[544] Hadoop Ecosystem

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Learning Objectives

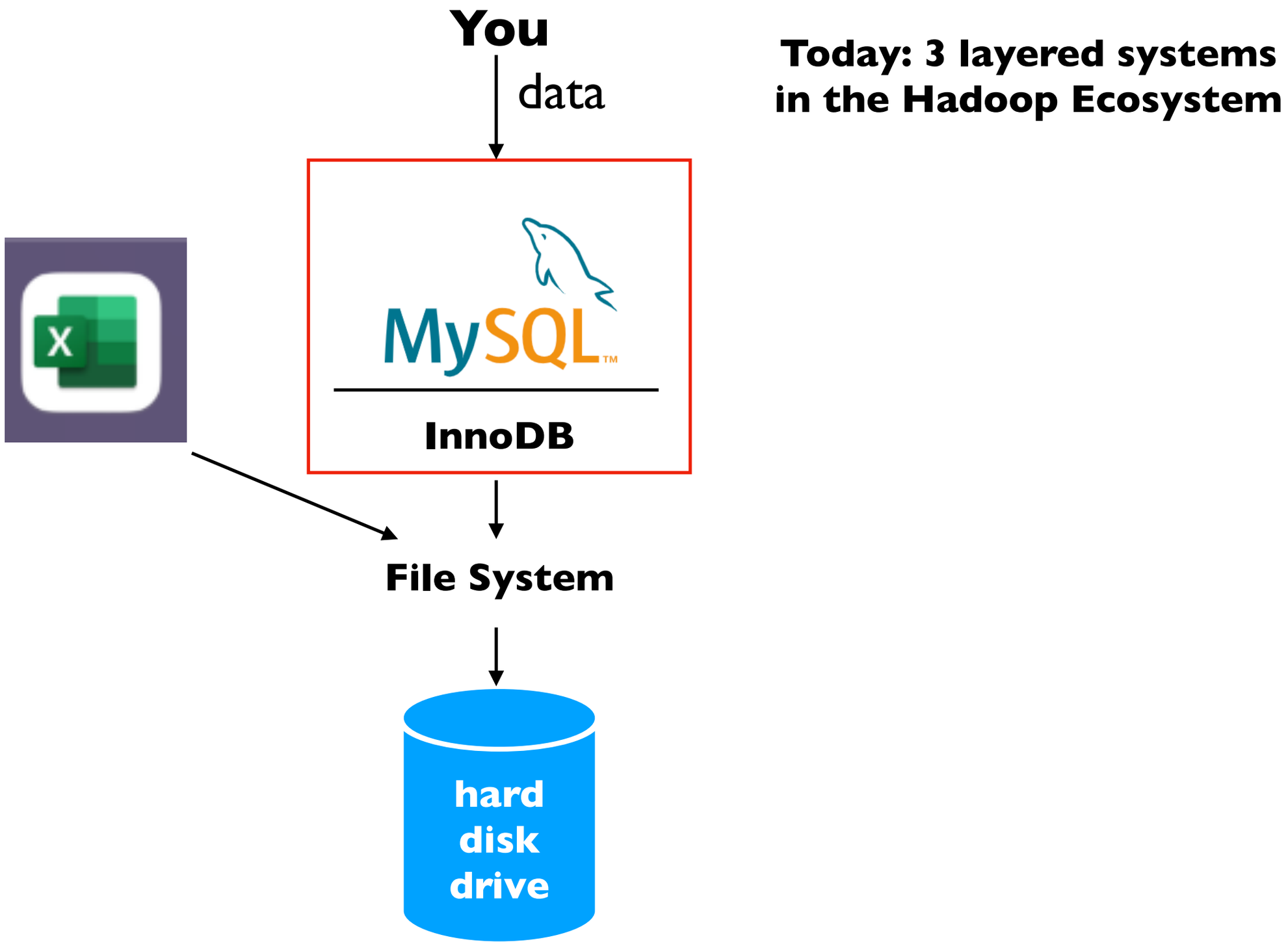
- describe the purpose of GFS, MapReduce, and BigTable (at a high level), and similar Hadoop systems (HDFS, Spark, and Cassandra)
- describe partitioning and replication and the motivation for each technique
- identify the role that clients, NameNodes, and DataNodes play for HDFS reads and writes

Outline: Hadoop Ecosystem

Motivation, Hadoop Ecosystem

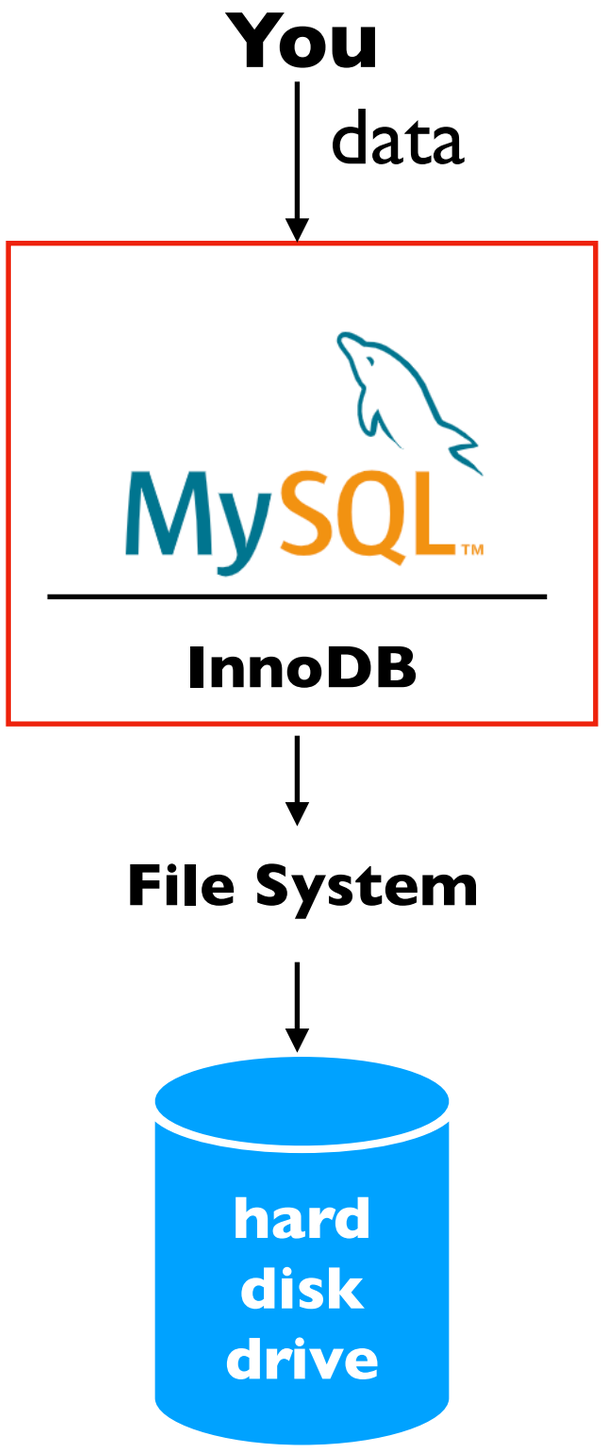
Hadoop File System (HDFS)

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

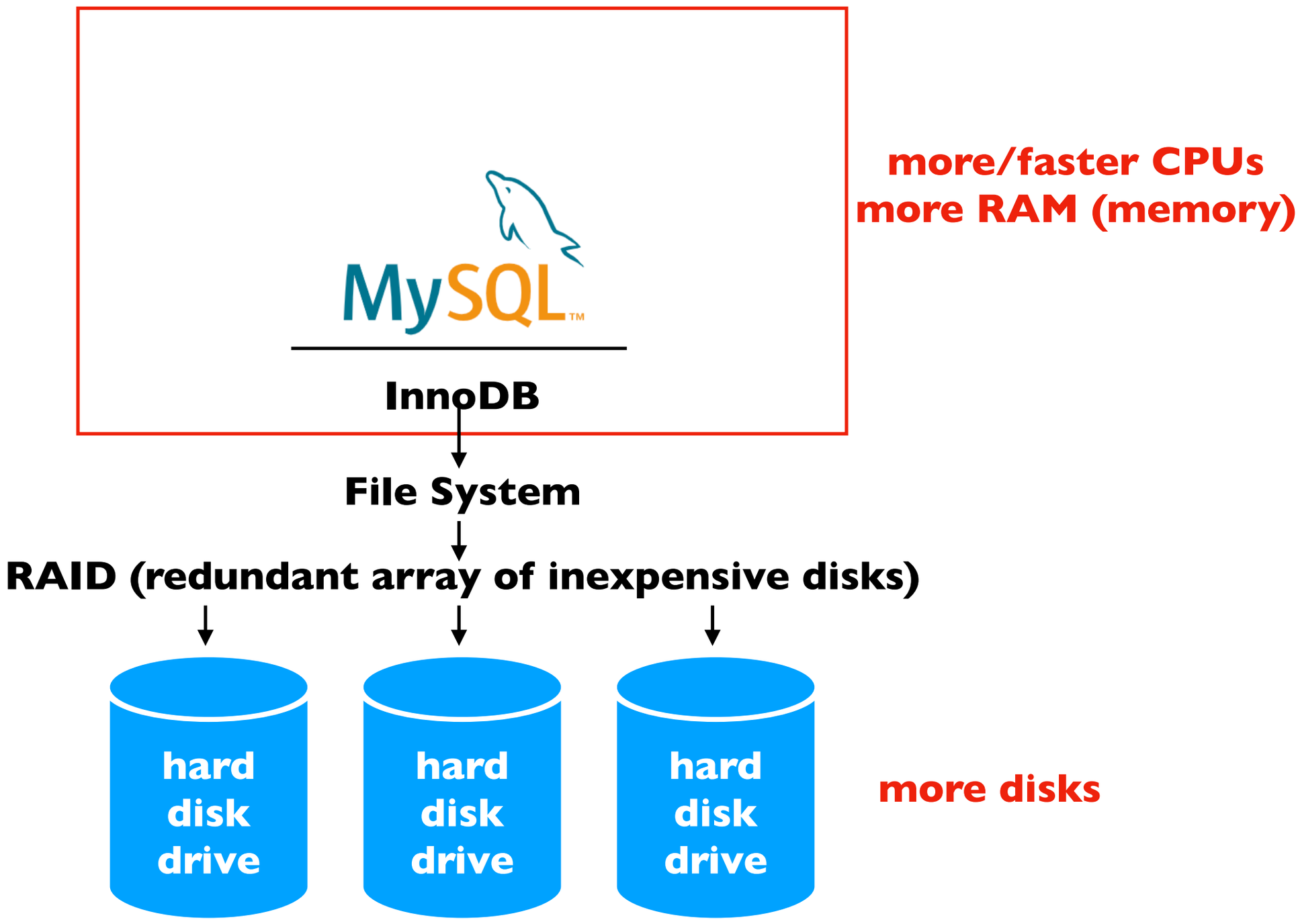


Today: 3 layered systems in the Hadoop Ecosystem

What if your data is too big for your server?

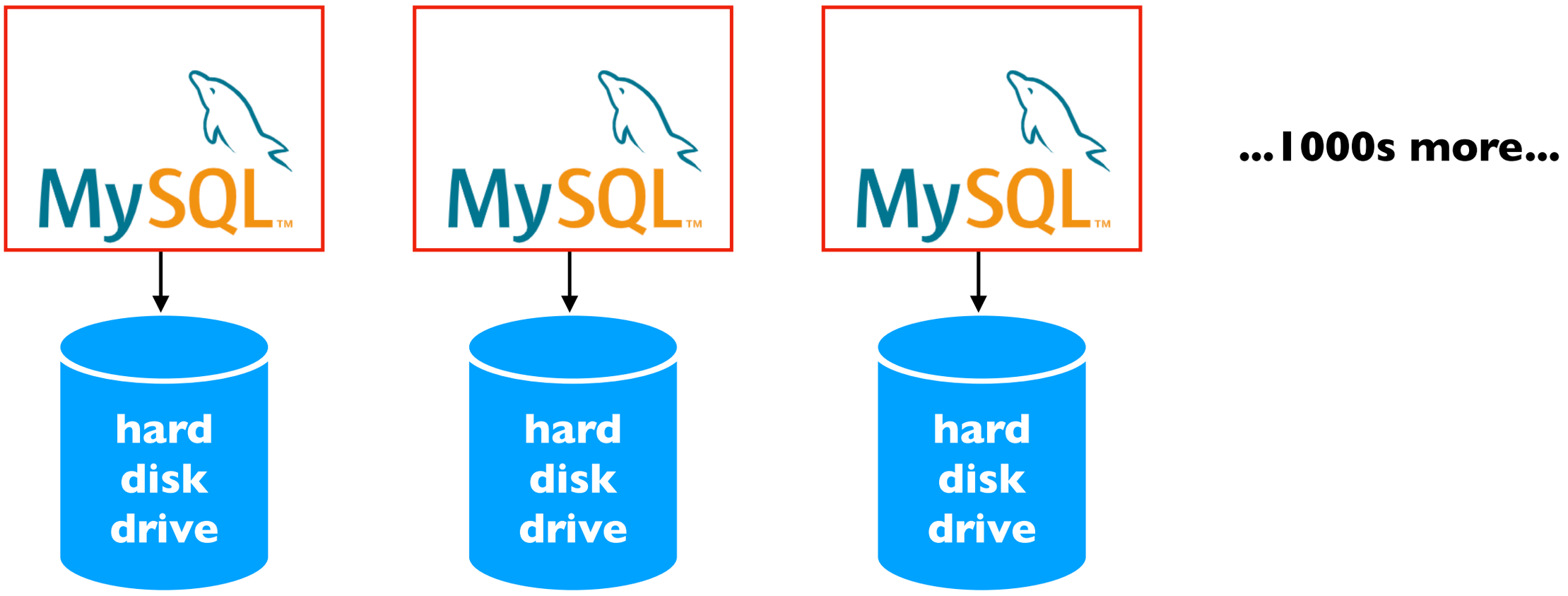


What if your data is too big for your server?
Option 1: scale up (buy better hardware)



What if your data is too big for your server?
Option 2: scale out (more machines)

where does the data actually go?



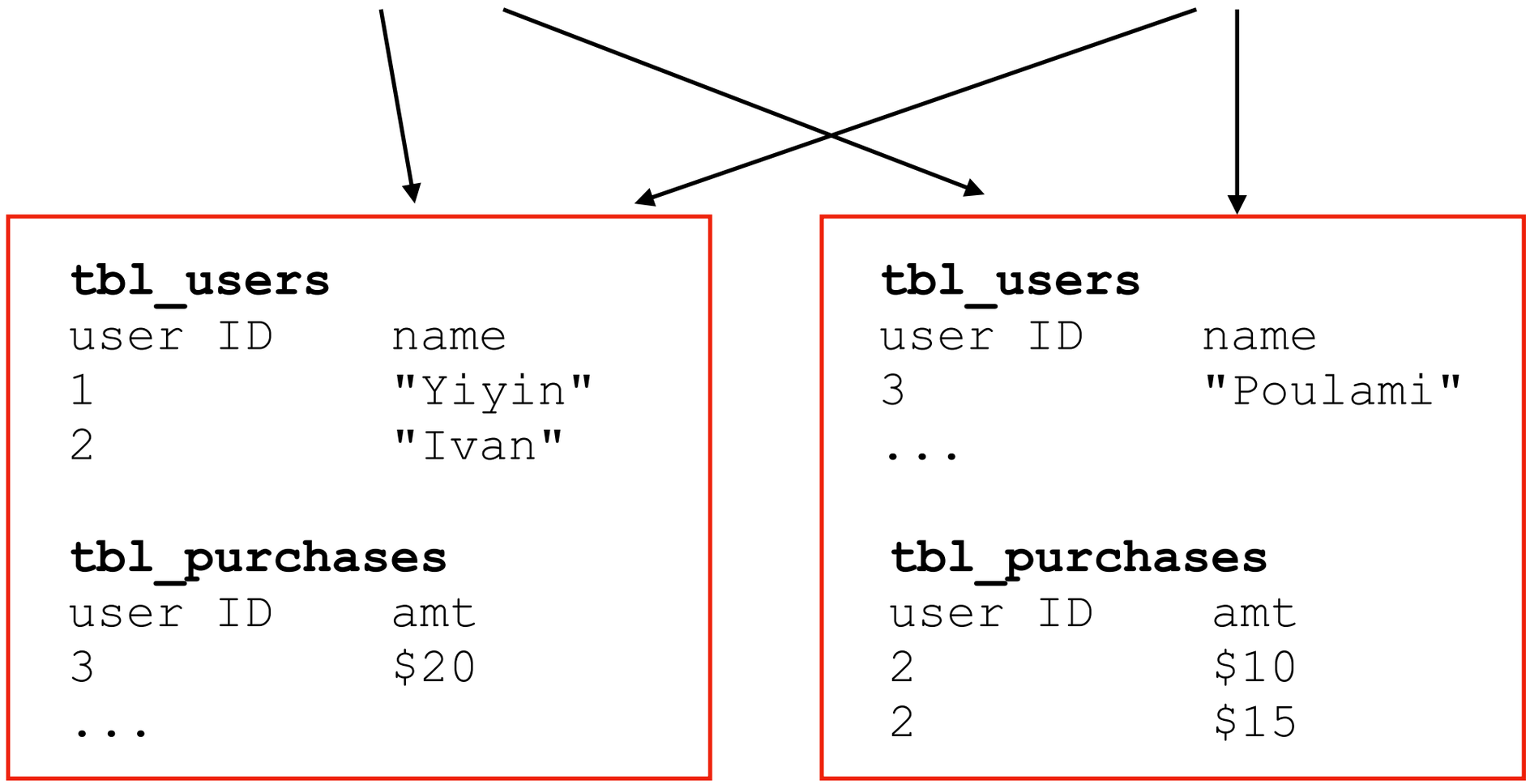
Approach: partition the tables

tbl_users

user ID	name
1	"Yiyin"
2	"Ivan"
3	"Poulami"
...	

tbl_purchases

user ID	amt
2	$10
2	$15
3	$20
...	



tbl_users

user ID	name
1	"Yiyin"
2	"Ivan"

tbl_purchases

user ID	amt
3	$20
...	

tbl_users

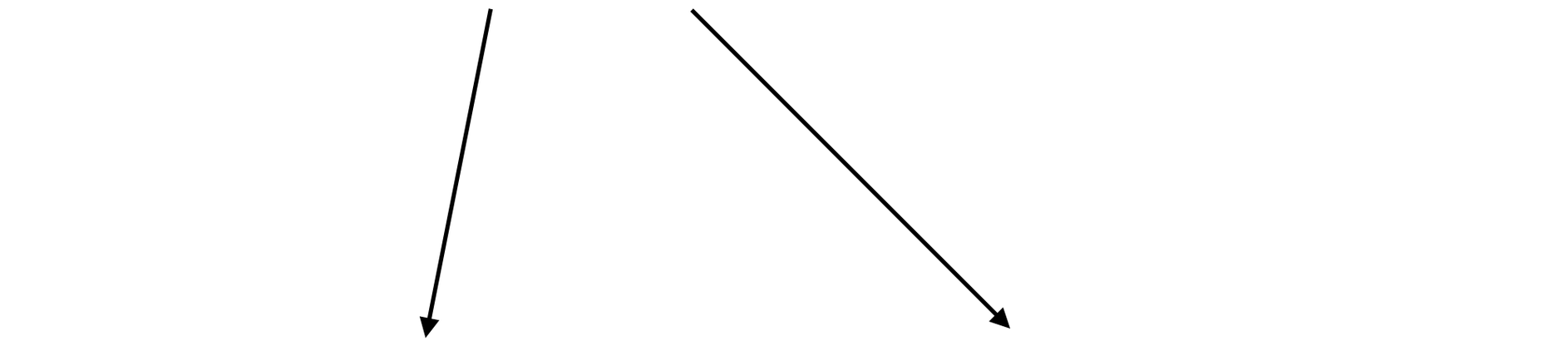
user ID	name
3	"Poulami"
...	

tbl_purchases

user ID	amt
2	$10
2	$15

Approach: send queries to multiple DBs...

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



tbl_users

user ID	name
1	"Yiyin"
2	"Ivan"

tbl_purchases

user ID	amt
3	$20
...	

tbl_users

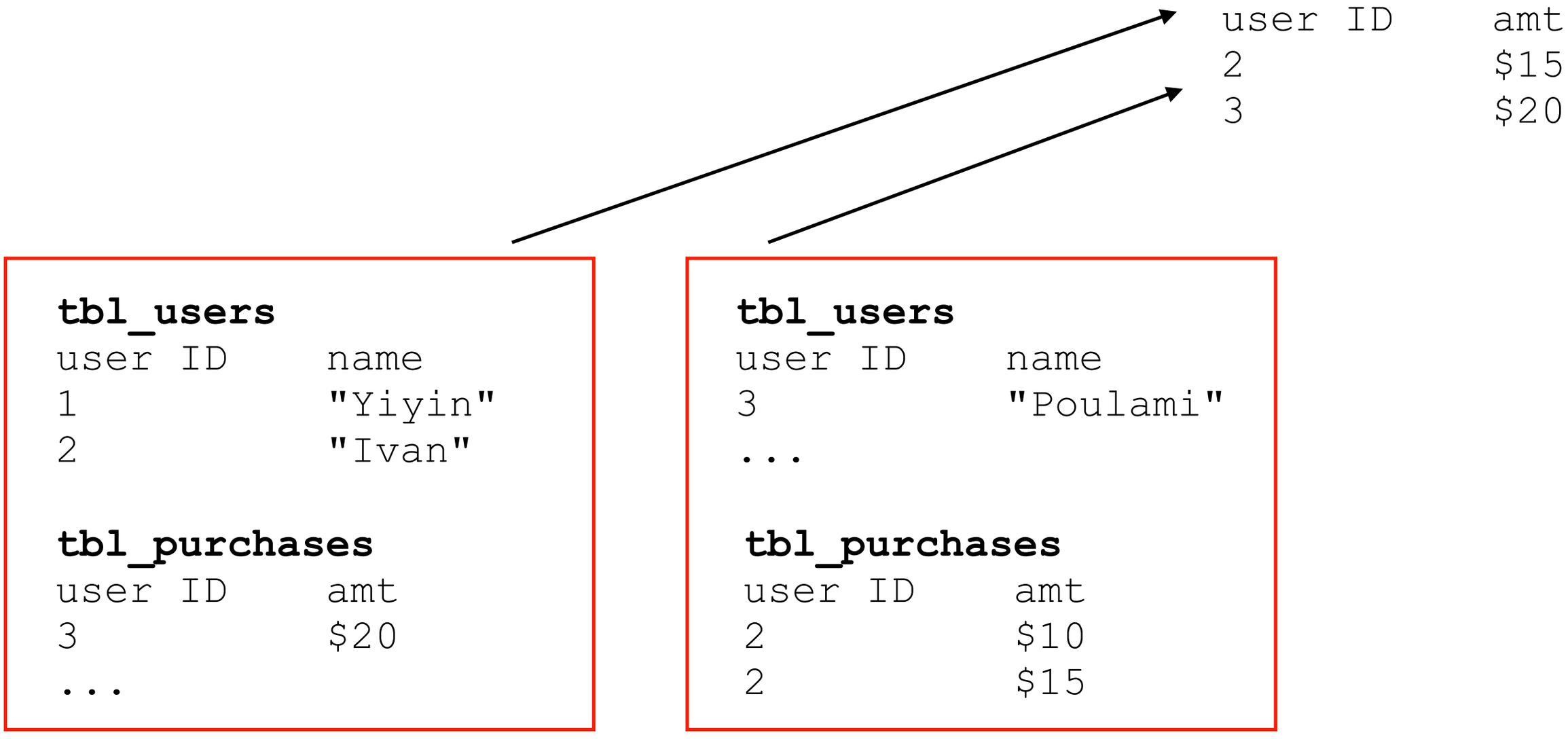
user ID	name
3	"Poulami"
...	

tbl_purchases

user ID	amt
2	$10
2	$15

...combine results

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



tbl_purchases

user ID	amt
2	$15
3	$20

tbl_users

user ID	name
1	"Yiyin"
2	"Ivan"

tbl_purchases

user ID	amt
3	$20
...	

tbl_users

user ID	name
3	"Poulami"
...	

tbl_purchases

user ID	amt
2	$10
2	$15

What is a query that would break things?

```
SELECT ...
```

tbl_users

user ID	name
1	"Yiyin"
2	"Ivan"

tbl_purchases

user ID	amt
3	$20
...	

tbl_users

user ID	name
3	"Poulami"
...	

tbl_purchases

user ID	amt
2	$10
2	$15

What is a query that would break things?

```
SELECT * FROM tbl_users
INNER JOIN tbl_purchases
ON tbl_users.user_id = tbl_purchases.user_id
```

tbl_users

user ID	name
1	"Yiyin"
2	"Ivan"

tbl_purchases

user ID	amt
3	$20
...	

tbl_users

user ID	name
3	"Poulami"
...	

tbl_purchases

user ID	amt
2	$10
2	$15

Why use a traditional/relational DB if basic things like JOIN don't easily work right at scale?

example: Cassandra documentation

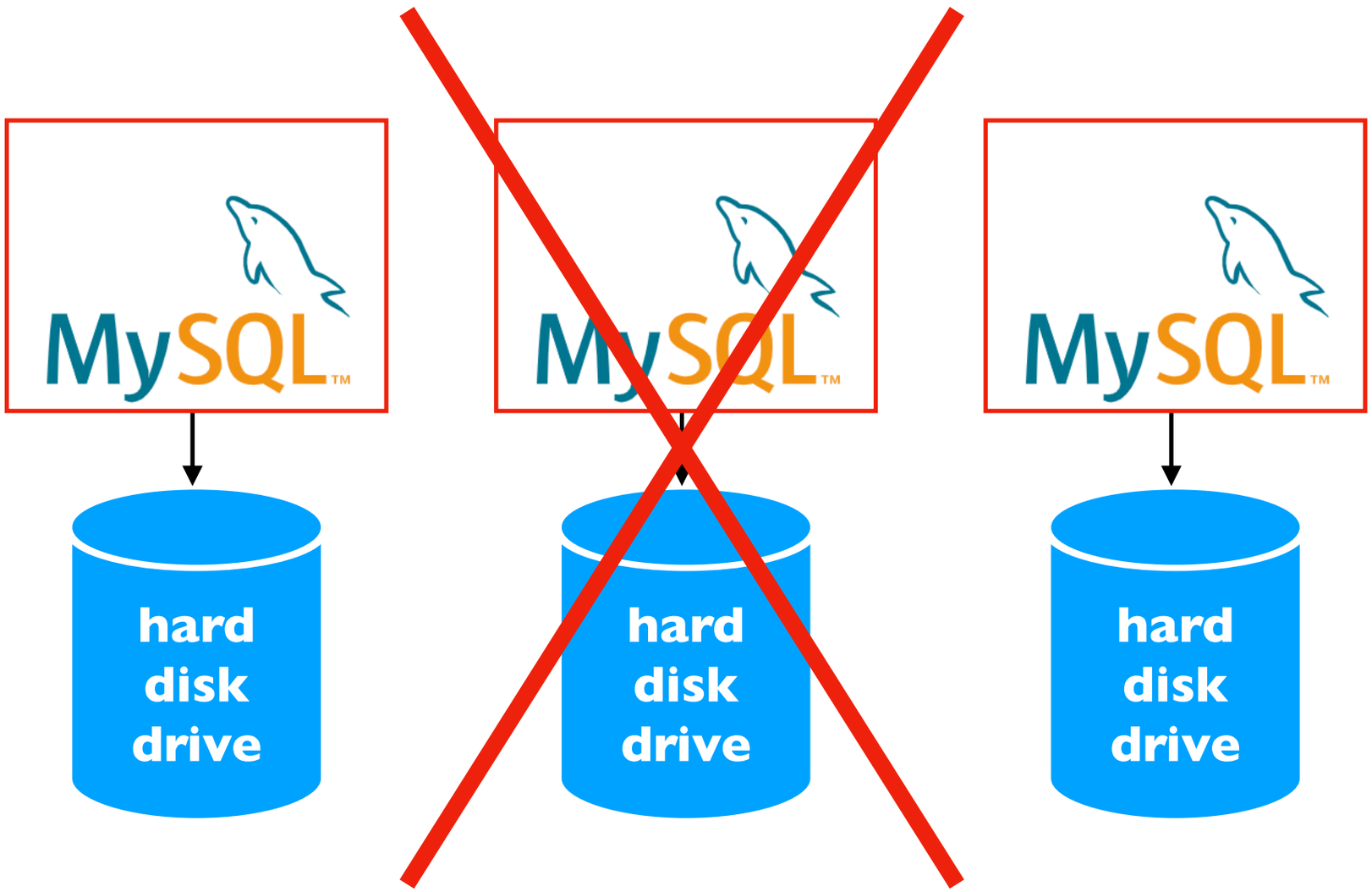
STEP 3: CREATE FILES

The Cassandra Query Language (CQL) is very similar to SQL but suited for the JOINless structure of Cassandra.

https://cassandra.apache.org/_/quickstart.html

What if a server dies?

happens all the time when you have 1000s of machines



...1000s more...

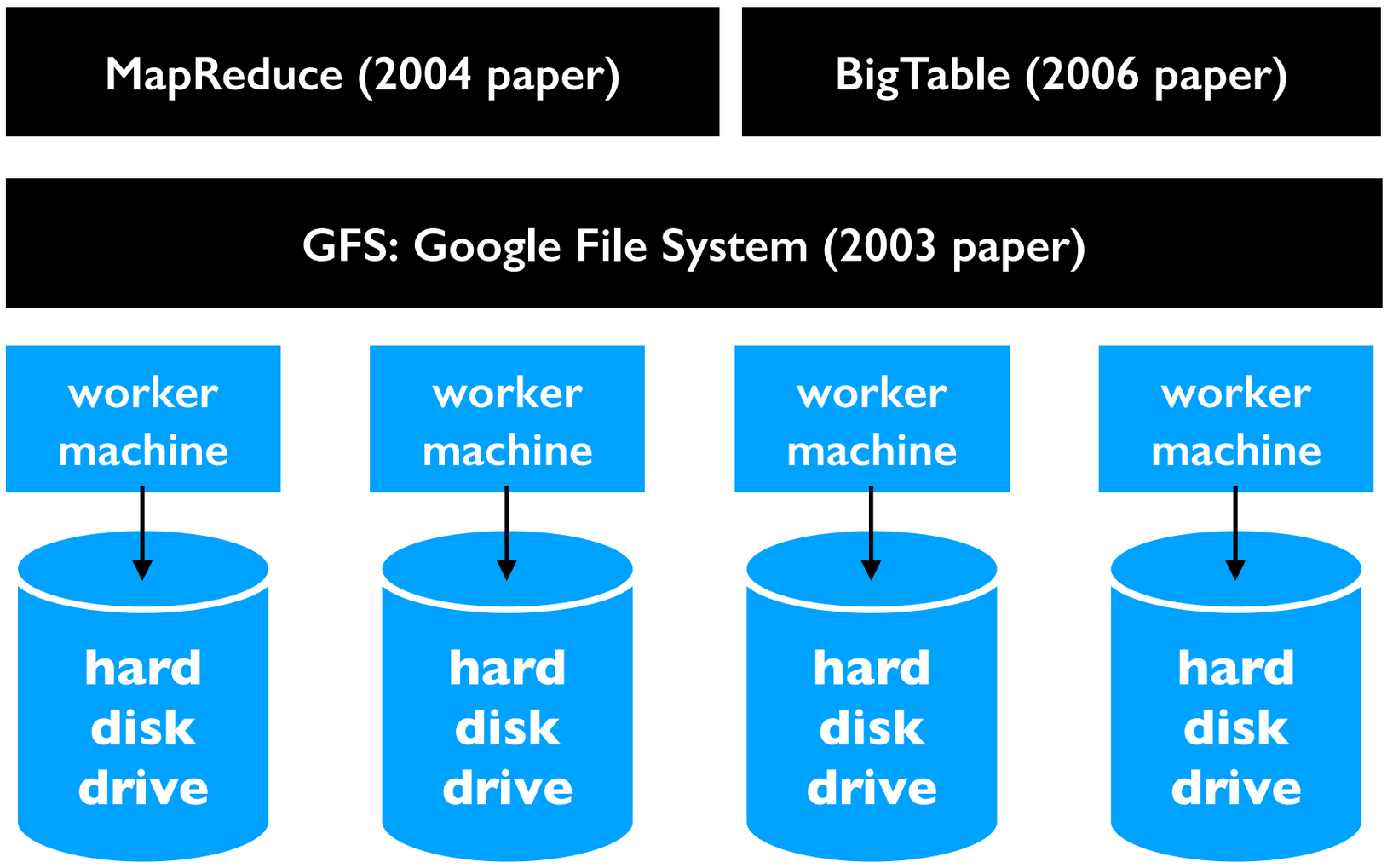
Motivation for System Redesign

Features

- classic features/guarantees
  - JOINs, GROUP BYs, other transformations
  - ACID: atomicity, consistency, isolation, durability

- perhaps sacrifice some class features/guarantees, prioritize:
  - scalability
  - elasticity
  - fault tolerance
  - availability

Google Architecture



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 systems

	Google (paper only)	Hadoop, 1st gen (open source)	Modern Hadoop
Distributed File System	GFS	HDFS	
Distributed Analytics	MapReduce	Hadoop MapReduce	Spark
Distributed Database	BigTable	HBase	Cassandra

Ecosystem: Ambari, Avro, Cassandra, Chukwa, HBase, Hive, Mahout, Ozone, Pig, Spark, Submarine, Tez, ZooKeeper

https://hadoop.apache.org/

Outline: Hadoop Ecosystem

Motivation, Hadoop Ecosystem

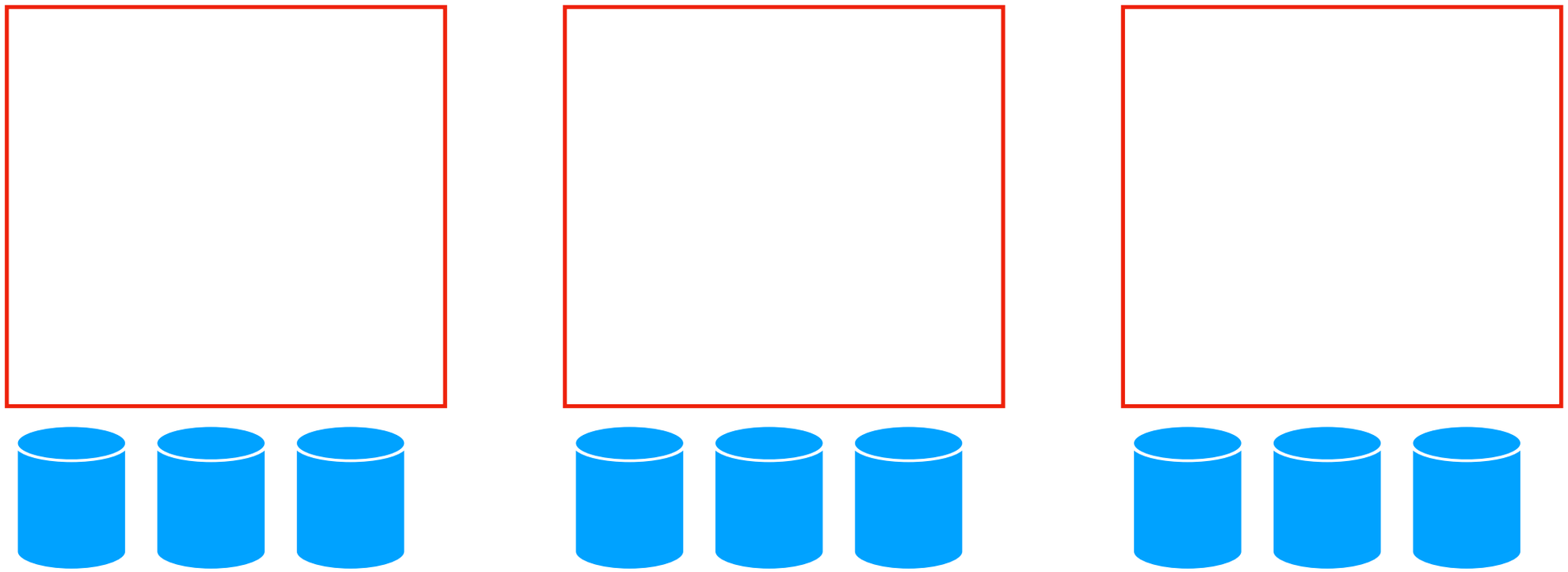
Hadoop File System (HDFS)

- Partitioning+Replication
- Input/Output
- Load Balance

HDFS: DataNodes store File Blocks

```
F1: "ABCD"                F2: "EFGHIJKL"
```

DataNode Computers

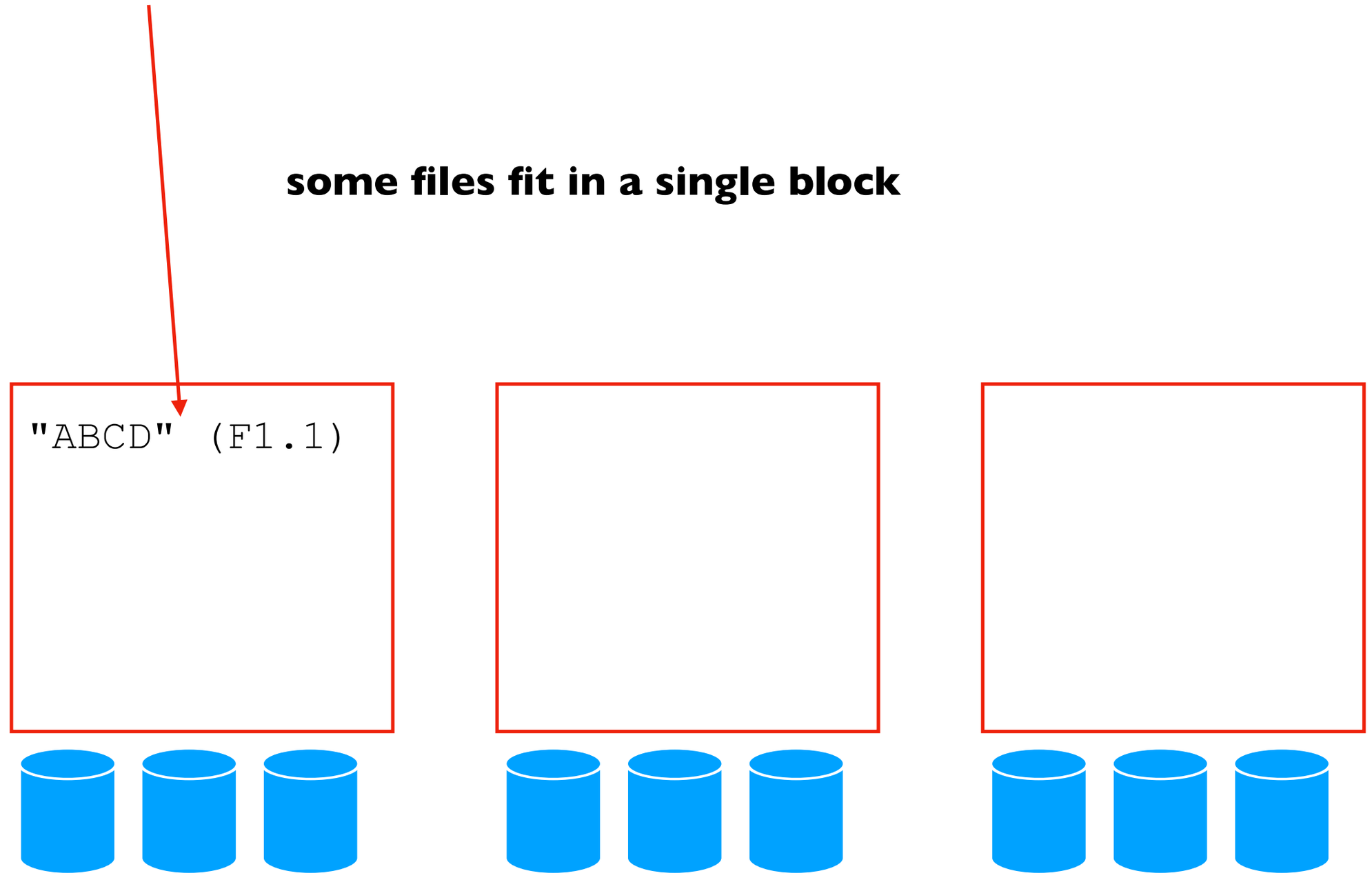


HDFS: DataNodes store File Blocks

F1: "ABCD"

F2: "EFGHIJKL"

some files fit in a single block



DataNode Computers

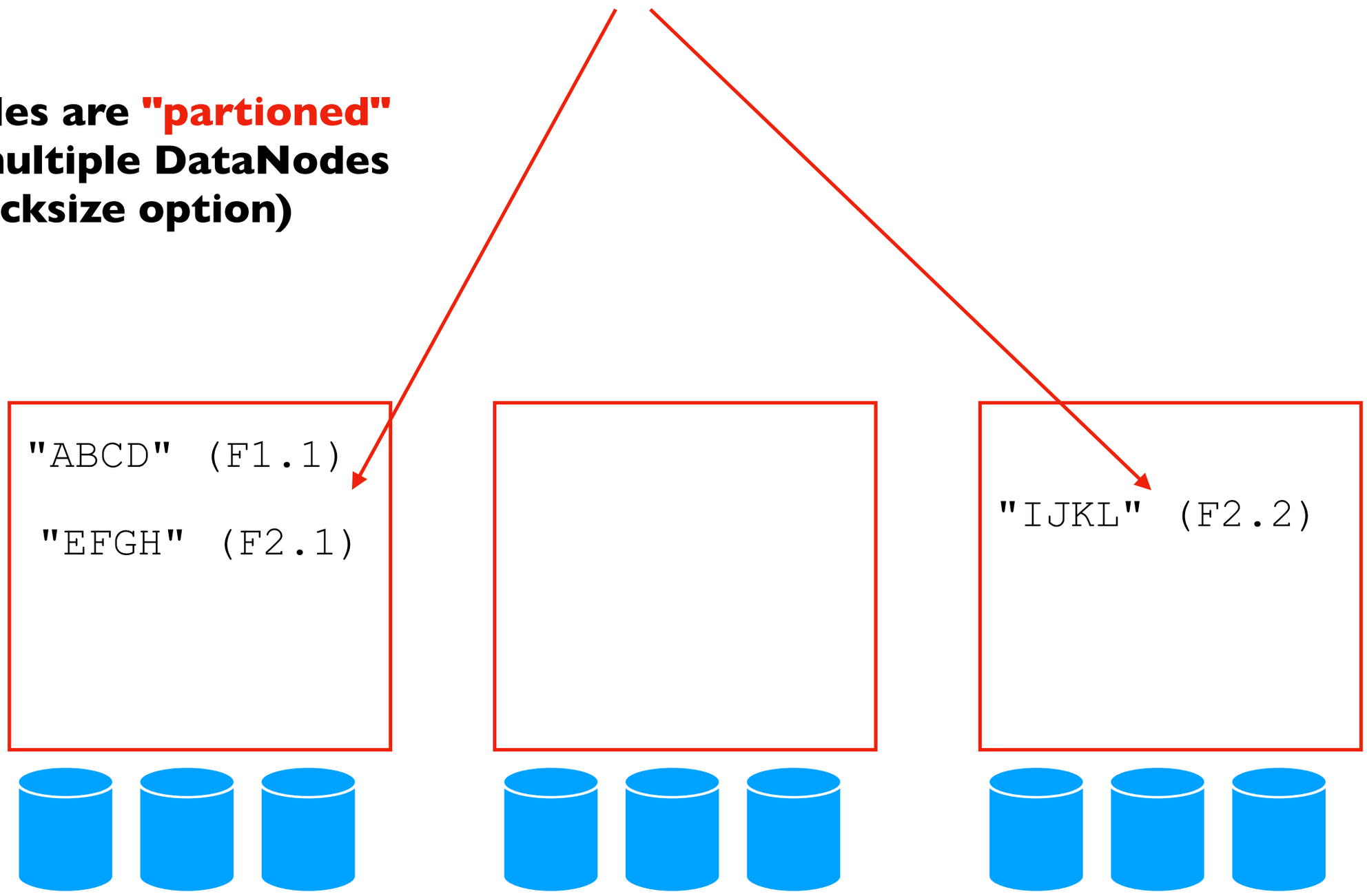
Partitioning Across DataNodes

F1: "ABCD"

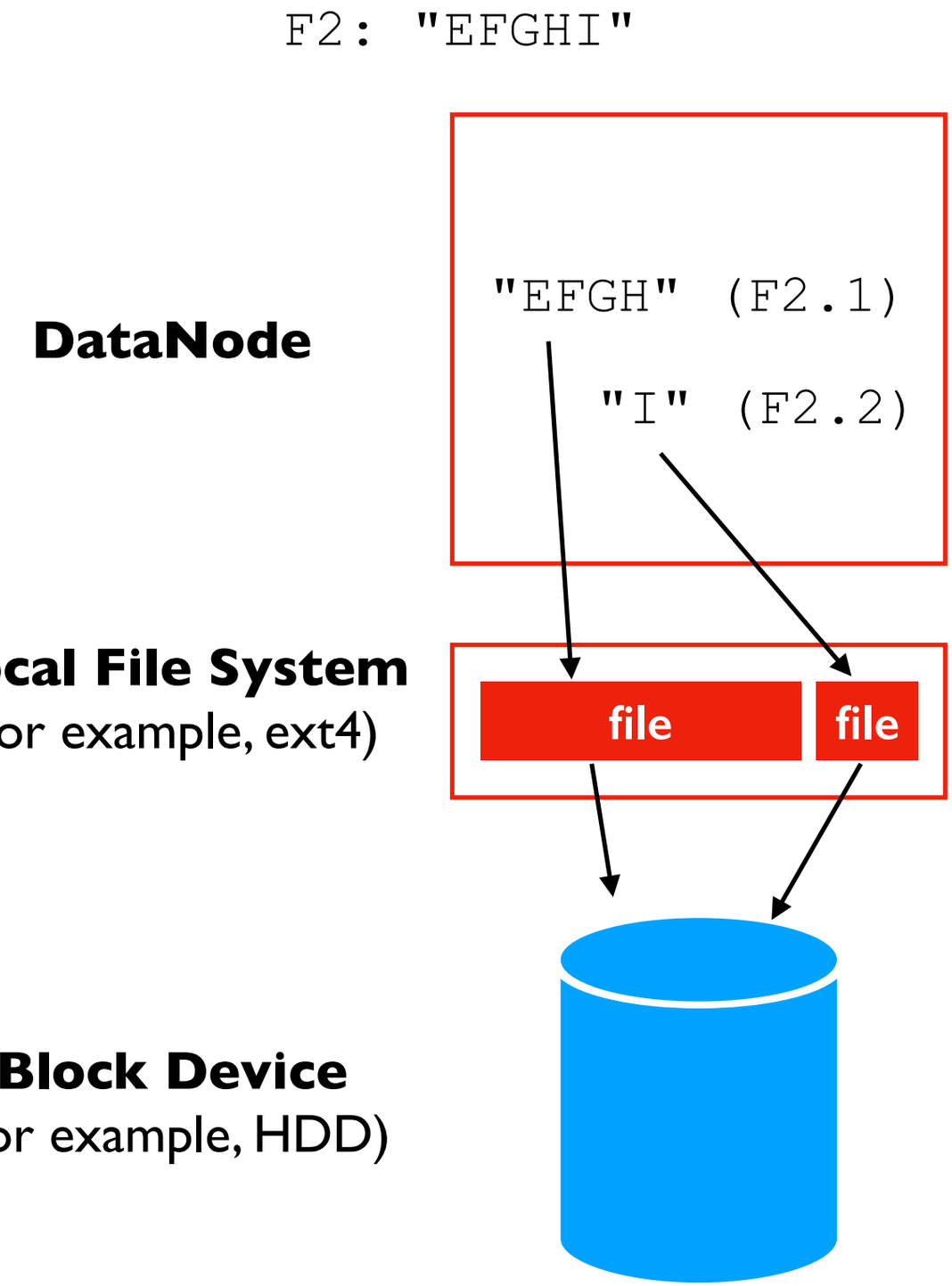
F2: "EFGHIJKL"

bigger files are "partioned" across multiple DataNodes (blocksize option)

DataNode Computers



Blocks Are Stored as Local Files



block size is specified per HDFS file

this will cap the size of the local files

example: 32 MB block size, and 40 MB file. Block 1 will be stored in a 32 MB file, and block 2 will be stored in a 8 MB file. The second block isn't wasting space just because it is much smaller that the block size.

Replication Across DataNodes

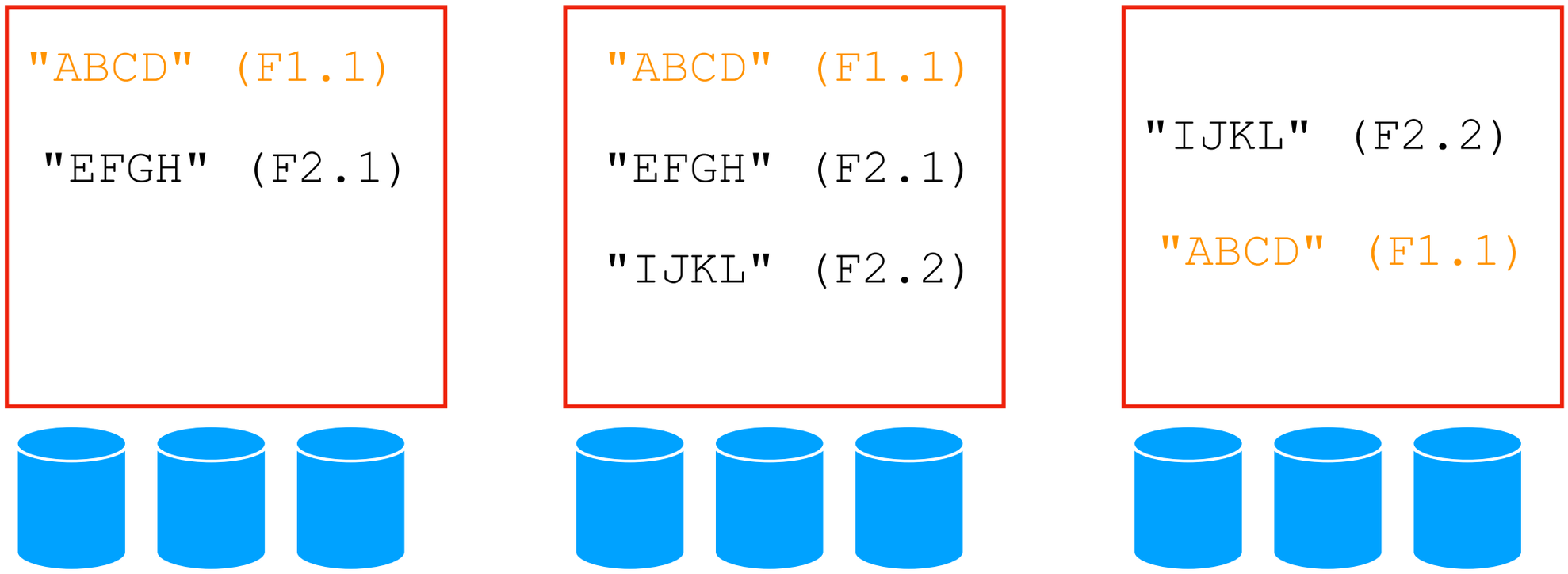
F1: "ABCD"

3x replication

F2: "EFGHIJKL"

2x replication

DataNode Computers



Replication Across DataNodes

F1: "ABCD"

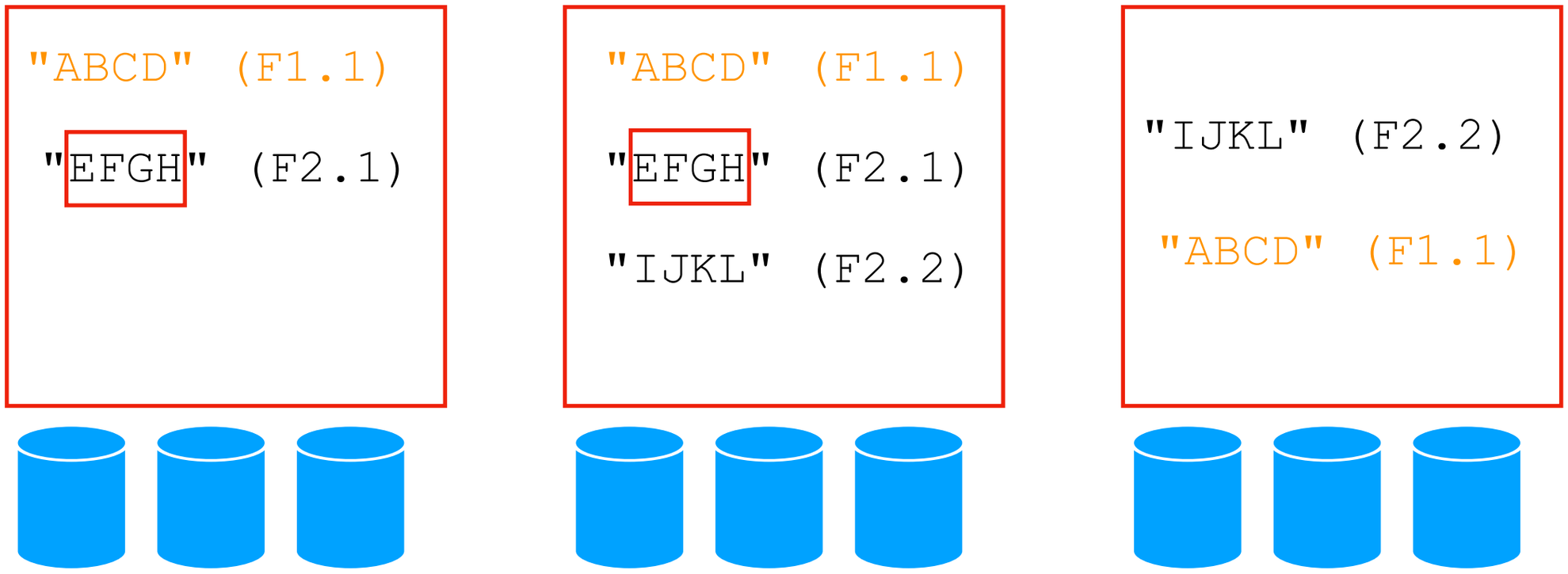
3x replication

F2: "EFGHIJKL"

2x replication

logical vs. physical blocks

DataNode Computers



Replication Across DataNodes

F1: "ABCD"

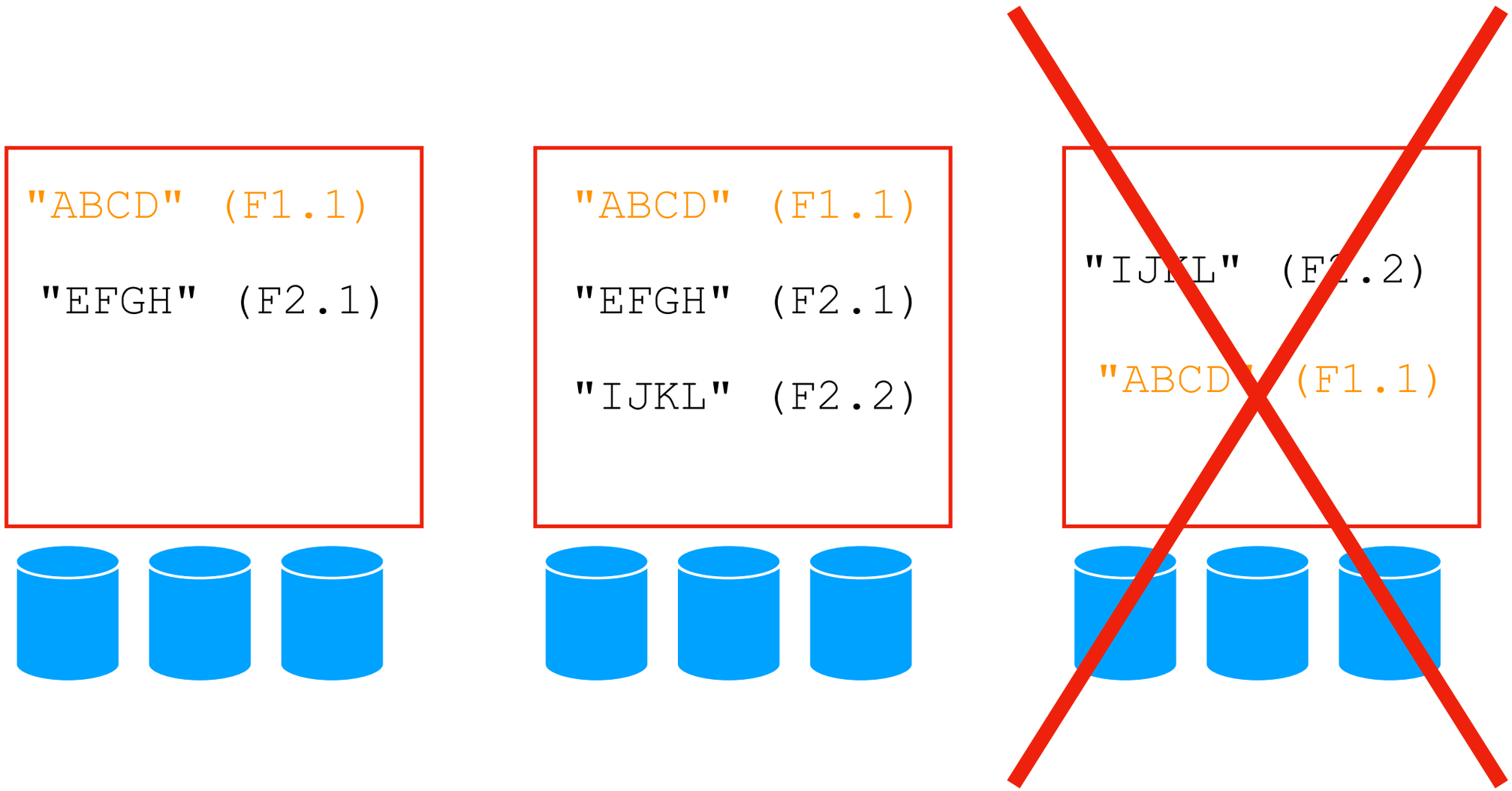
3x replication

F2: "EFGHIJKL"

2x replication

if a DataNode dies, we still have all the data.
Which file (F1 or F2) is safer in general?

DataNode Computers



Replication Across Racks

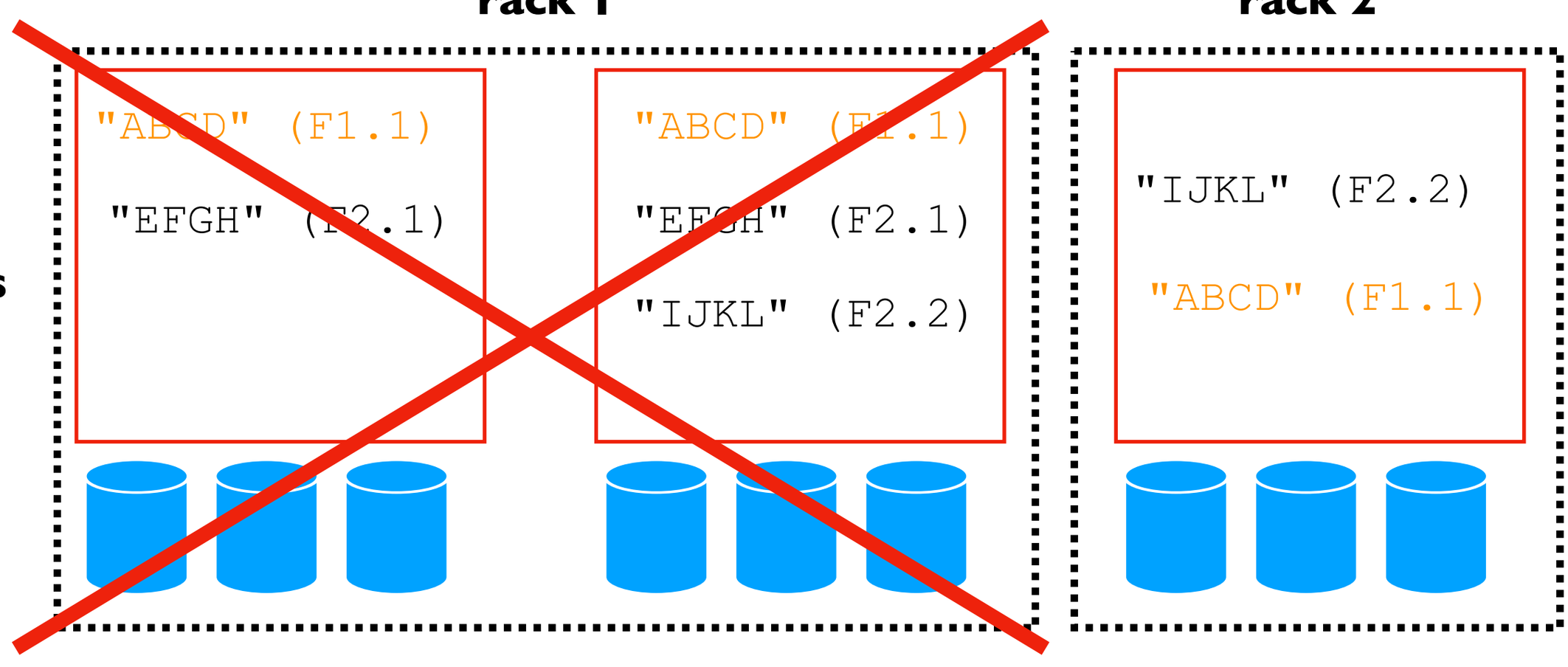
F1: "ABCD"

3x replication

F2: "EFGHIJKL"

2x replication

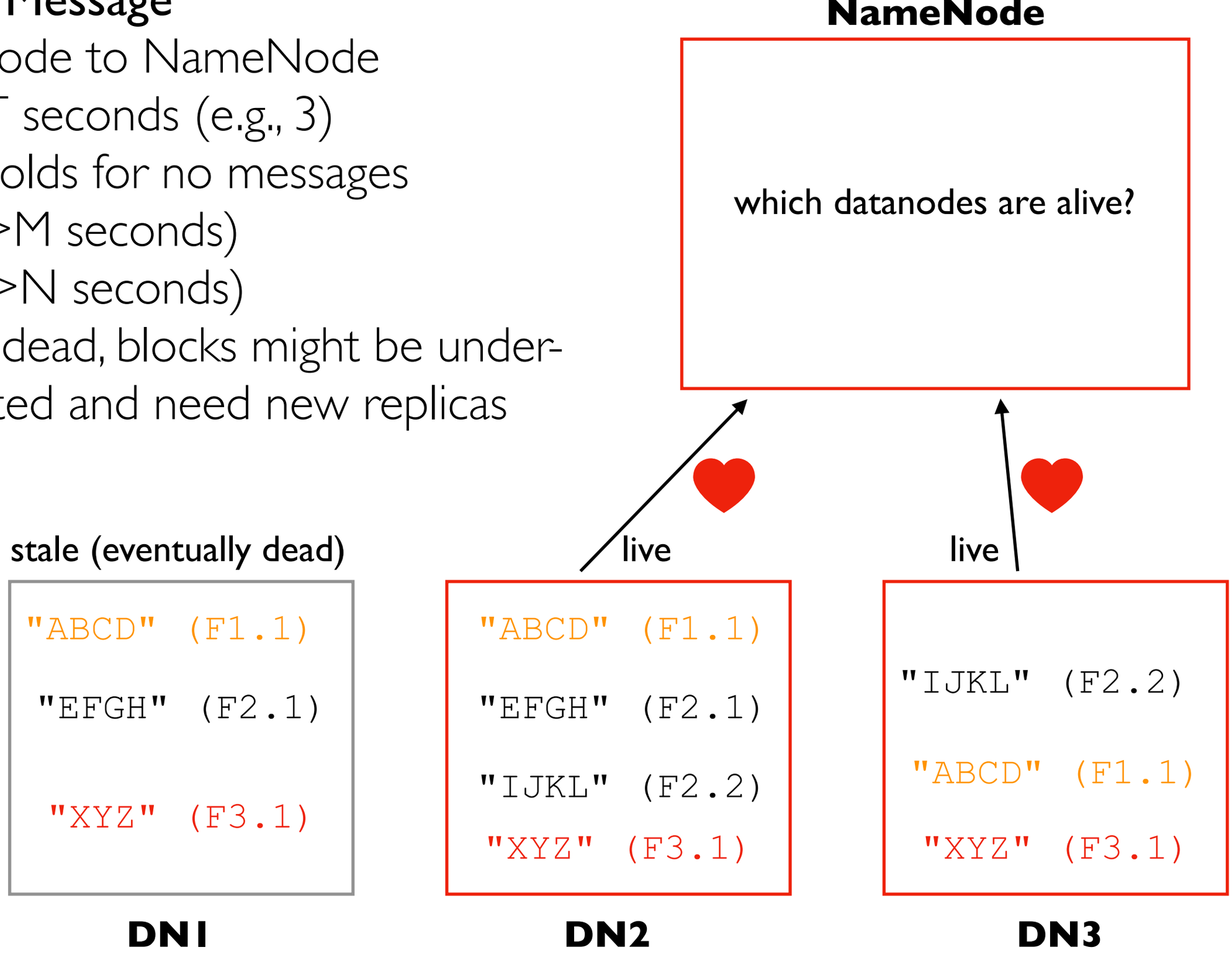
careful! if rack 1 fails, we lose block F1.1.
HDFS tries to distribute replicas across racks for this reason.



How do we know when a DataNode fails?

Heartbeat Message

- DataNode to NameNode
- Every T seconds (e.g., 3)
- Thresholds for no messages
  stale (>M seconds)
  dead (>N seconds)
- When dead, blocks might be under-replicated and need new replicas



Aside: Replication vs. Erasure Encoding

HDFS Strategies for handling node failure

Replication

- original strategy, used for new/hot data
- covered in CS 544

Erasure Encoding

- more space efficient, less I/O efficient
- recent HDFS feature used for cold data (NOT covered in CS 544)

https://hadoop.apache.org/docs/stable/hadoop-project-dist/hadoop-hdfs/HDFSErasureCoding.html

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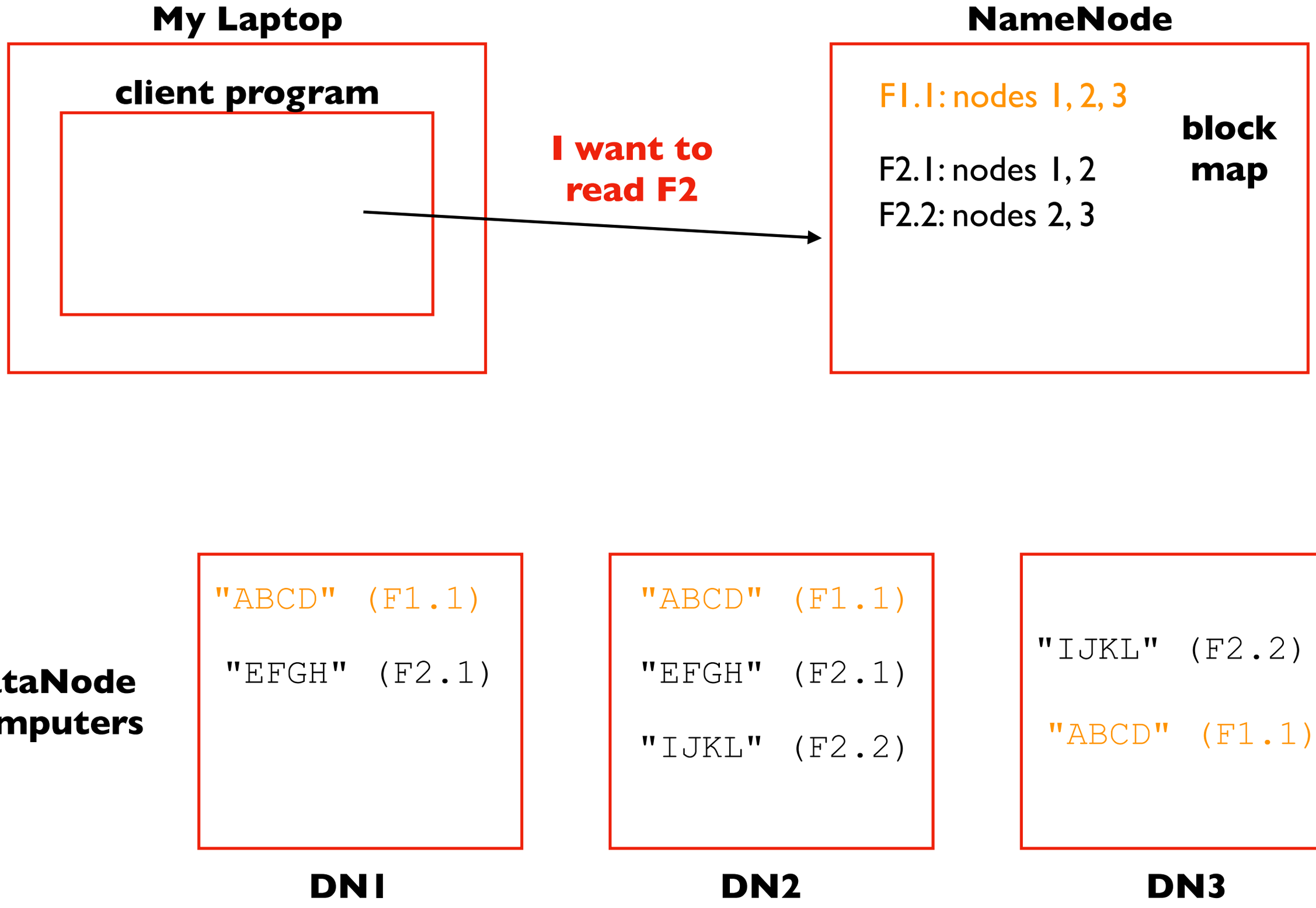
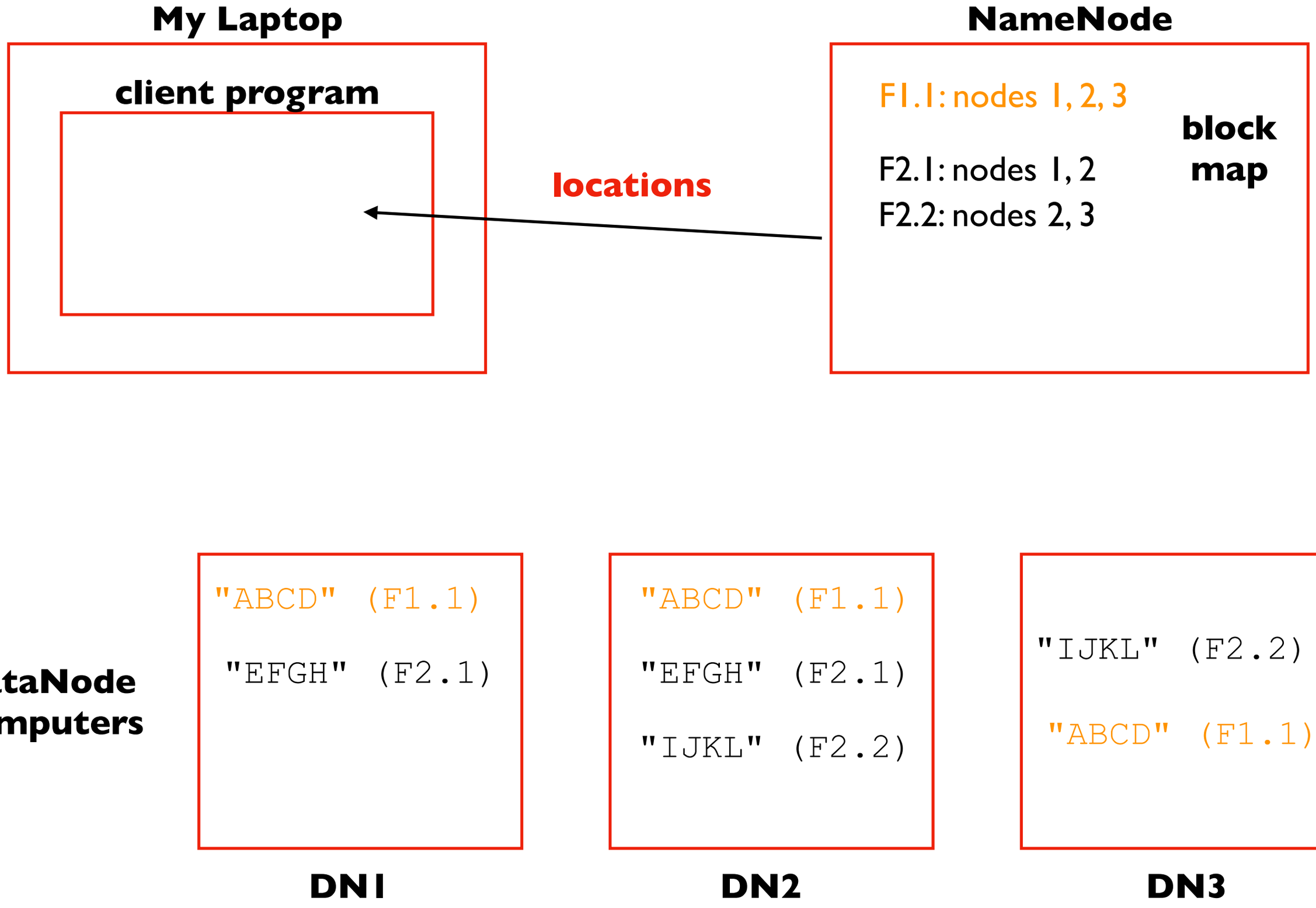
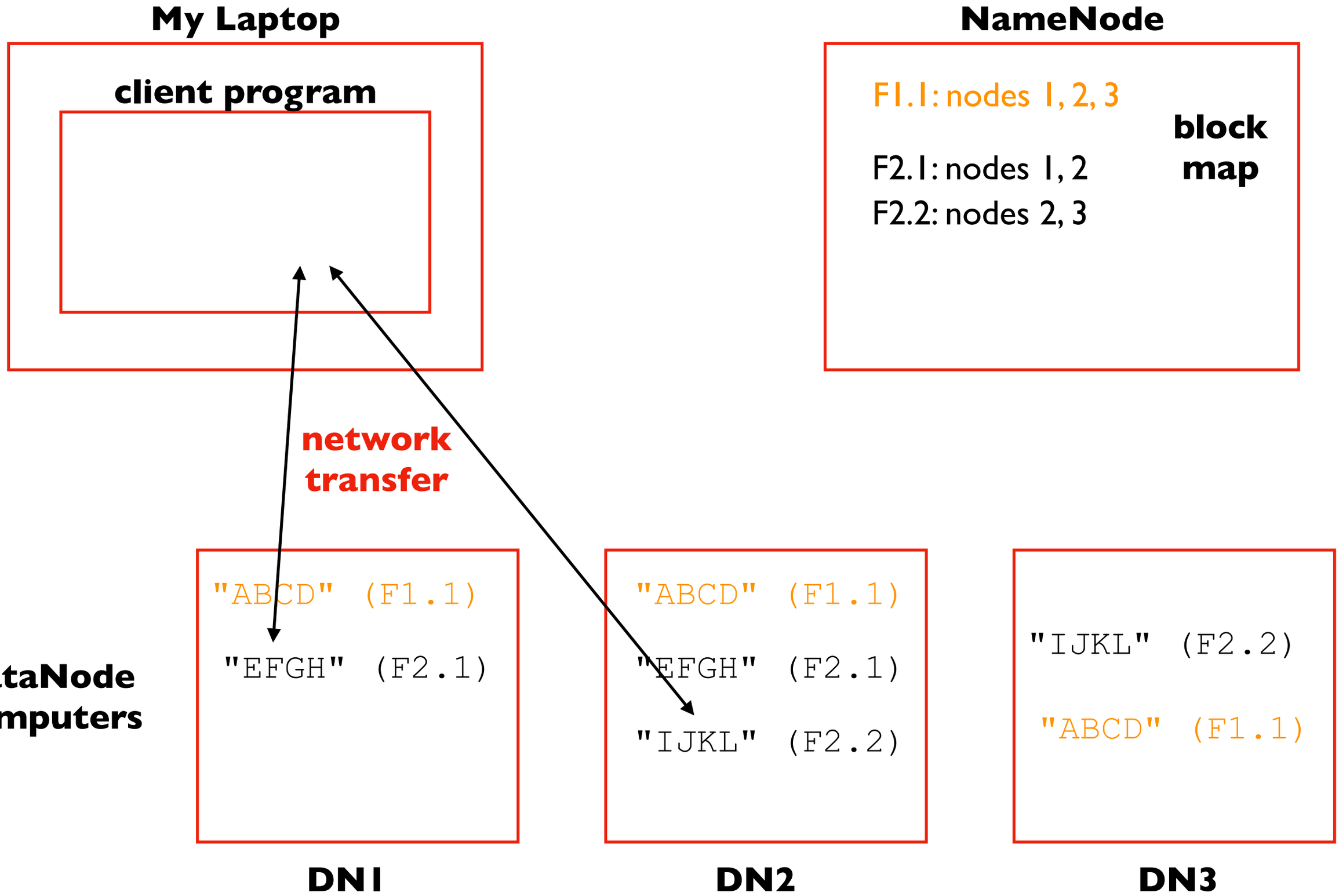
Boss (NameNode)/Worker Architecture



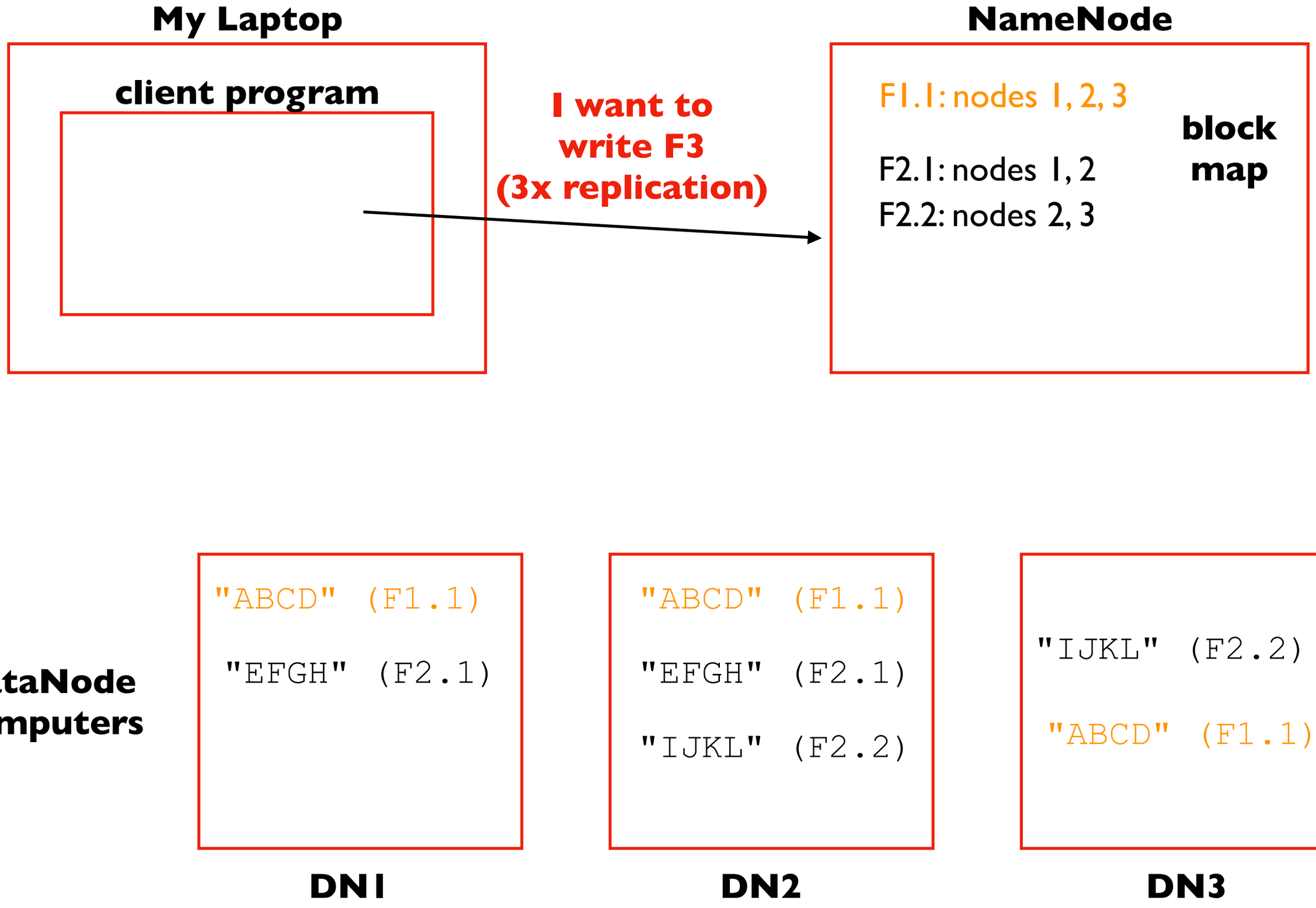
Boss (NameNode)/Worker Architecture



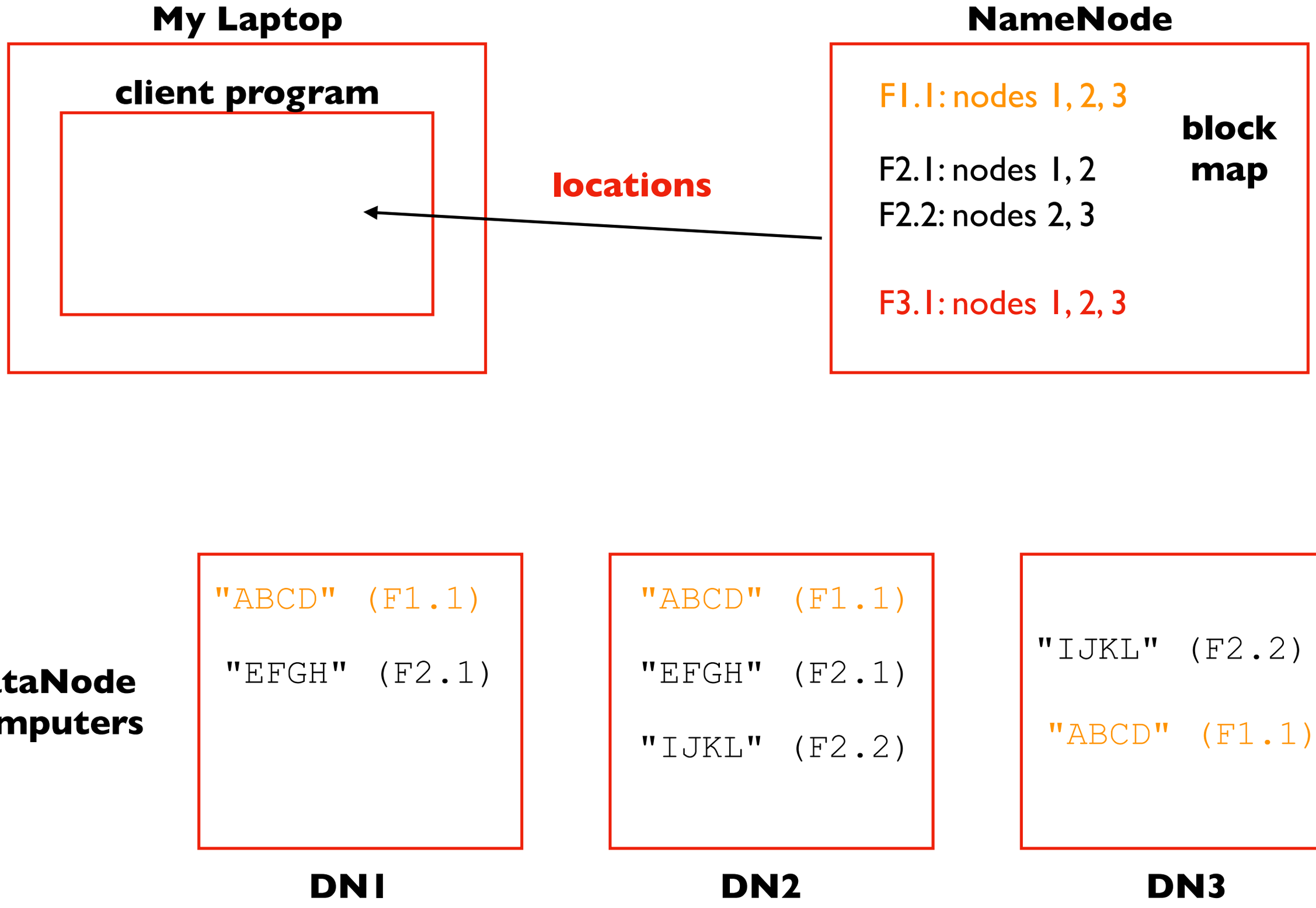
Boss (NameNode)/Worker Architecture



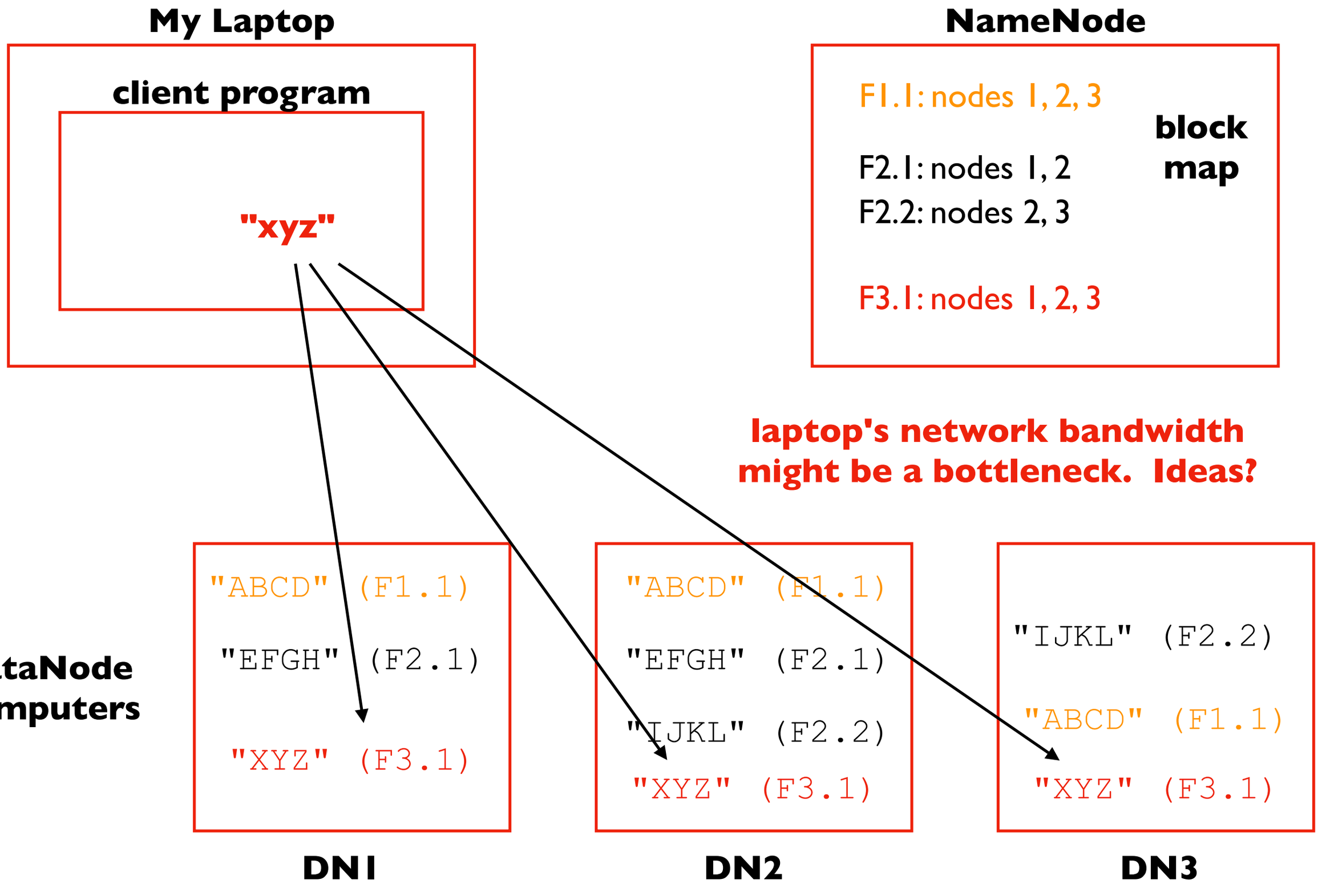
Boss (NameNode)/Worker Architecture



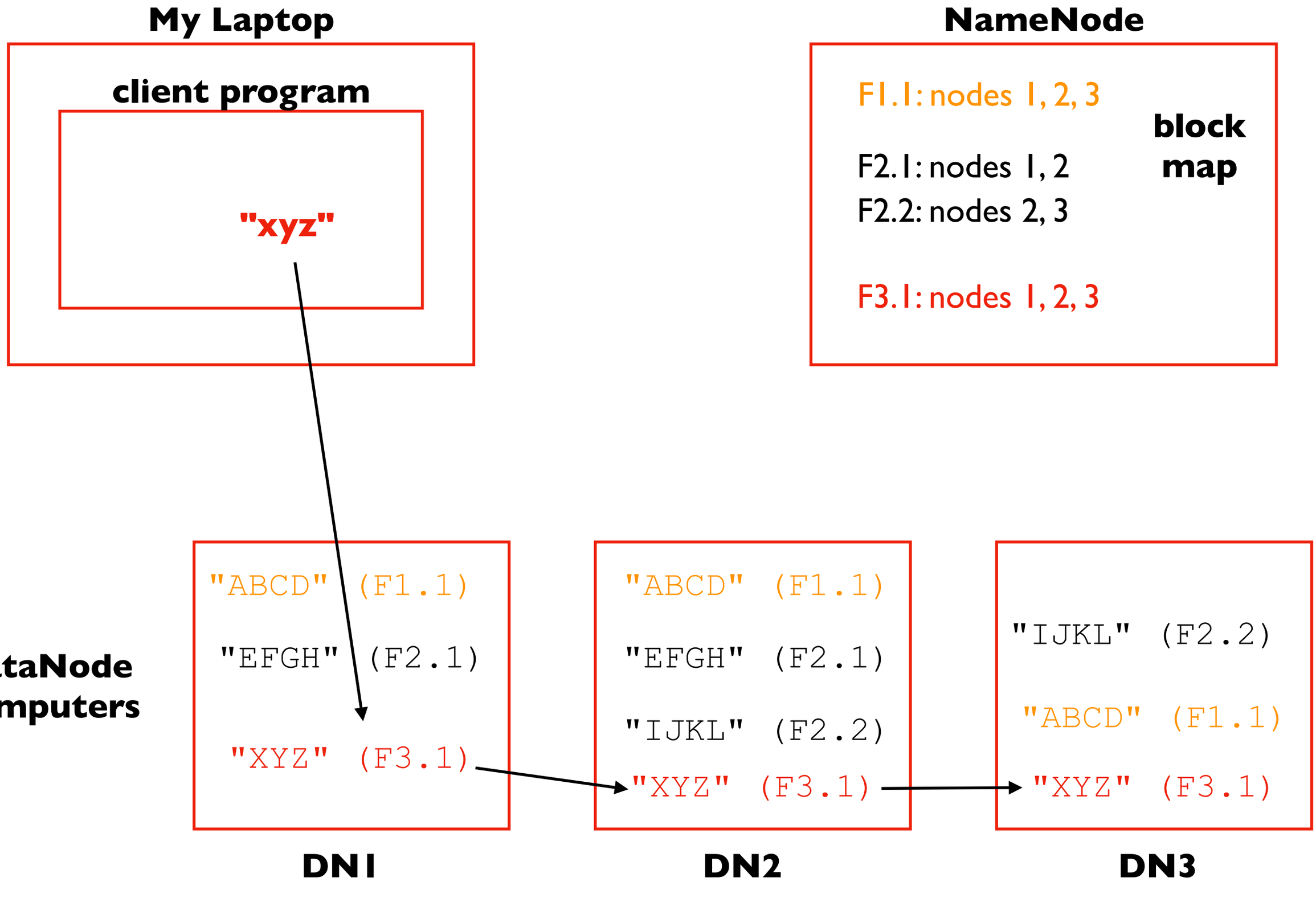
Boss (NameNode)/Worker Architecture



How HDFS does NOT write data…



HDFS Approach: Pipelined Writes



How are reads/writes amplified at disk level?

if a client **writes** 4 MB to a 2x replicated file, how much data do we **write** to hard drives?

if a client **reads** 2 MB to a 3x replicated file, how much data do we **read** from hard drives?

NameNode

F1.1: nodes 1, 2, 3

F2.1: nodes 1, 2

F2.2: nodes 2, 3

F3.1: nodes 1, 2, 3

block map

DataNode Computers

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

What are the tradeoffs of replication factor and block size?

benefits of high replication?

benefits of low replication?

benefits of large block size?

benefits of small block size?

NameNode

F1.1: nodes 1, 2, 3

F2.1: nodes 1, 2

F2.2: nodes 2, 3

F3.1: nodes 1, 2, 3

block map

DataNode Computers

"ABCD" (F1.1)

"EFGH" (F2.1)

"XYZ" (F3.1)

DN1

"ABCD" (F1.1)

"EFGH" (F2.1)

"IJKL" (F2.2)

"XYZ" (F3.1)

DN2

"IJKL" (F2.2)

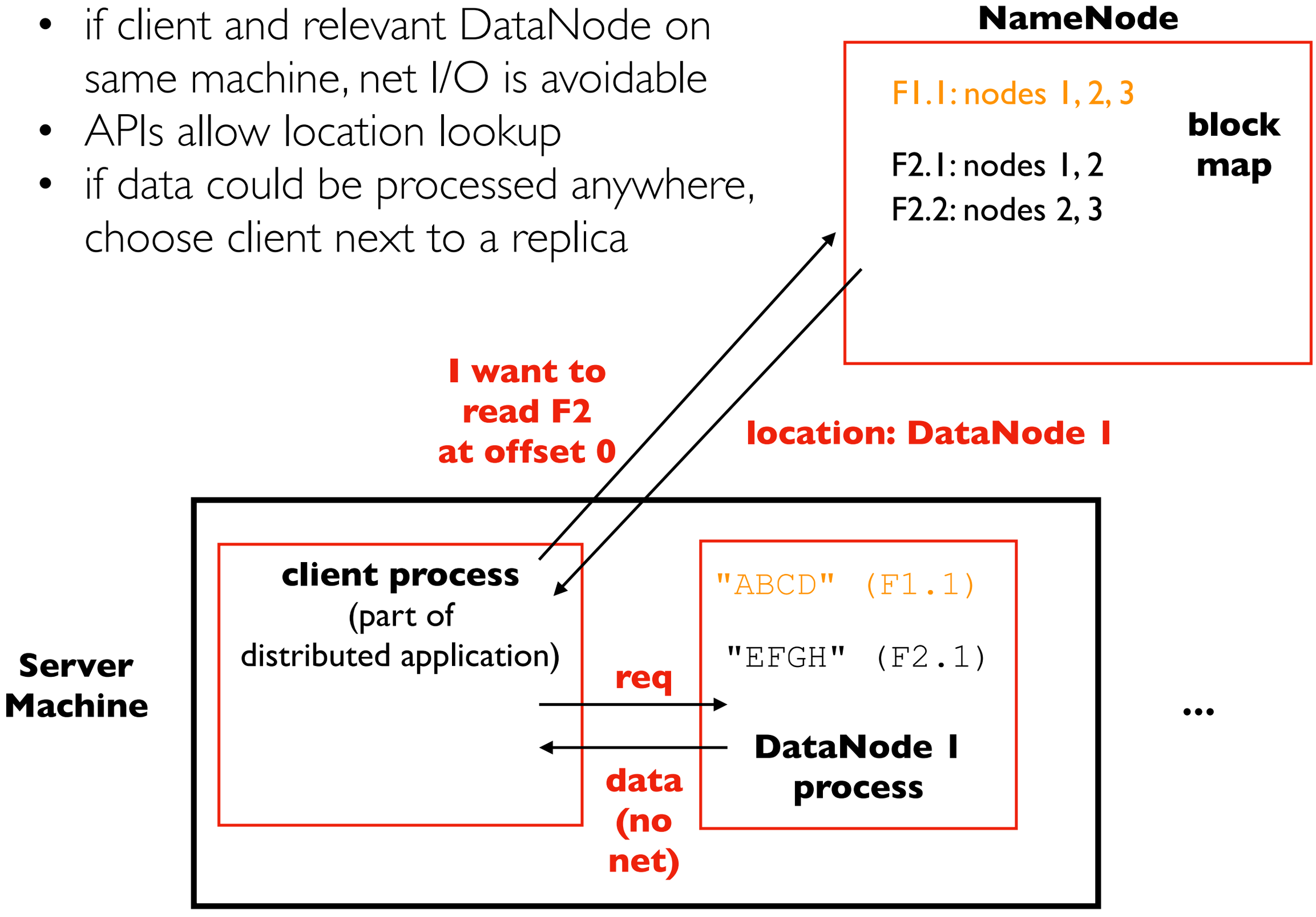
"ABCD" (F1.1)

"XYZ" (F3.1)

DN3

Data Locality (co-locate compute and storage)

- if client and relevant DataNode on same machine, net I/O is avoidable
- APIs allow location lookup
- if data could be processed anywhere, choose client next to a replica



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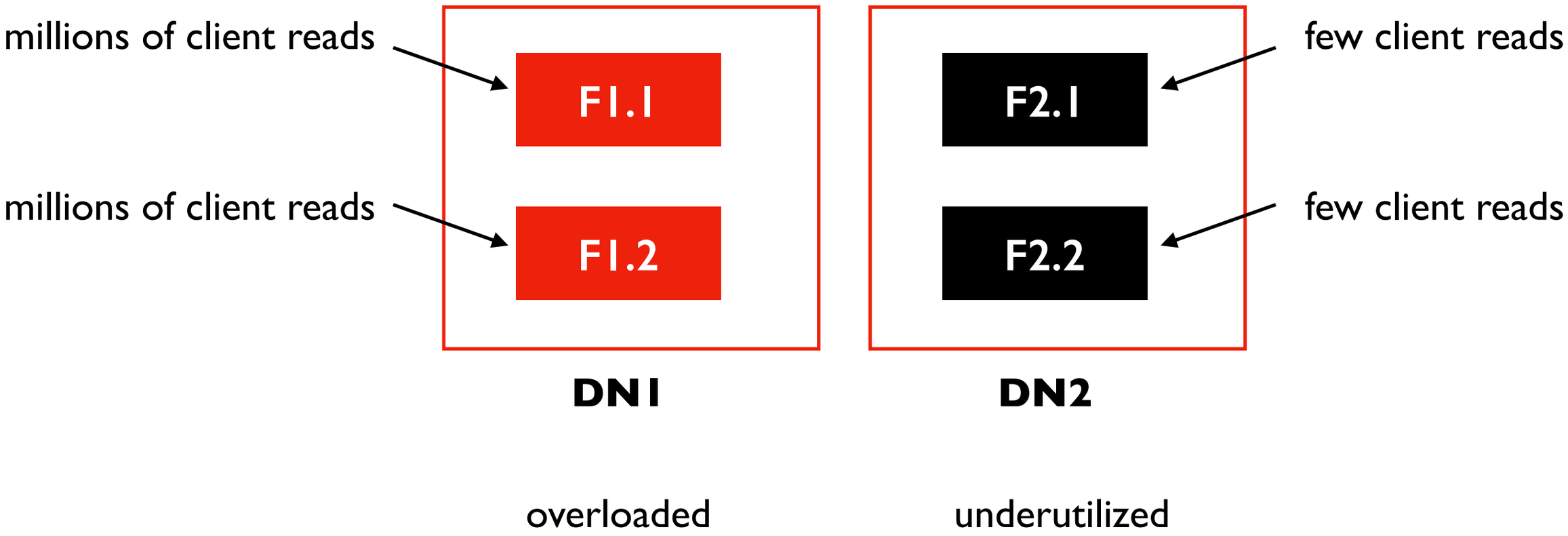
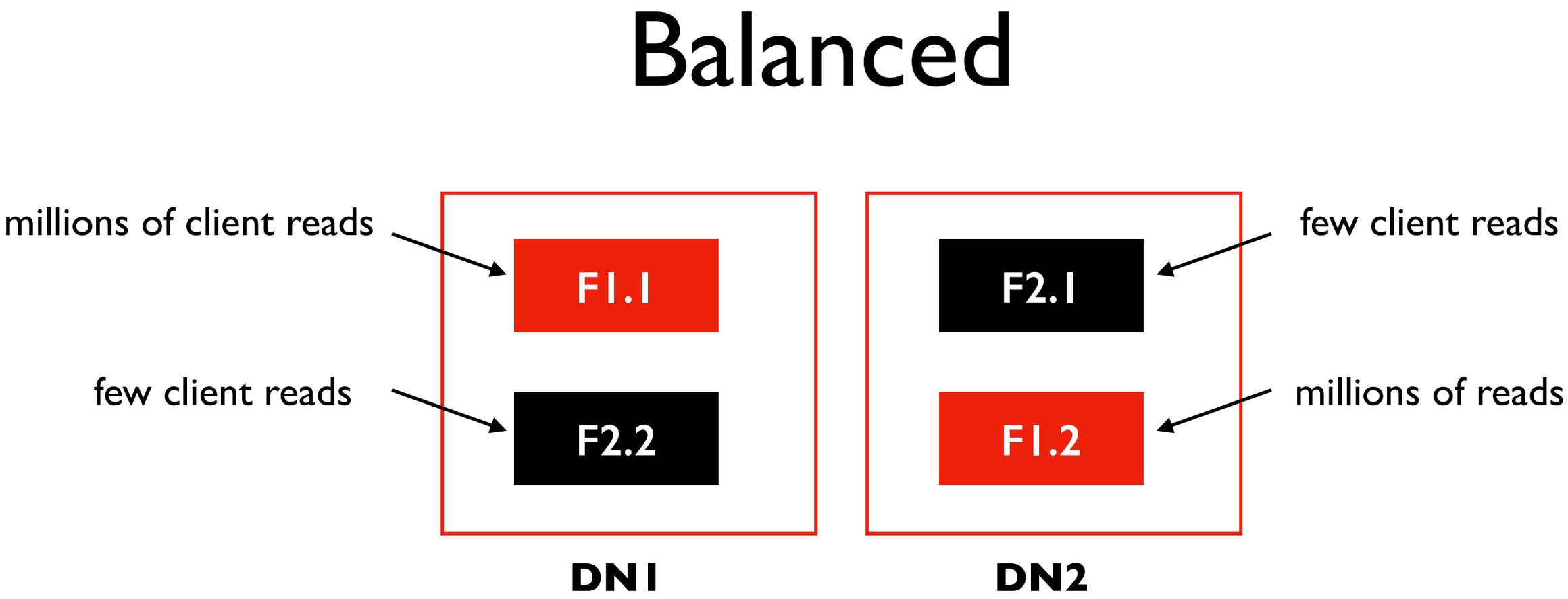
Load Balance: I/O

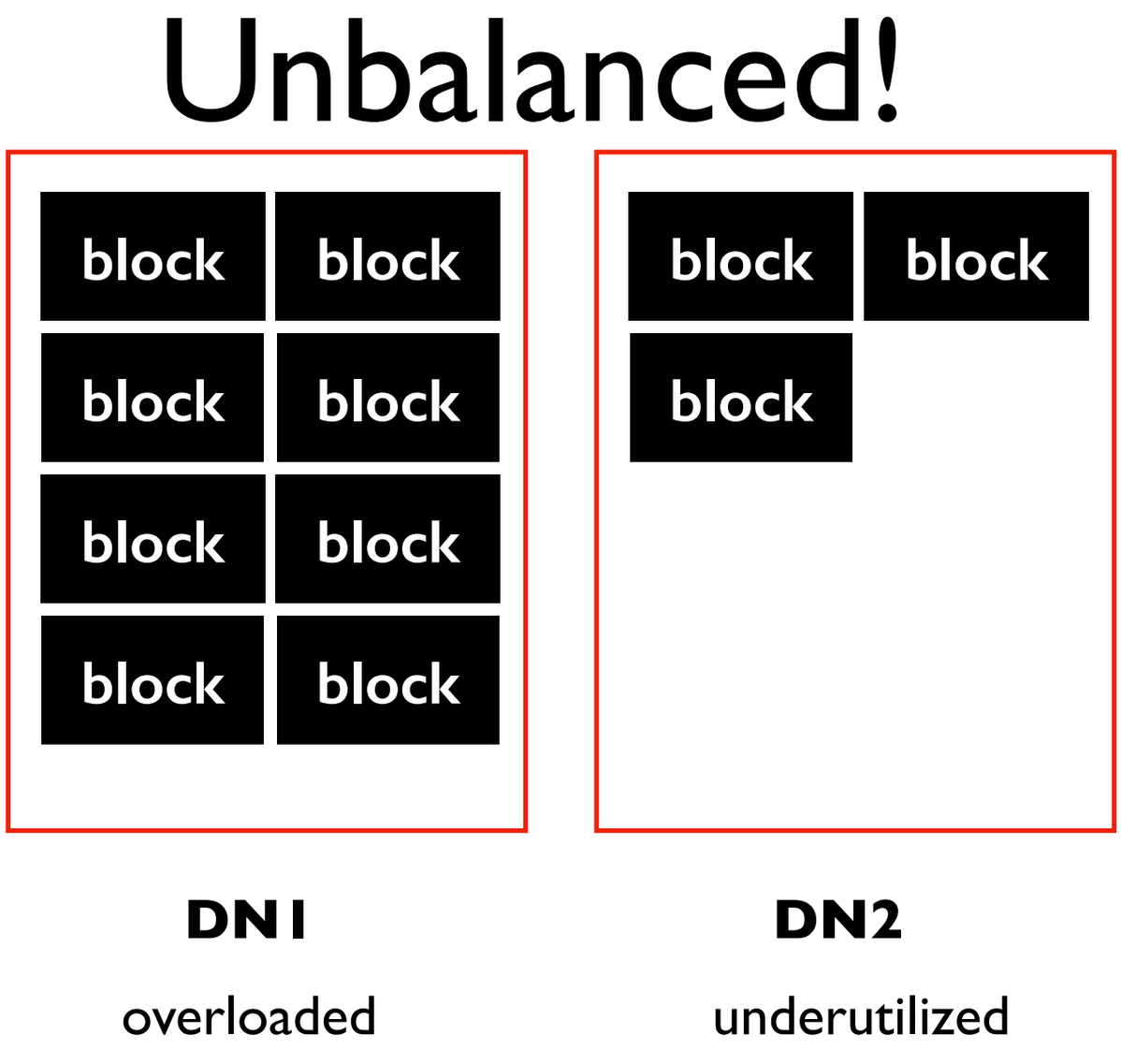
Unbalanced!



Load Balance: I/O



Load Balance: Storage Consumption



Sometime storage may be unbalanced while I/O is balanced, or vice versa.

HDFS Storage Balancing Strategies

Strategy 1: when writing new data, prefer underutilized nodes

- depends on policy (pluggable) and configuration
- example: AvailableSpaceBlockPlacementPolicy
- cheap: we were going to write the data anyway!

Placement limitations

- don't put all replicas of same block in same rack, even if that rack is lightly loaded
- don't overload newly added DataNodes with all incoming writes
- what if everything is balanced perfectly, and then a big file is deleted?

Strategy 2: run a balancer tool

- move data around after the fact, to even the load
- run manually (admin), or on a schedule
- careful! re-distributing large files has high network I/O costs

Summary: Some Key Ideas Applied to 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, co-locate compute with storage