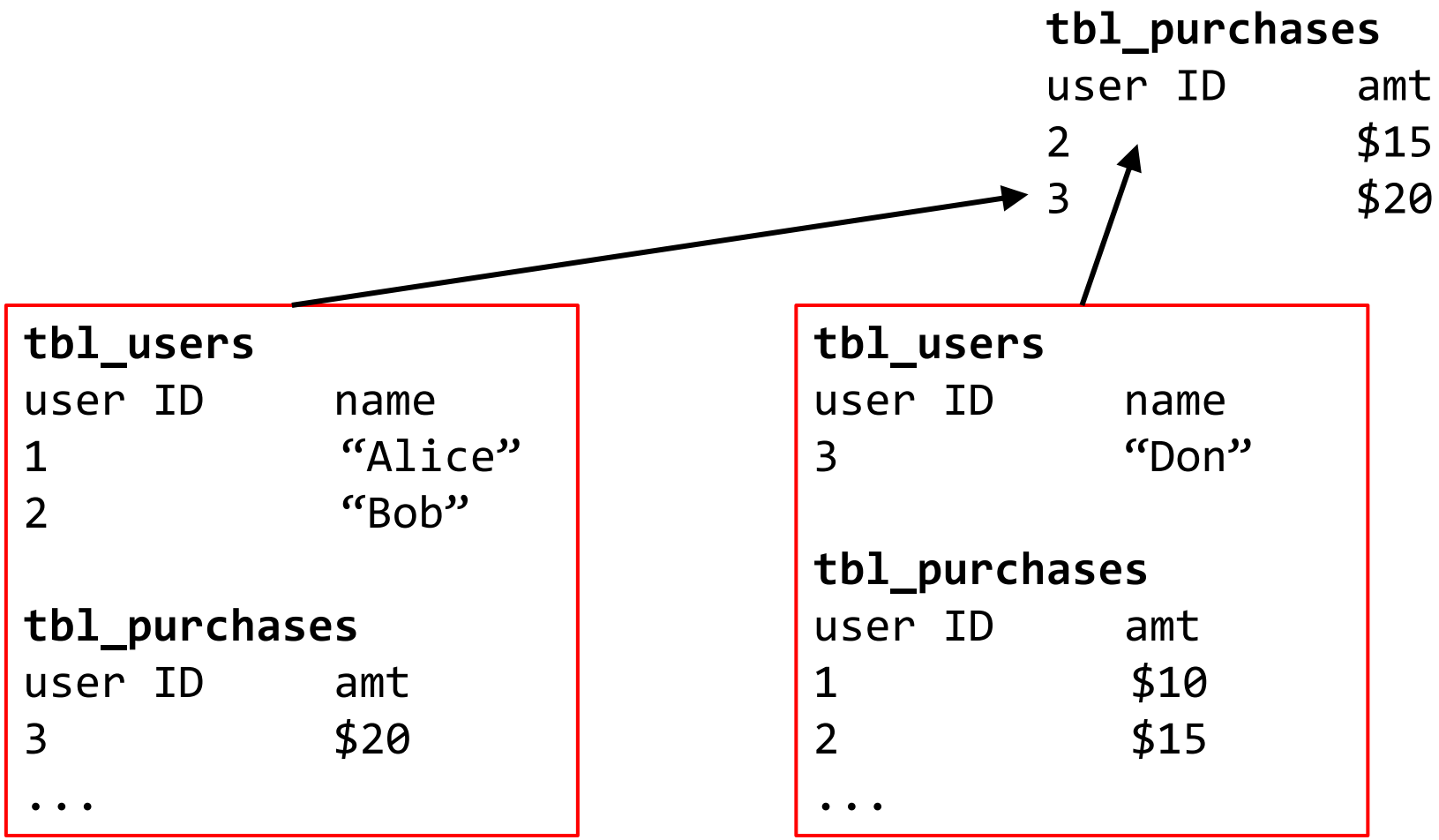
Approach: Send queries to multiple DBs

```
SELECT * FROM tbl_purchases WHERE amt > 12
```



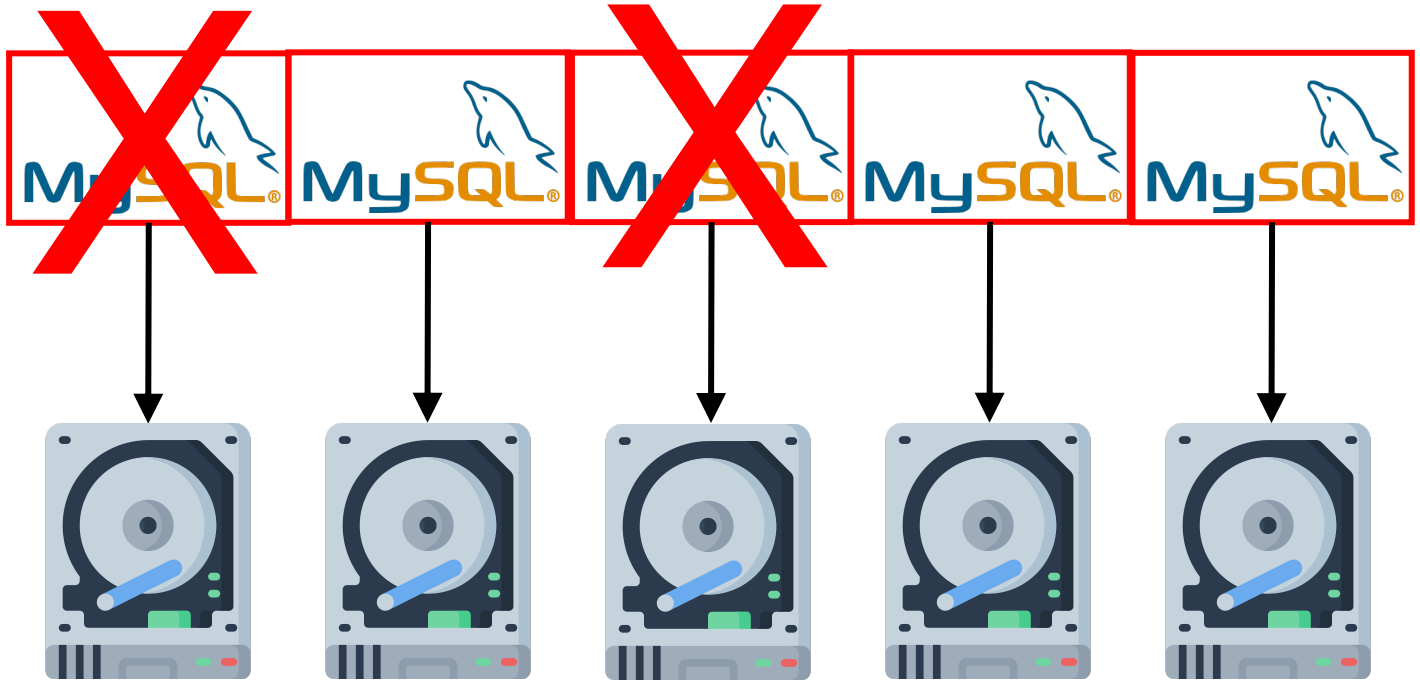
… Combine results

```
SELECT * FROM tbl_purchases WHERE amt > 12
```



Problem 2: What if your server dies?

Happens all the time when you have 1000s of machines…

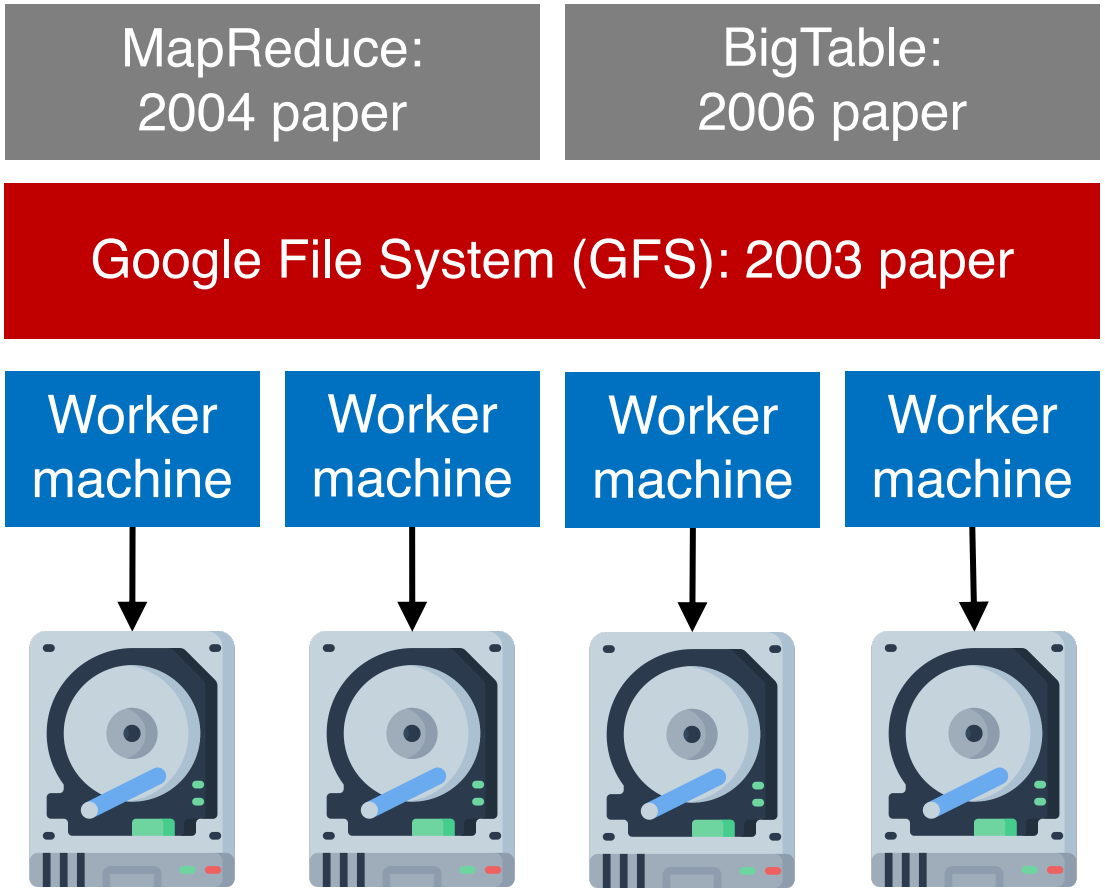


…1000 more…

Motivation for large DFS (GFS / HDFS)

- Scaling to many machines is essential
- Fault tolerance is essential

Google big data infrastructure



Radical idea: base everything on lots of cheap, commodity hardware

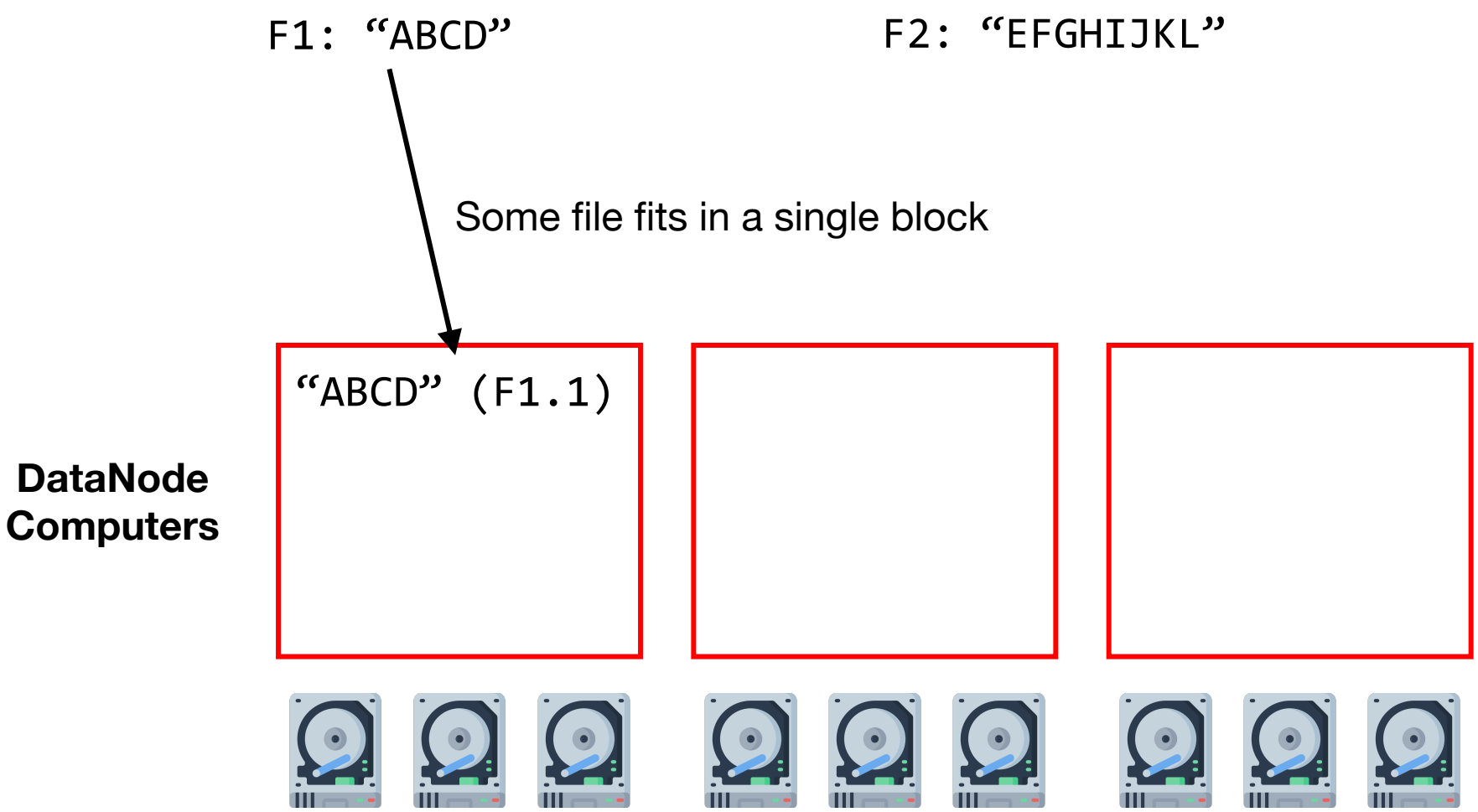
Hadoop ecosystem

Yahoo, Facebook, Cloudera, and others developed open-source Hadoop ecosystem, mirroring Google's big data systems

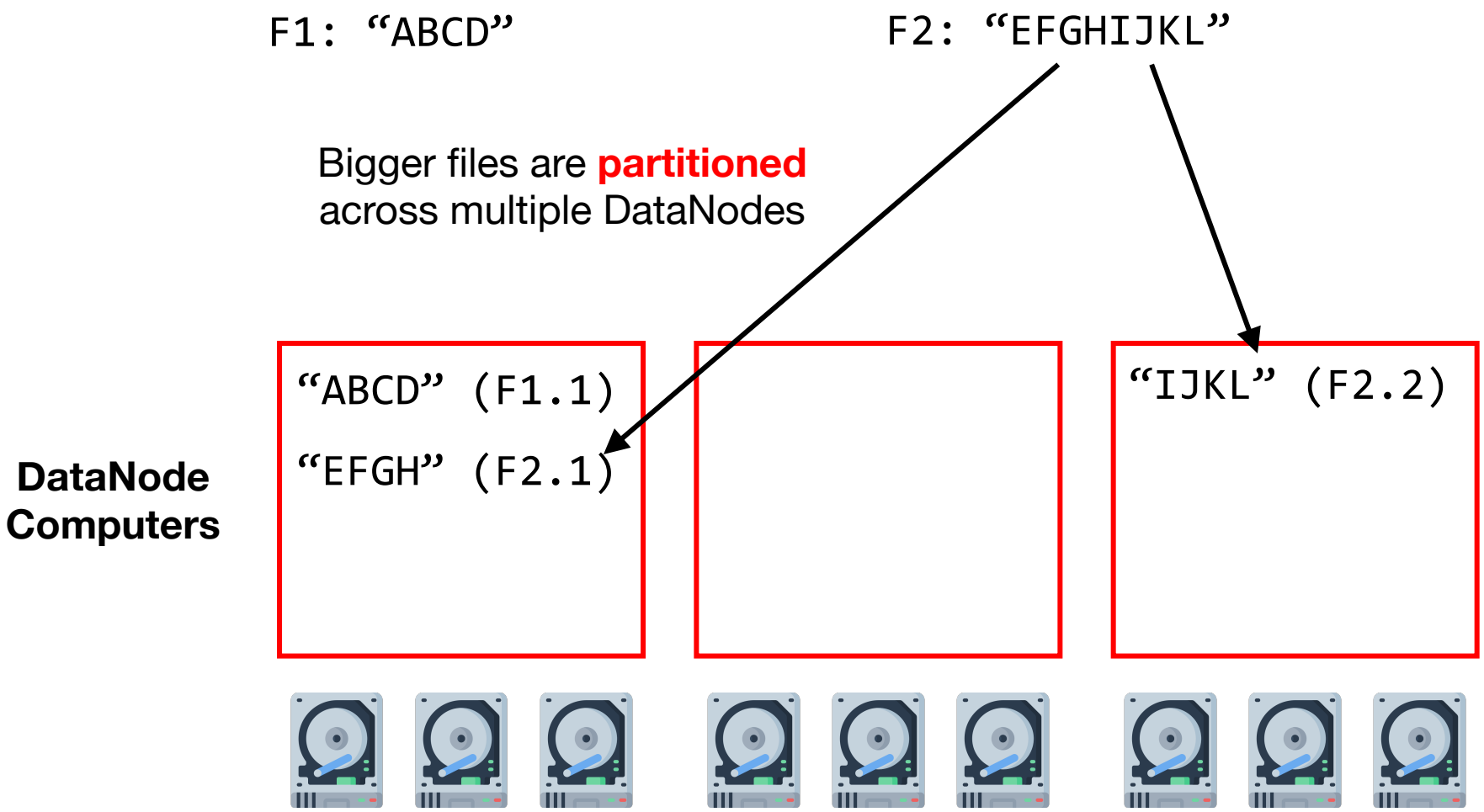
	Google (paper only)	Hadoop (open source)	Modern Hadoop
Distributed File System	GFS	HDFS	
Distributed Processing & Analytics	MapReduce	Hadoop MapReduce	Spark
Distributed Database	BigTable	HBase	MongoDB

https://hadoop.apache.org/

HDFS: DataNodes store file blocks



HDFS: Partitioning across DataNodes



HDFS: Replication across DataNodes

F1: “ABCD”

3x replication

F2: “EFGHIJKL”

2x replication

DataNode Computers

HDFS: Replication across DataNodes

F1: “ABCD”

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2x replication

Logical blocks vs. physical blocks

DataNode Computers

HDFS: Replication across DataNodes

F1: “ABCD”

3x replication

F2: “EFGHIJKL”

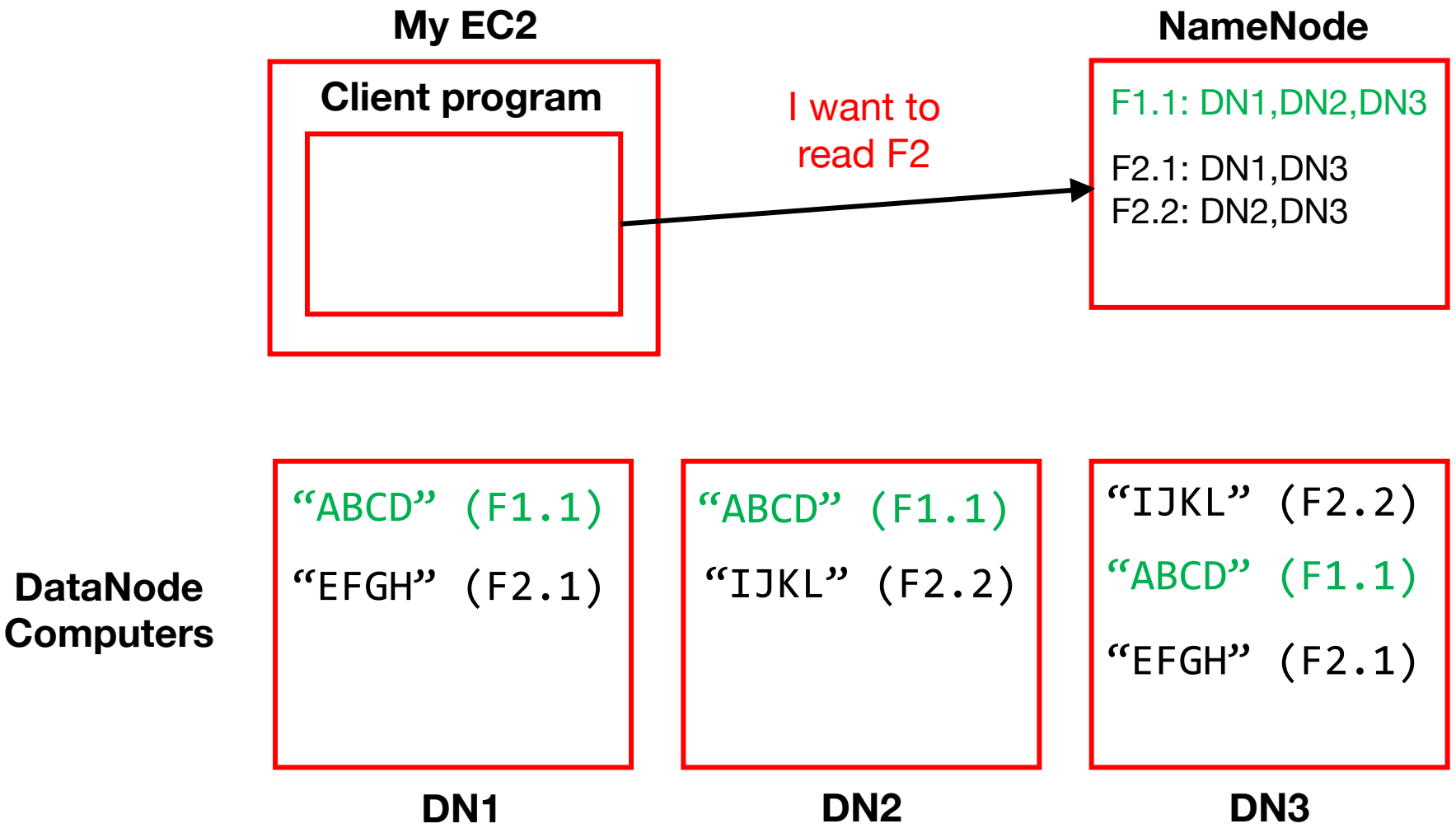
2x replication

If a DataNode dies, we still have all the data.

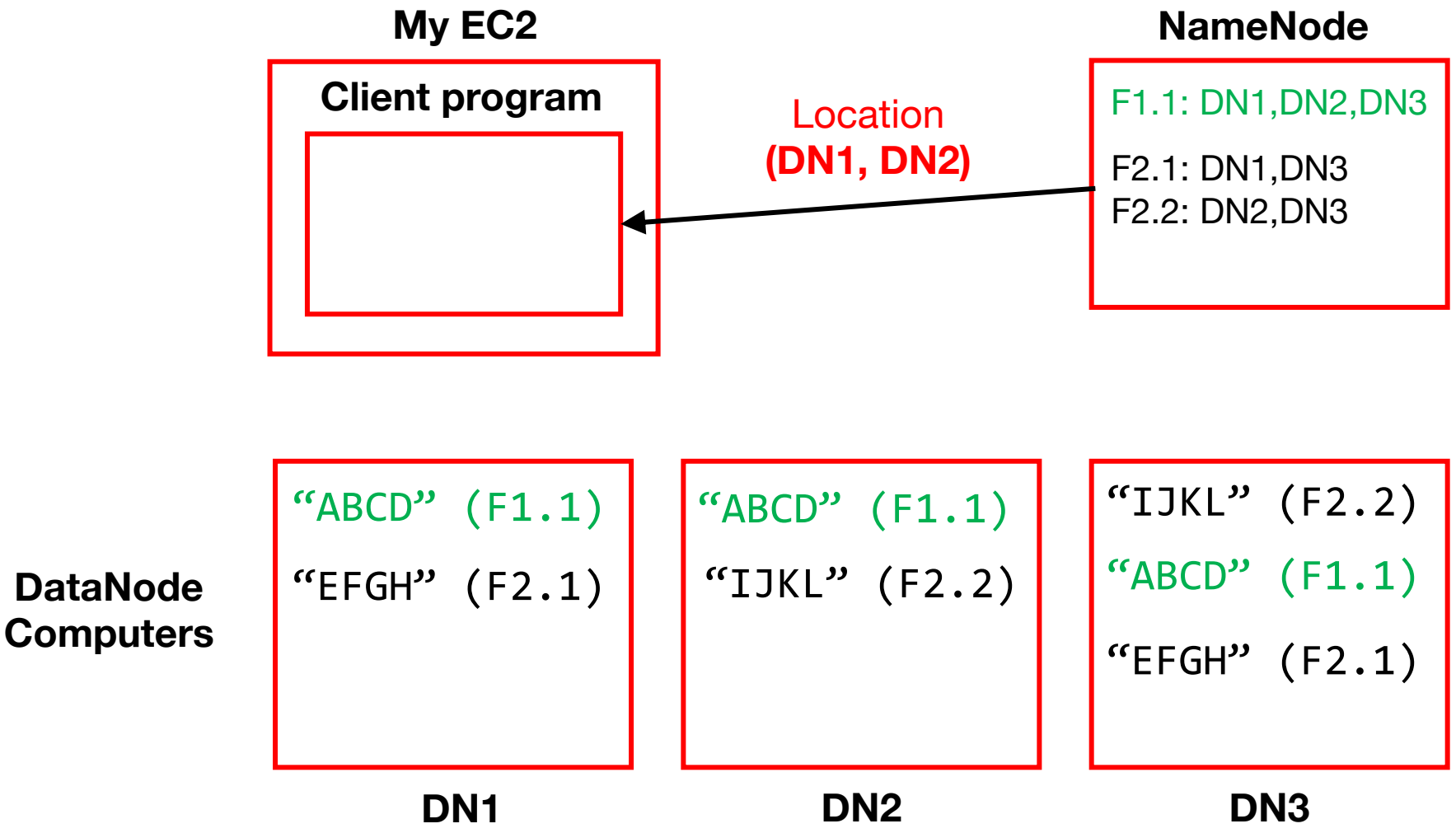
Which file is safer in general? F1 or F2?

DataNode Computers

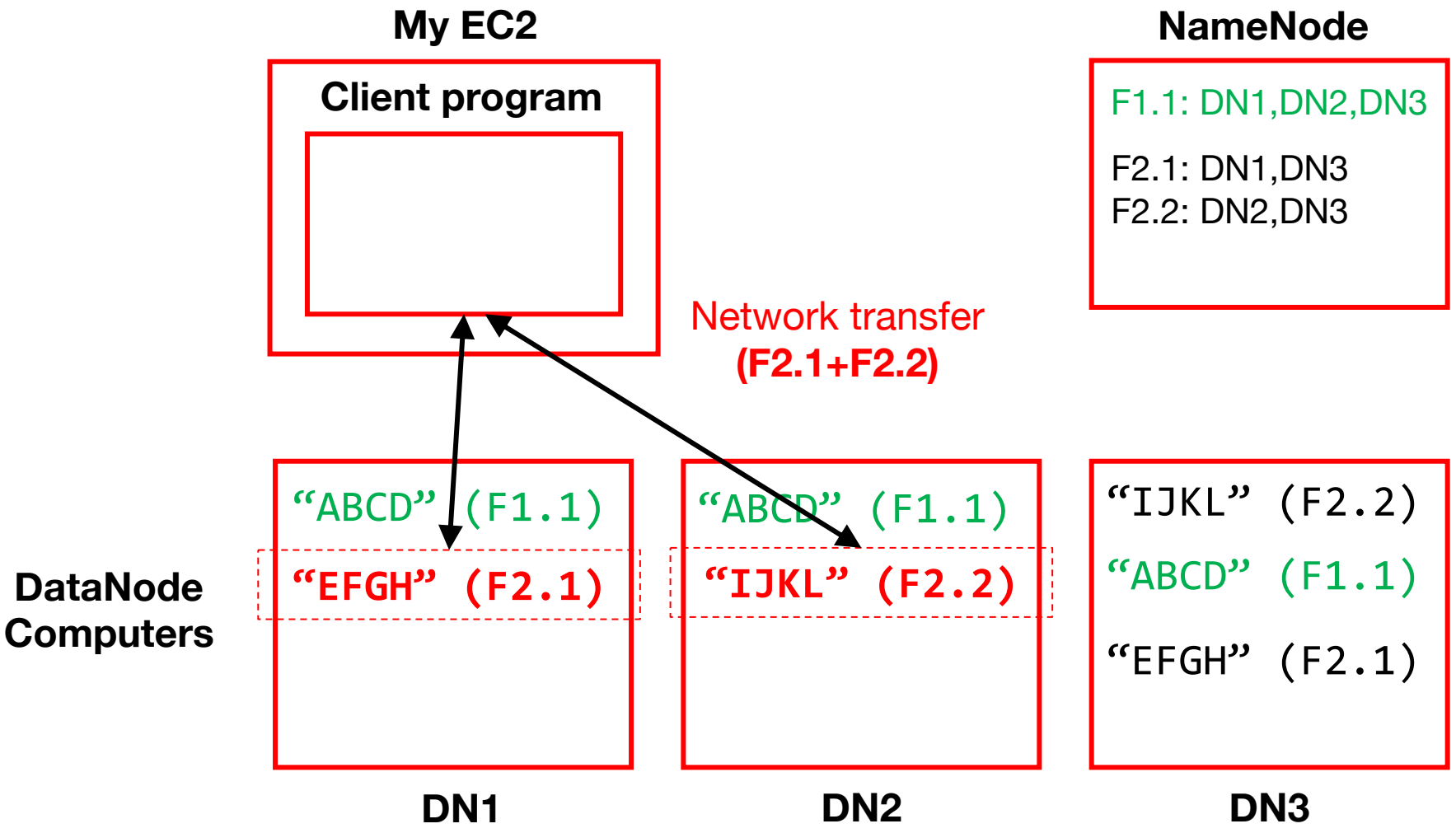
NameNode/Worker architecture



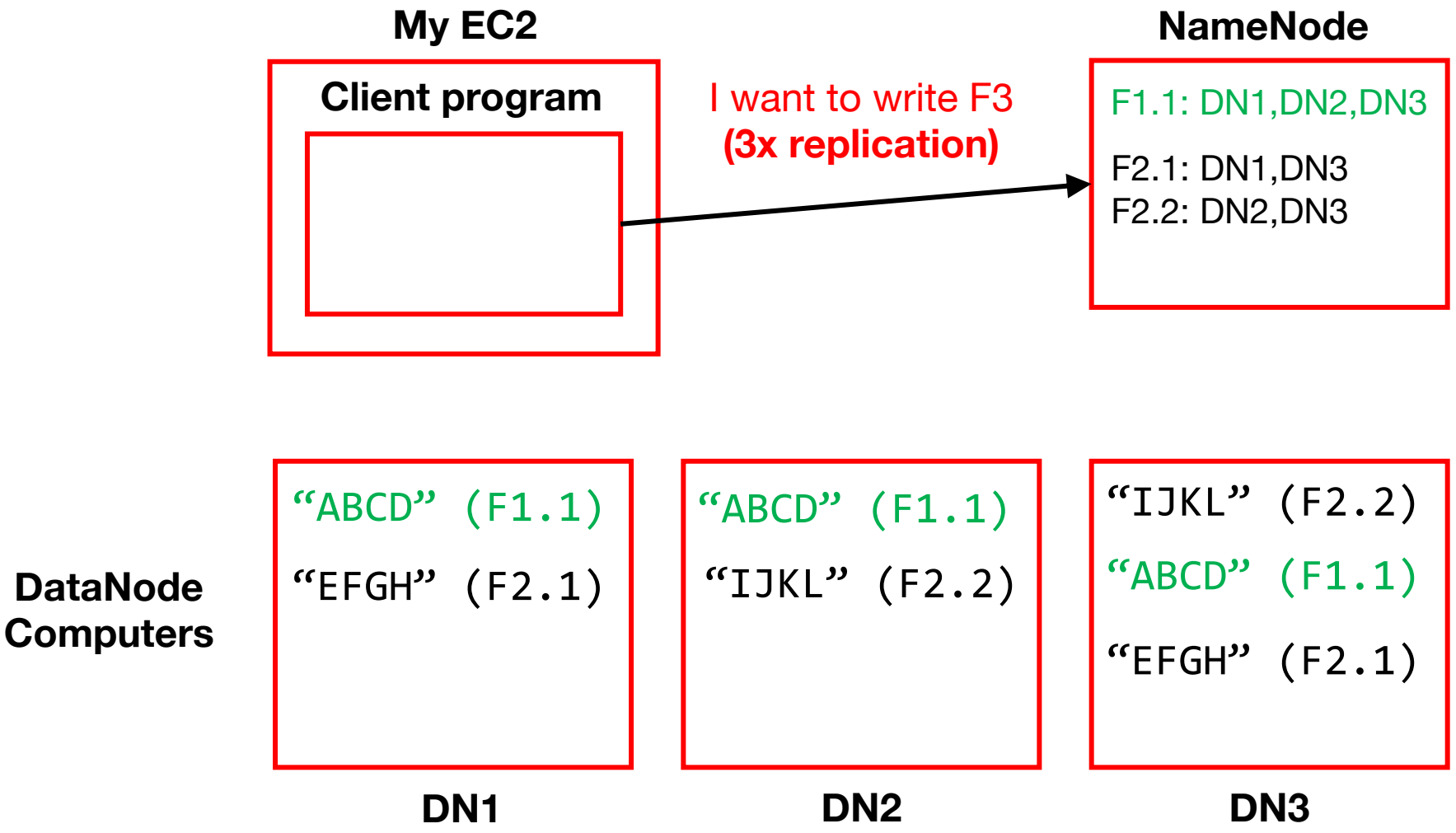
NameNode/Worker architecture



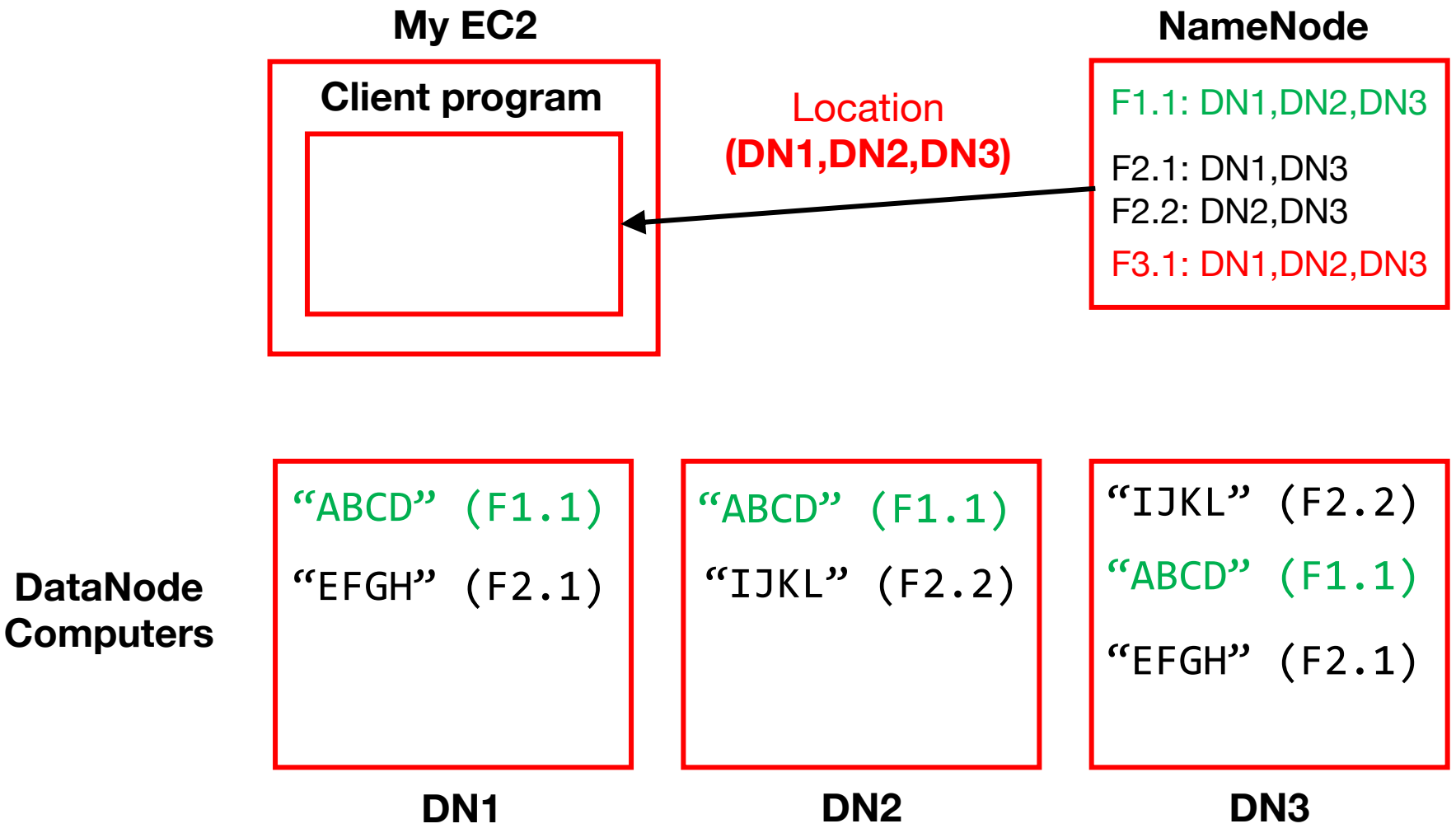
NameNode/Worker architecture



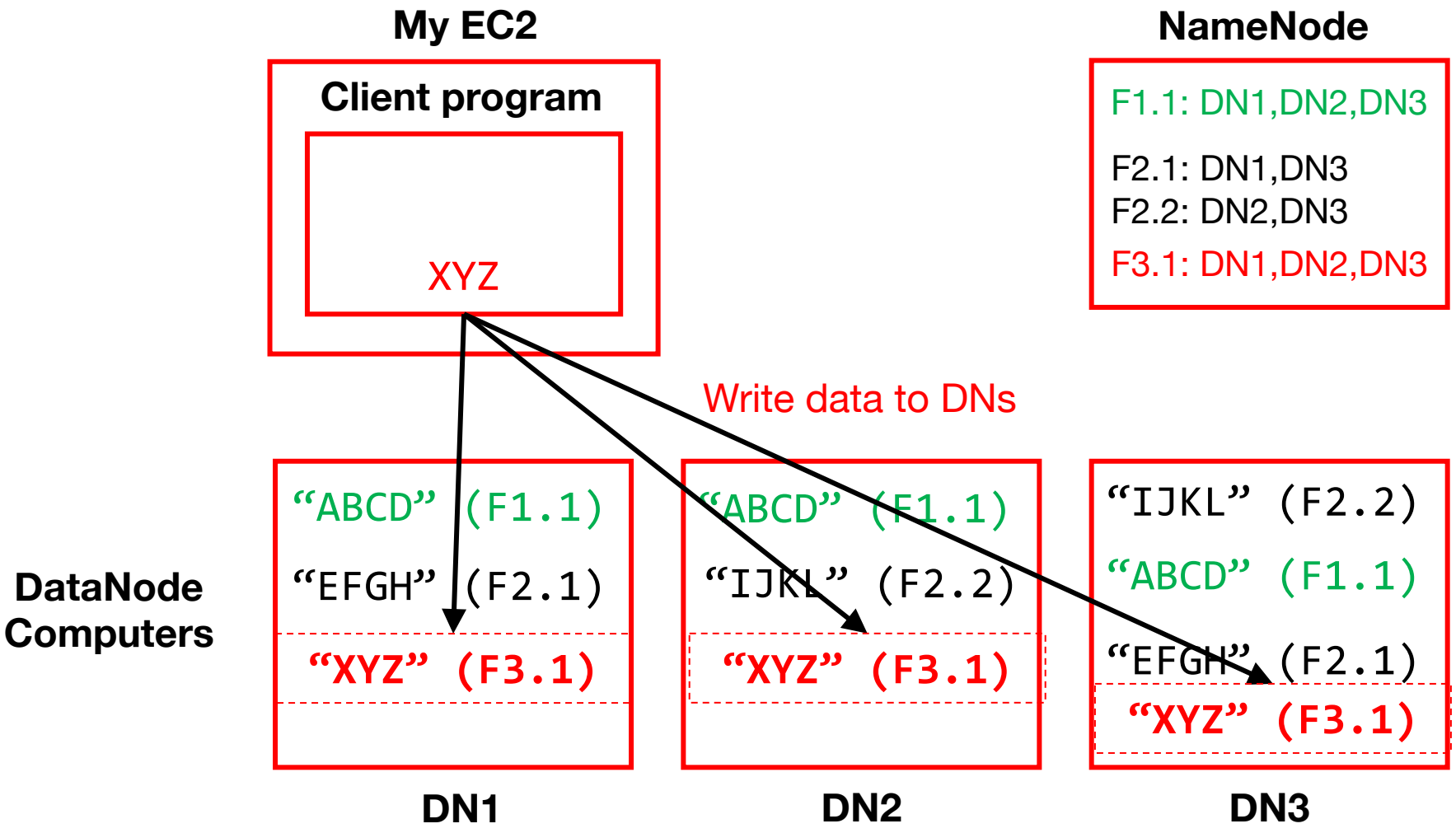
NameNode/Worker architecture



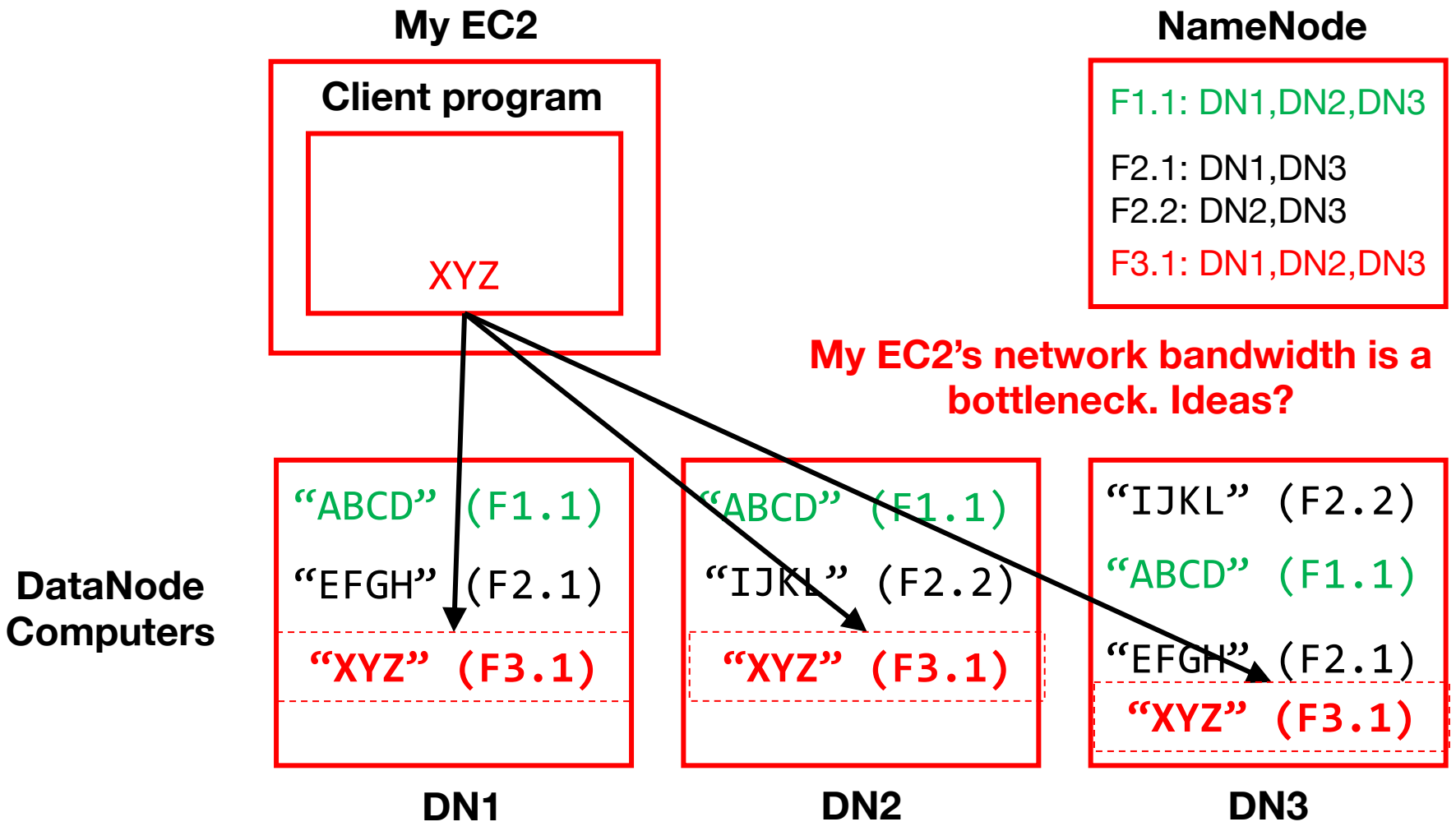
NameNode/Worker architecture



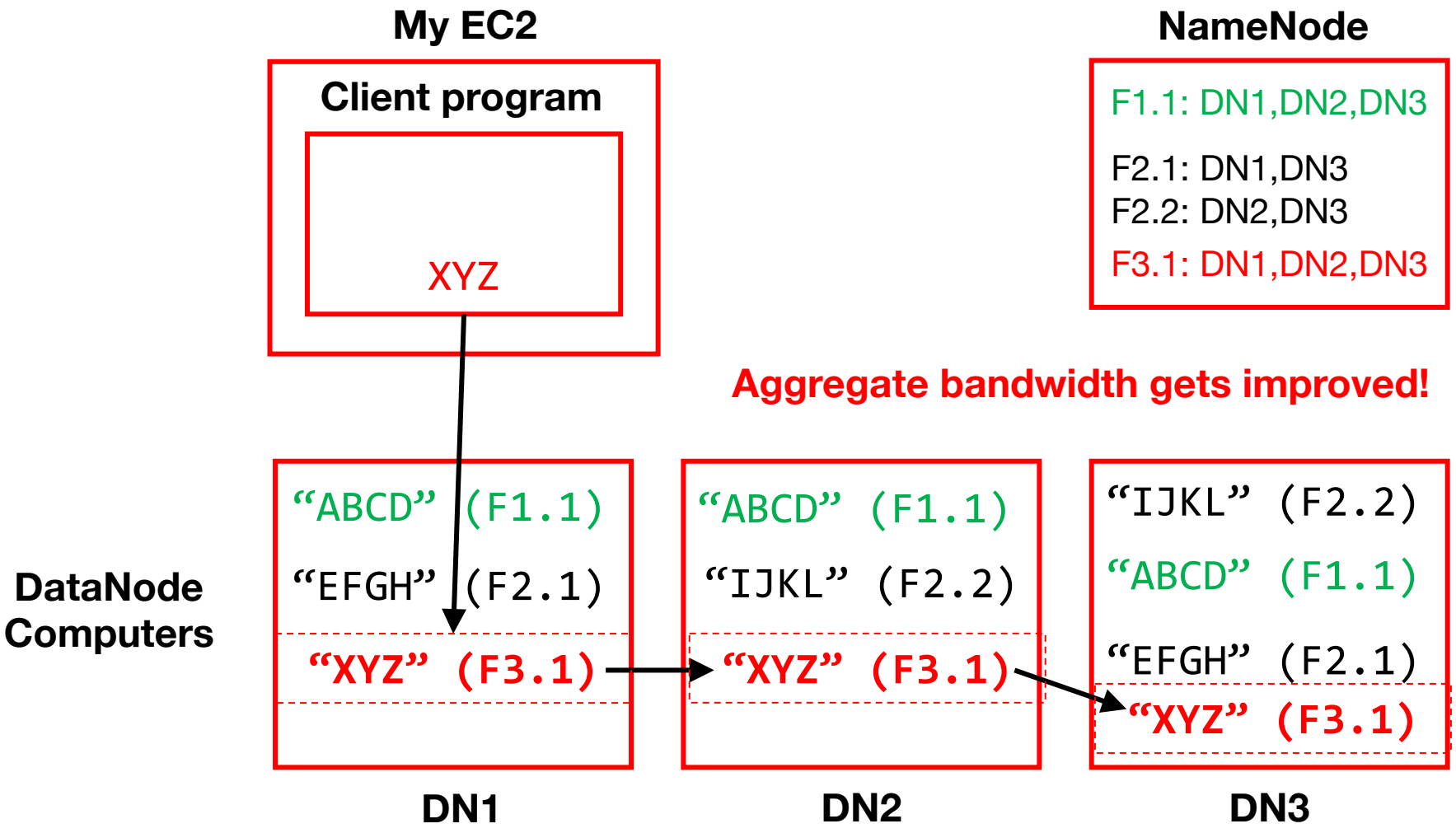
NameNode/Worker architecture



NameNode/Worker architecture



Pipelined writes



How are reads/writes amplified at disk level?

Q1: If a client **writes** 4MB to a 2x replicated file, how much data does HDFS **write** to disks?

Q2: If a client **reads** 2MB from a 3x replicated file, how much data do we **read** from disks?

NameNode

F1.1: DN1,DN2,DN3

F2.1: DN1,DN3
F2.2: DN2,DN3

F3.1: DN1,DN2,DN3

DataNode Computers

DN1	DN2	DN3
"ABCD" (F1.1)	"ABCD" (F1.1)	"IJKL" (F2.2)
"EFGH" (F2.1)	"IJKL" (F2.2)	"ABCD" (F1.1)
"XYZ" (F3.1)	"XYZ" (F3.1)	"EFGH" (F2.1)
		"XYZ" (F3.1)

What are the tradeoffs of replication factor and block size?

Benefit of high replication?

Benefit of low replication?

Benefit of large block size?

Benefit of small block size?

NameNode

F1.1: DN1,DN2,DN3

F2.1: DN1,DN3
F2.2: DN2,DN3

F3.1: DN1,DN2,DN3

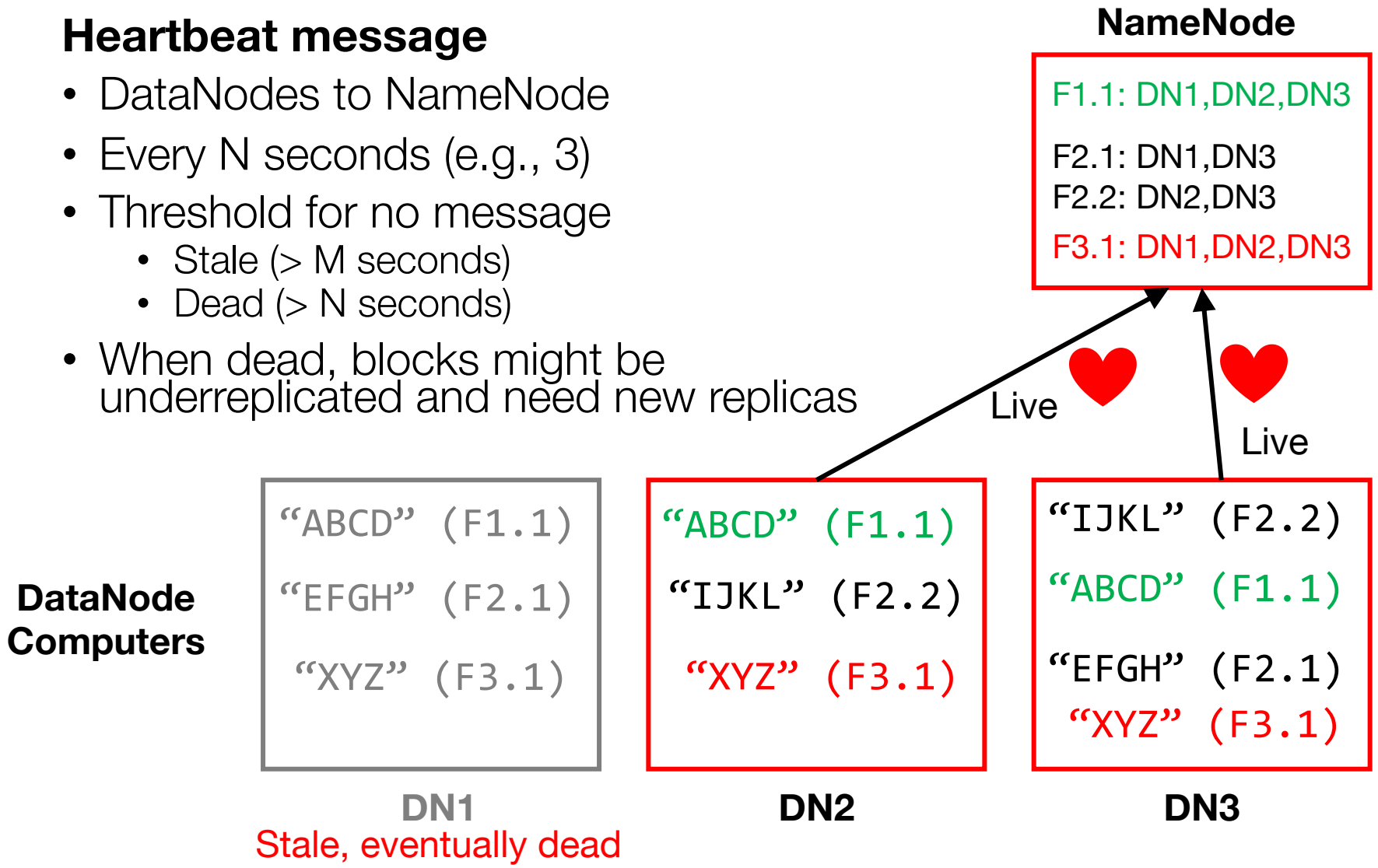
DataNode Computers

DN1	DN2	DN3
"ABCD" (F1.1)	"ABCD" (F1.1)	"IJKL" (F2.2)
"EFGH" (F2.1)	"IJKL" (F2.2)	"ABCD" (F1.1)
"XYZ" (F3.1)	"XYZ" (F3.1)	"EFGH" (F2.1)
		"XYZ" (F3.1)

How do we know when a DataNode fails?

Heartbeat message

- DataNodes to NameNode
- Every N seconds (e.g., 3)
- Threshold for no message
  - Stale (> M seconds)
  - Dead (> N seconds)
- When dead, blocks might be underreplicated and need new replicas



Summary: Some key ideas applied to GFS/HDFS

- To build complex systems…
- To scale out…
- To handle faults…
- To detect faults…
- To optimize I/O…

Summary: Some key ideas applied to GFS/HDFS

- To build complex systems…
  - Compose layers of subsystems
- To scale out…
  - Partition your data
- To handle faults…
  - Replicate your data
- To detect faults…
  - Send heartbeats
- To optimize I/O…
  - Pipeline writes

Discussion: GFS eval (GFS paper)

List your takeaways from “Fig 3: Aggregate Throughput”