ETH zürich

Ghislain Fourny

Big Data for Engineers Spring 2020

4. Distributed file systems

Kheng Ho Toh / 123RF Stock Photo

Poll

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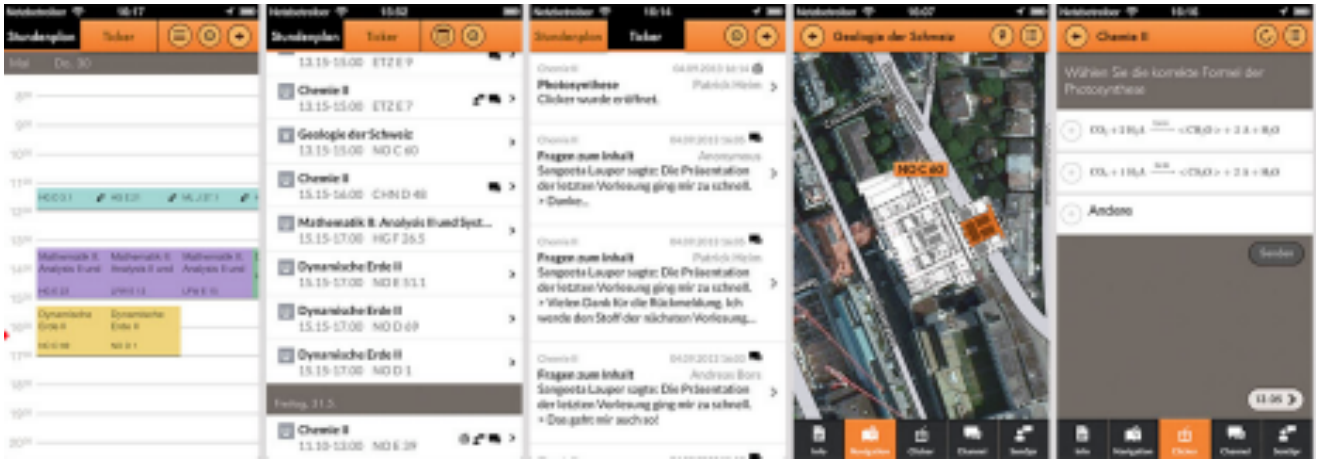
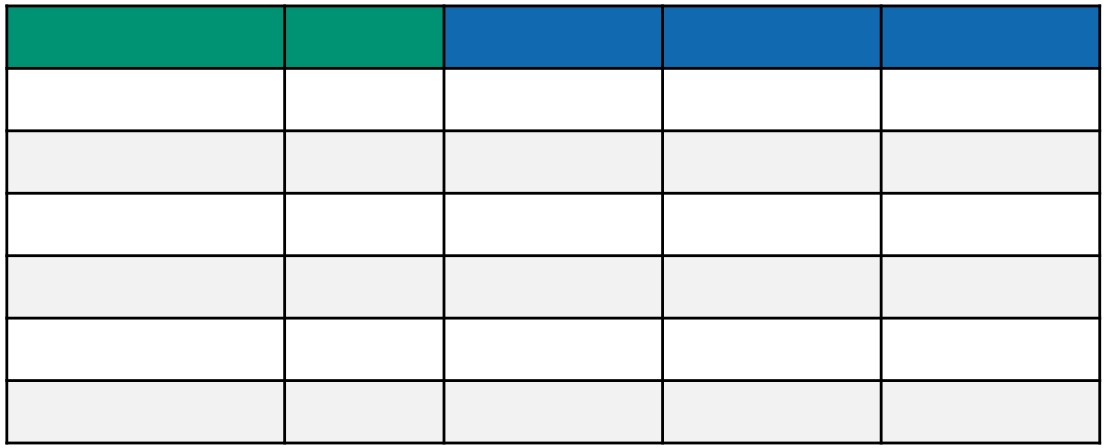


So far...

We've rehearsed relational databases

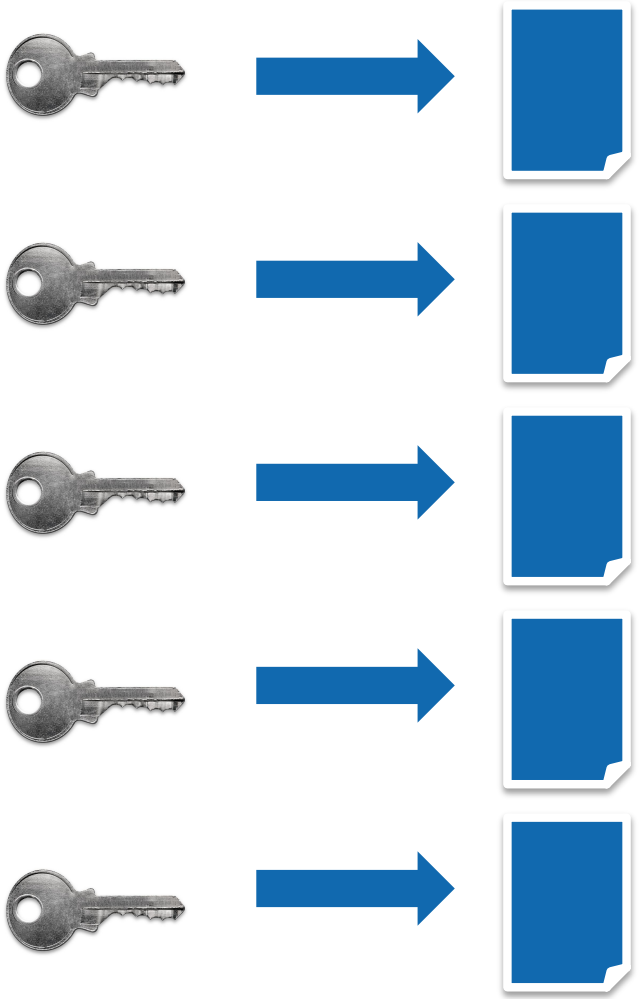


So far...

We've looked into **scaling out**

So far...

We've seen **Object storage**



Where does the data come from?

Sensors
Measurements
Events
Logs

Oleg Dudko / 123RF Stock Photo

Raw Data

Aggregated data
Intermediate data

Anton Starikov / 123RF Stock Photo

Derived Data

There is

Big Data

Anna Liebiedieva / 123RF Stock Photo

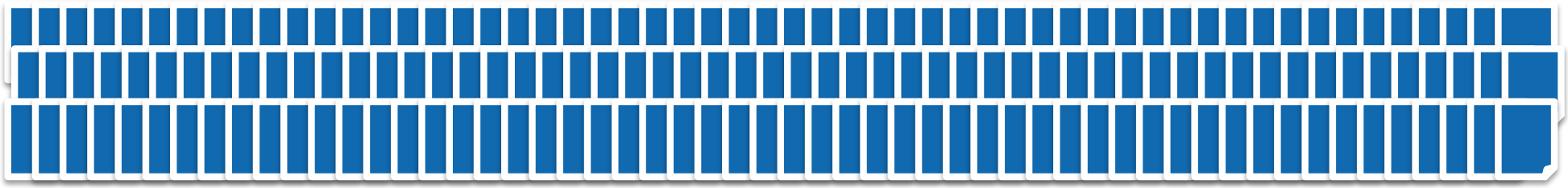
and

Vadym Kurgak / 123RF Stock Photo

Big Data

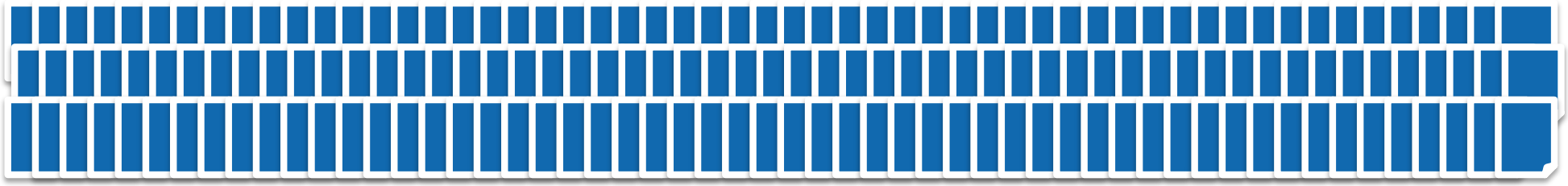
Use cases

A huge amount of large files?

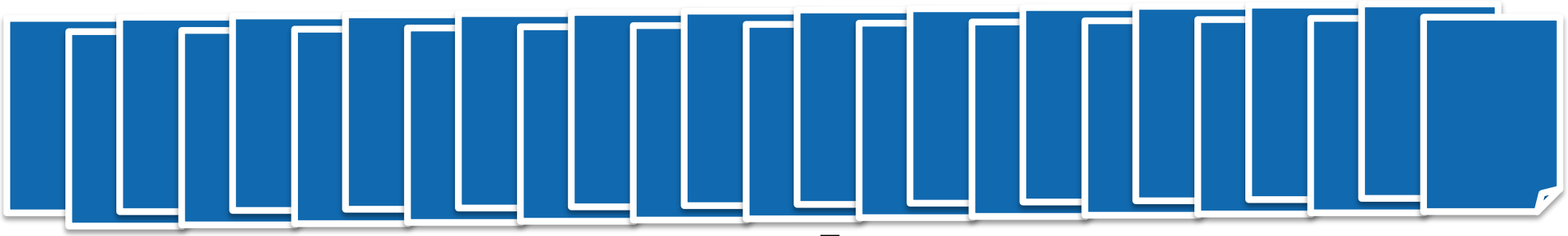


Use cases

A **huge** amount of **large** files?



vs.



A **large** amount of **huge** files?

Use cases

Billions of TB files

vs.

Millions of PB files

Technologies and models

Key-Value Model

Object Storage

Billions of <TB files

VS.

Millions of **<PB** files

Technologies and models

Key-Value Model

Object Storage

File System

Block Storage

Billions of <TB files

VS.

Millions of **<PB** files

Distributed file systems: inception

13

Fault tolerance and robustness

Vitaly Korovin / 123RF Stock Photo

Local disk

It might fail

Fault tolerance and robustness

Vitaly Korovin / 123RF Stock Photo

Local disk

It might fail

Kheng Ho Toh / 123RF Stock Photo

Cluster with 100s to10,000s of machines

nodes will fail

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Fault tolerance and robustness

Monitoring

Fault tolerance and robustness

Error detection

Monitoring

Fault tolerance and robustness

Automatic Recovery

Error detection

Monitoring

Kheng Ho Toh / 123RF Stock Photo

Fault tolerance and robustness

Fault tolerance

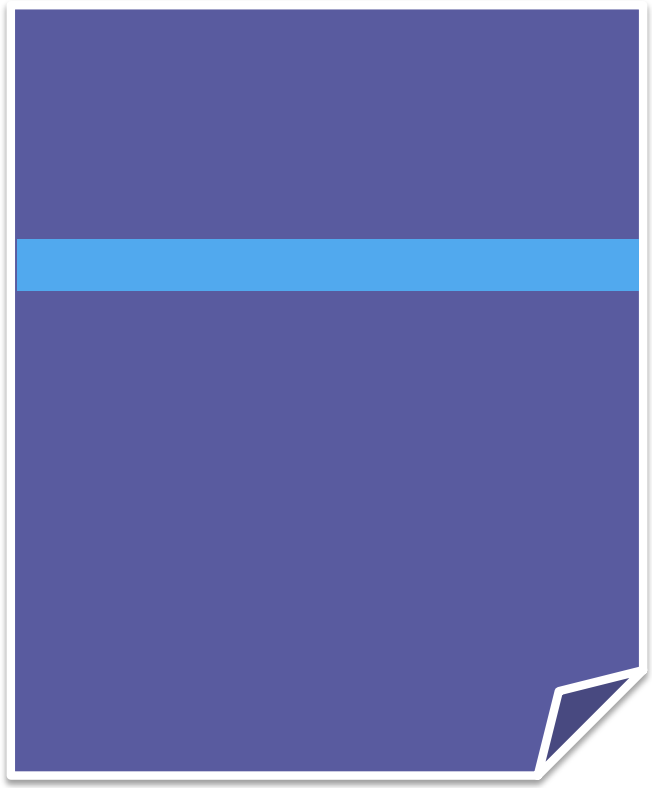
Automatic Recovery

Error detection

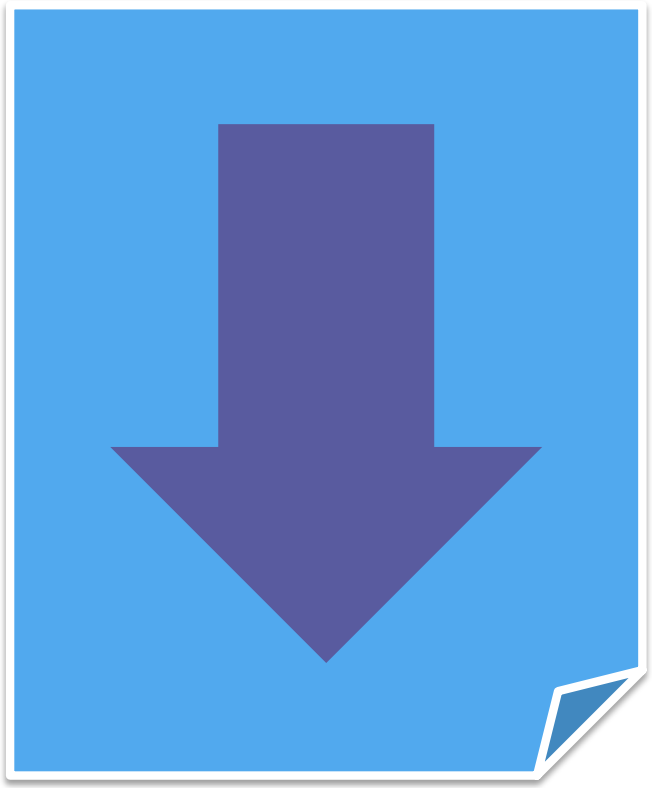
Monitoring

Kheng Ho Toh / 123RF Stock Photo

File read model



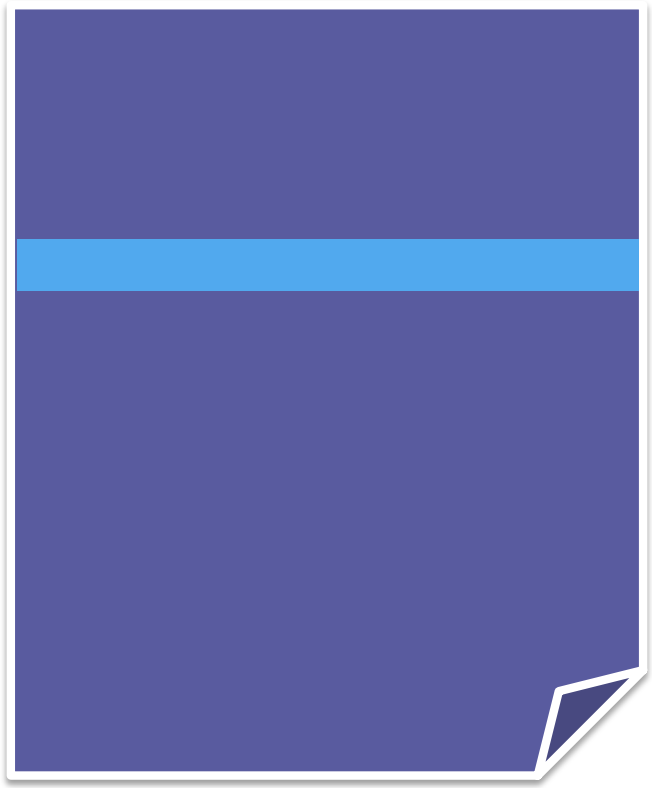
VS.



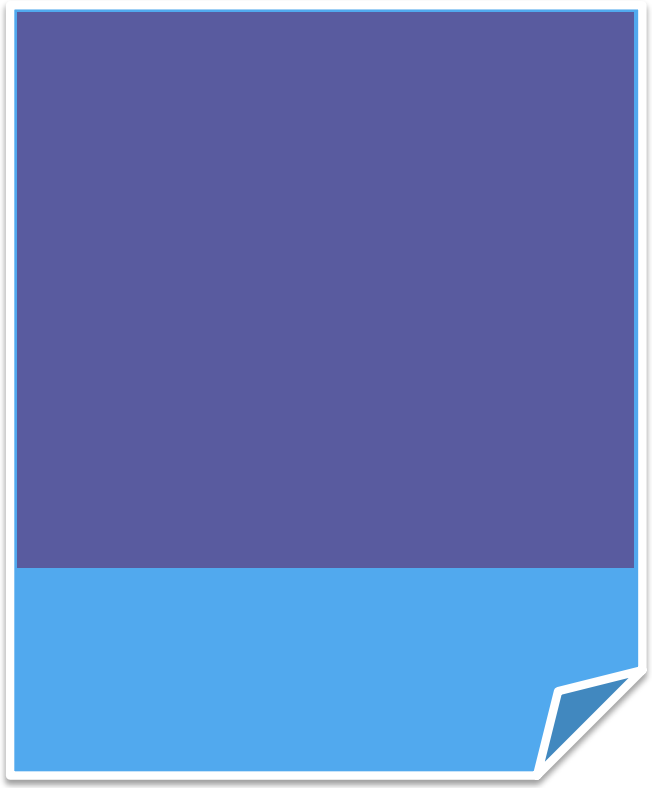
Random access

Scan the file

File update model



VS.



Random access

Append

File update model

suitable for

Sensors

Logs

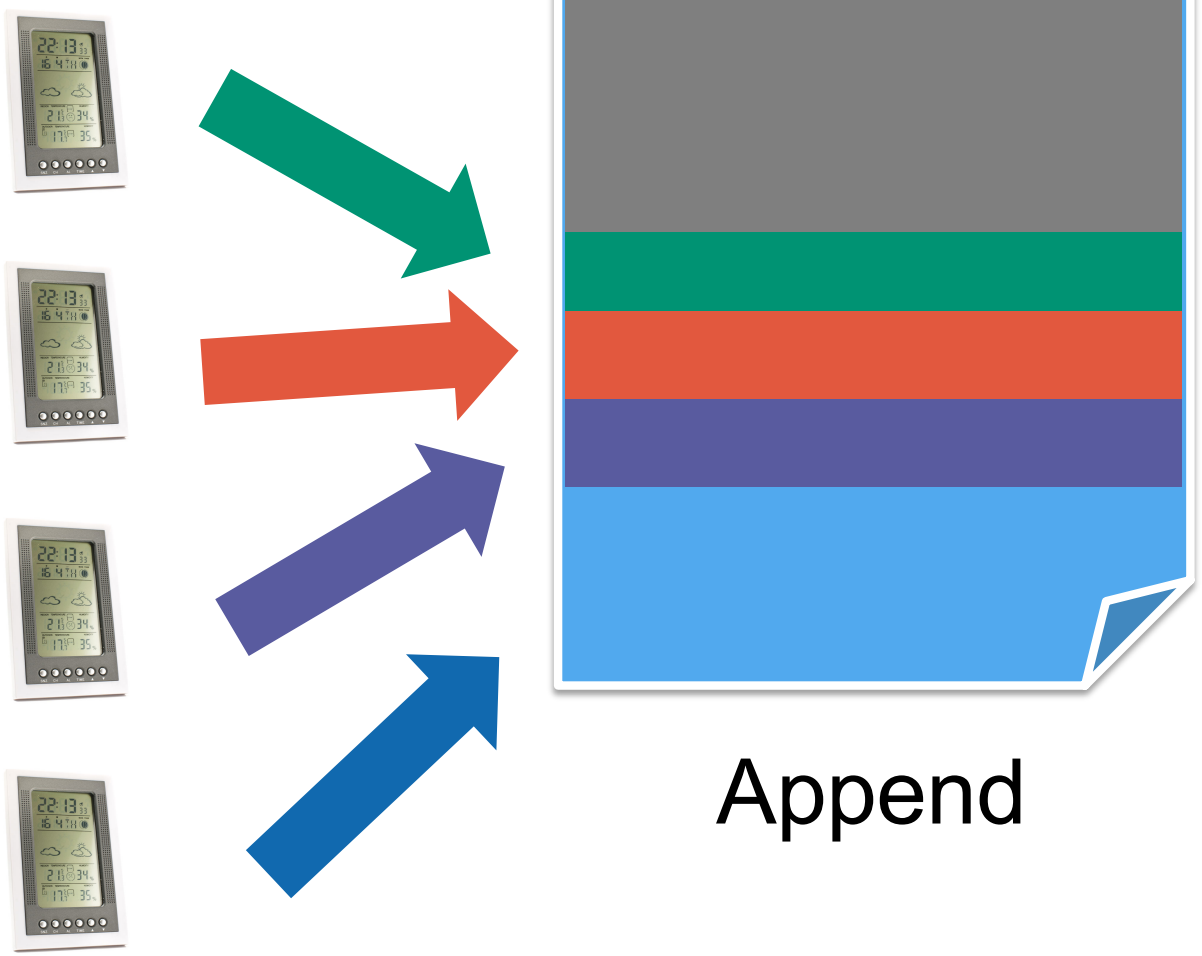
Intermediate data

Append

Appends

100s of clients
in parallel

atomic



Append

Performance requirements

Top priority:

Throughput

Performance requirements

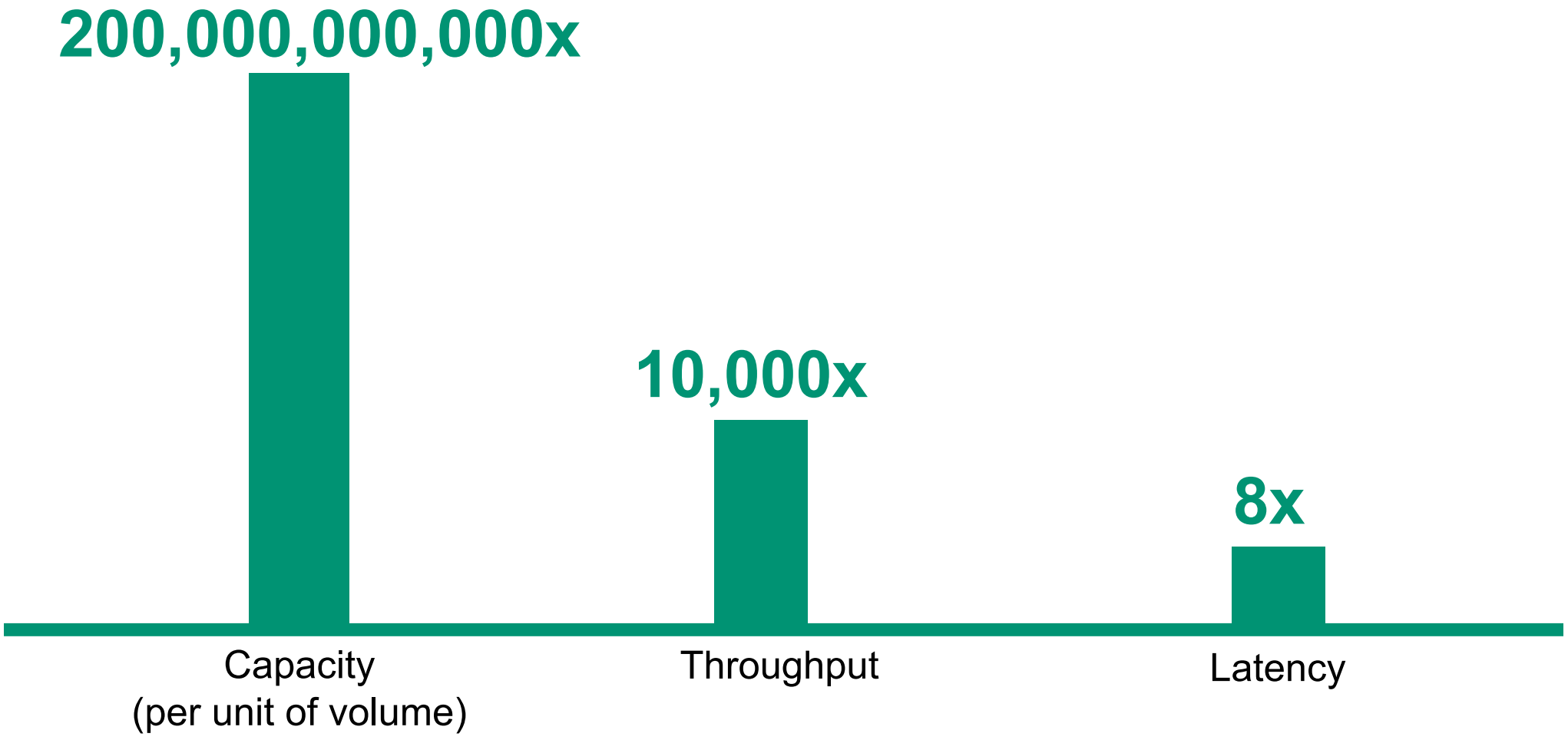
Top priority:

Throughput

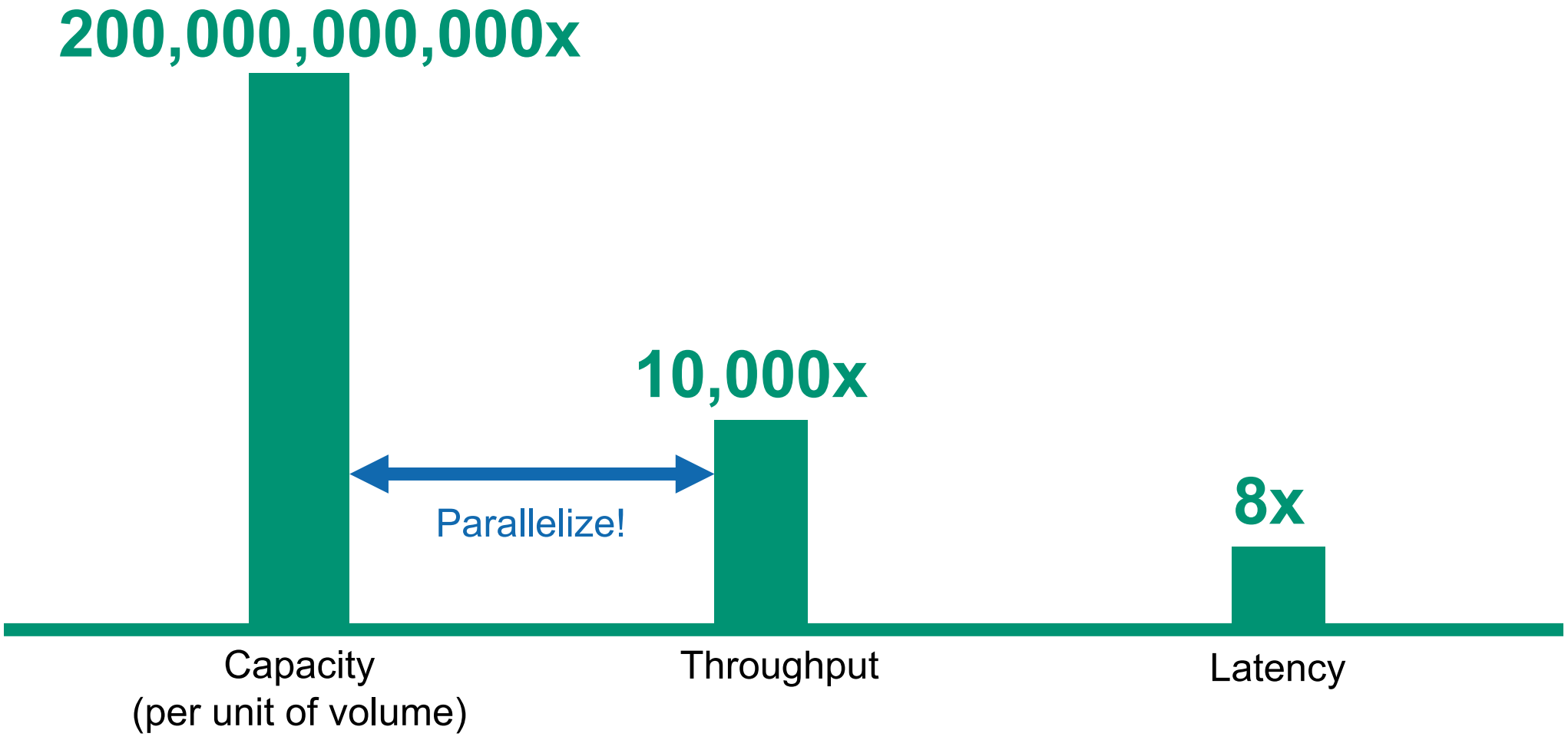
Secondary:

Latency

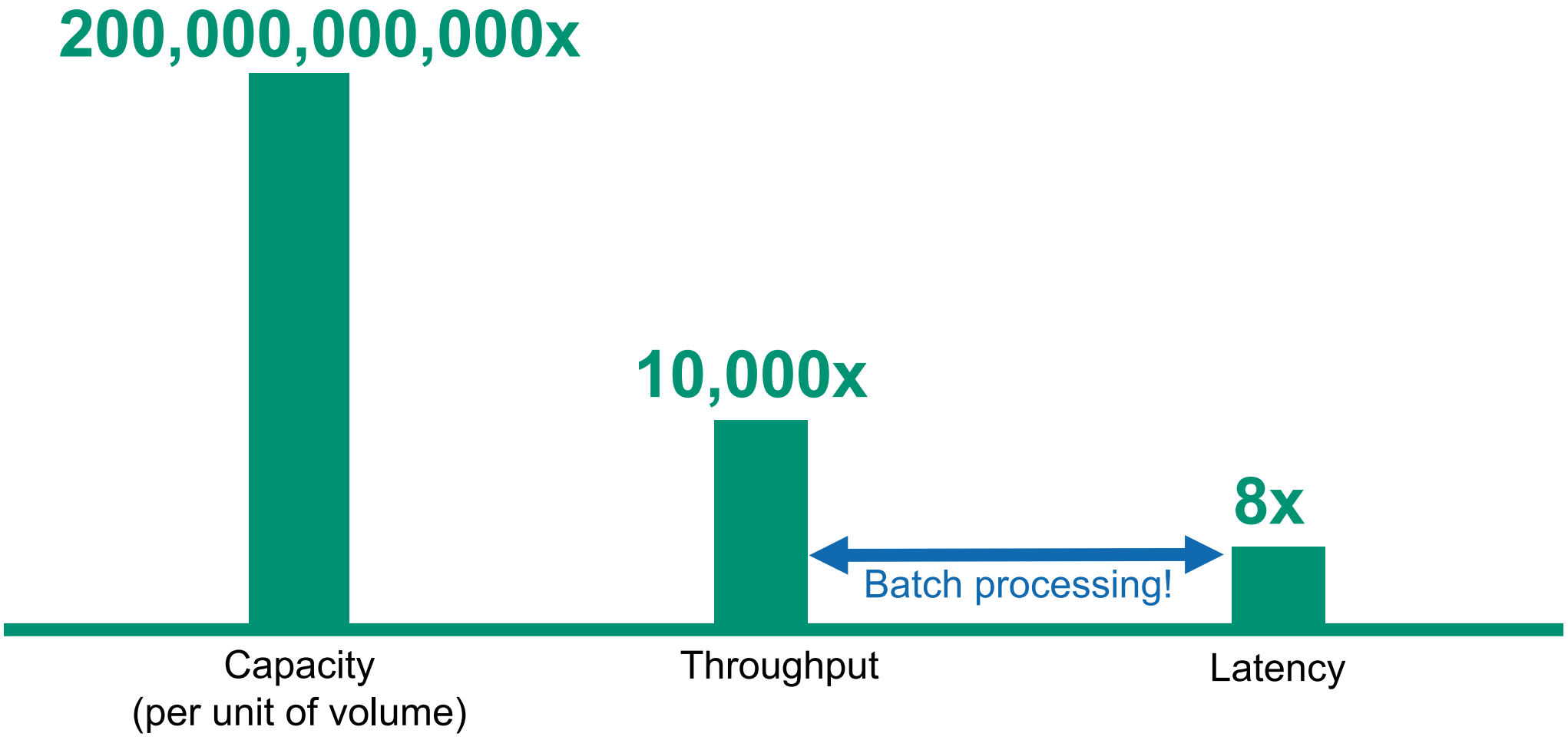
The progress made (1956-2020): Logarithmic



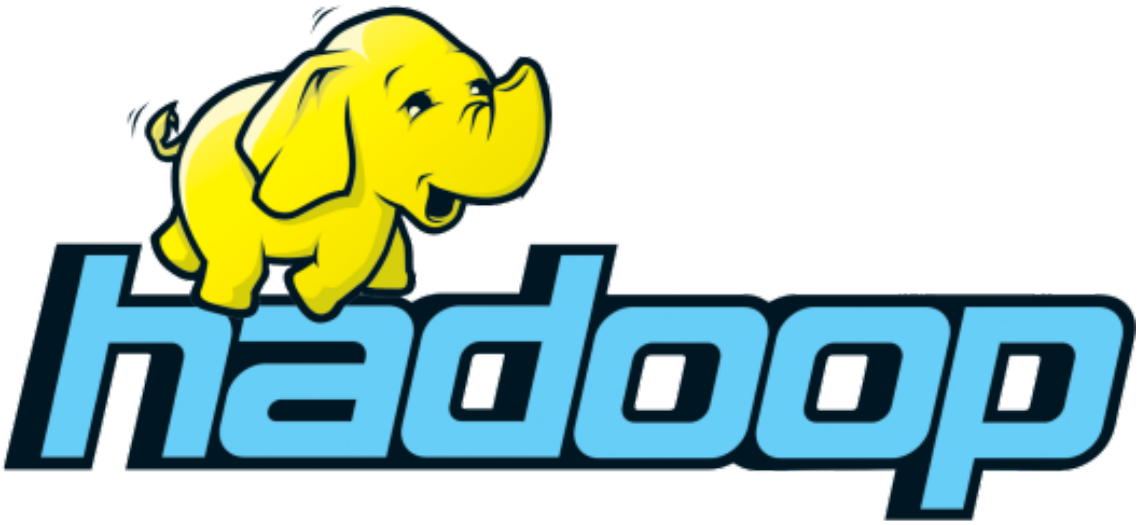
The progress made (1956-2020): Logarithmic



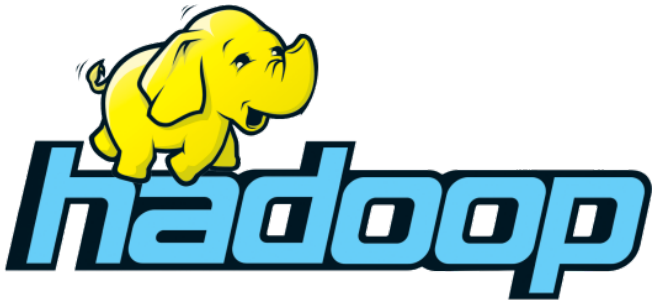
The progress made (1956-2020): Logarithmic



Hadoop



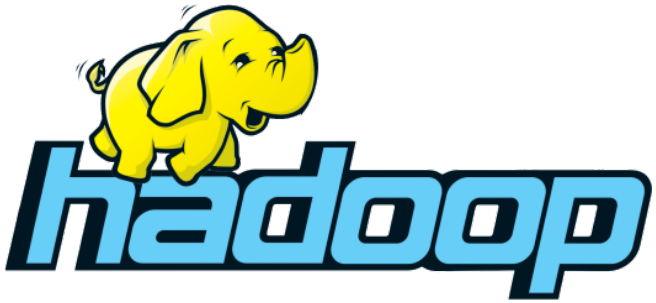
Hadoop



Initiated in

2006

Hadoop

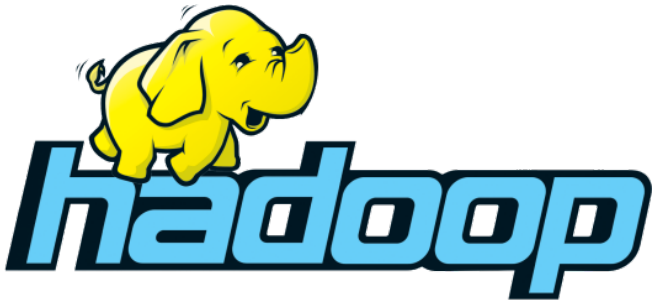


Covered in this lecture

Primarily:

- Distributed File System (HDFS)
- MapReduce
- Wide column store (HBase)

Hadoop



Inspired by Google's

- GFS (2003)
- MapReduce (2004)
- BigTable (2006)

Size timeline

Date	Size reported by Yahoo
April 2006	188
May 2006	300
October 2006	600
April 2007	1,000
February 2008	10,000 (index generation)
March 2009	24,000 (17 clusters)
June 2011	42,000 (100+ PB)
November 2016	100,000? (600PB)

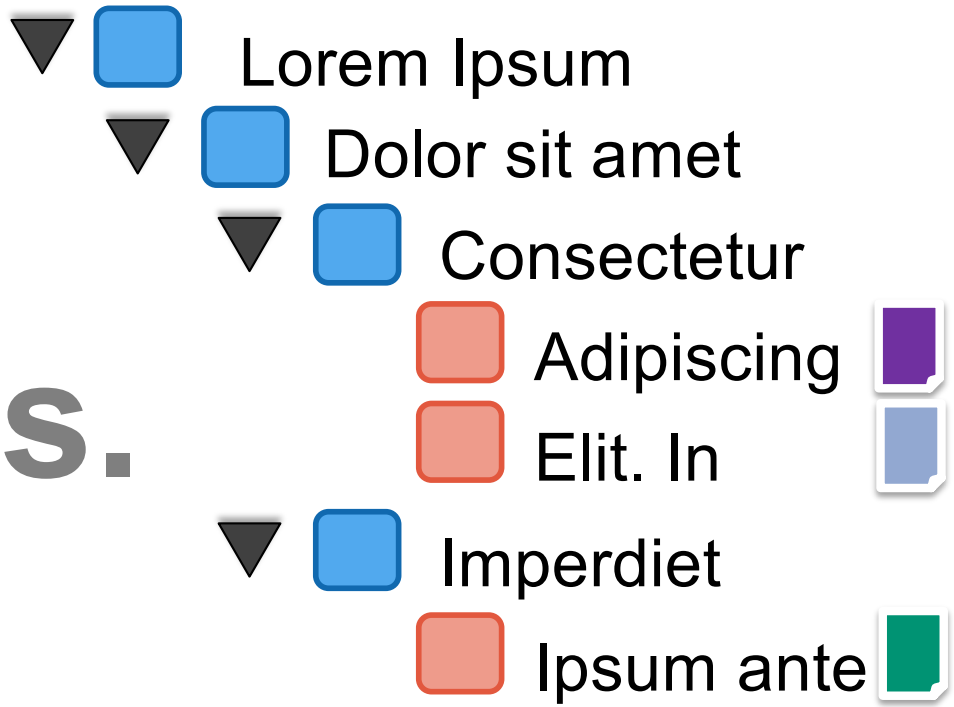
Distributed file systems: the model

File Systems (Logical Model)

Lorem Ipsum	
Dolor sit amet	
Consectetur	
Adipiscing	
Elit. In	
Imperdiet	
Ipsum ante	

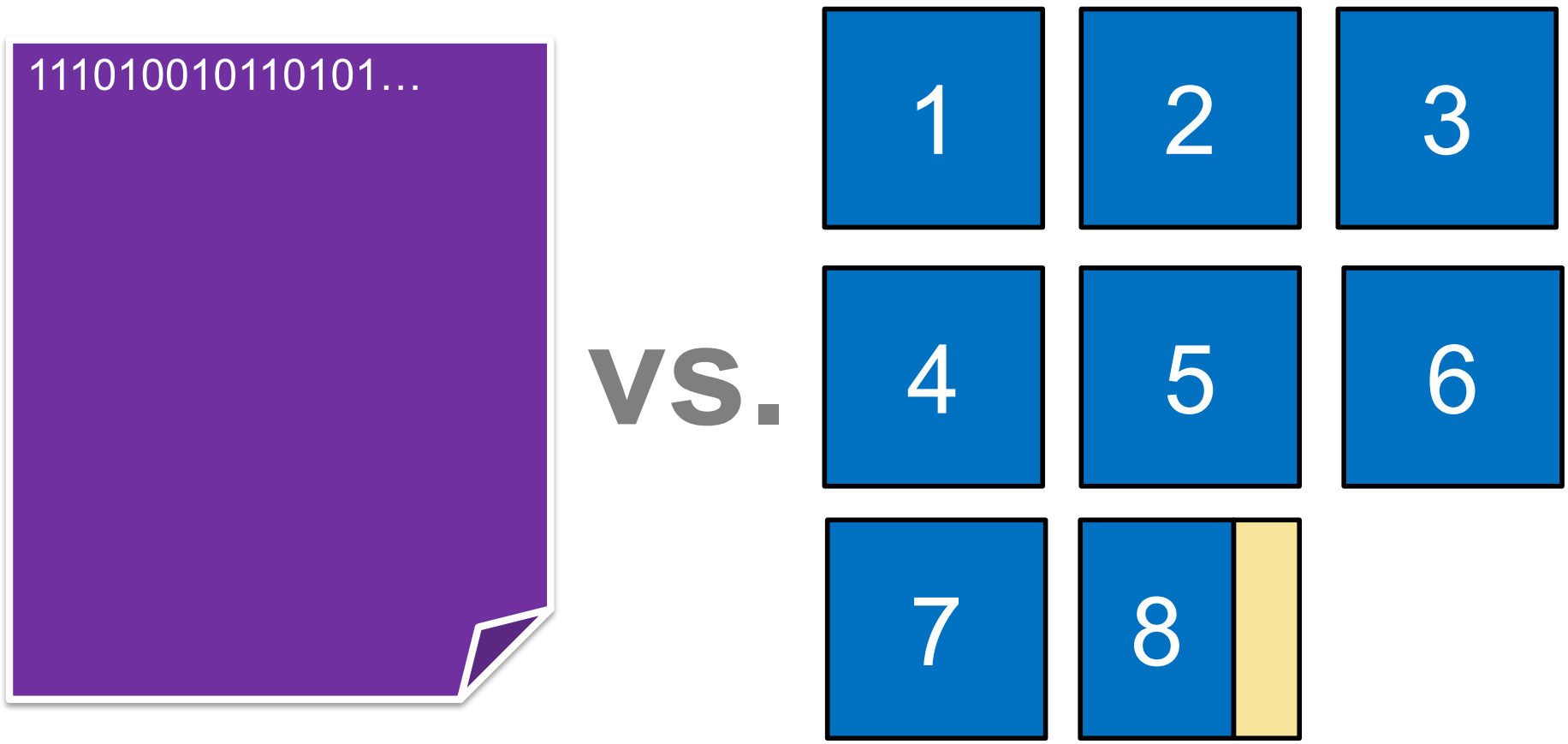
Key-Value Model

vs.



File Hierarchy

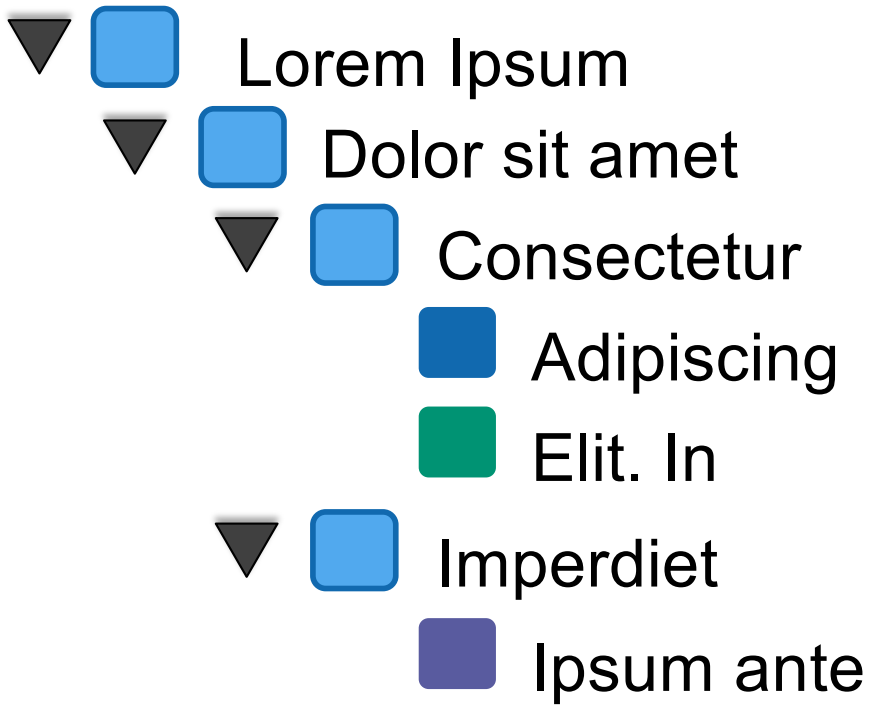
Block Storage (Physical Storage)



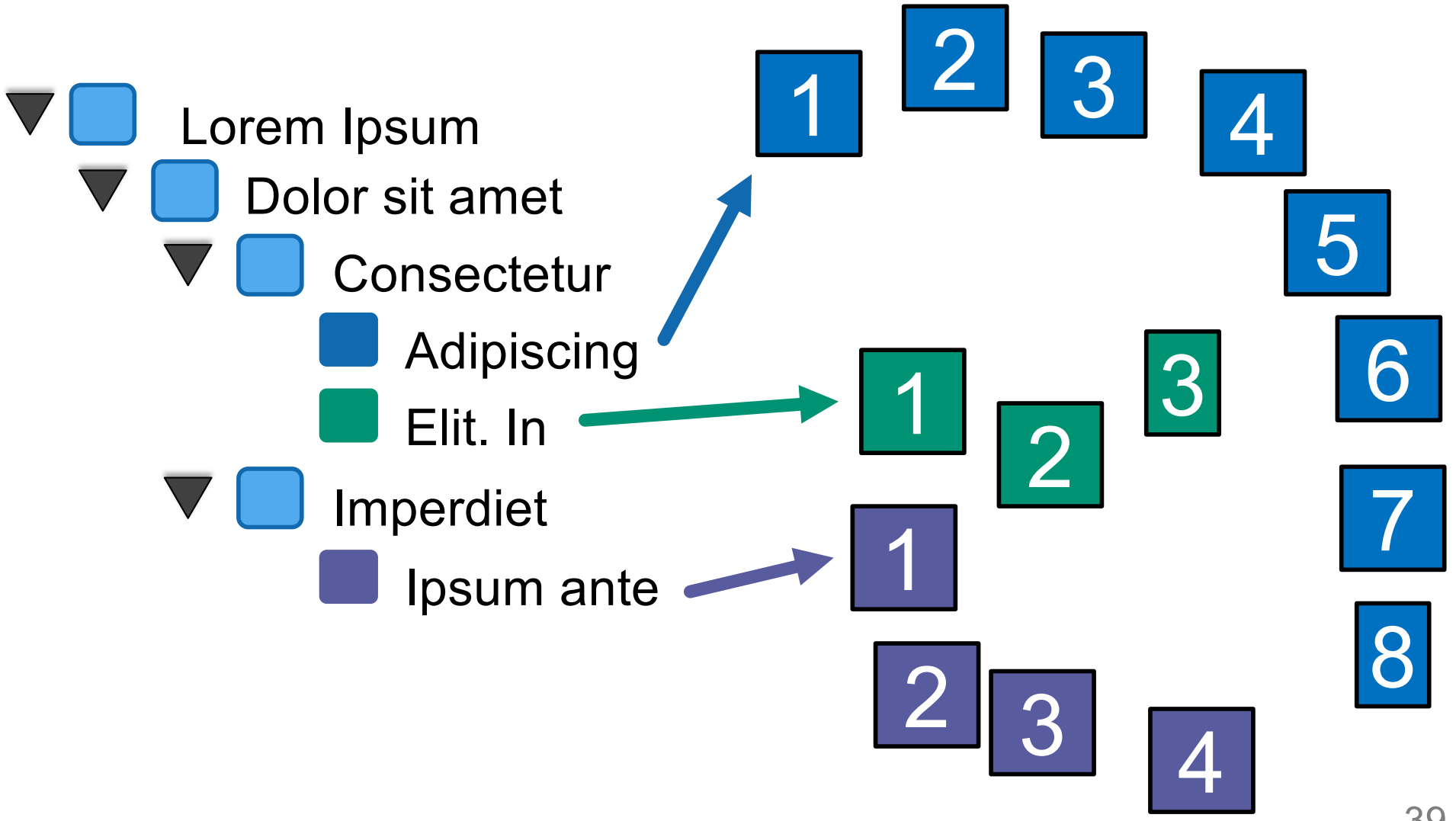
Terminology

HDFS: Block
GFS: Chunk

Files and blocks



Files and blocks



Why blocks?

Why blocks?

1. Files bigger than a disk

PBs!

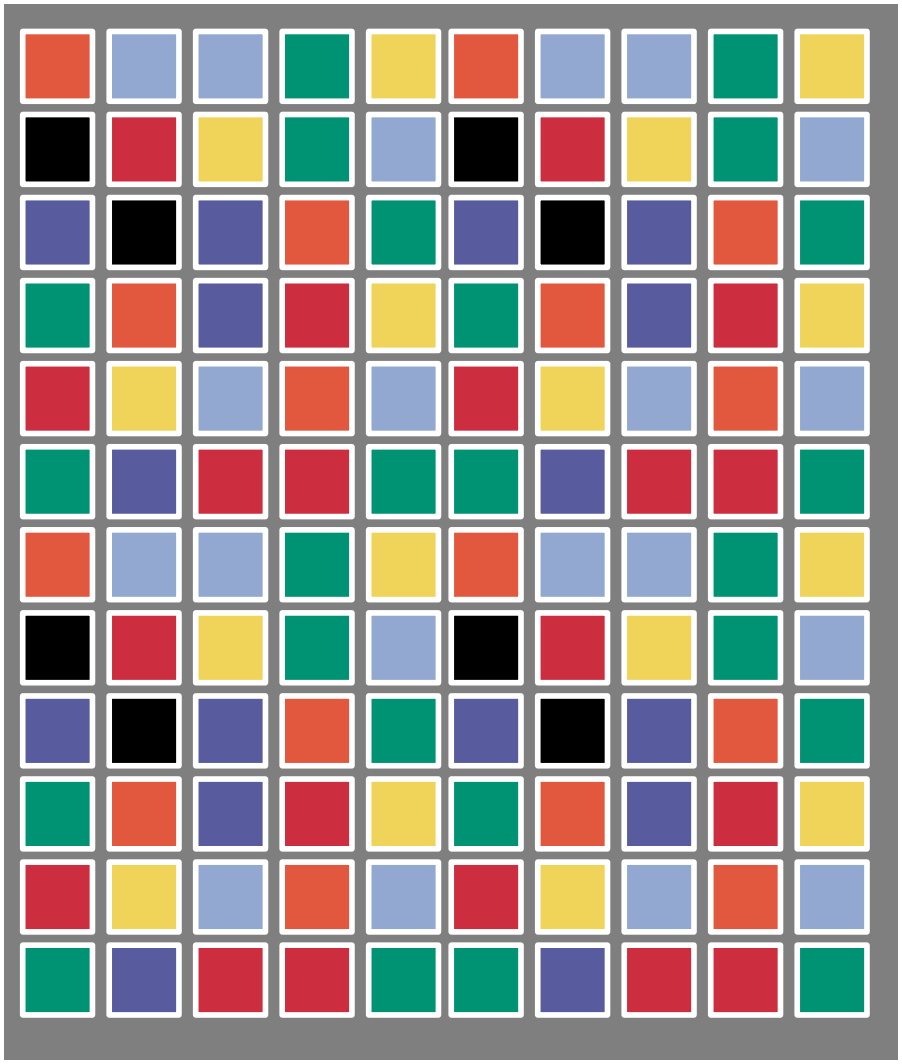
Why blocks?

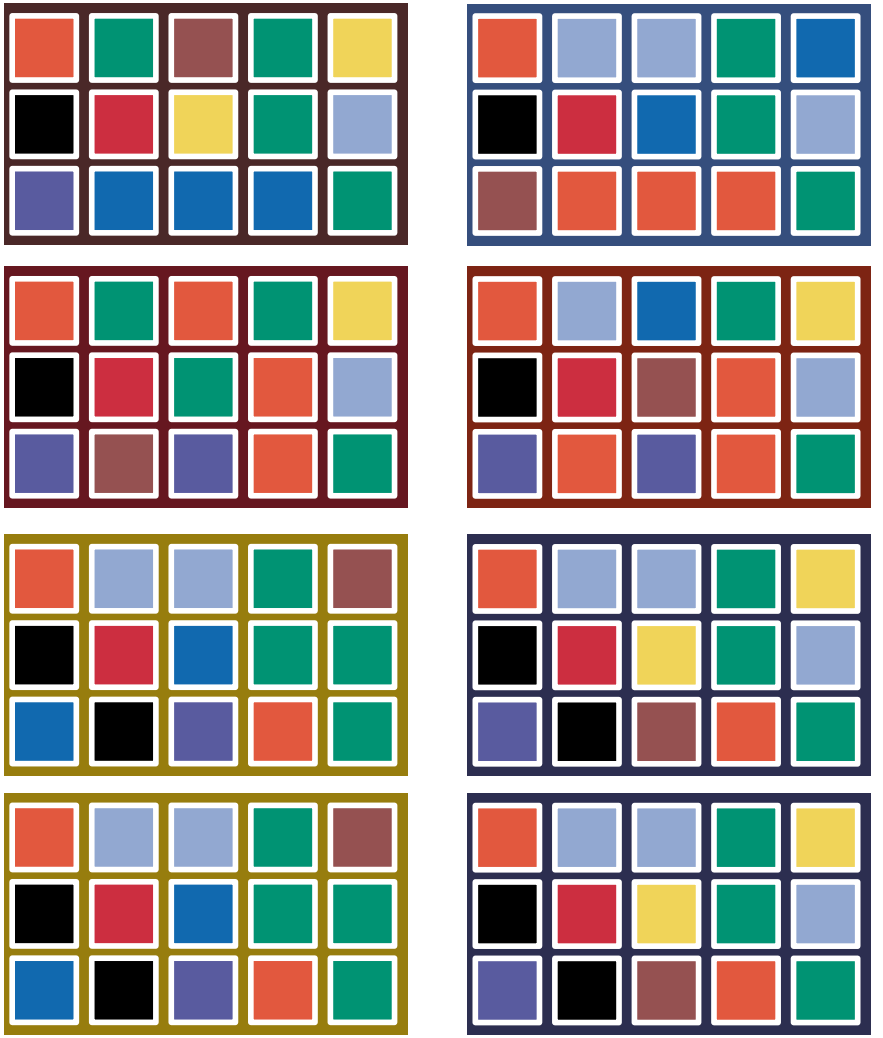
1. Files bigger than a disk

PBs!

2. Simpler level of abstraction

Single machine vs. distributed





The right block size

4 kB

Simple file system

Poll

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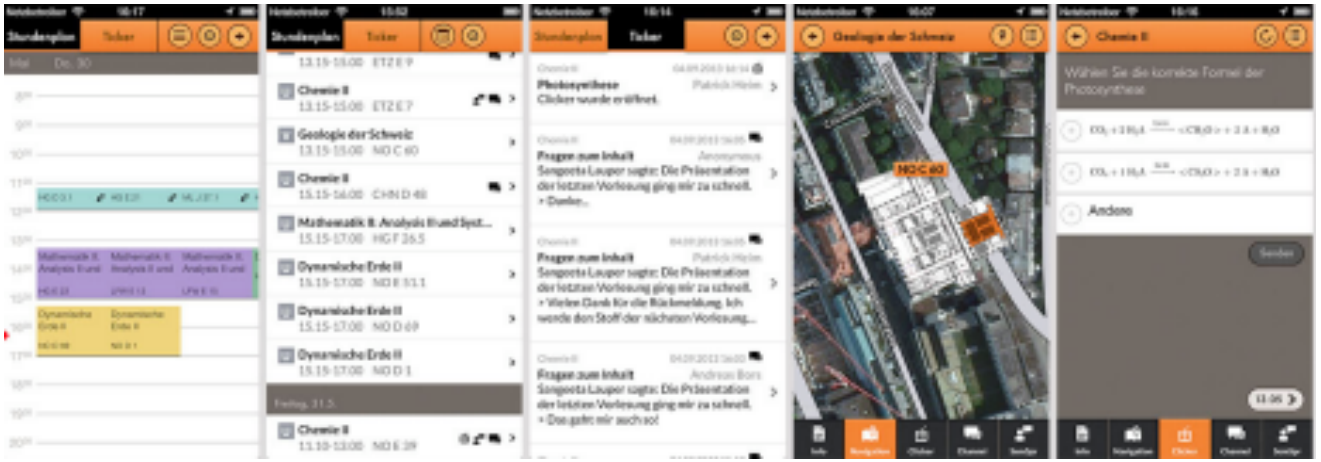


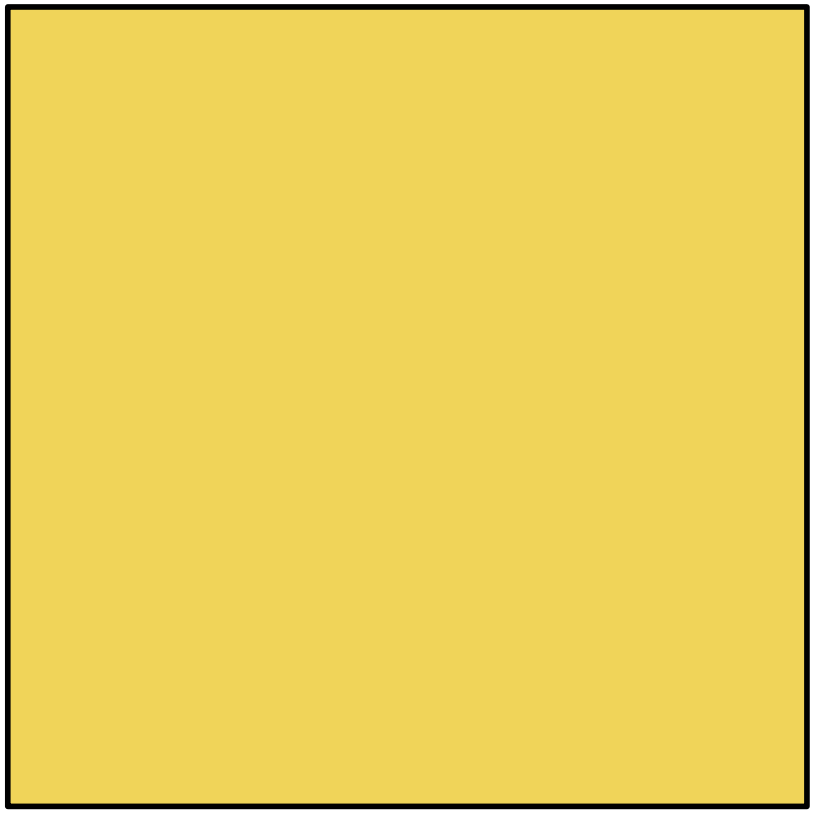
The right block size

4 kB

Simple file system

4 kB – 32 kB

Relational Database



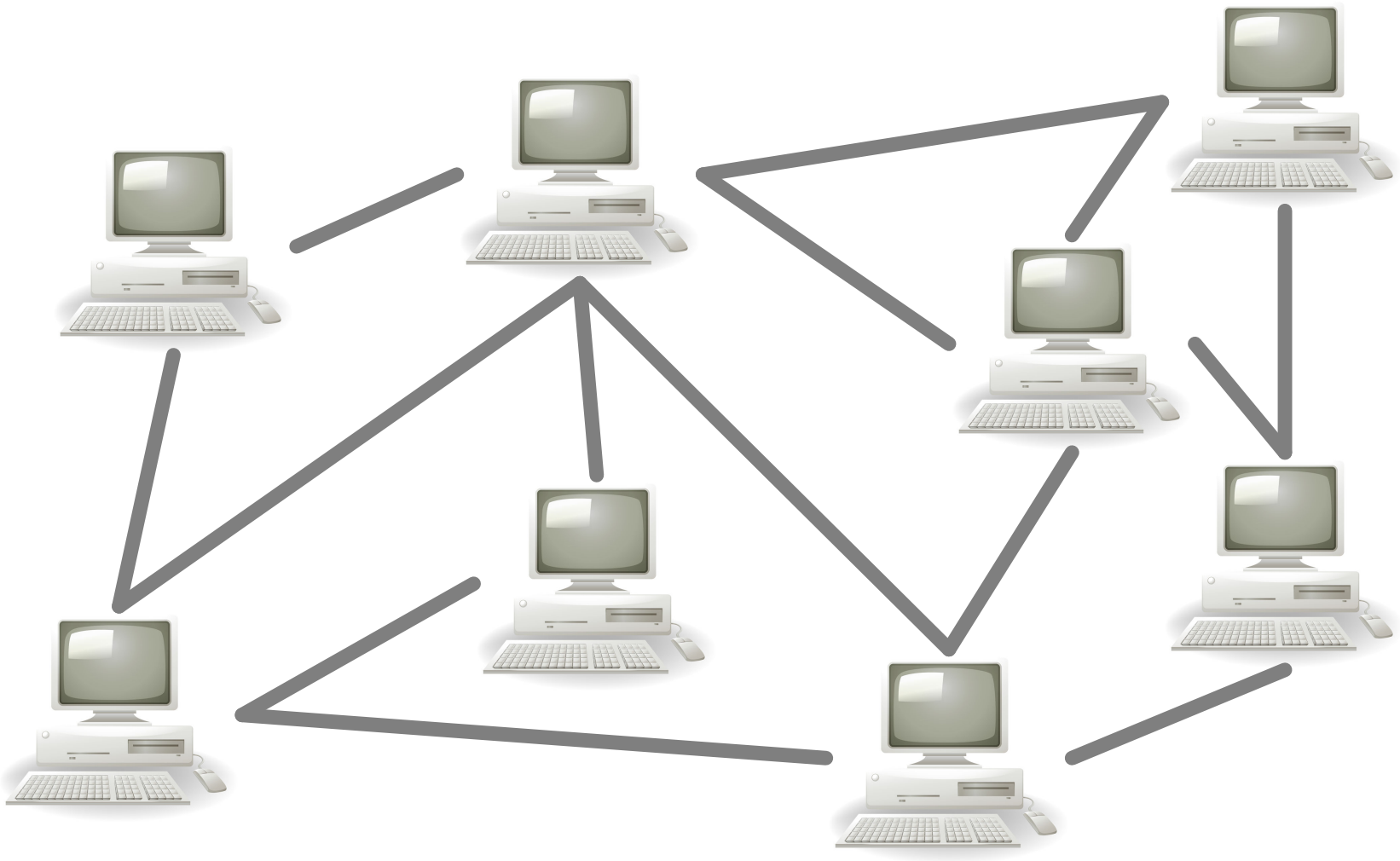
64 MB – 128 MB

Distributed file system

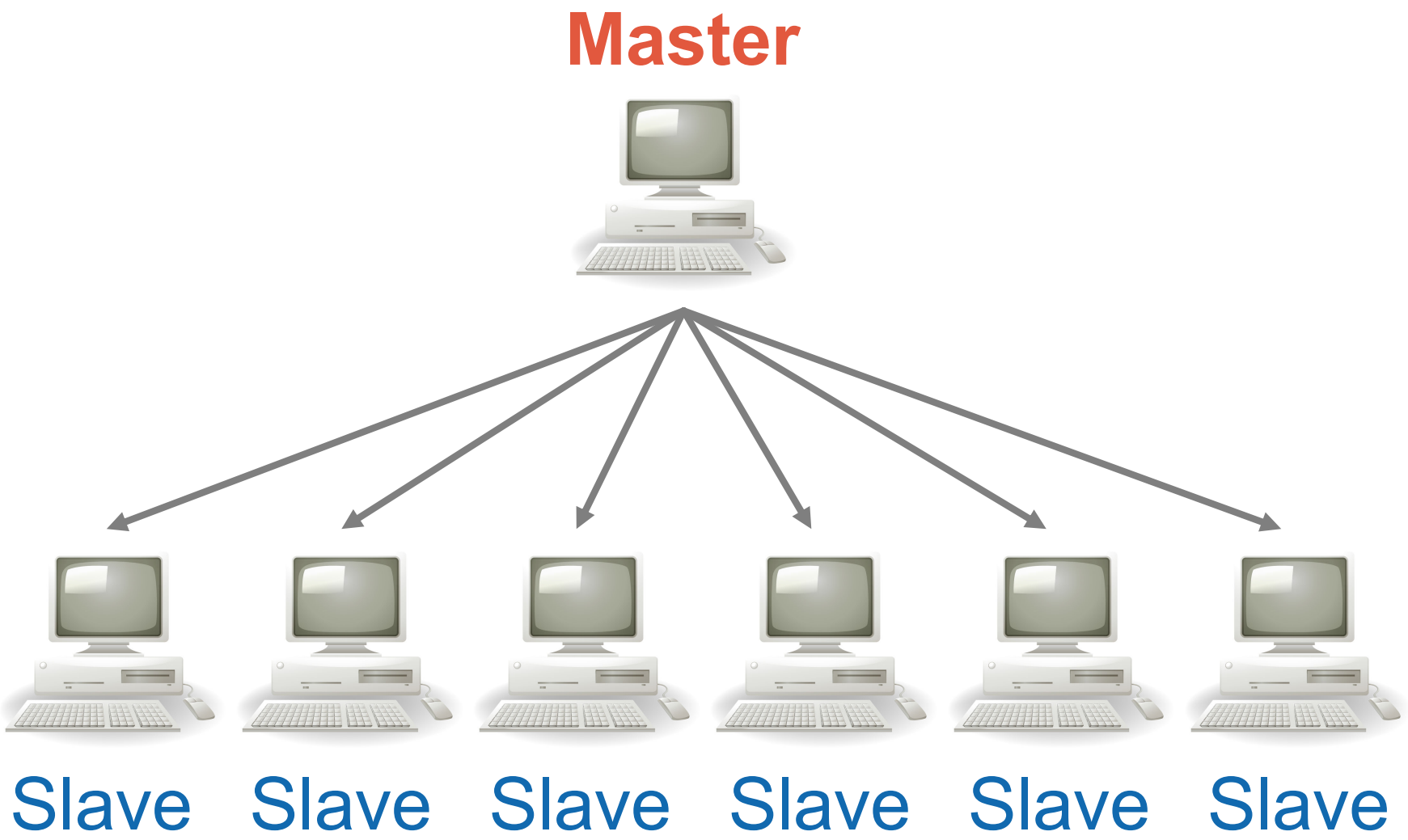
HDFS Architecture

How do we connect the many machines?

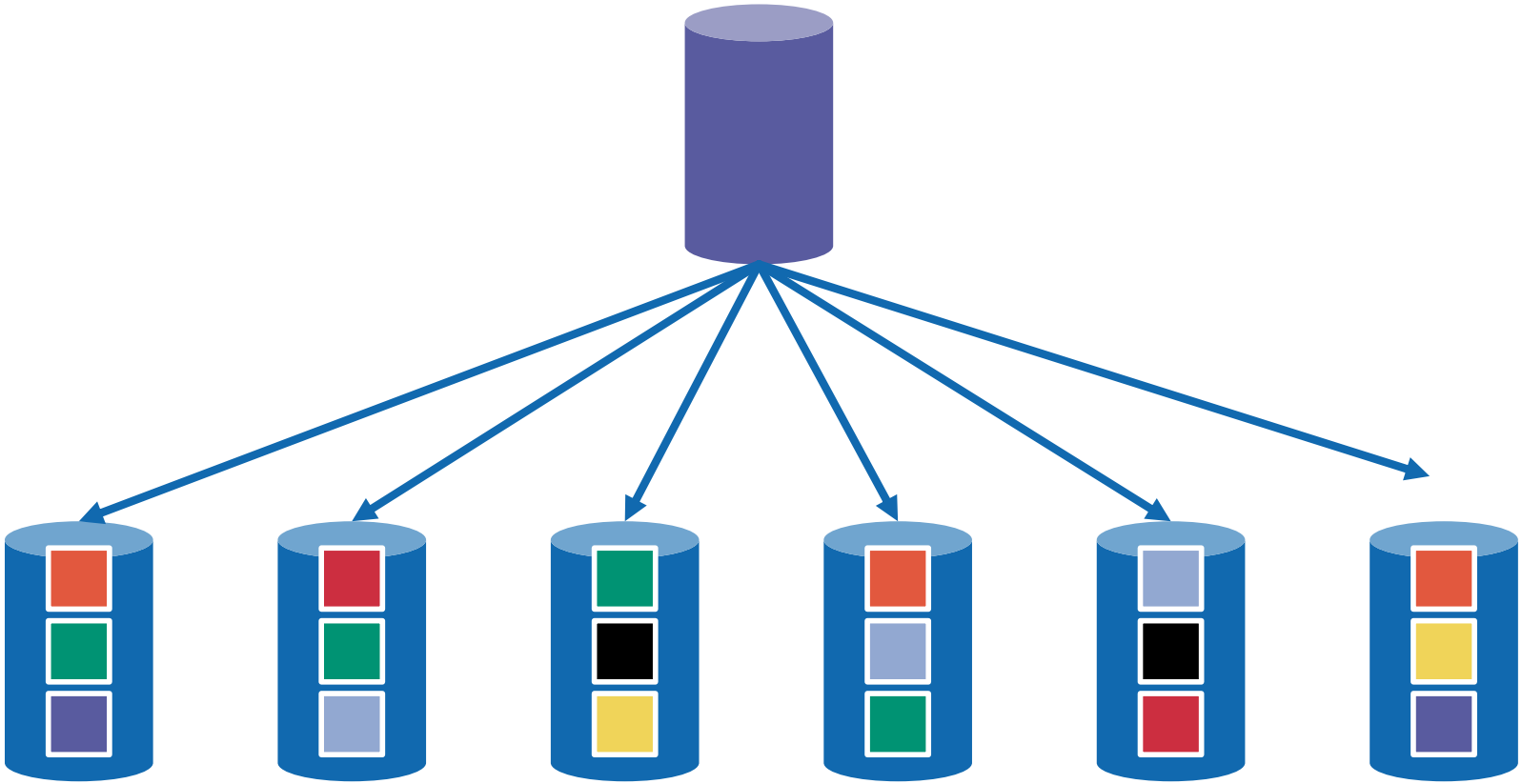
Peer-to-peer architecture



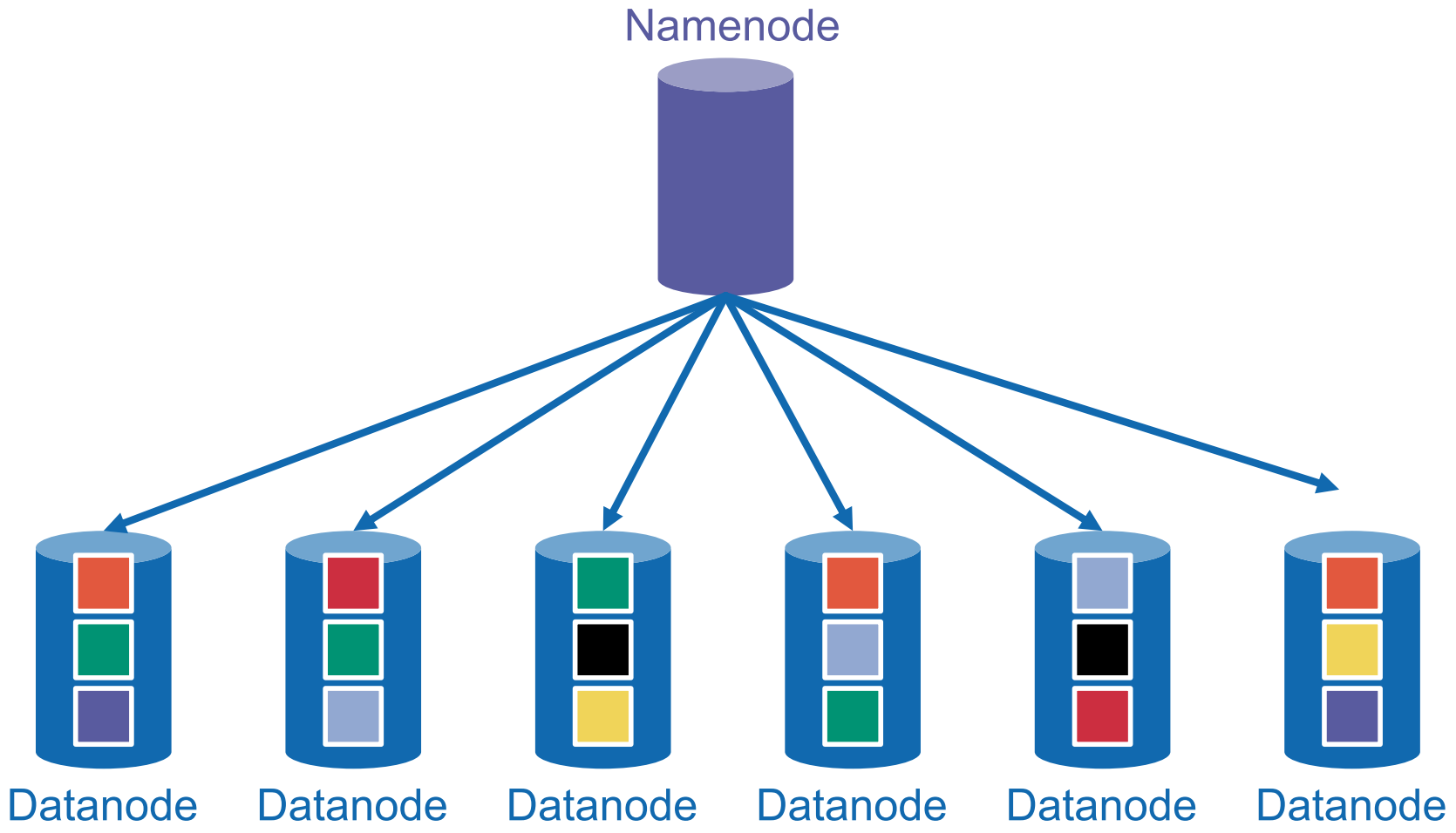
Master-slave architecture



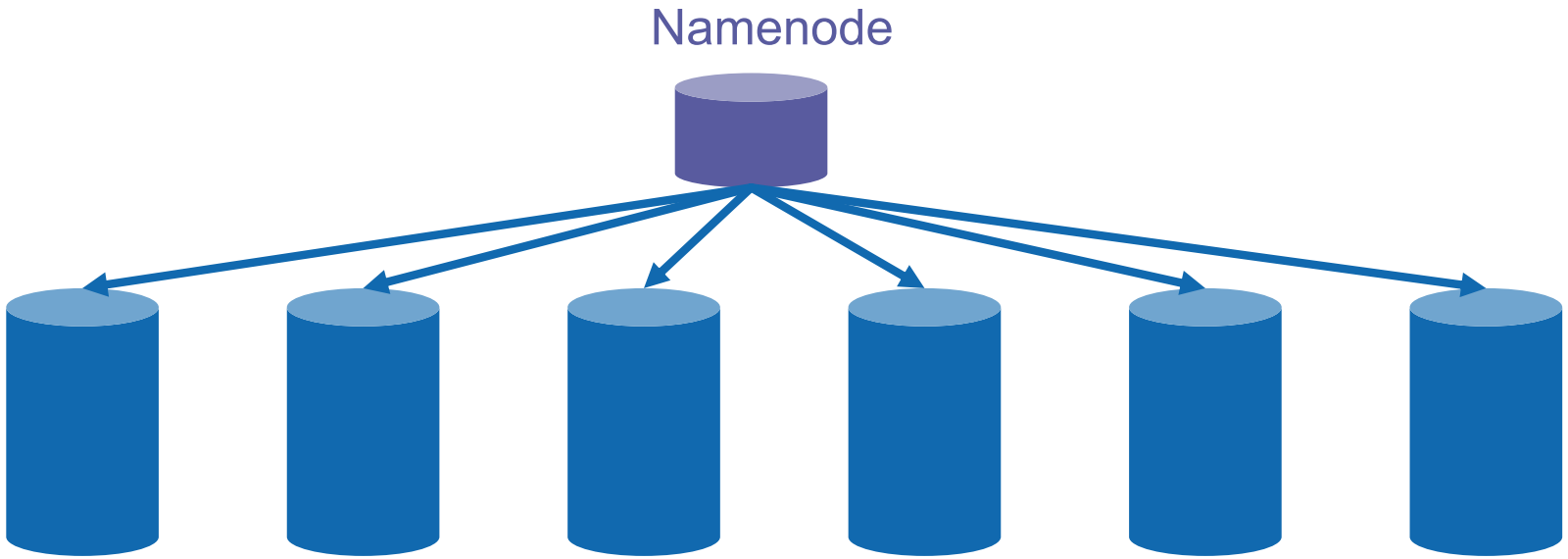
HDFS server architecture



HDFS server architecture

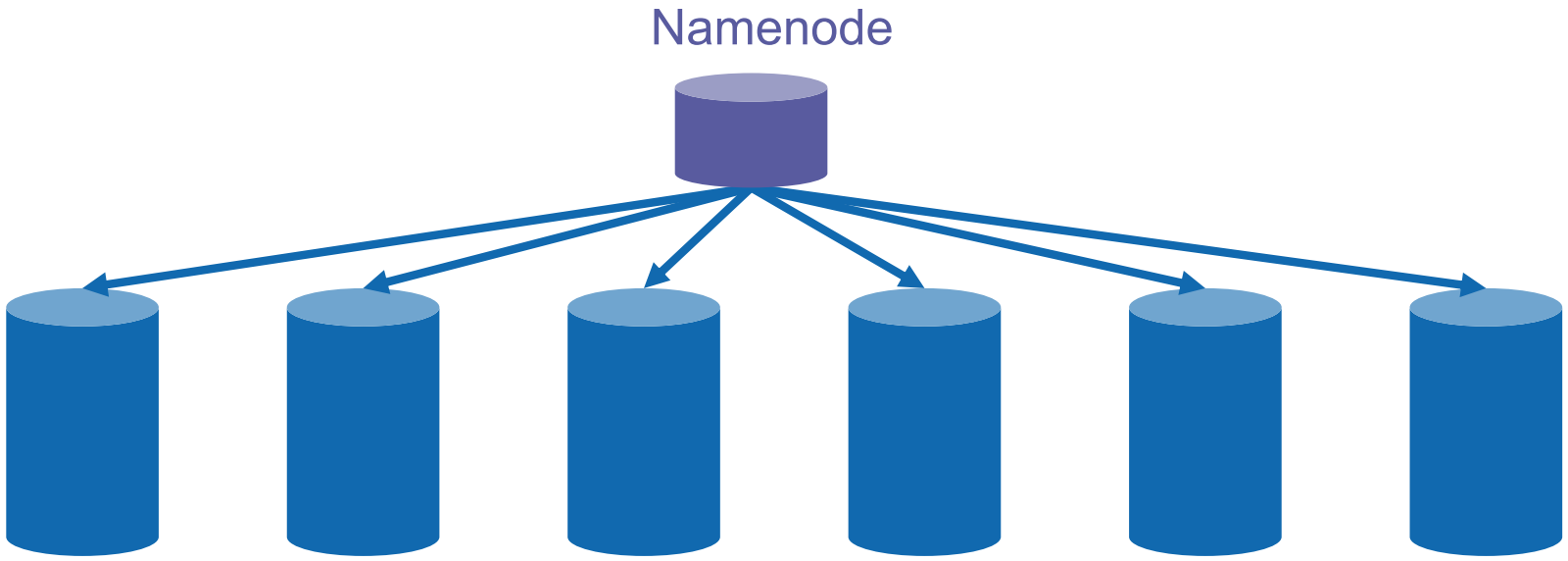


From the file perspective



File...

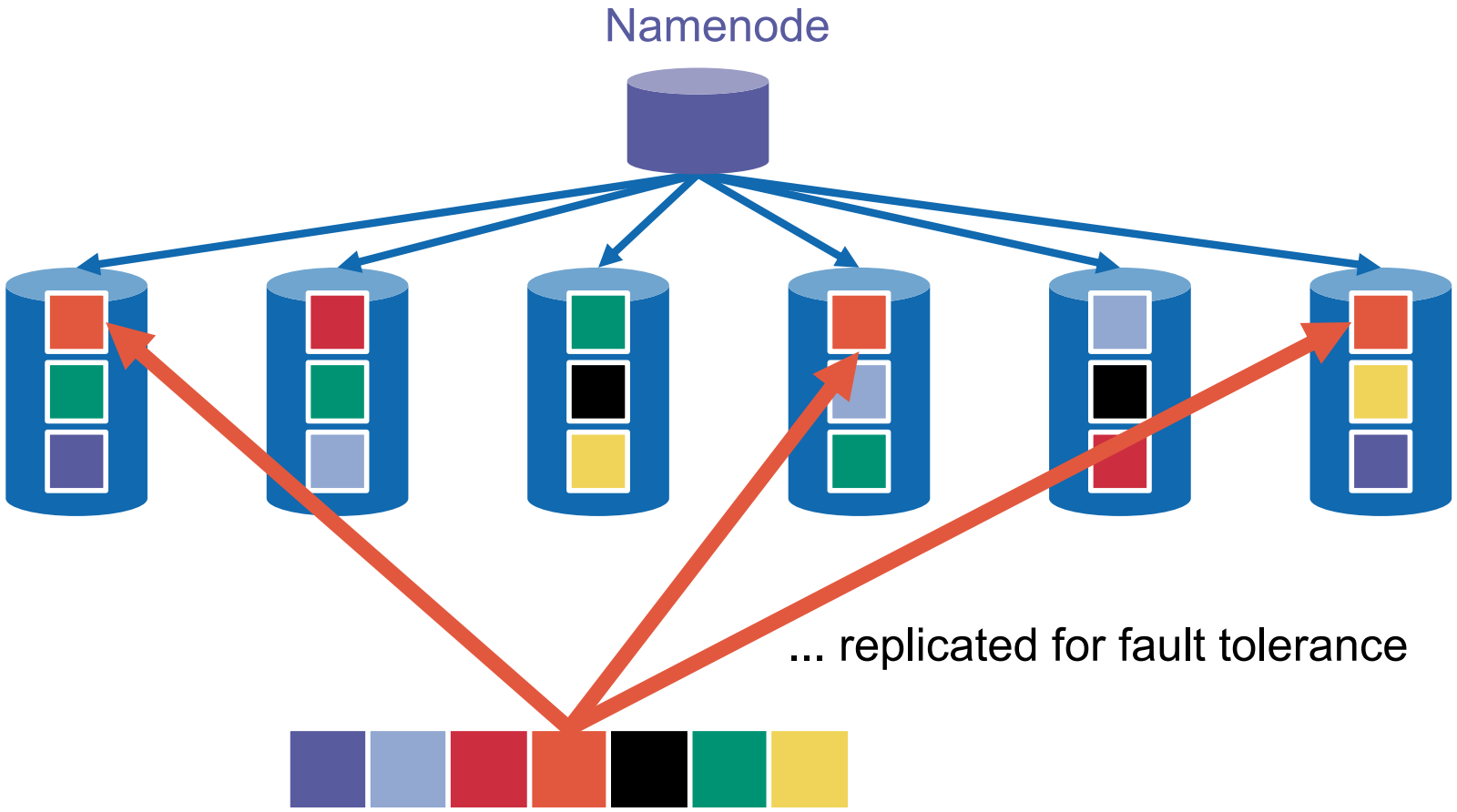
From the file perspective



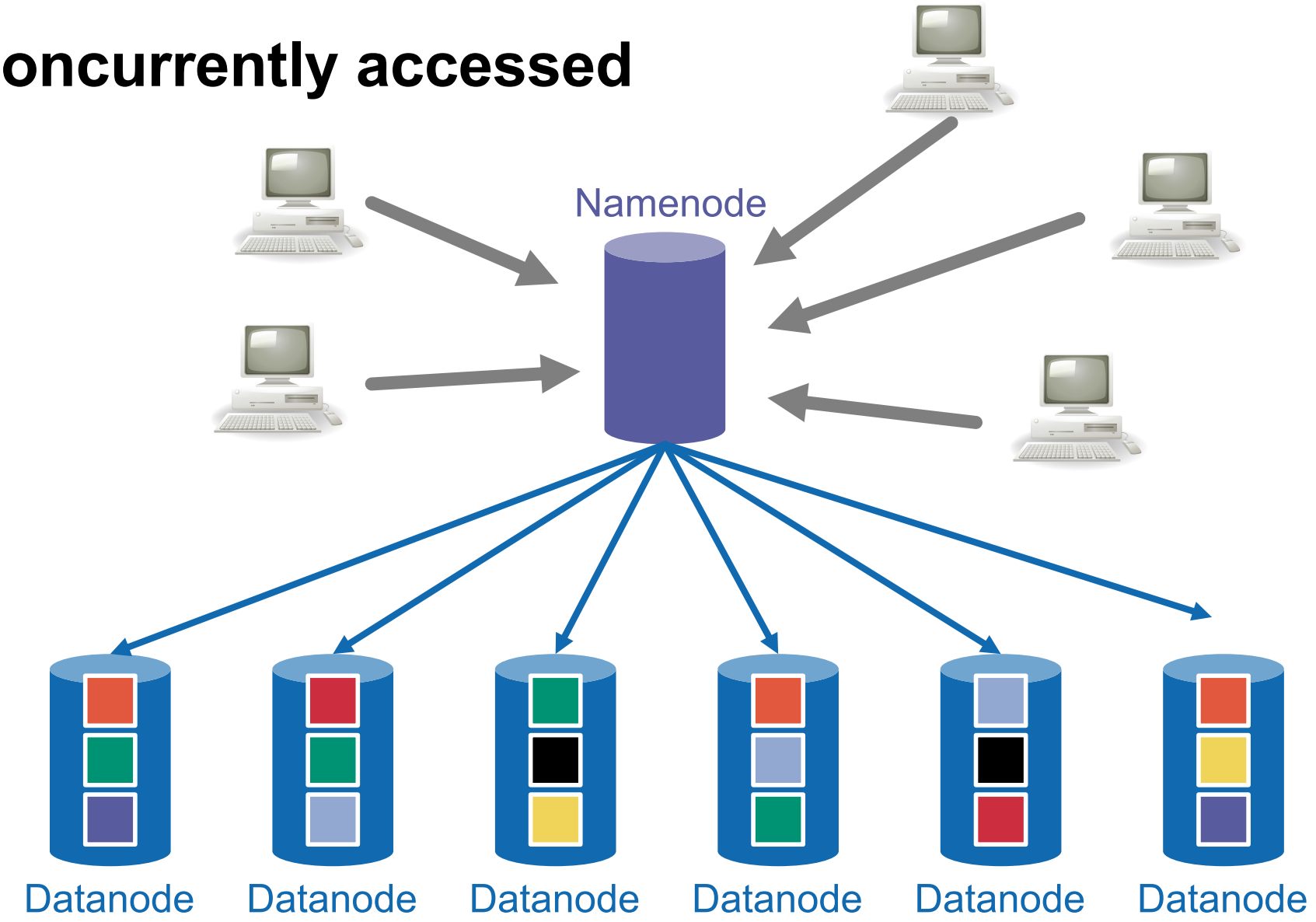
...divided into 128MB chunks...

File... 

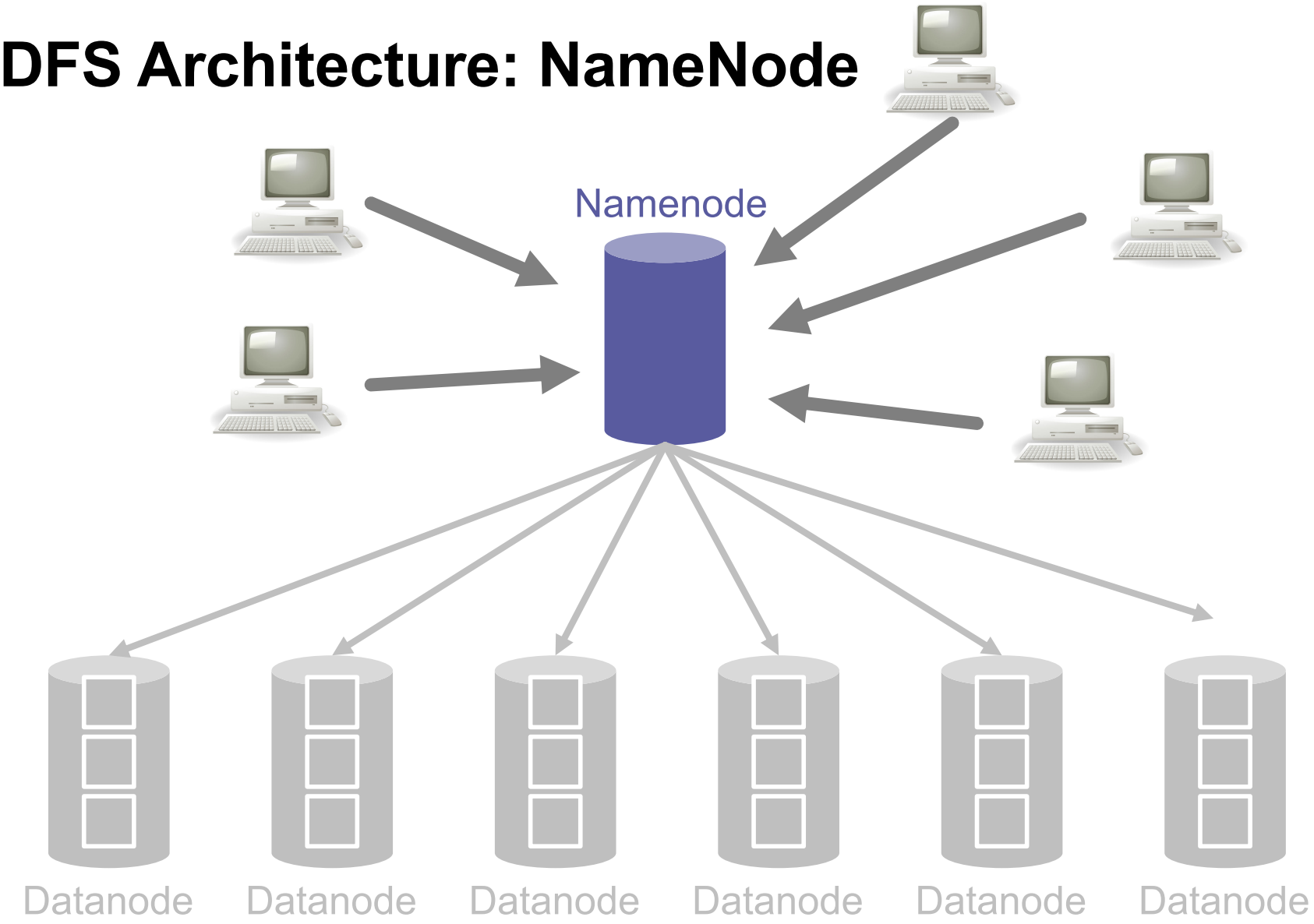
From the file perspective



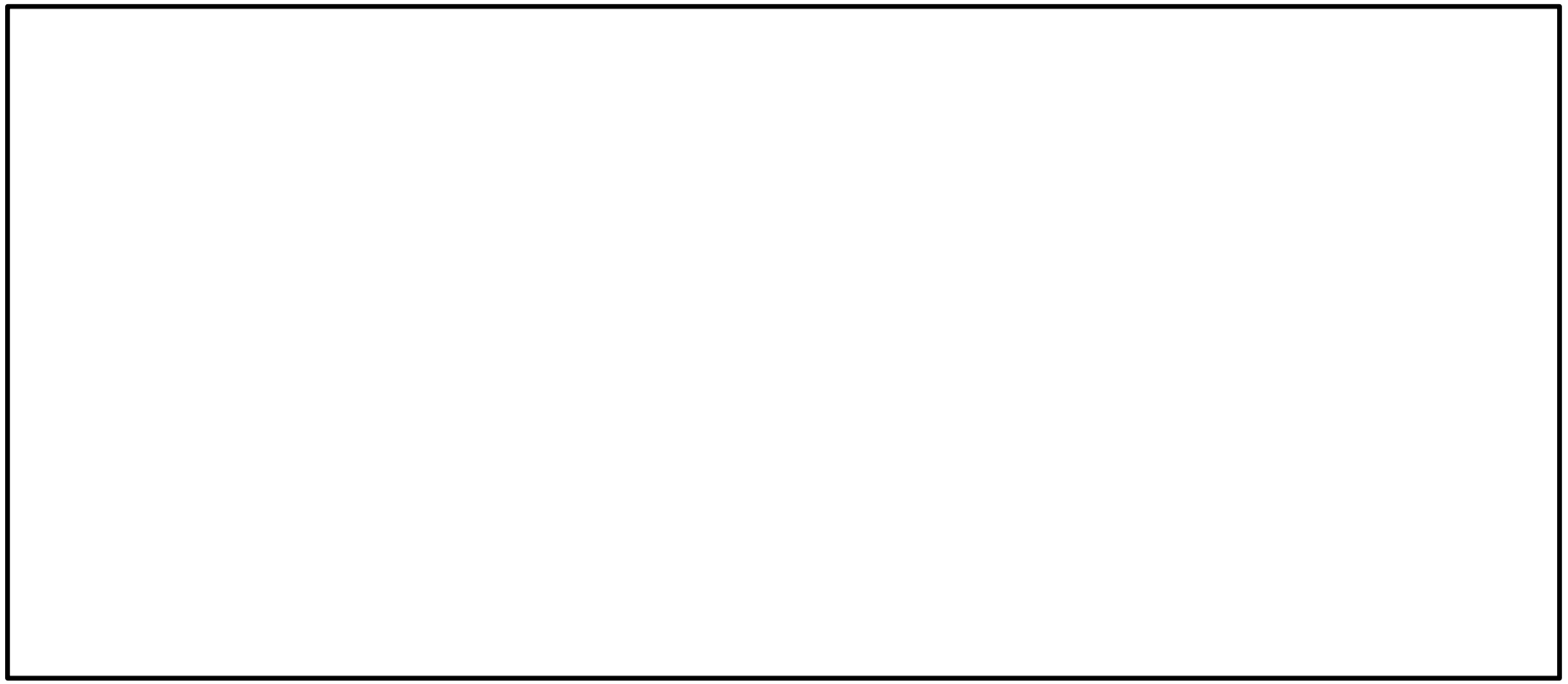
Concurrently accessed



HDFS Architecture: NameNode



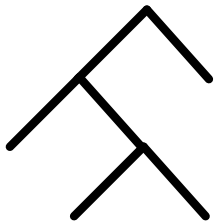
NameNode: all system-wide activity



NameNode: all system-wide activity

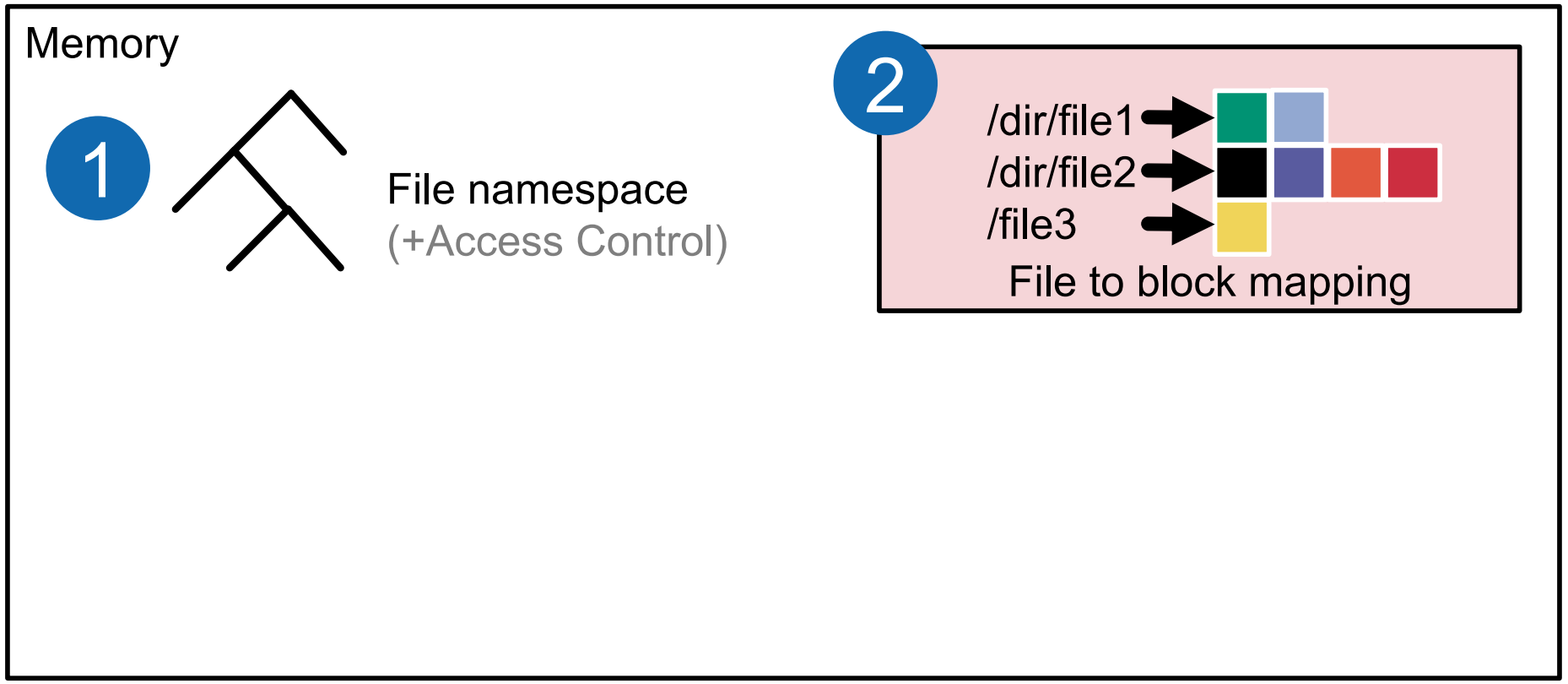
Memory

1

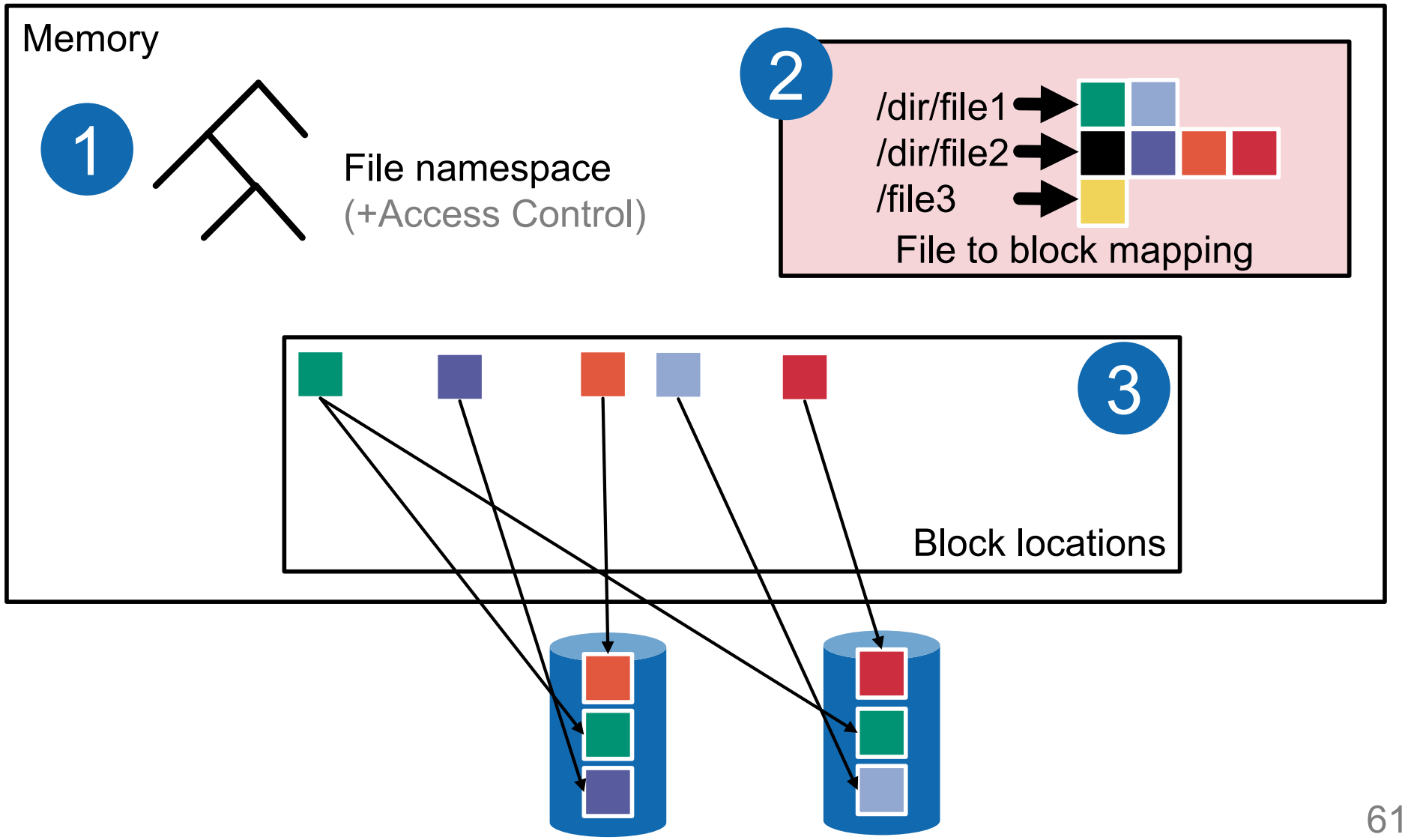


File namespace
(+Access Control)

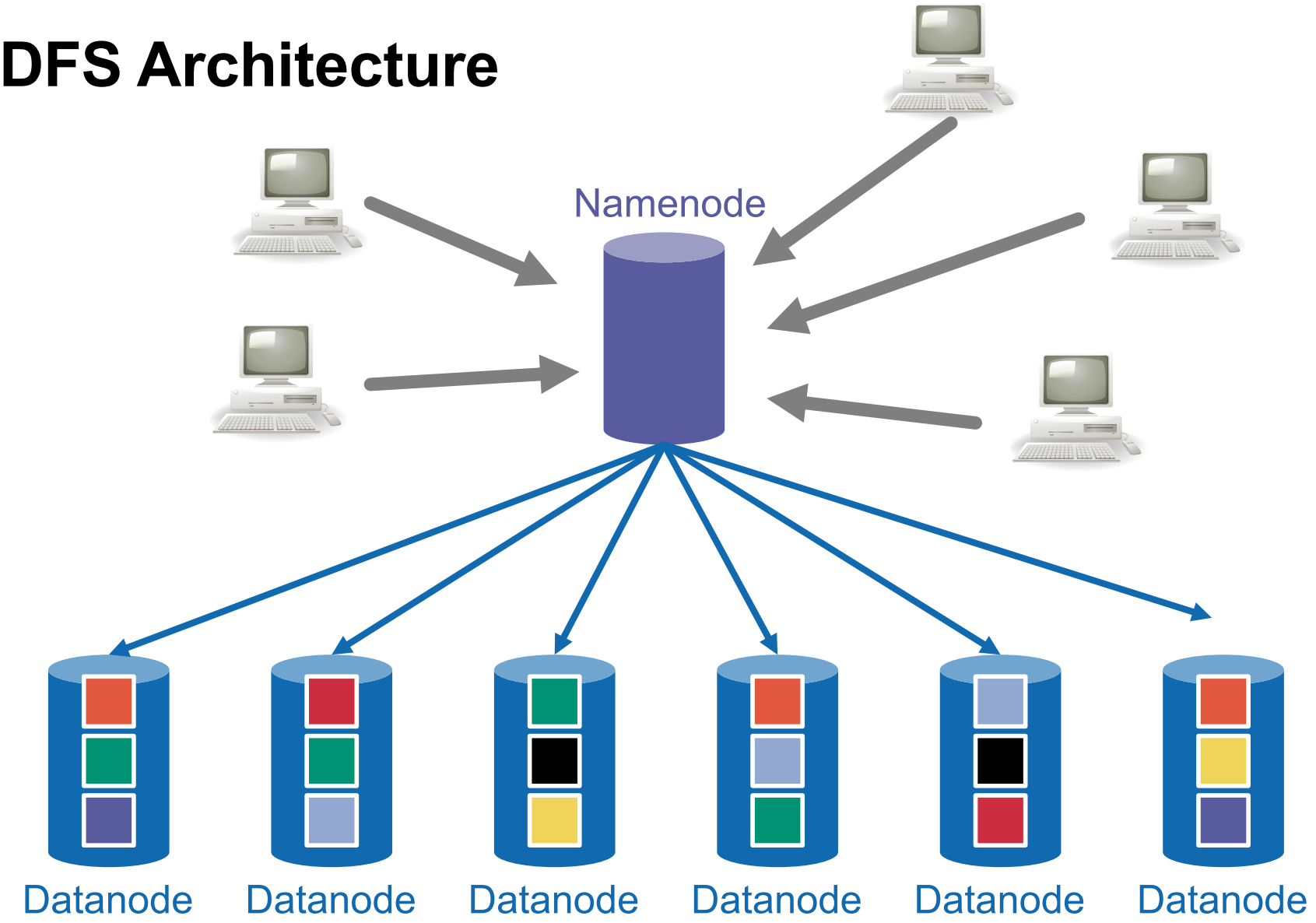
NameNode: all system-wide activity



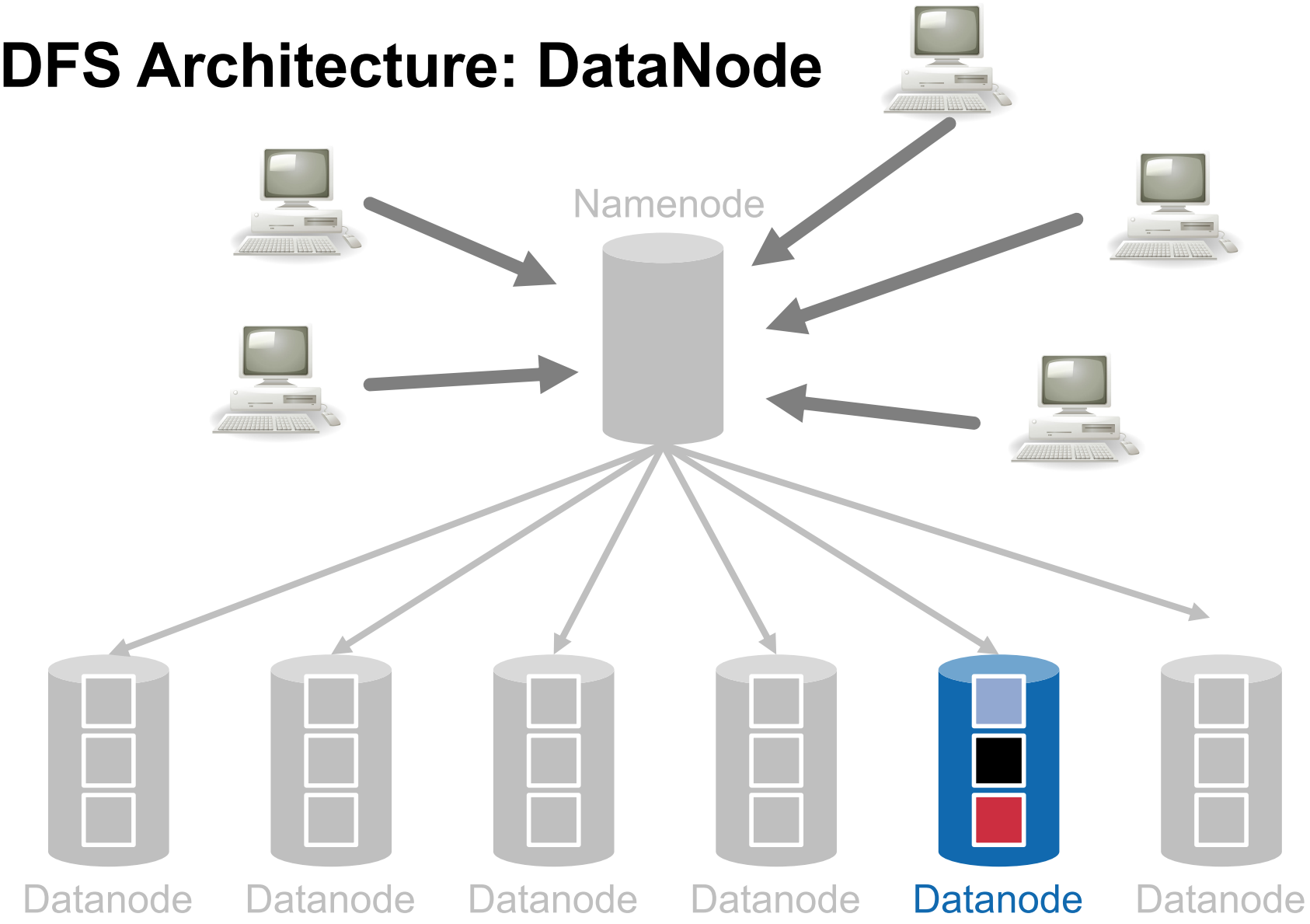
NameNode: all system-wide activity



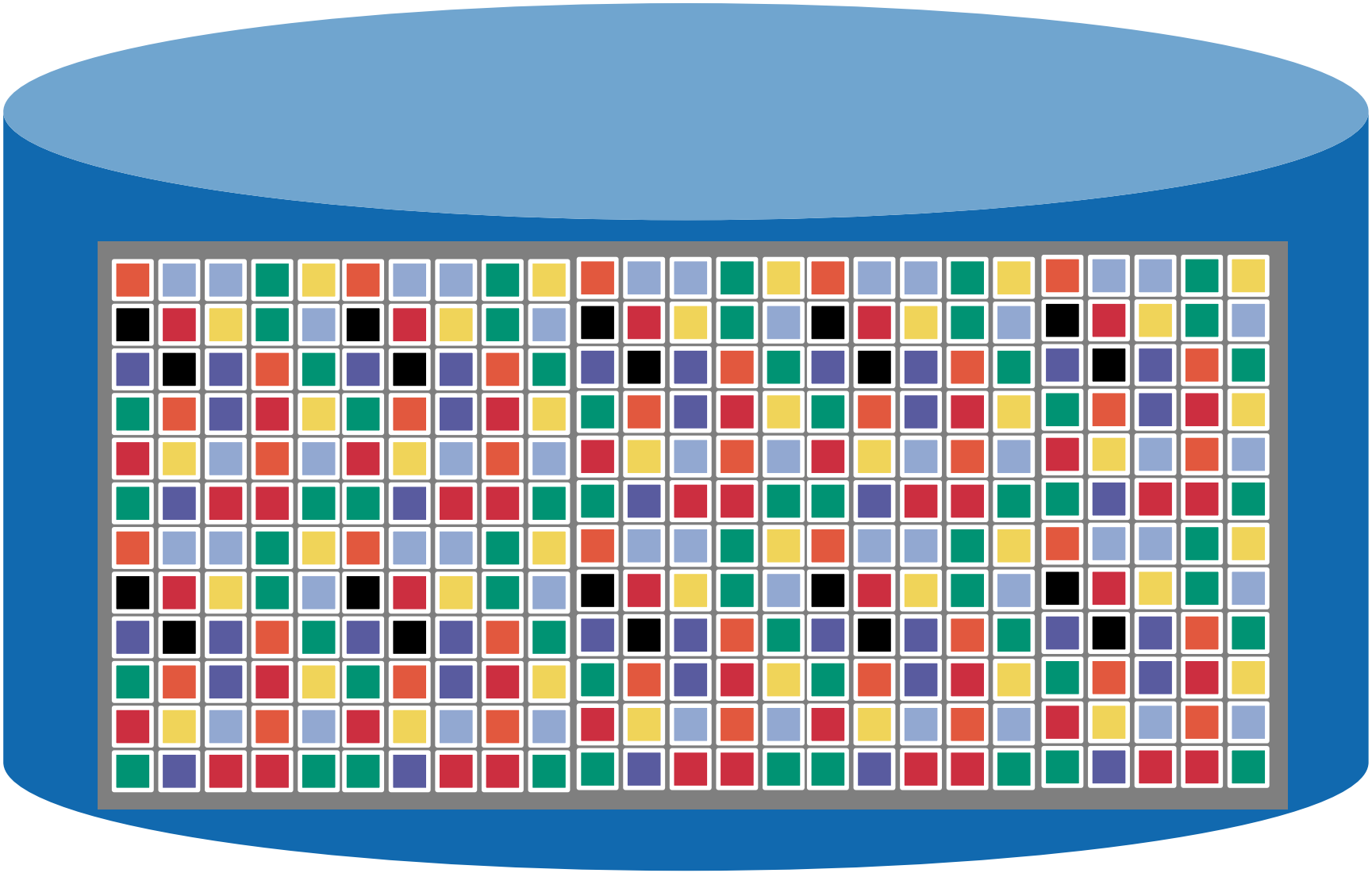
HDFS Architecture



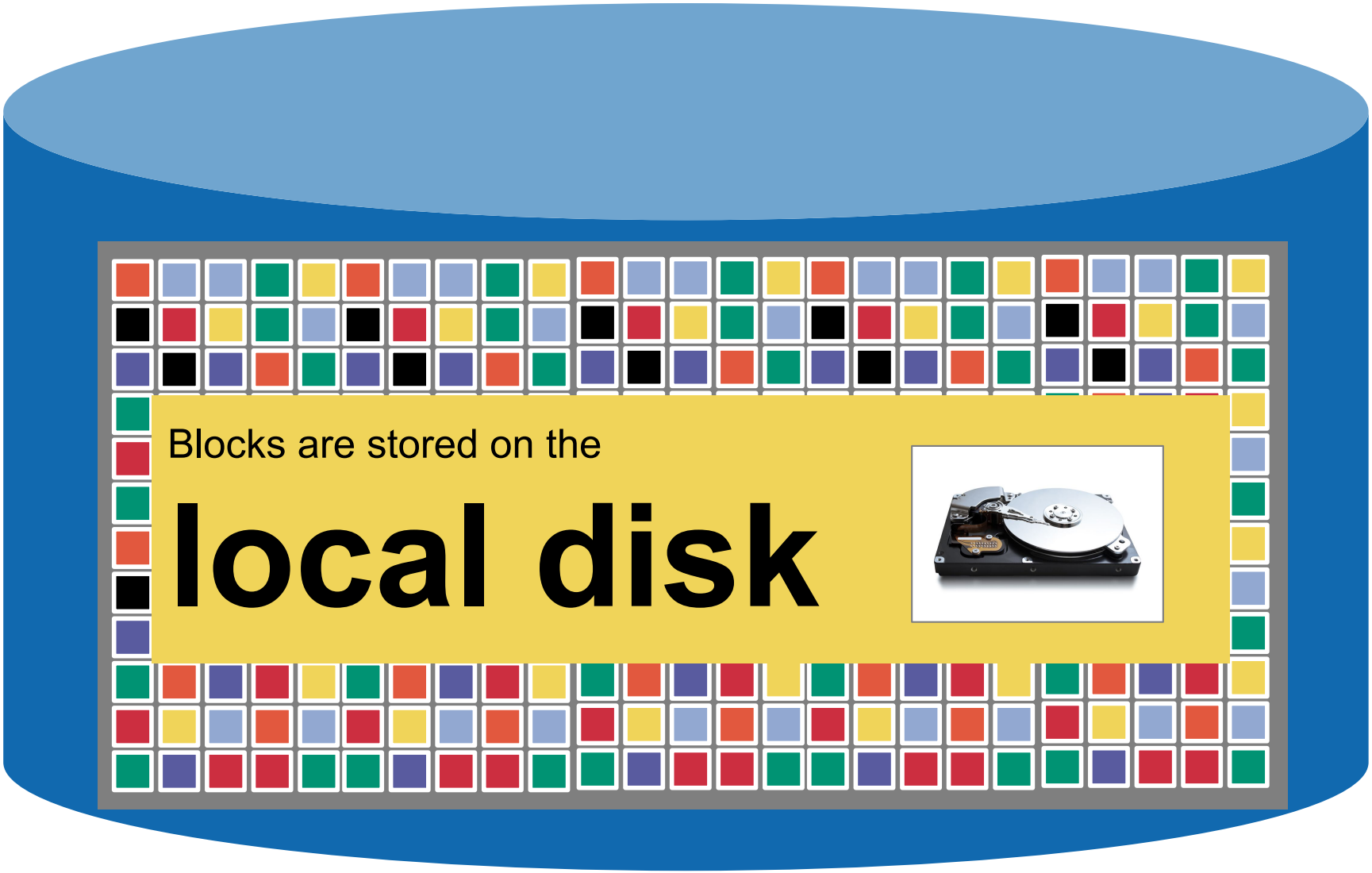
HDFS Architecture: DataNode



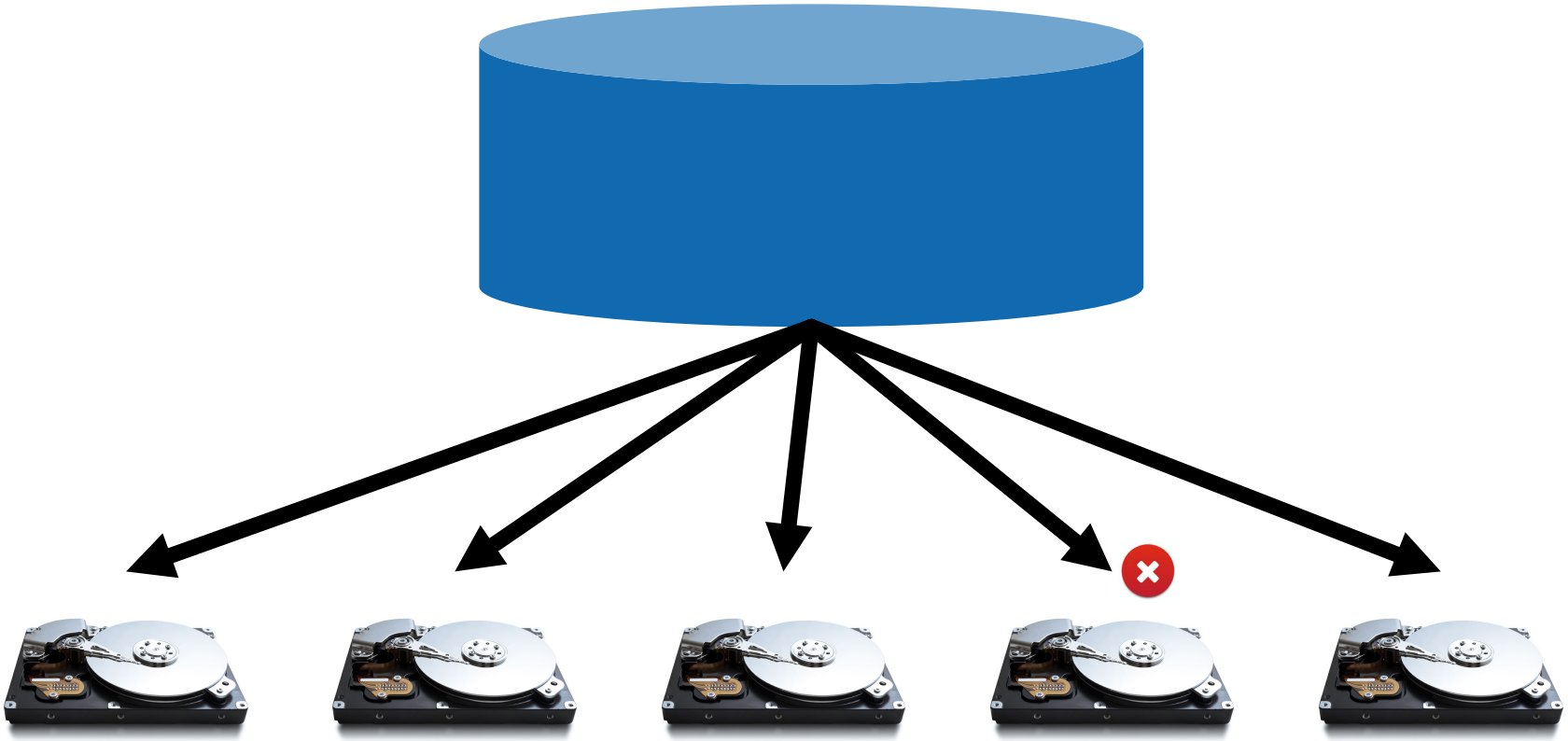
DataNode



DataNode

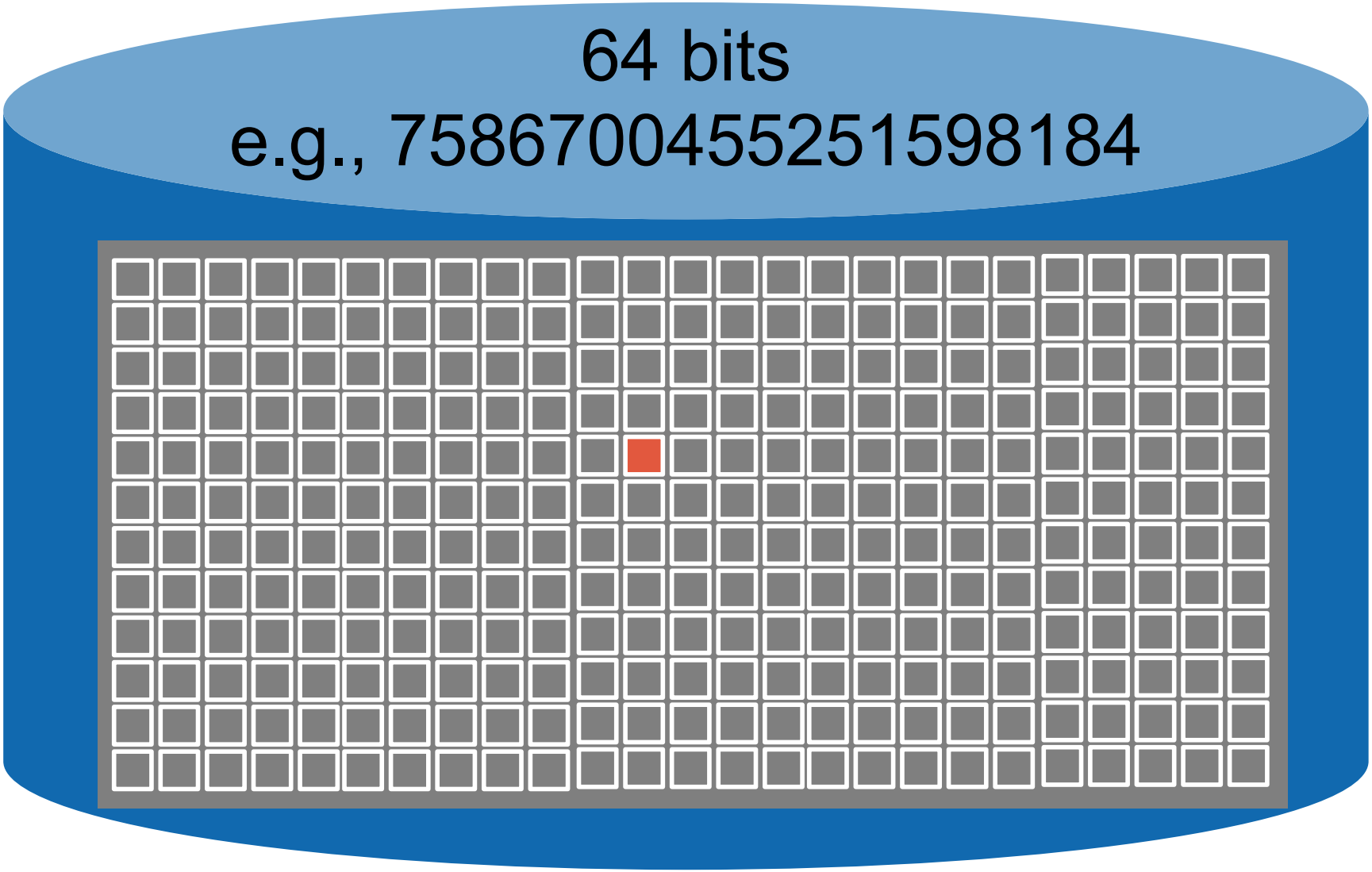


DataNode

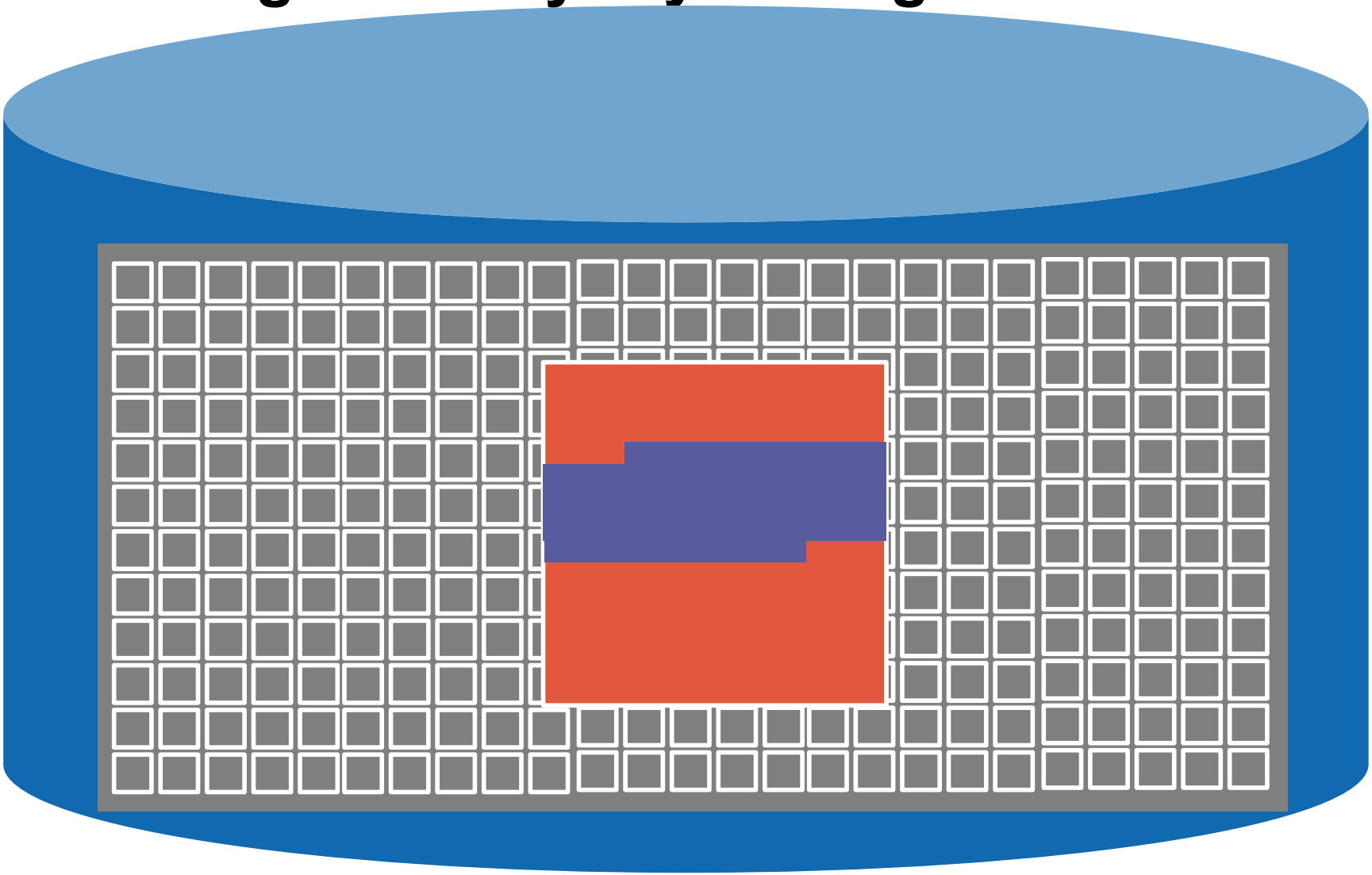


Proximity to hardware facilitates disk failure detection

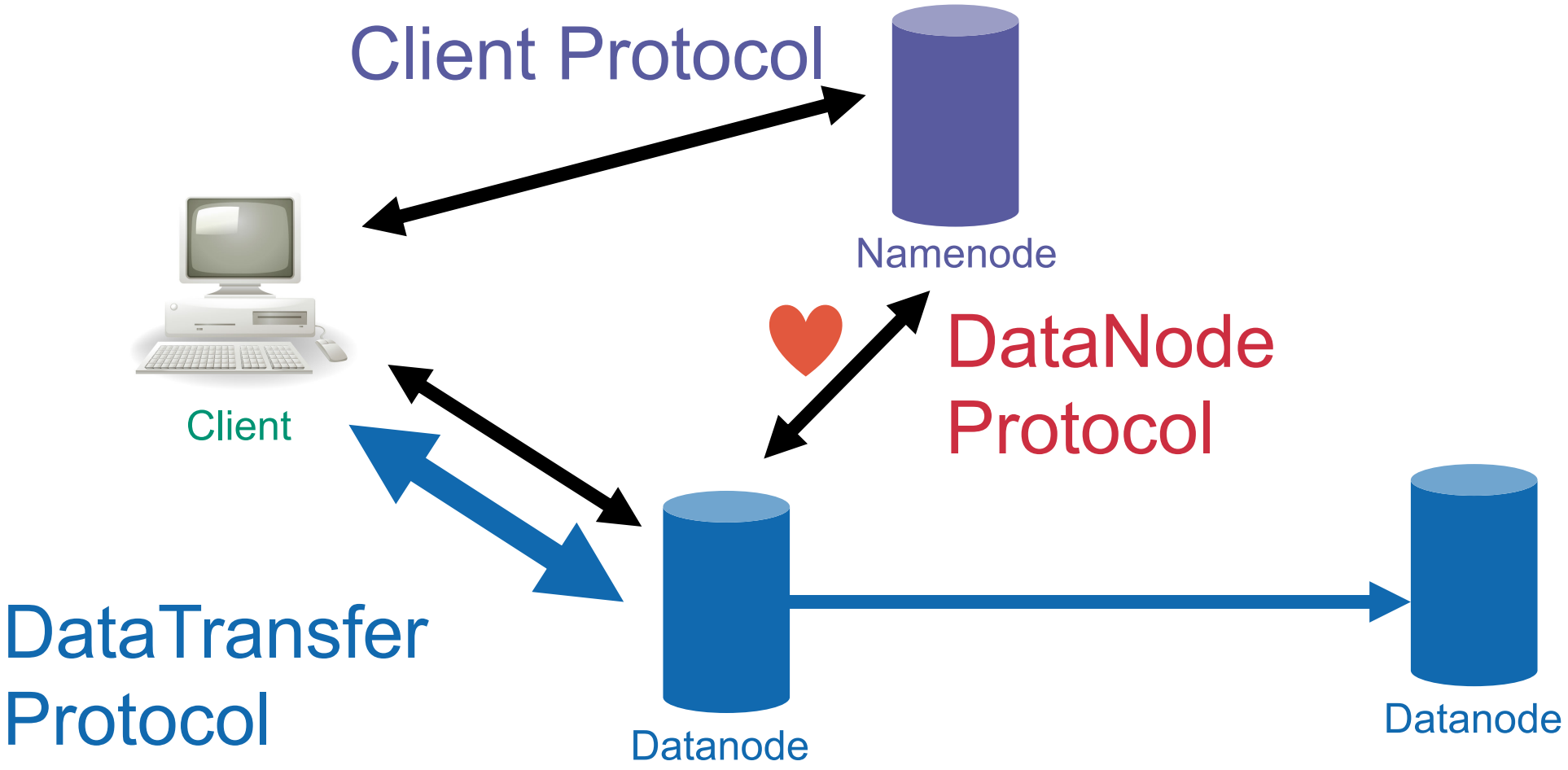
Block IDs



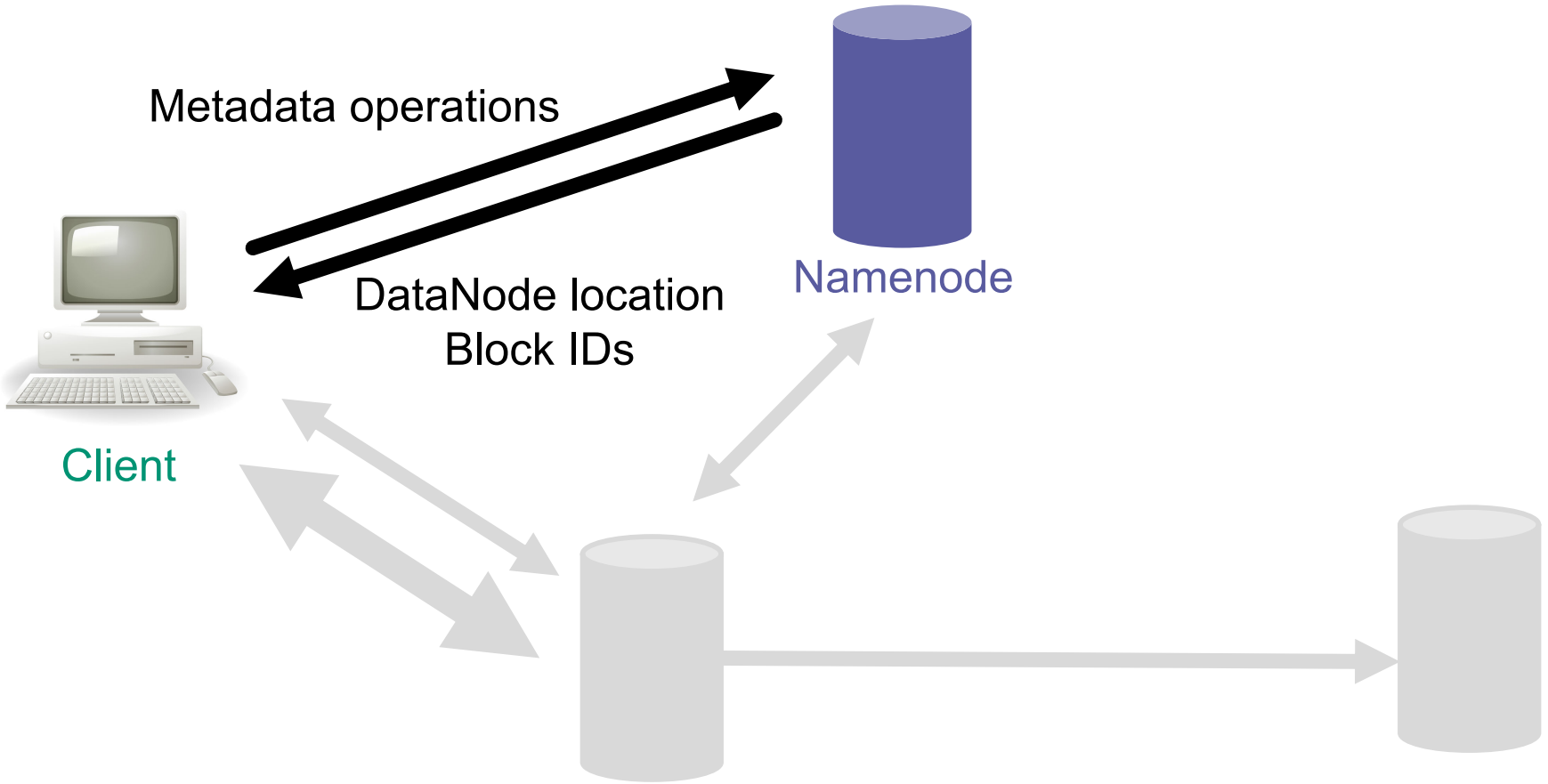
Subblock granularity: Byte Range



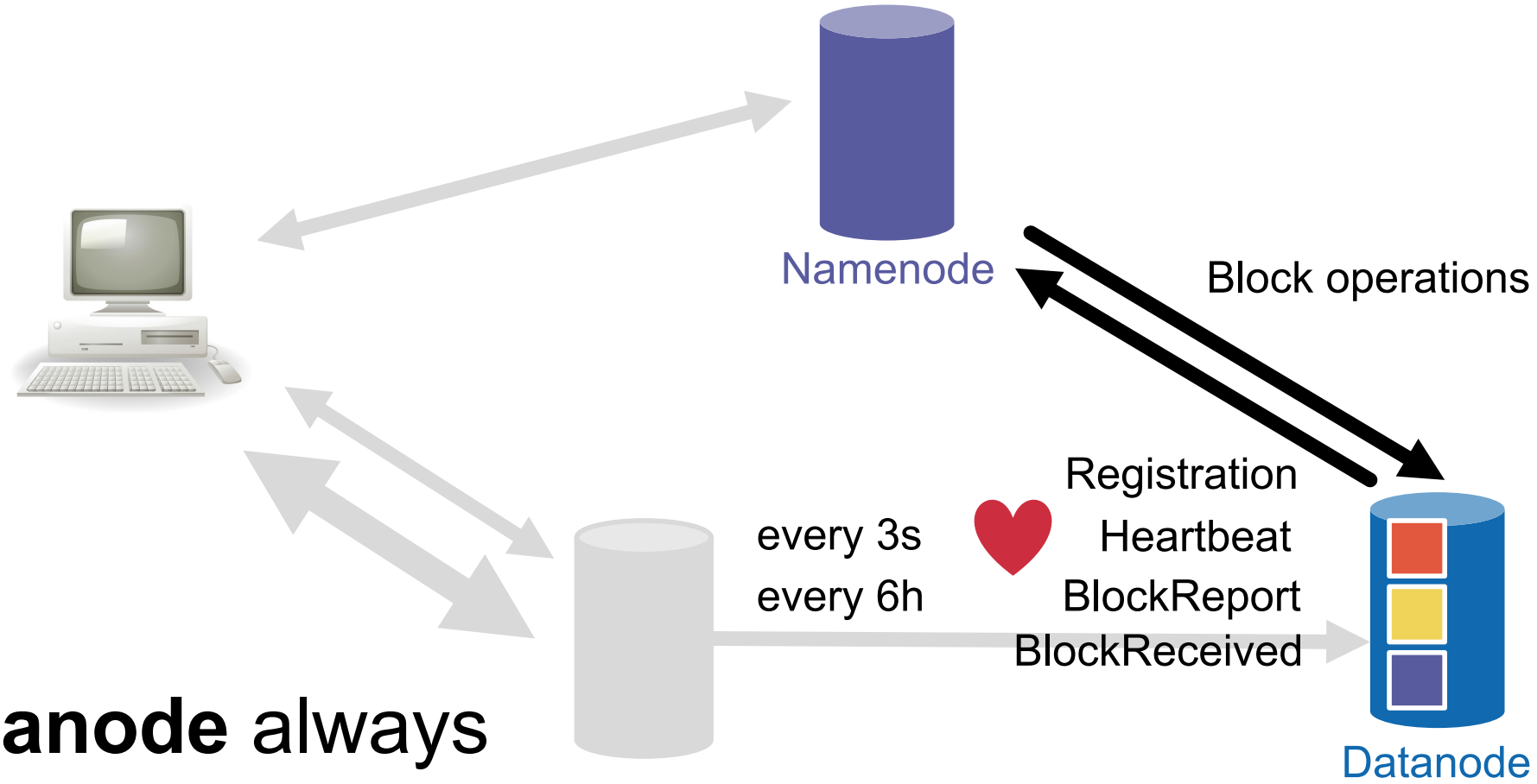
Communication



Client Protocol

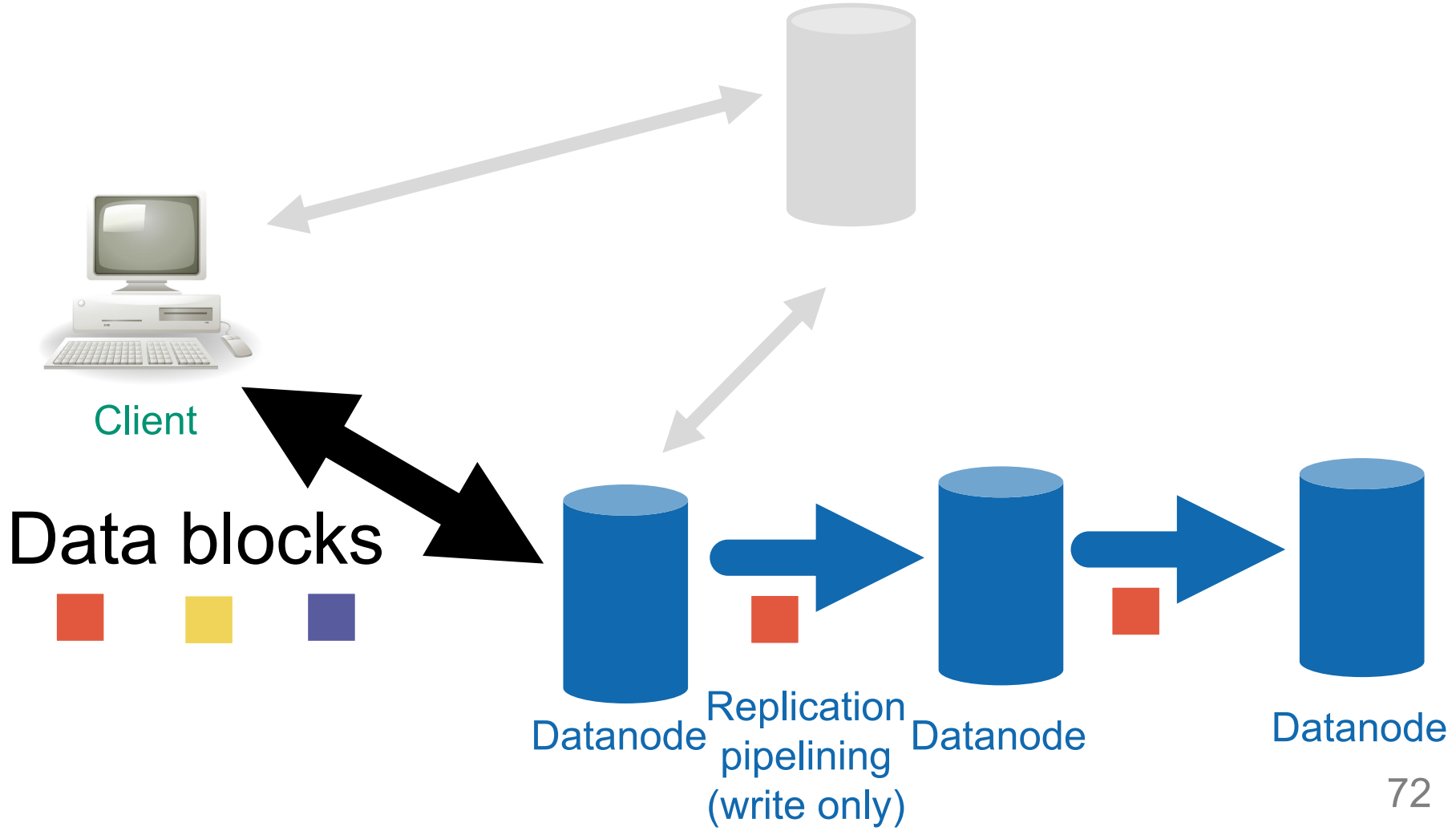


DataNode Protocol



Datanode always initiates connection!

Data Transfer Protocol



Metadata functionality

Create directory

Delete directory

Write file

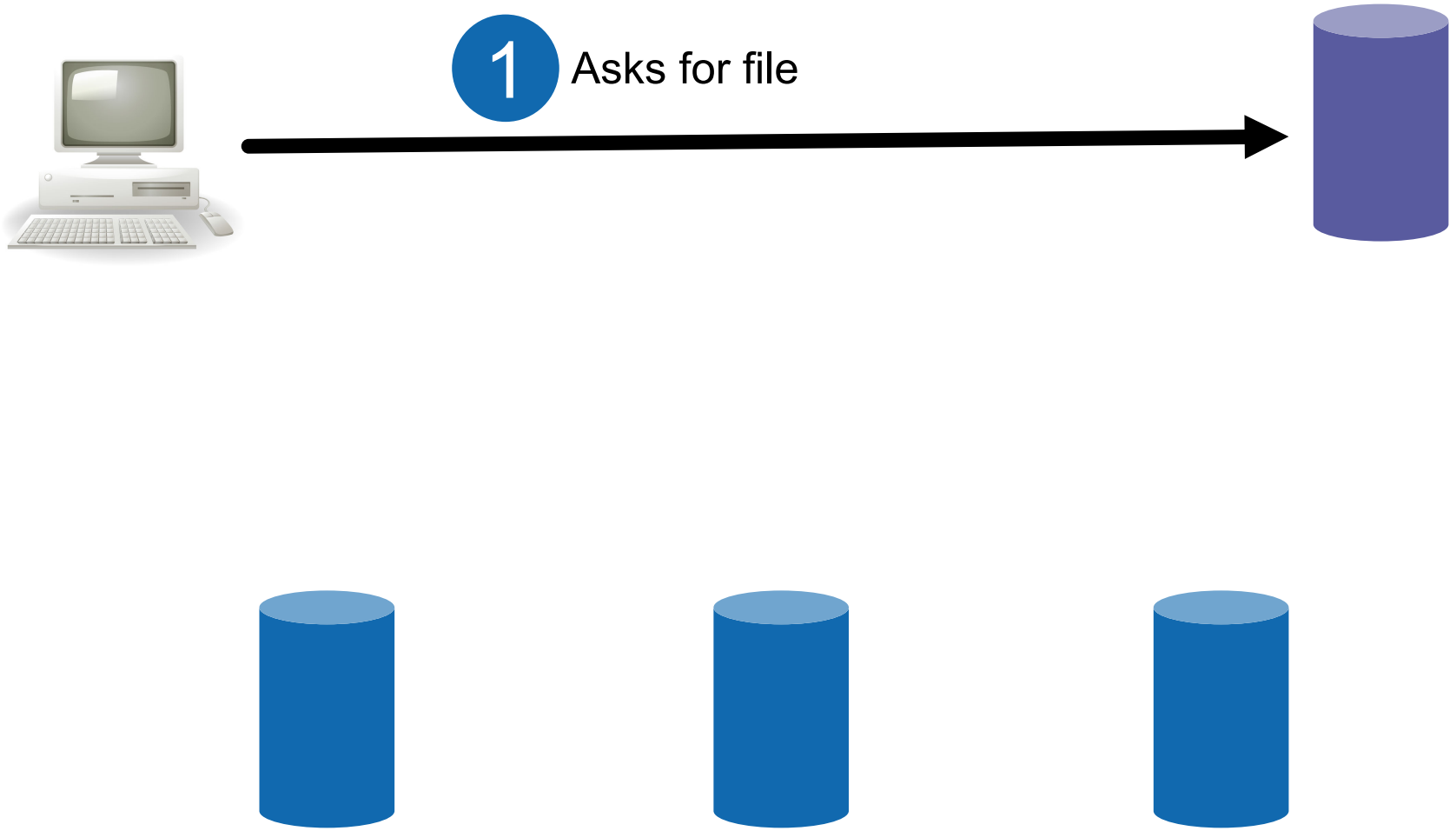
Append to file

Read file

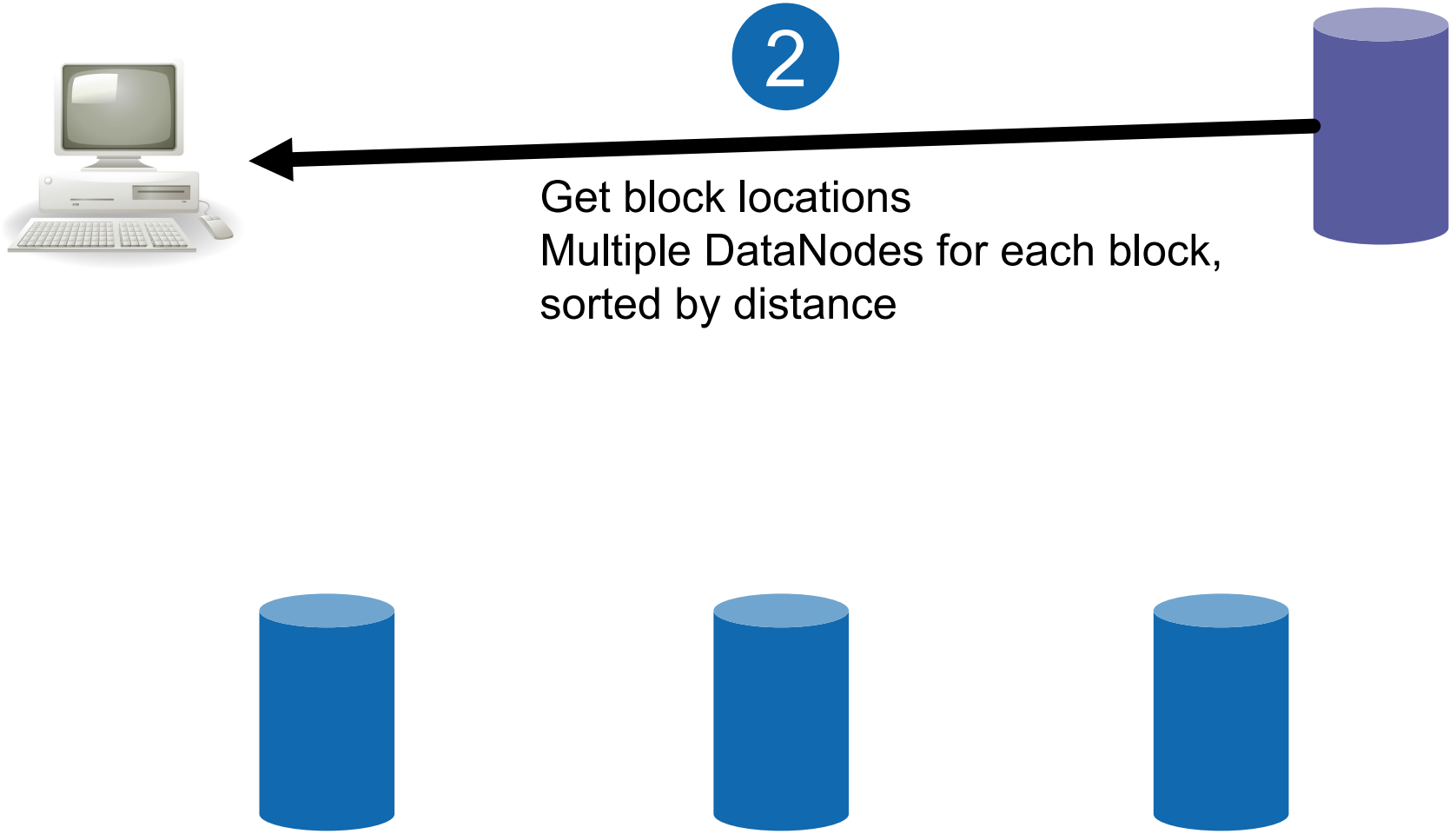
Delete file

Client reads a file

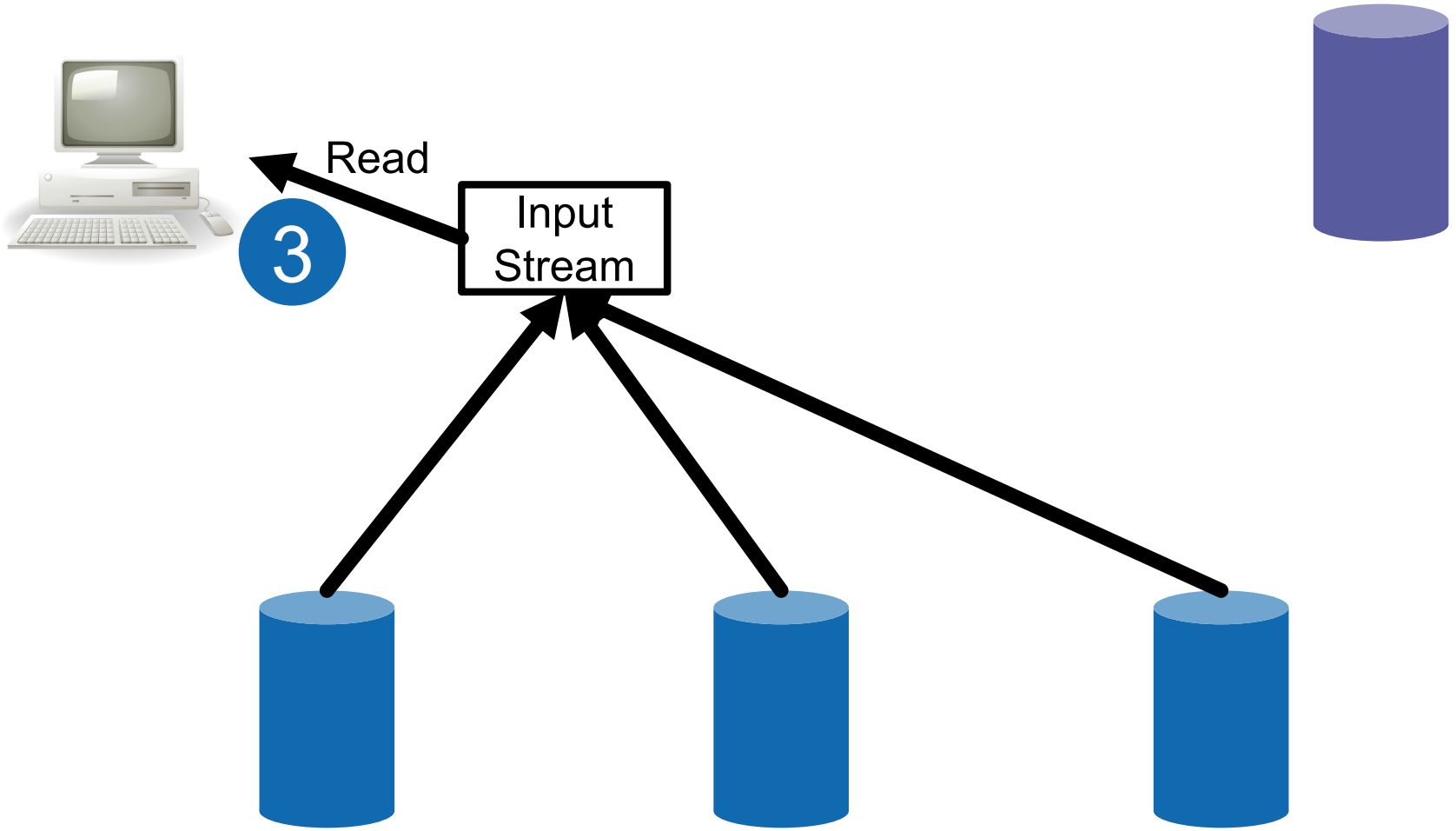
Client reads a file



Client reads a file

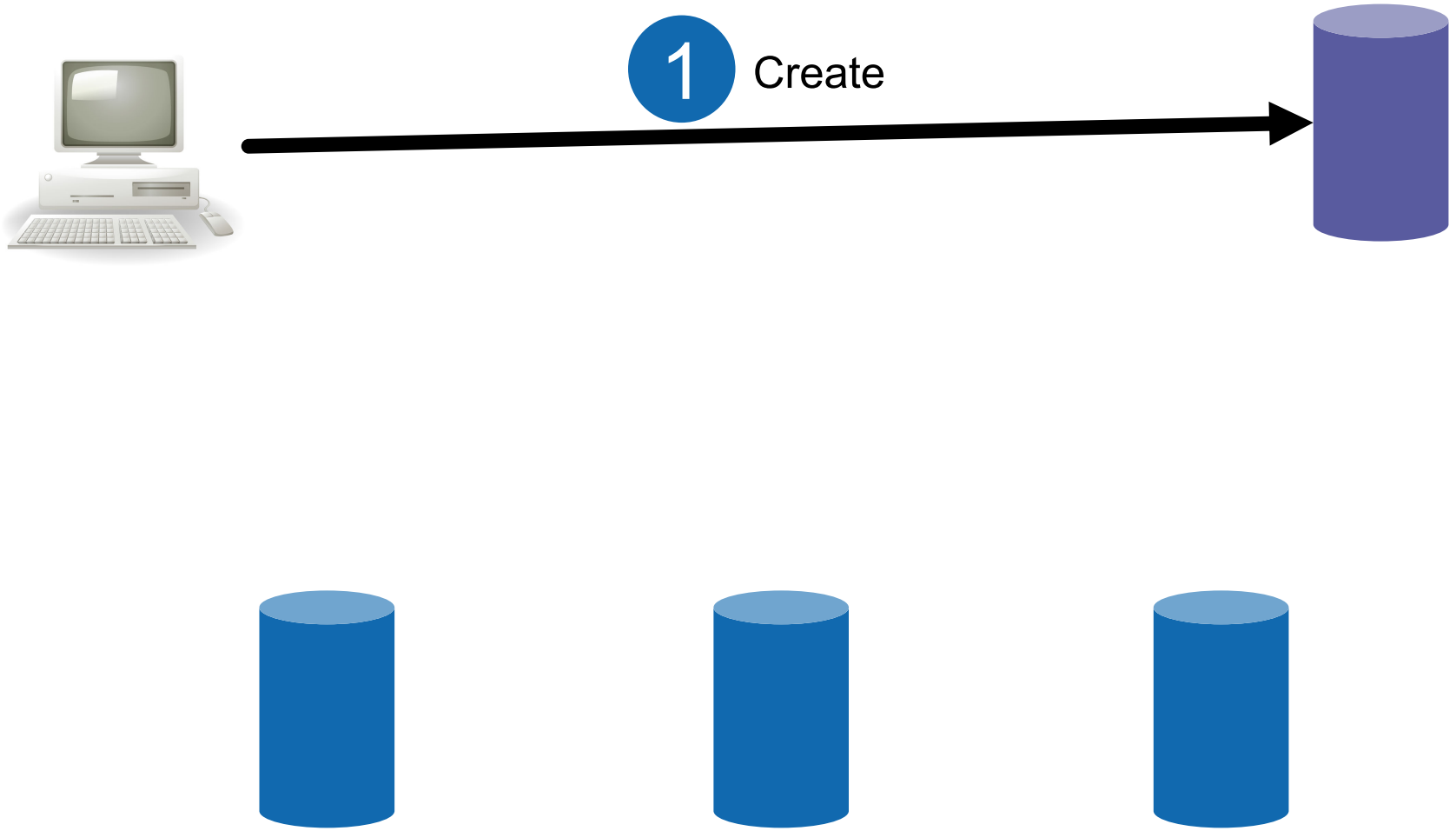


Client reads a file

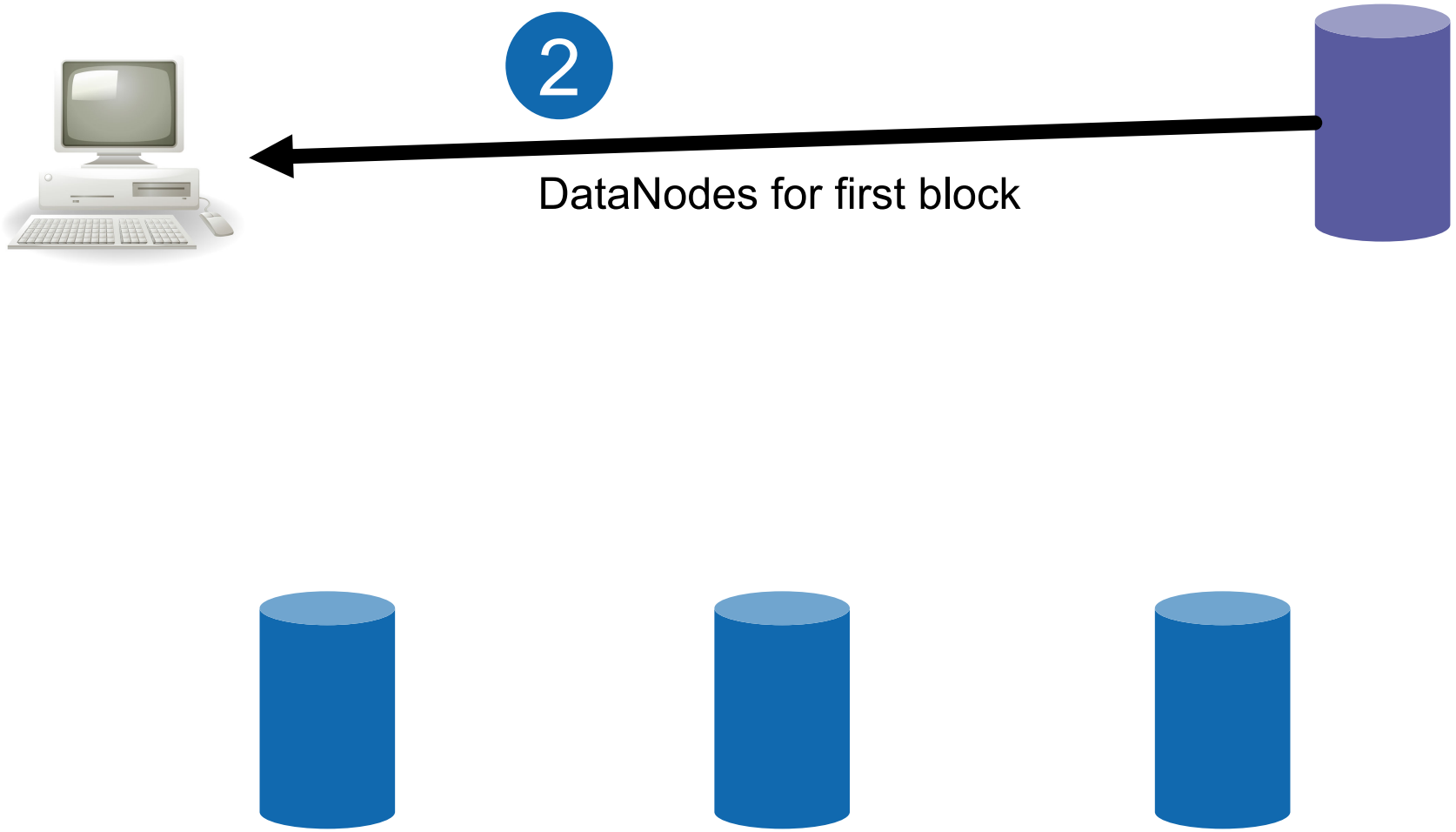


Client writes a file

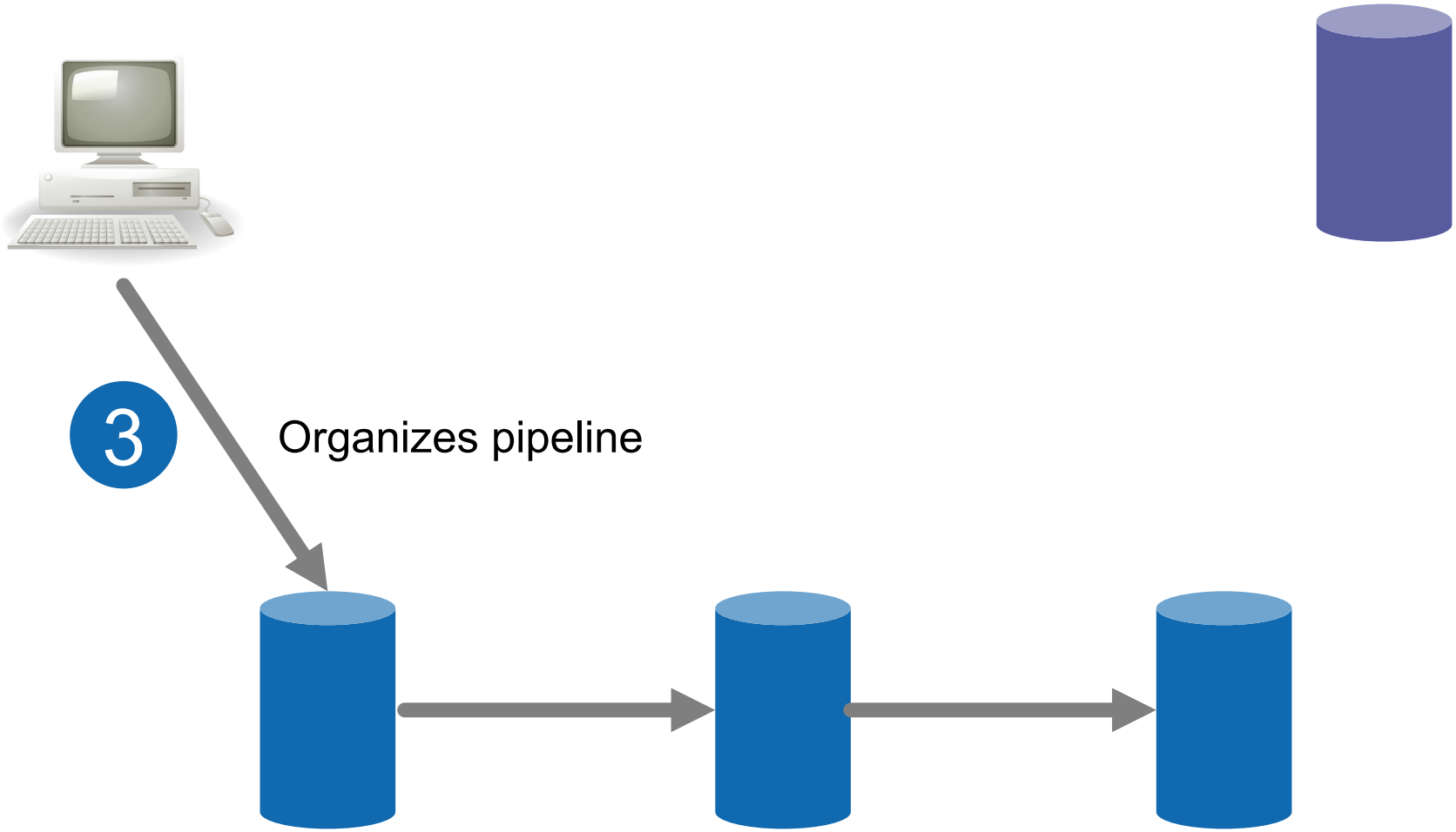
Client writes a file



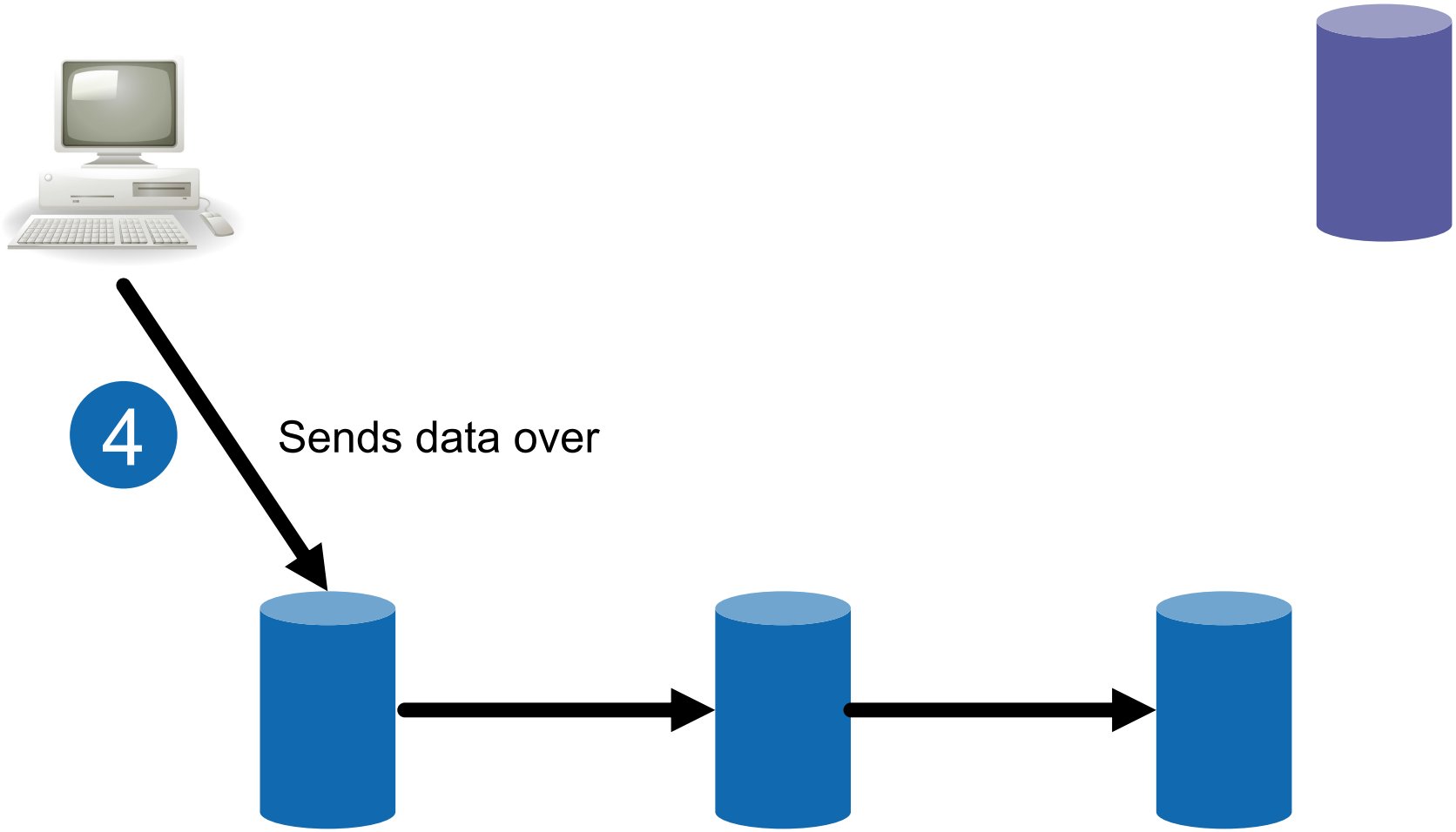
Client writes a file



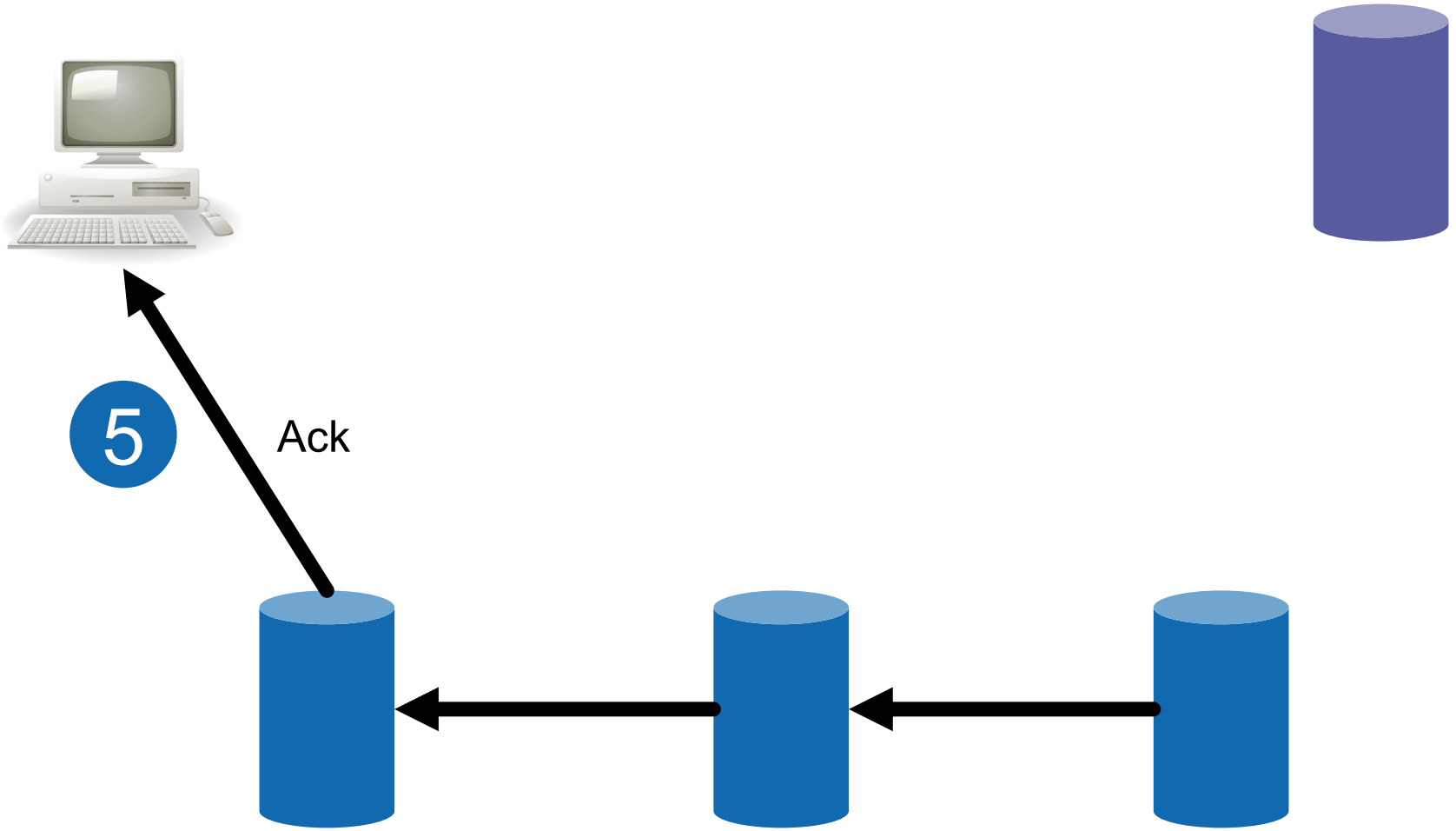
Client writes a file



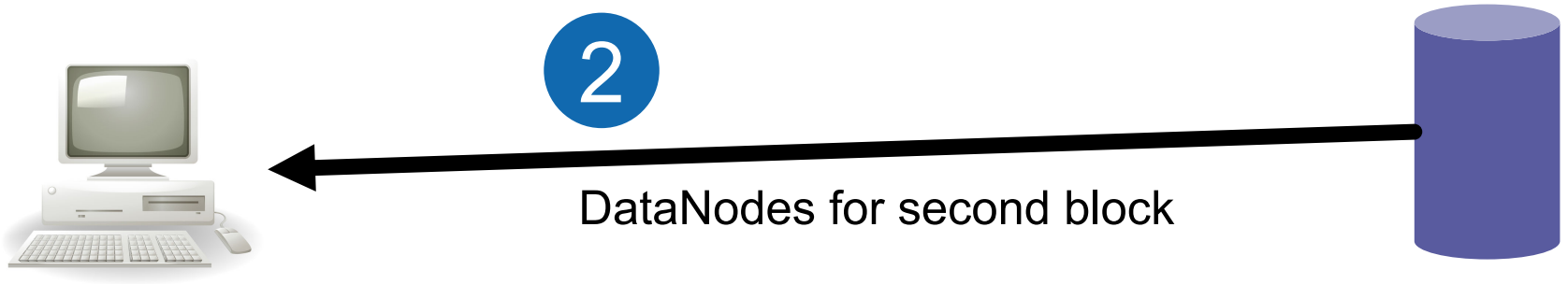
Client writes a file



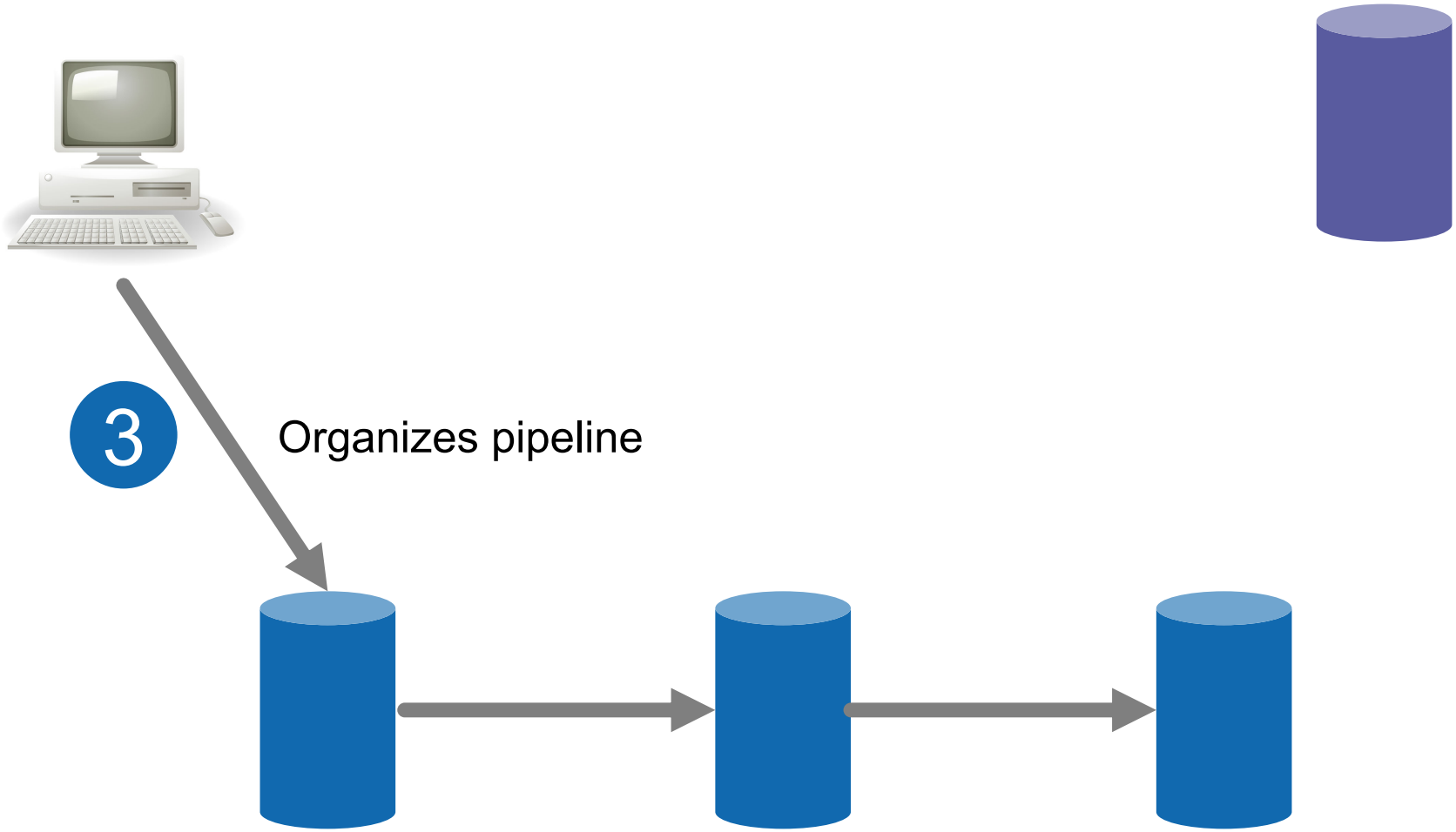
Client writes a file



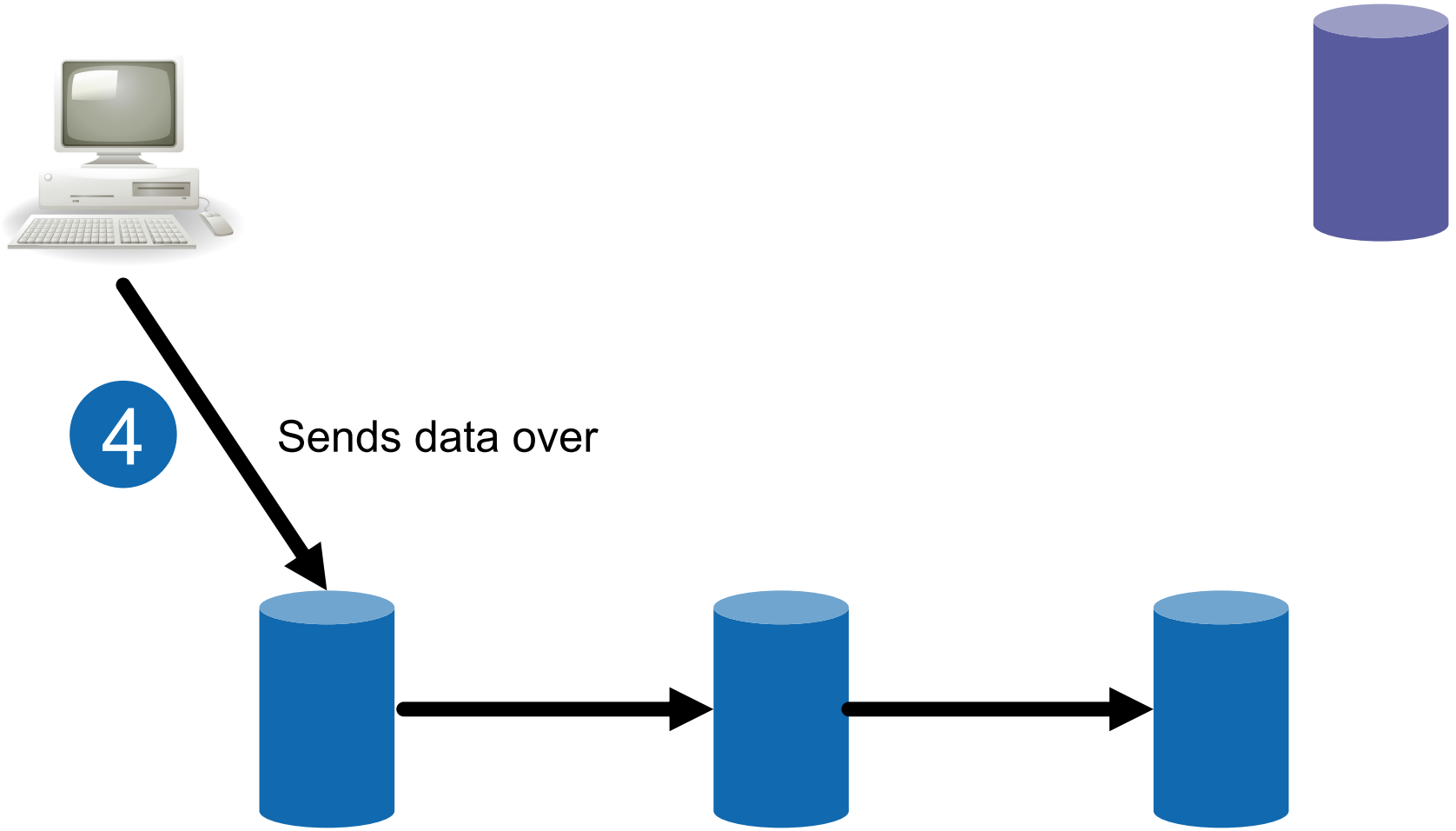
Client writes a file



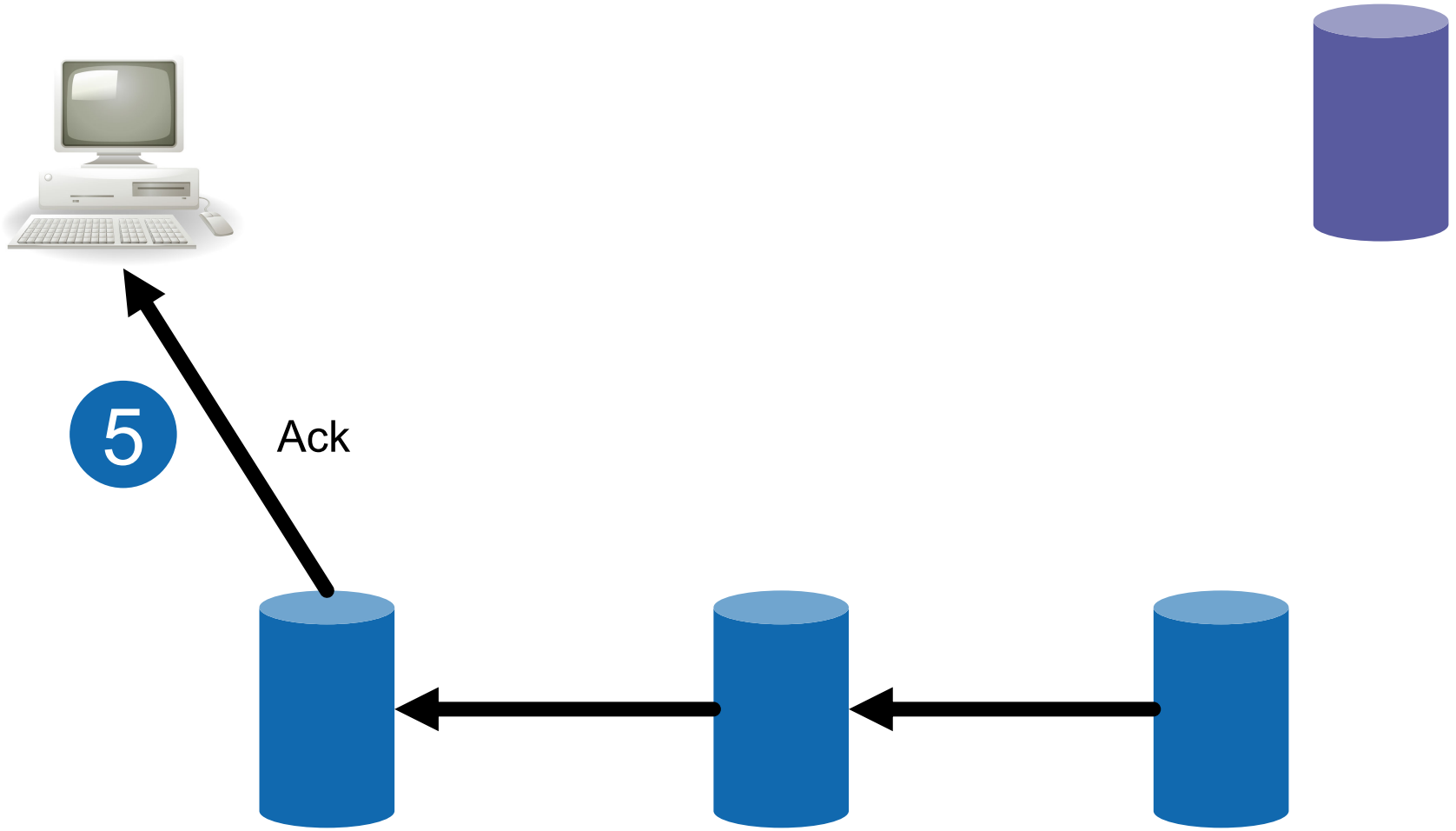
Client writes a file



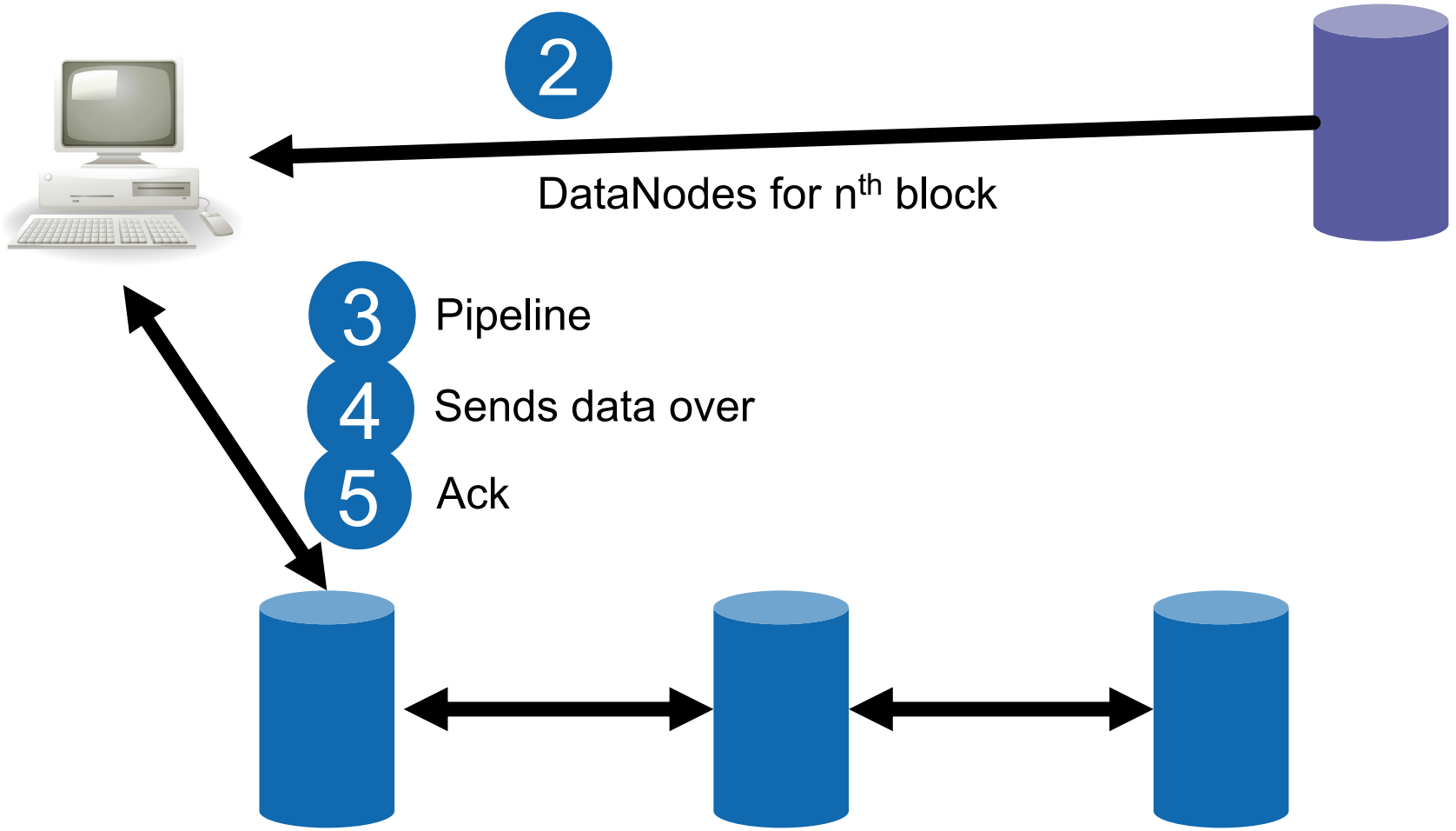
Client writes a file



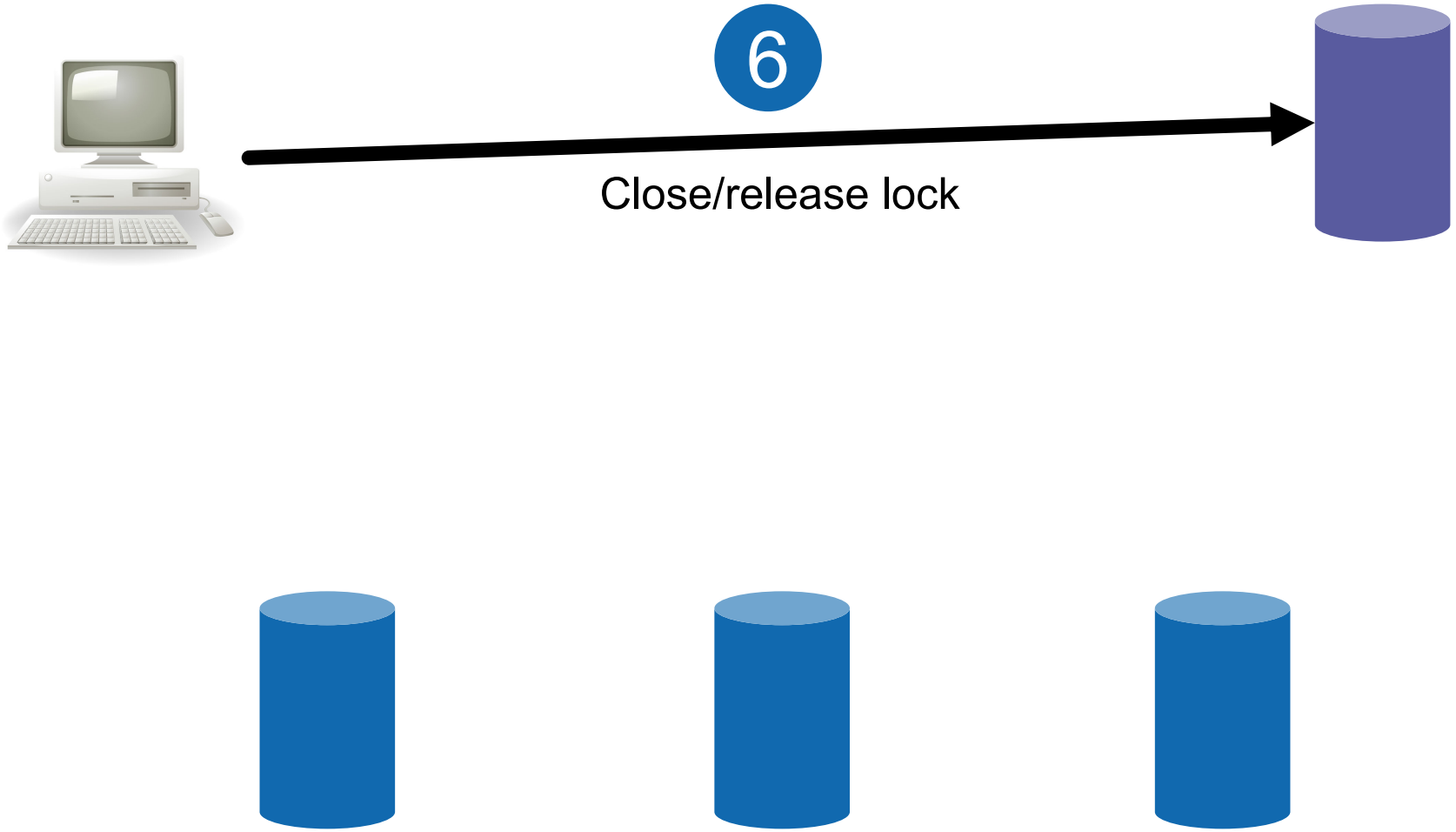
Client writes a file



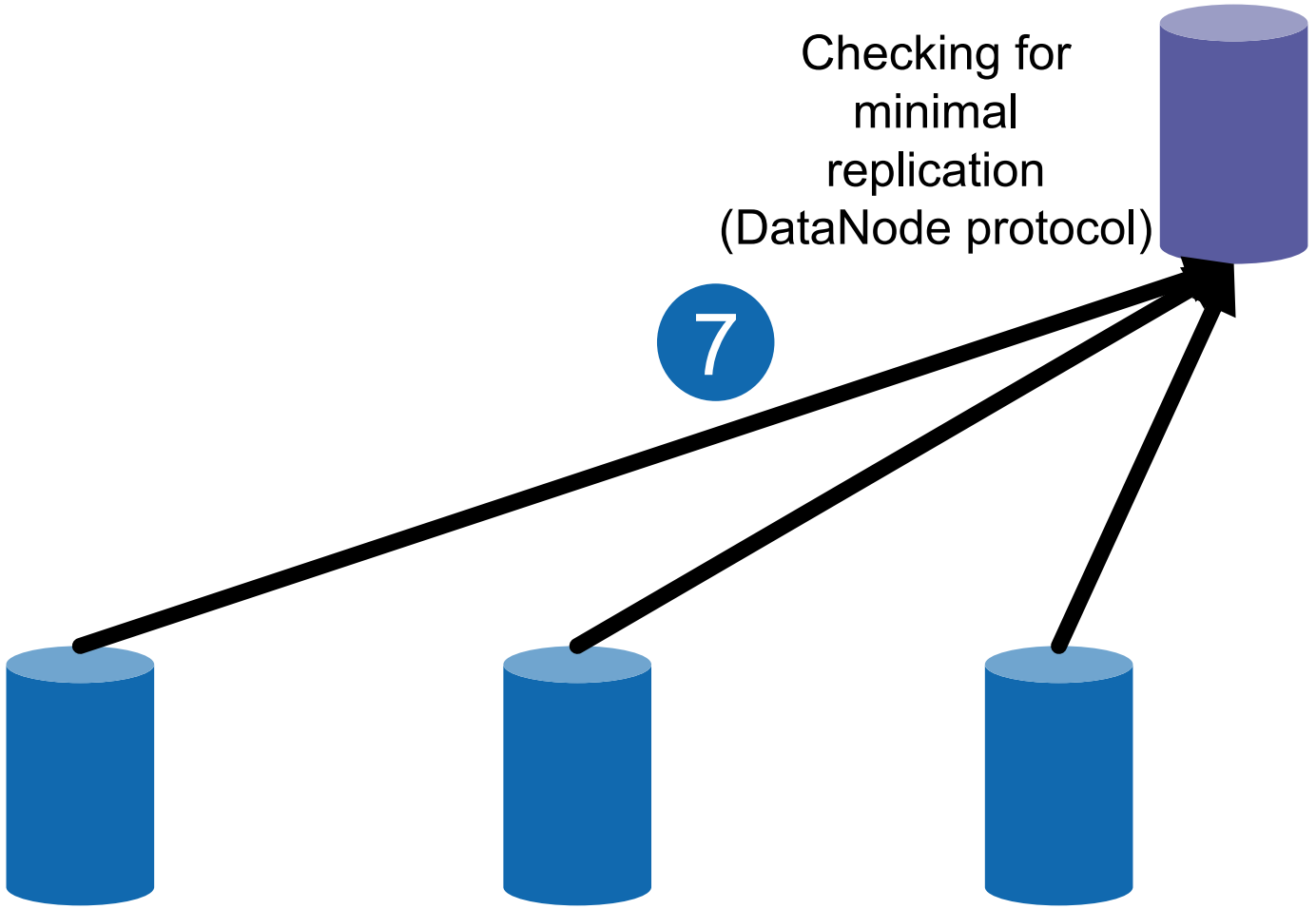
This is all done simultaneously under DFSOutputStream (streaming through)



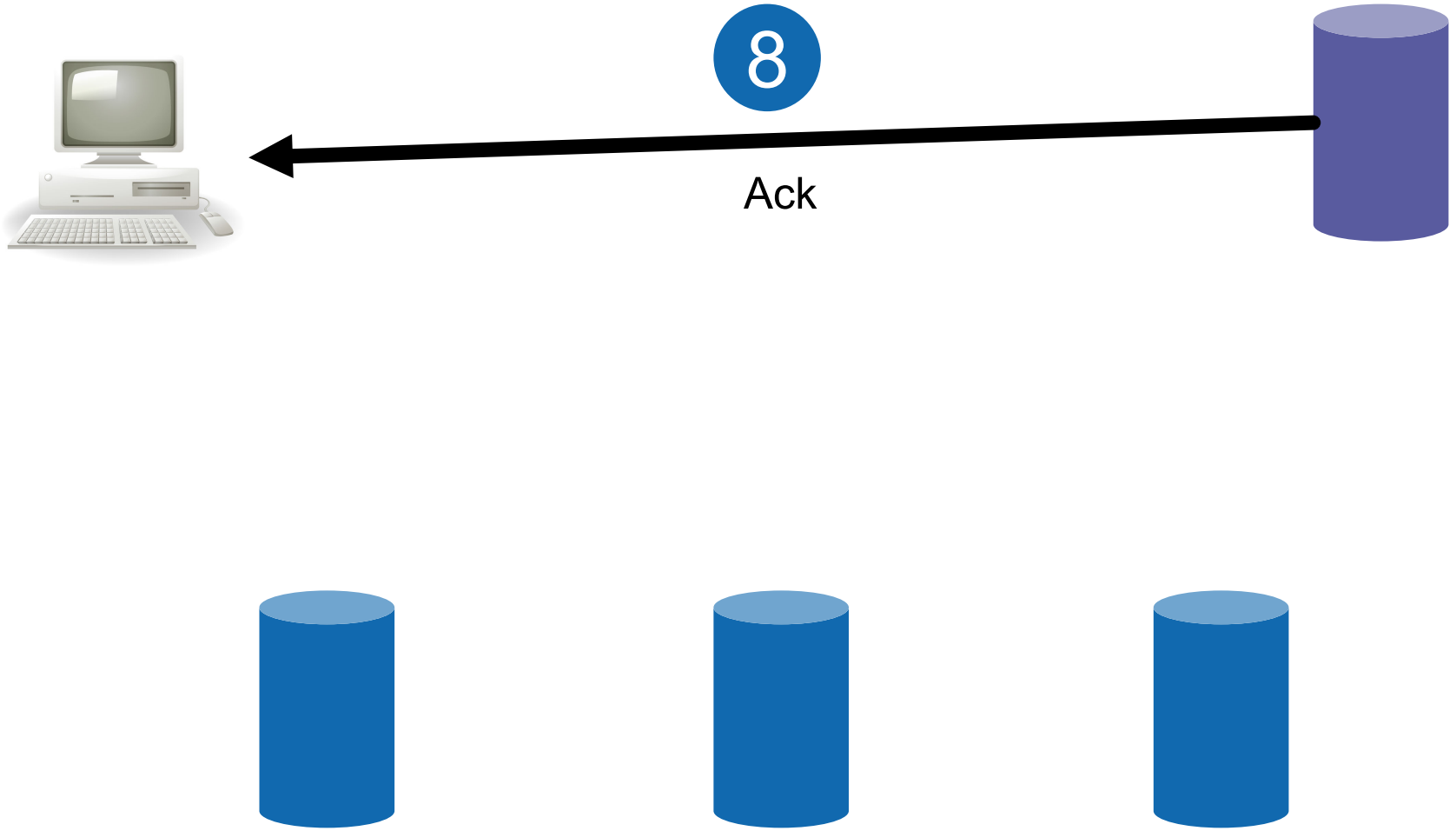
Client writes a file



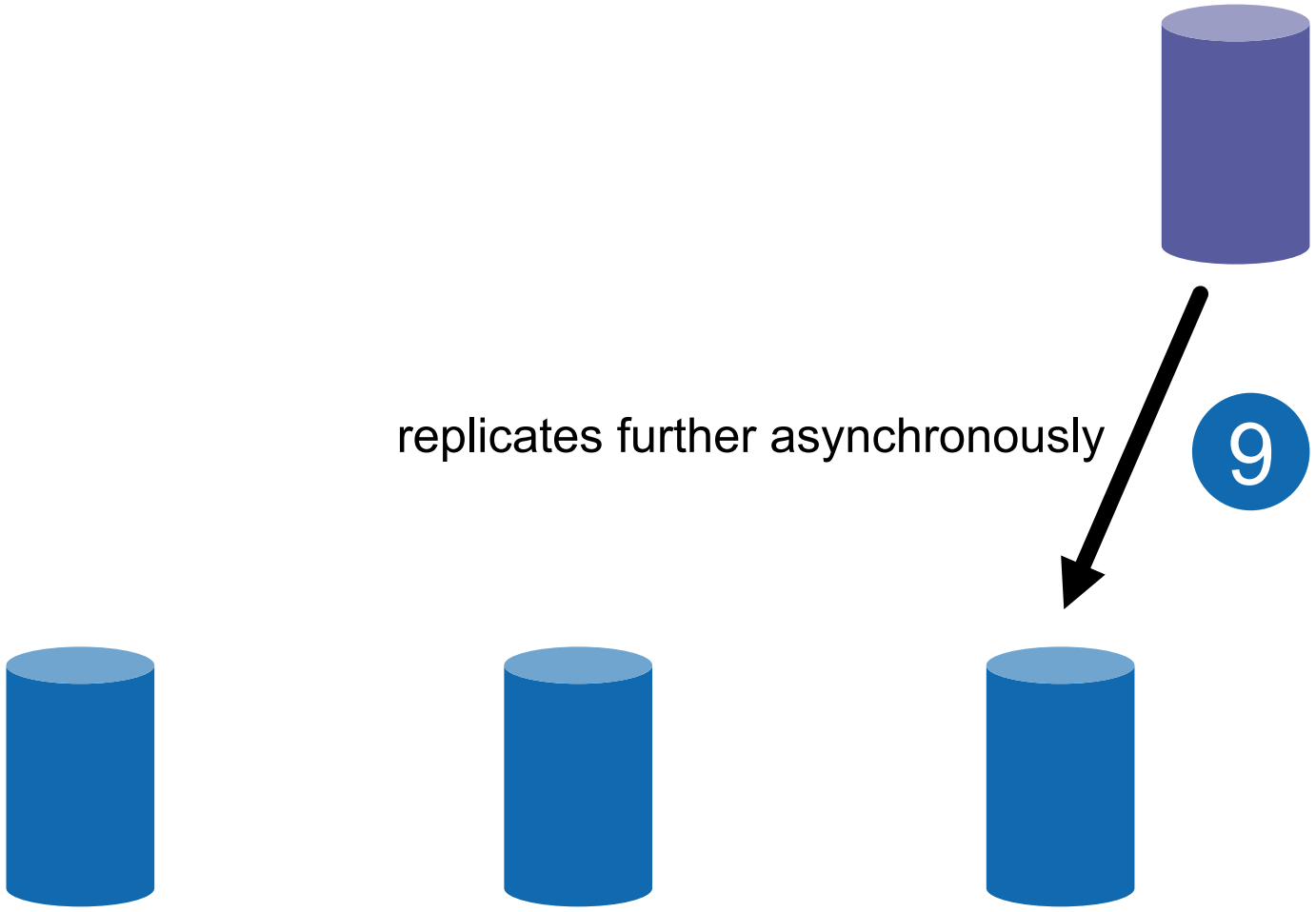
Client writes a file

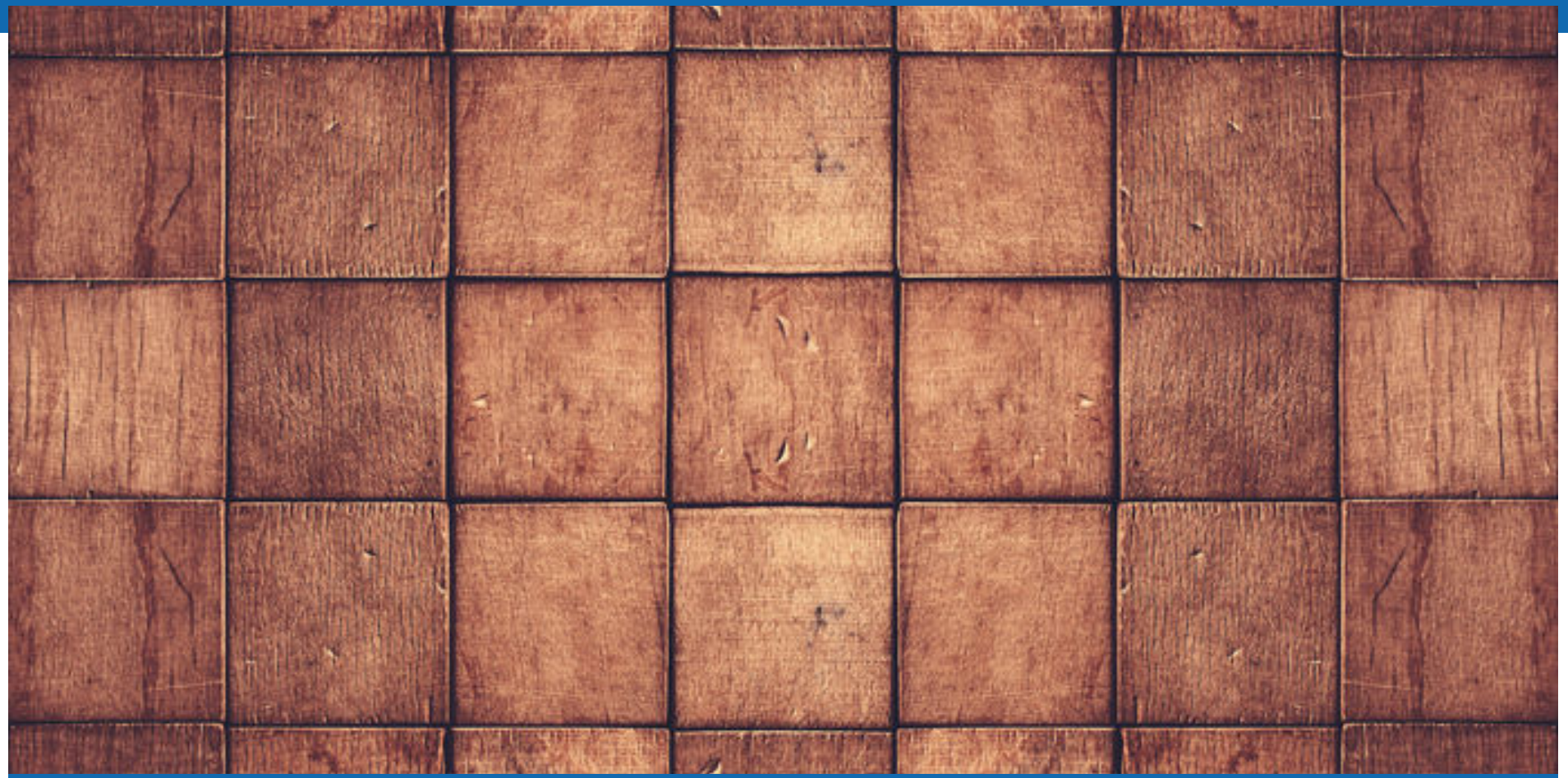


Client writes a file



Client writes a file





Replicas

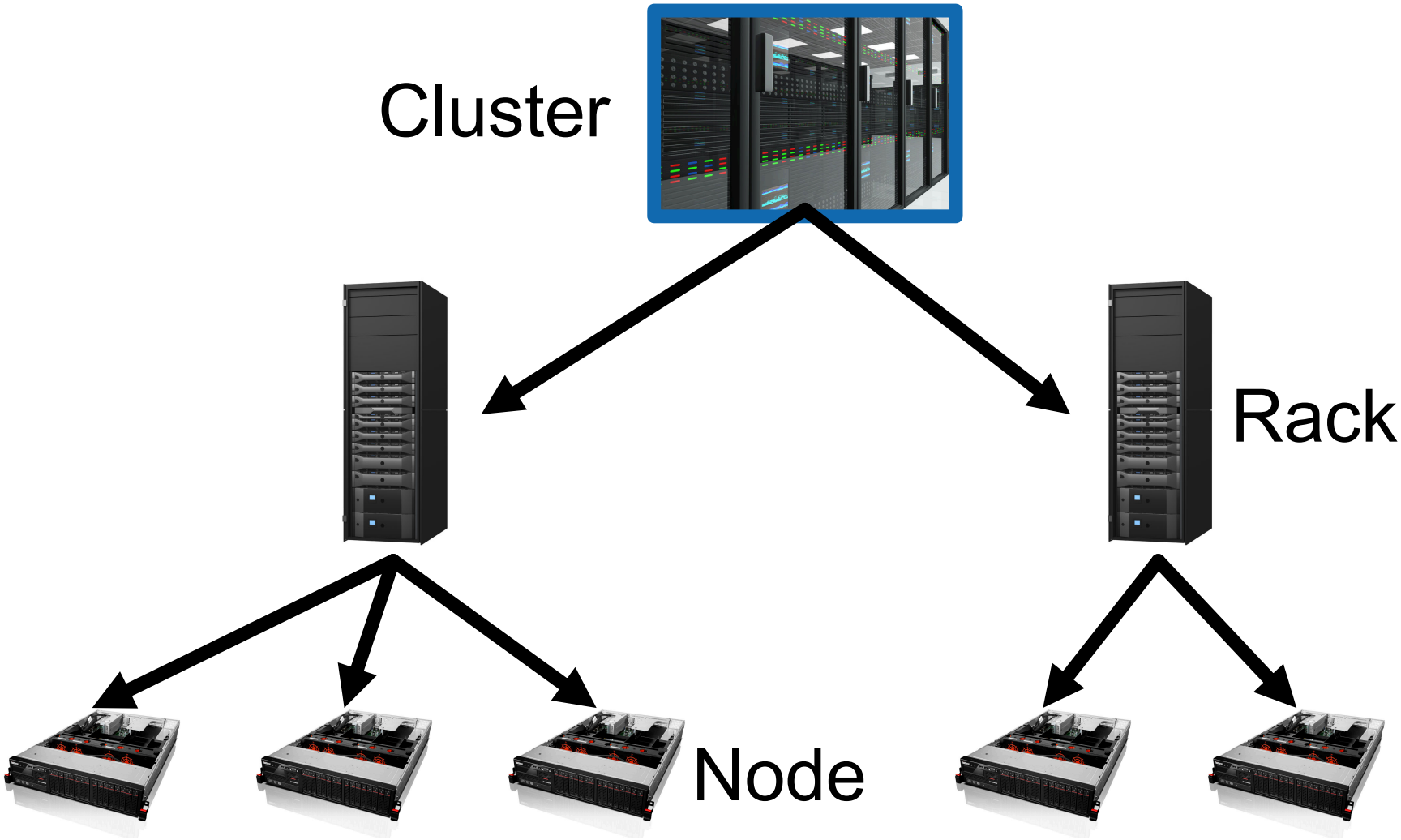
Replicas

Number of replicas specified

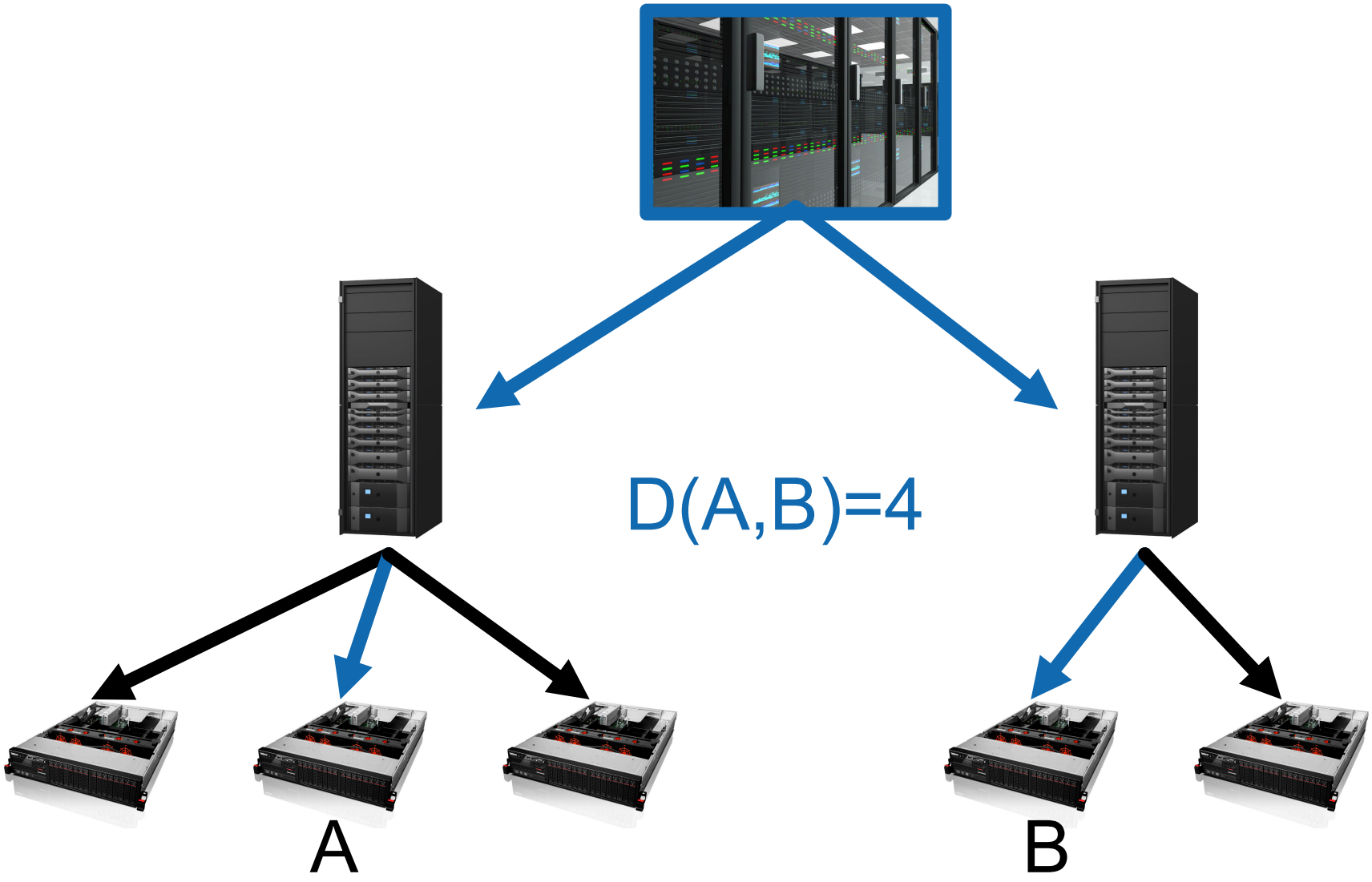
per file

default:3

Replica placement: Reminder on topology



Replica placement: Distance



Replica placement

Replica 1: same node as client (or random), rack A

Replica placement

- Replica 1: same node as client (or random), rack A
- Replica 2: a node in a different rack B

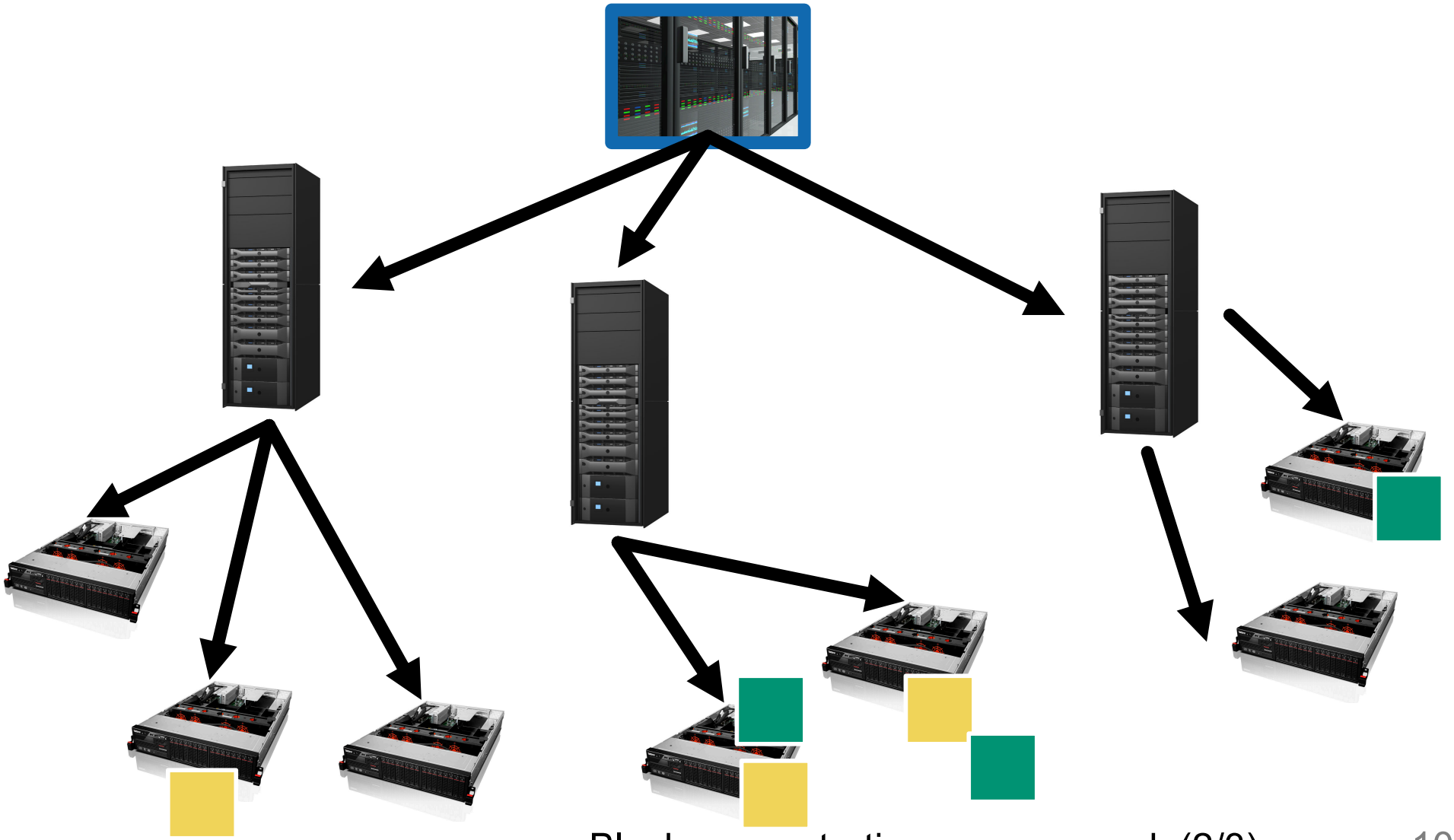
Replica placement

- Replica 1: same node as client (or random), rack A
- Replica 2: a node in a different rack B
- Replica 3: a node in same rack B

Replica placement

- Replica 1: same node as client (or random), rack A
- Replica 2: a node in a different rack B
- Replica 3: a node in same rack B
- Replica 4 and beyond: random, but if possible:
  - at most one replica per node
  - at most two replicas per rack

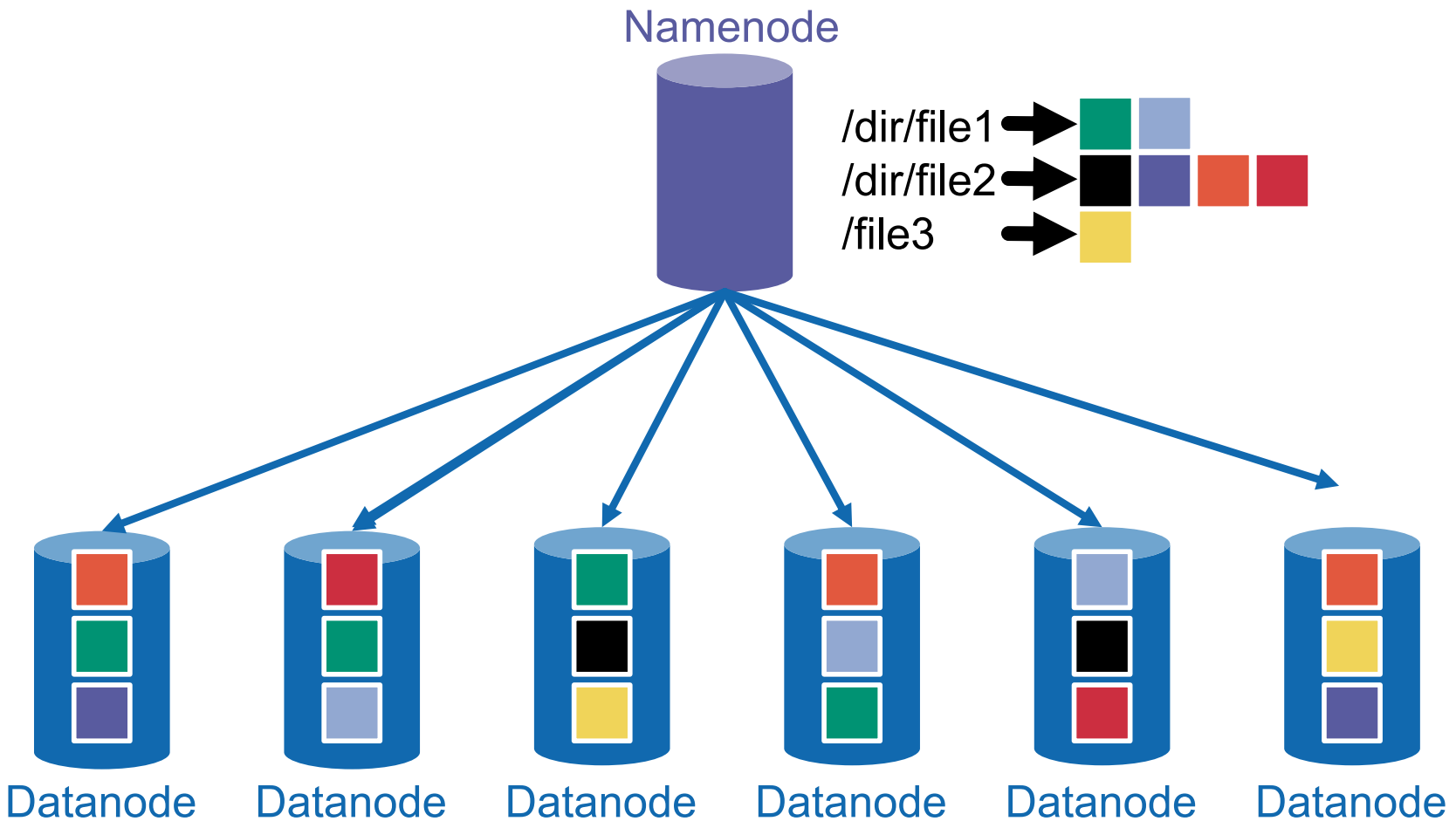
If replicas 1+2 were on same rack...



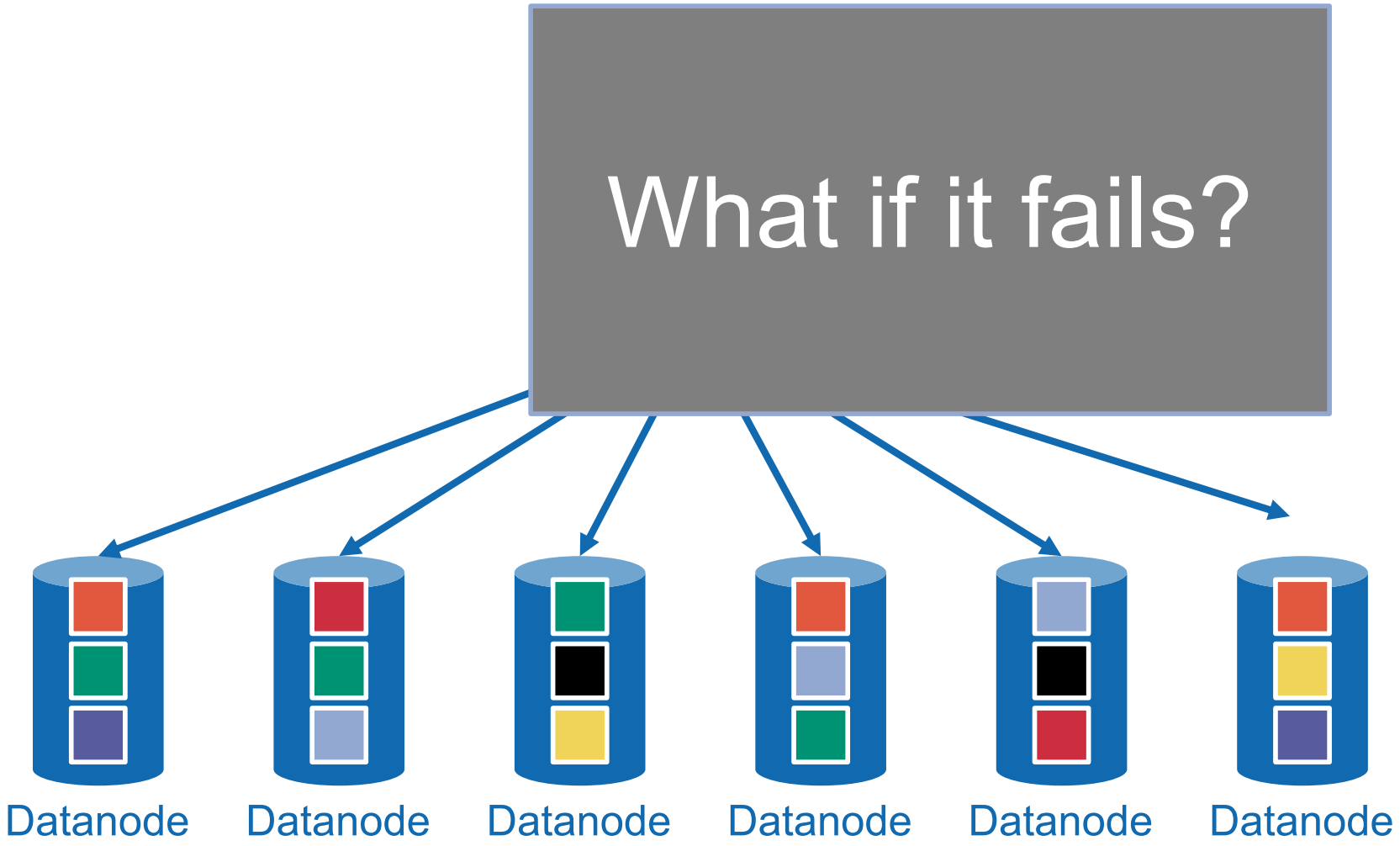
Block concentration on same rack (2/3)

Performance and availability

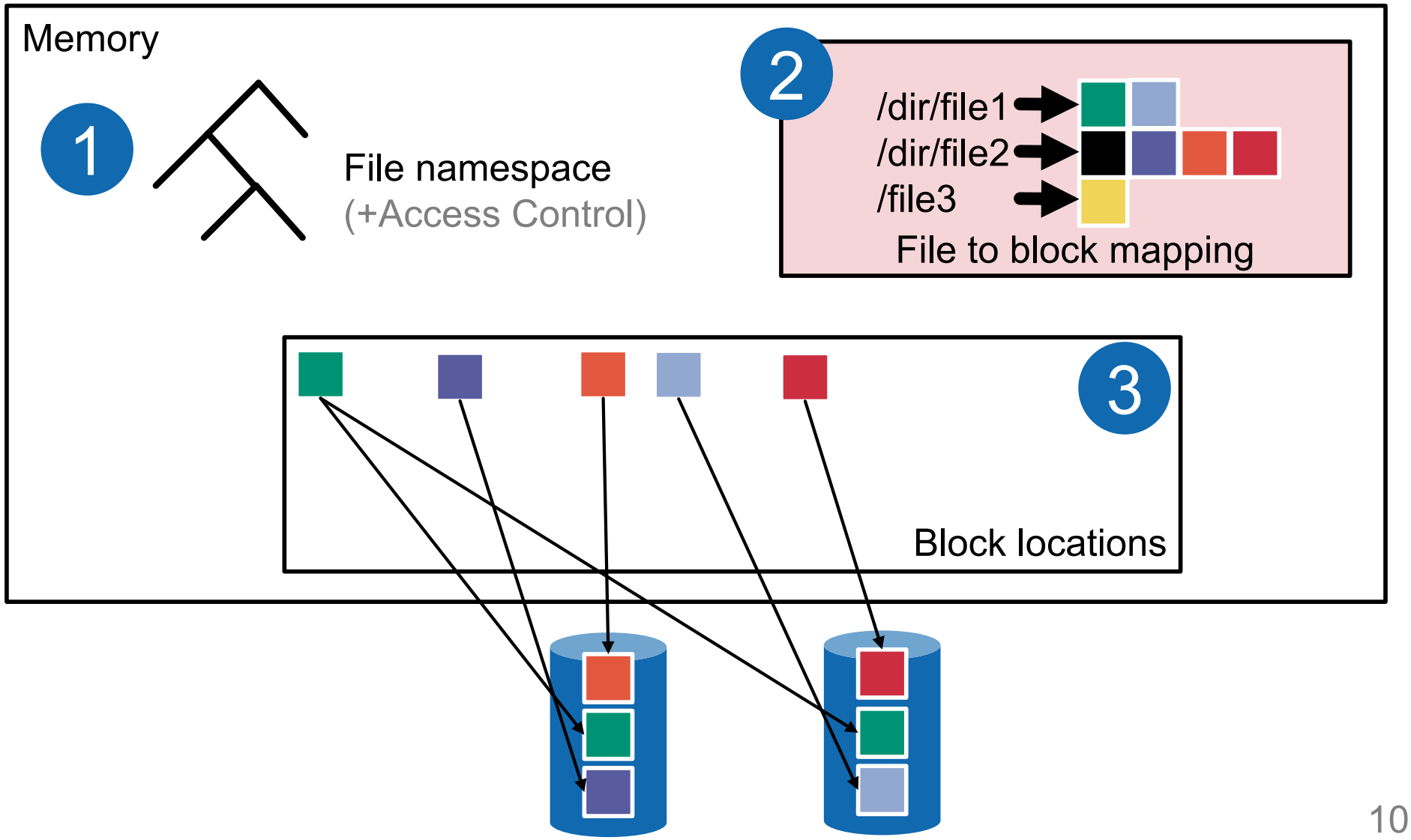
The NameNode is a single point of failure



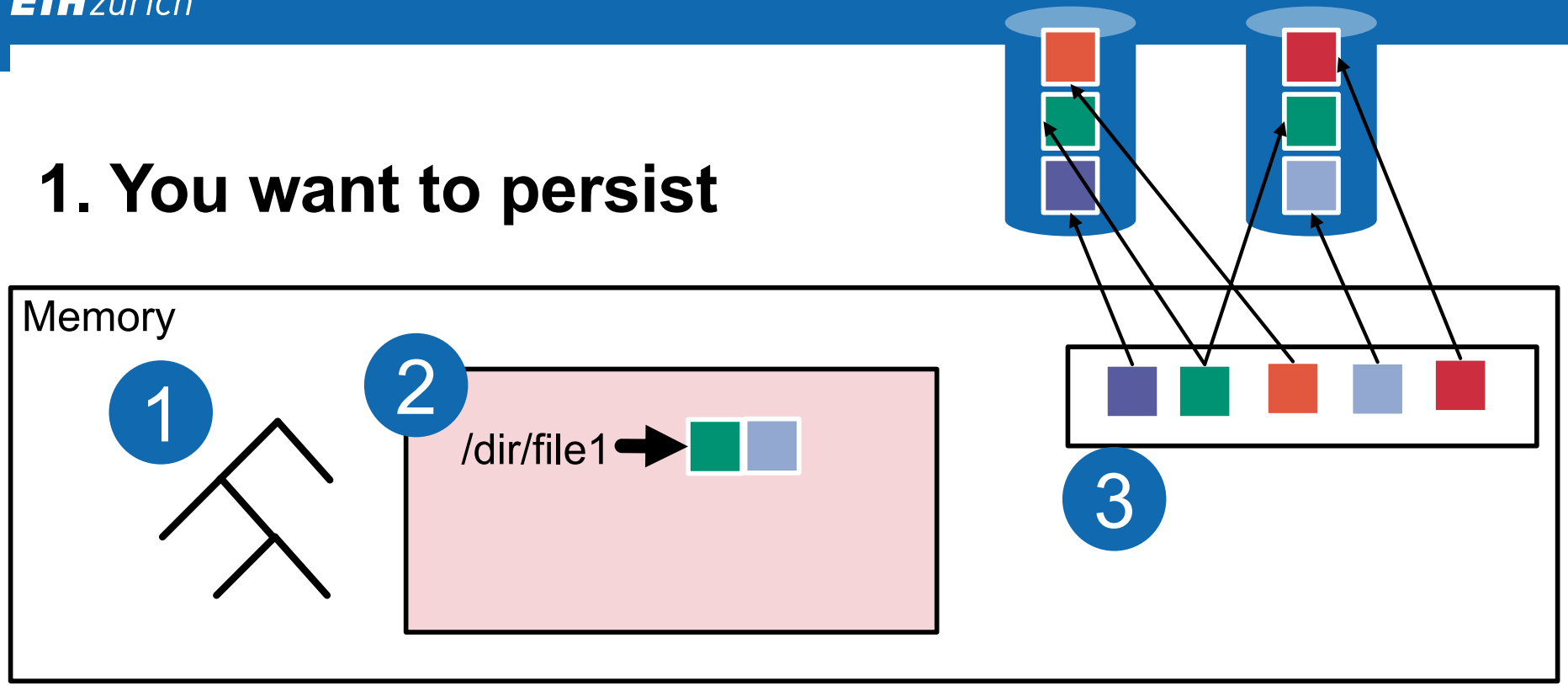
The NameNode is a single point of failure...



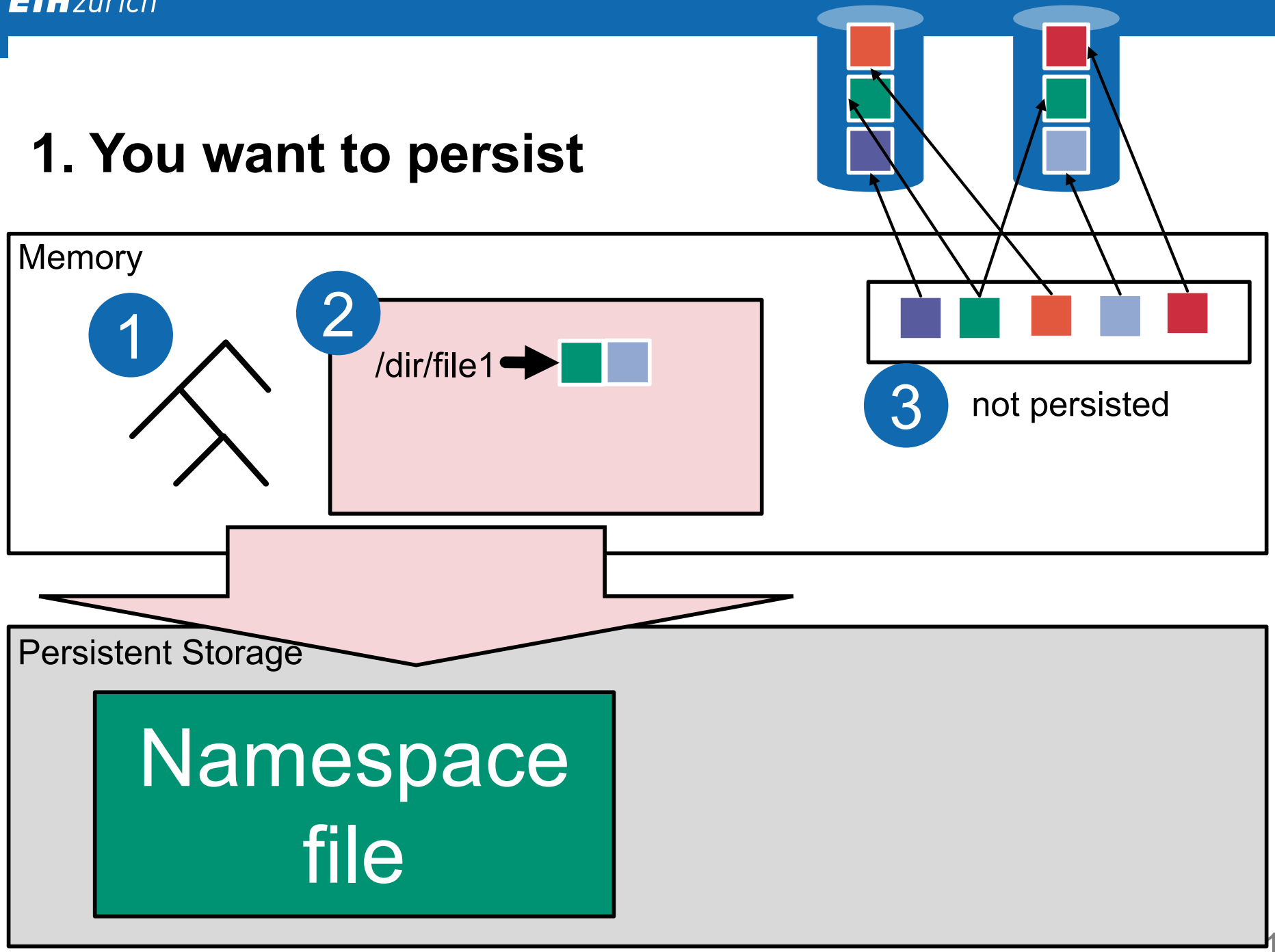
NameNode: all system-wide activity



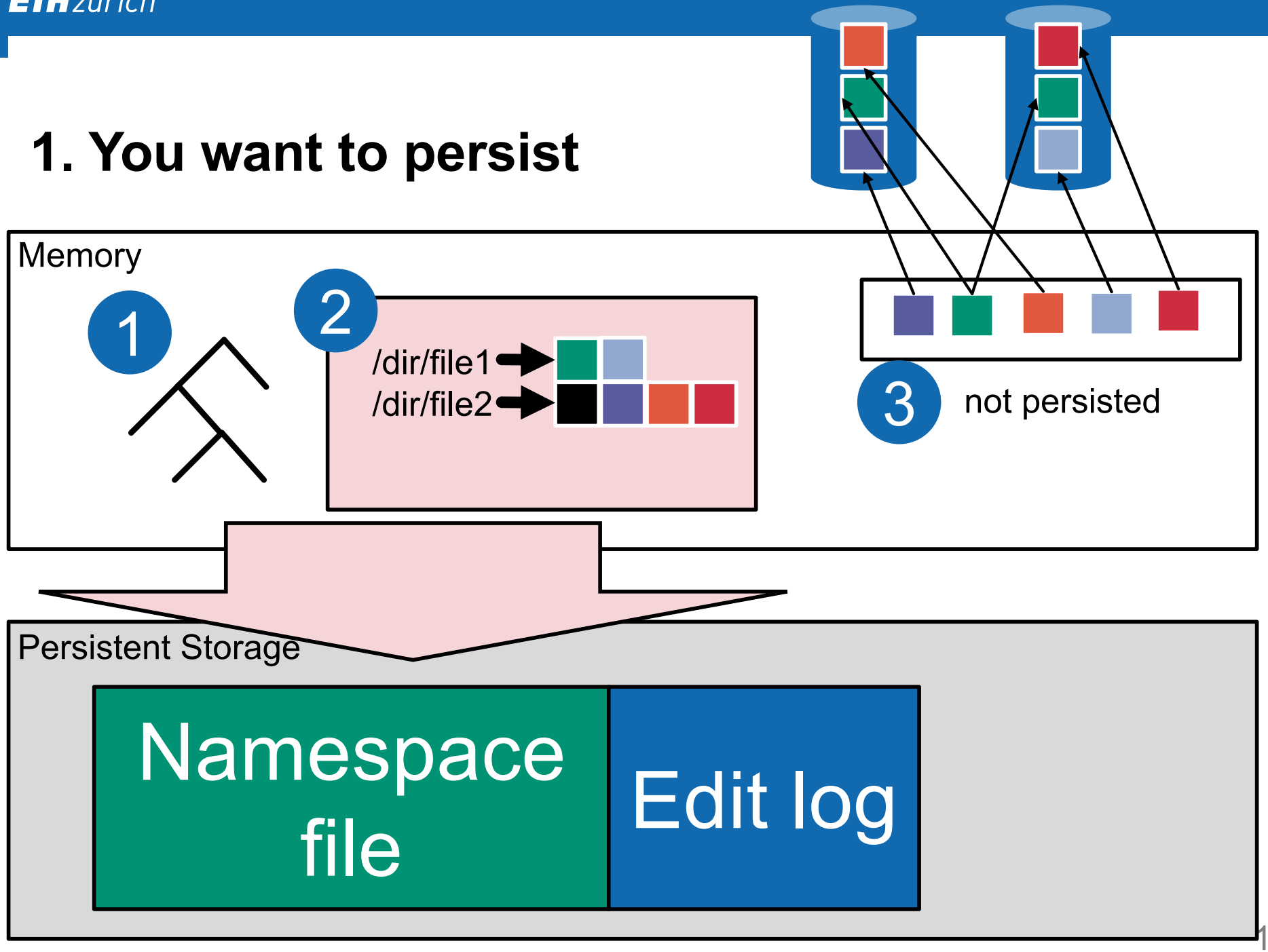
1. You want to persist



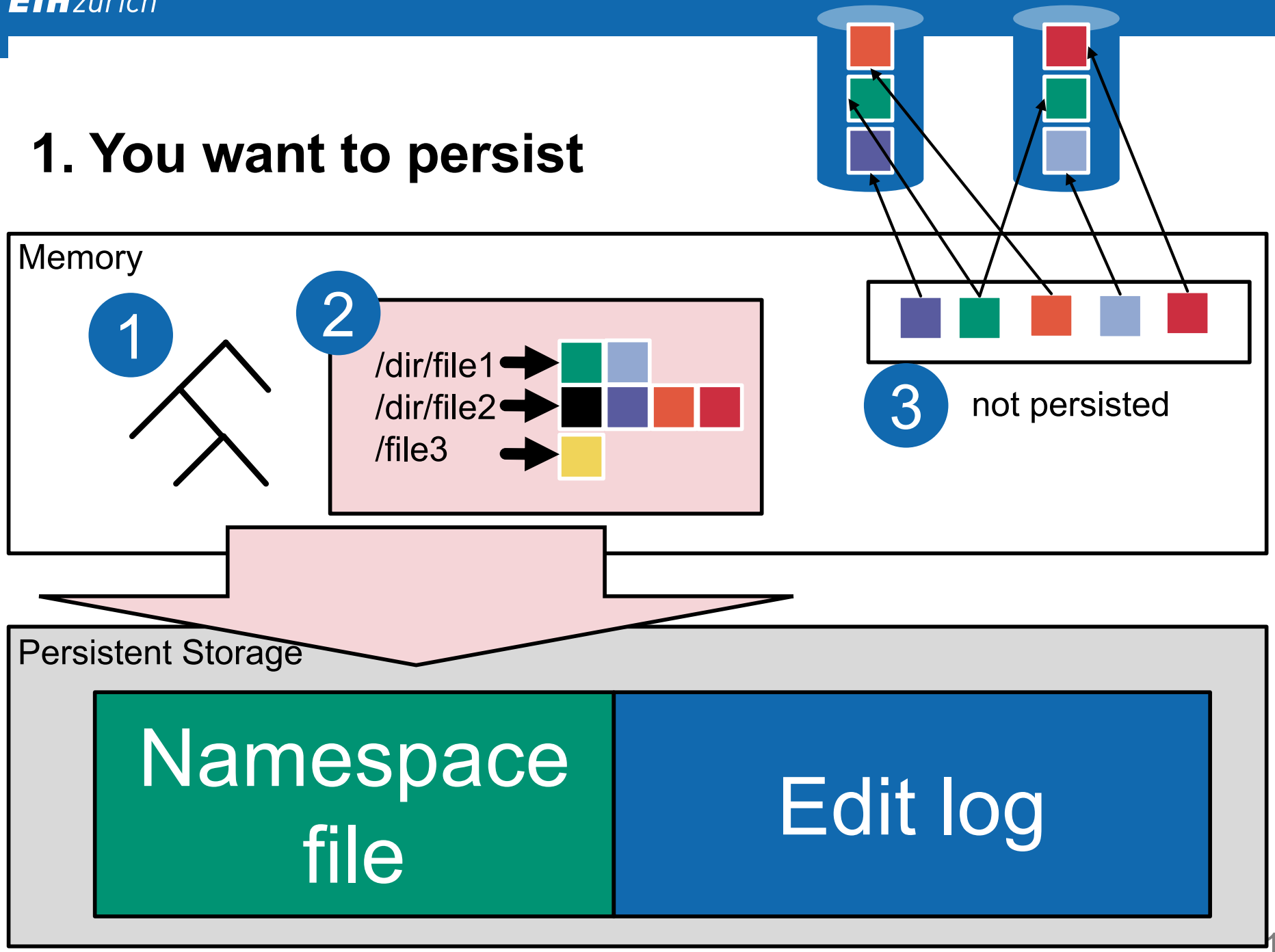
1. You want to persist



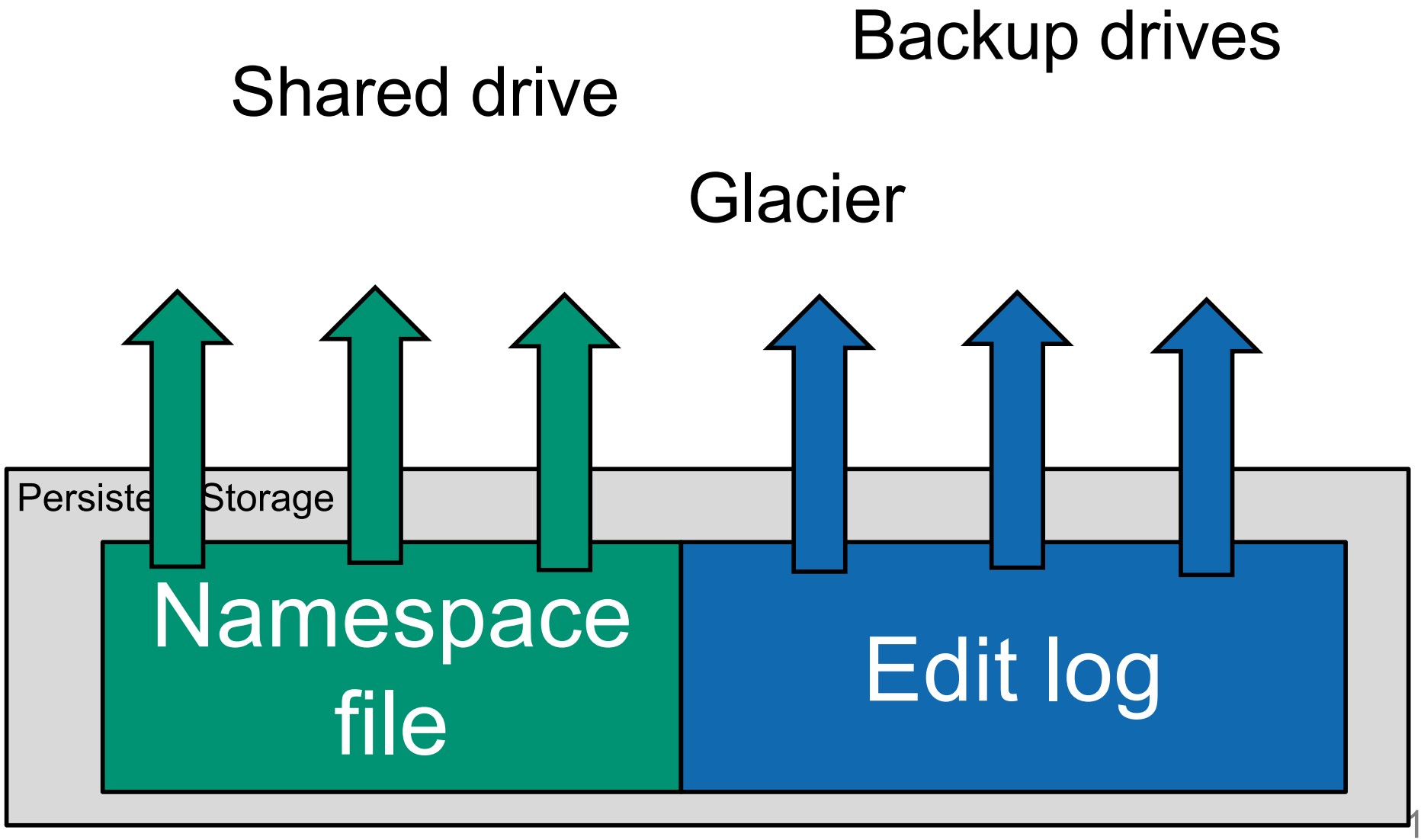
1. You want to persist



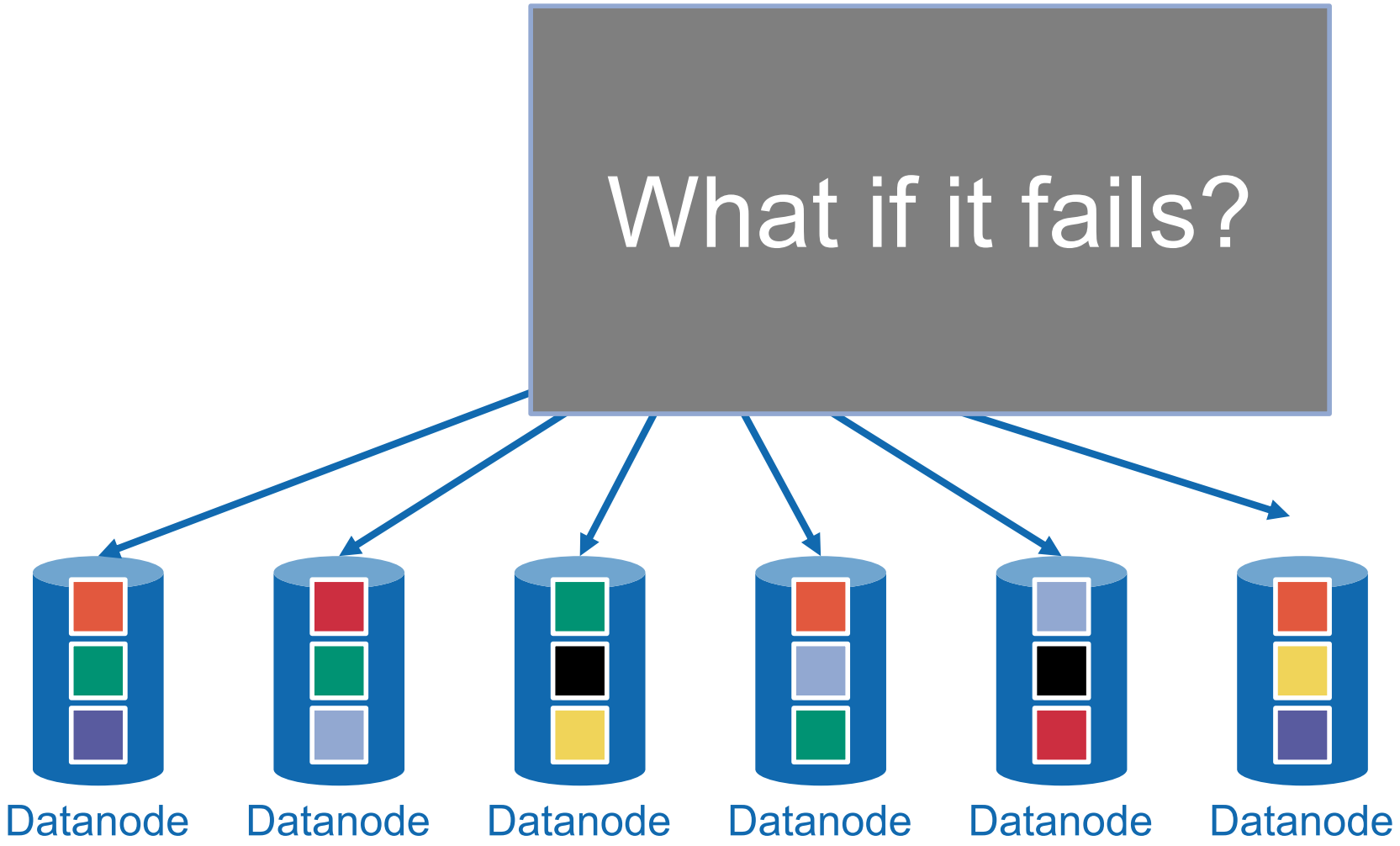
1. You want to persist



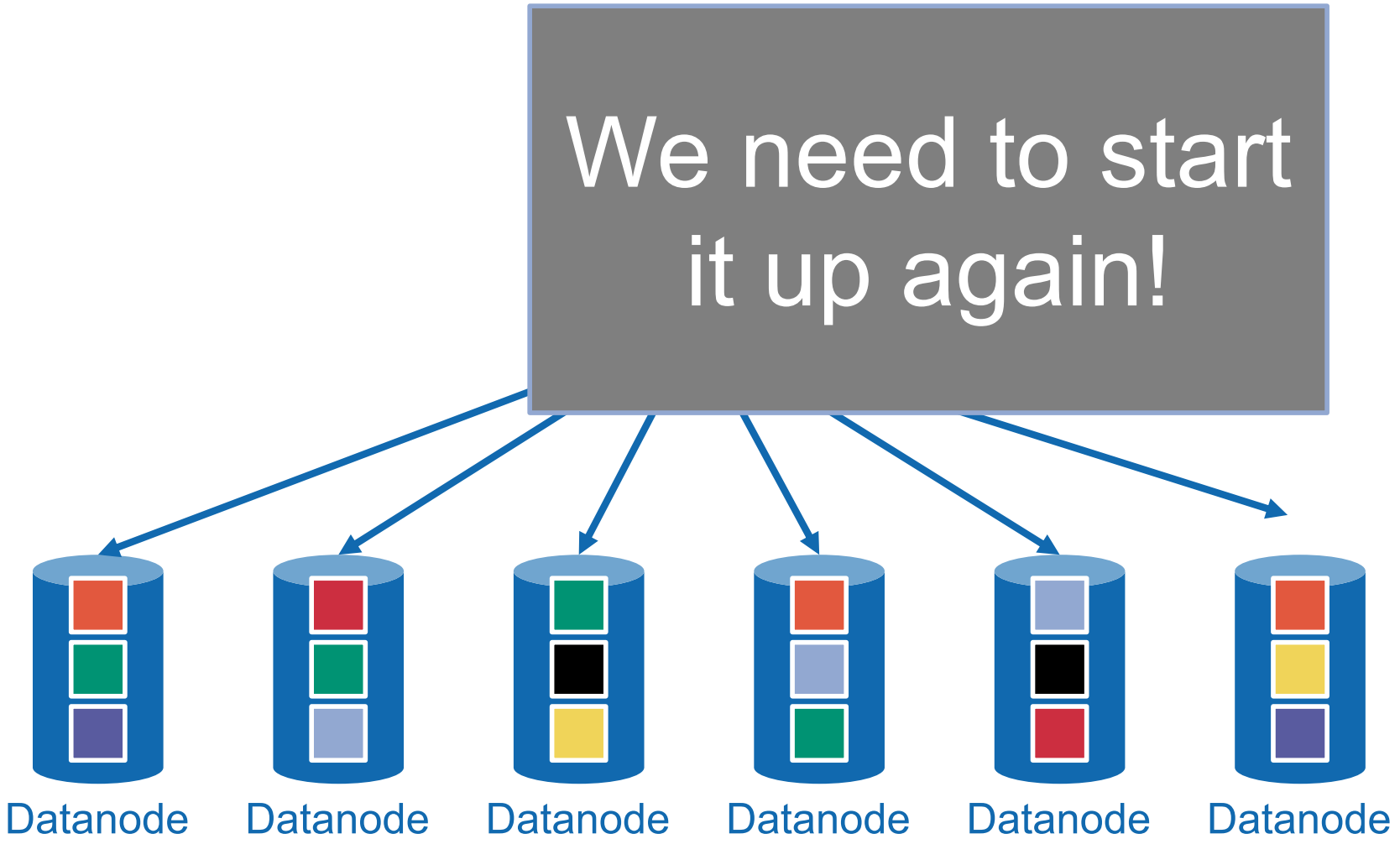
2. You want to backup



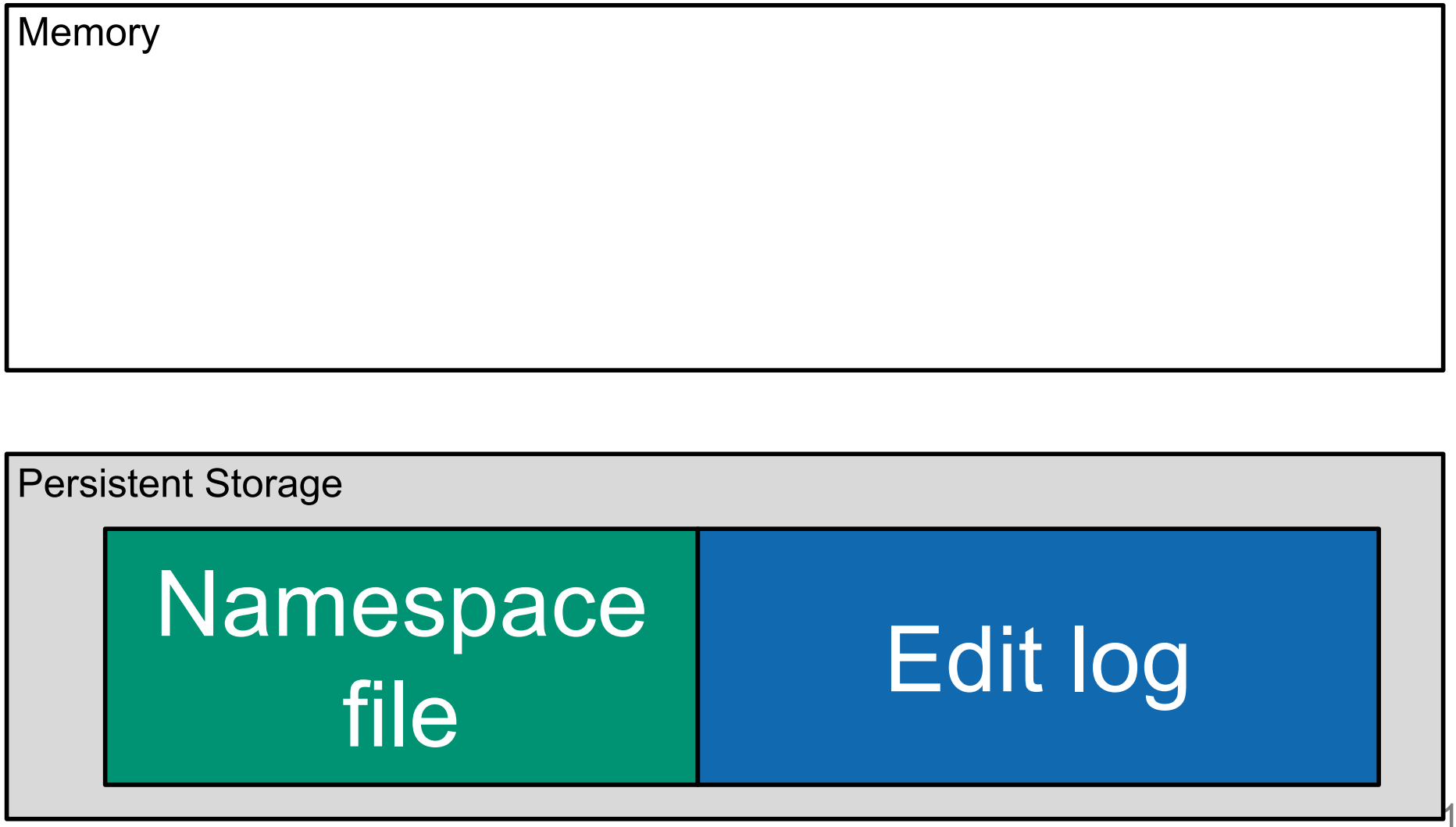
The namenode is a single point of failure...



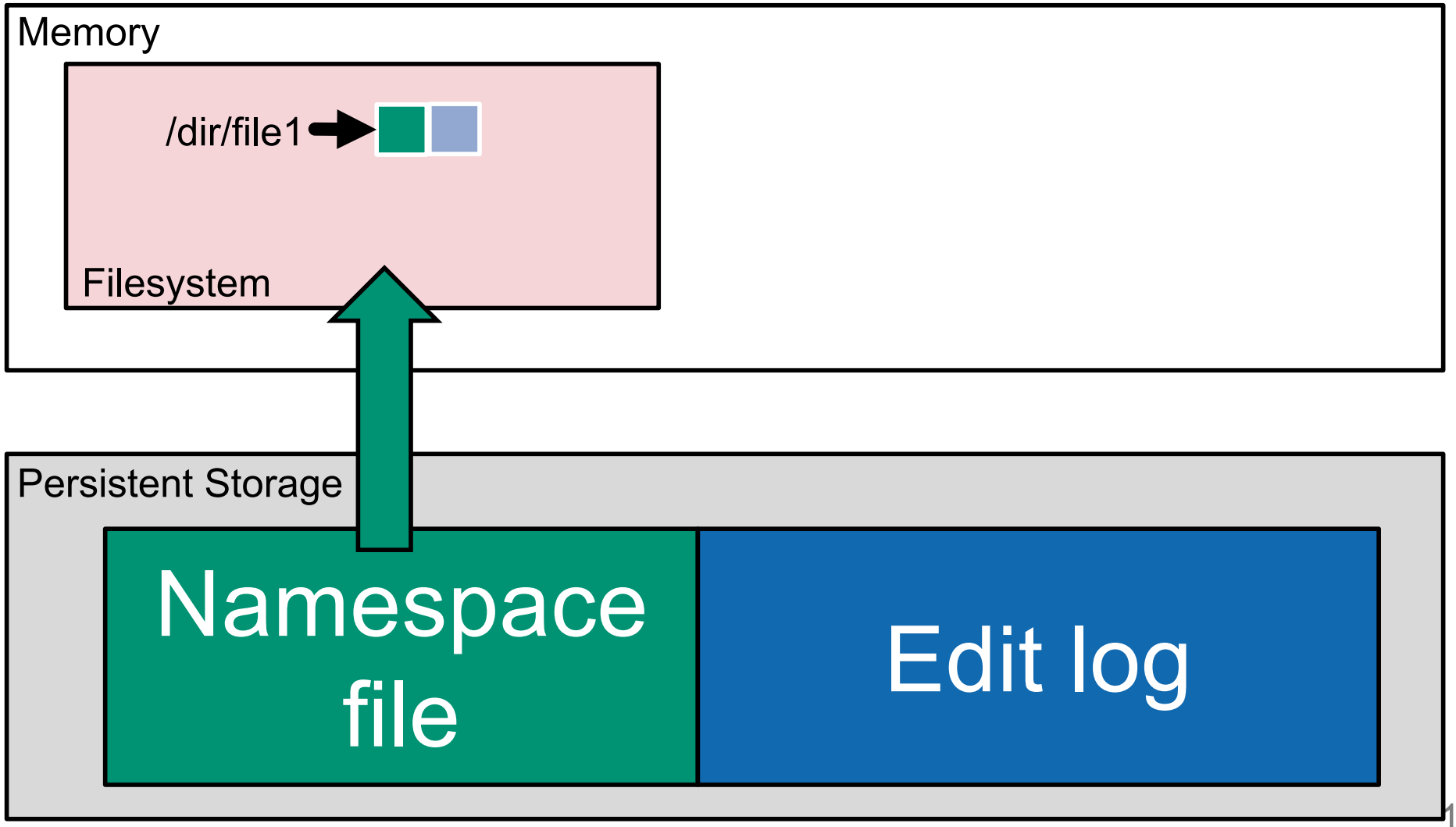
The namenode is a single point of failure...



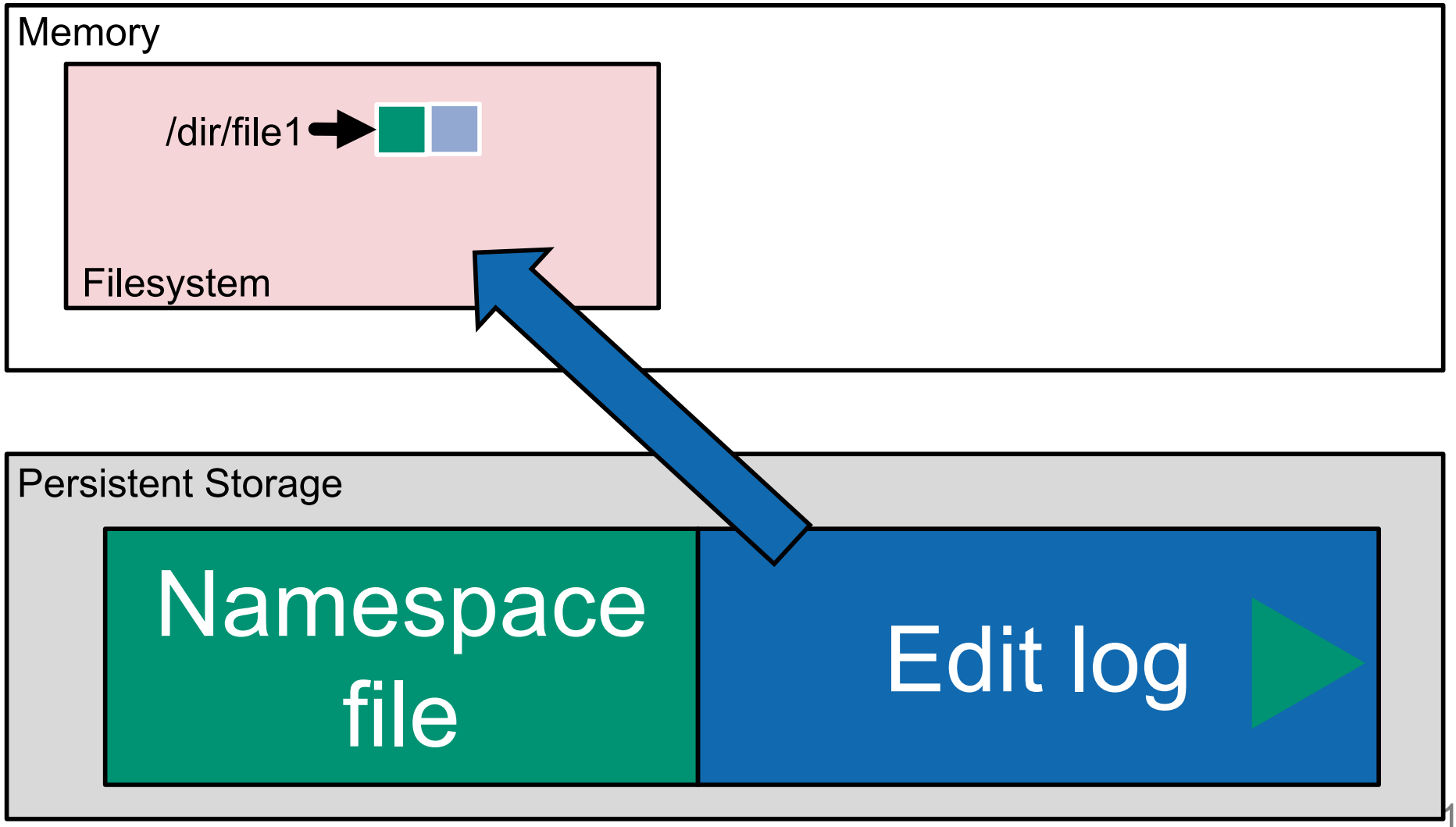
Namenodes: Startup



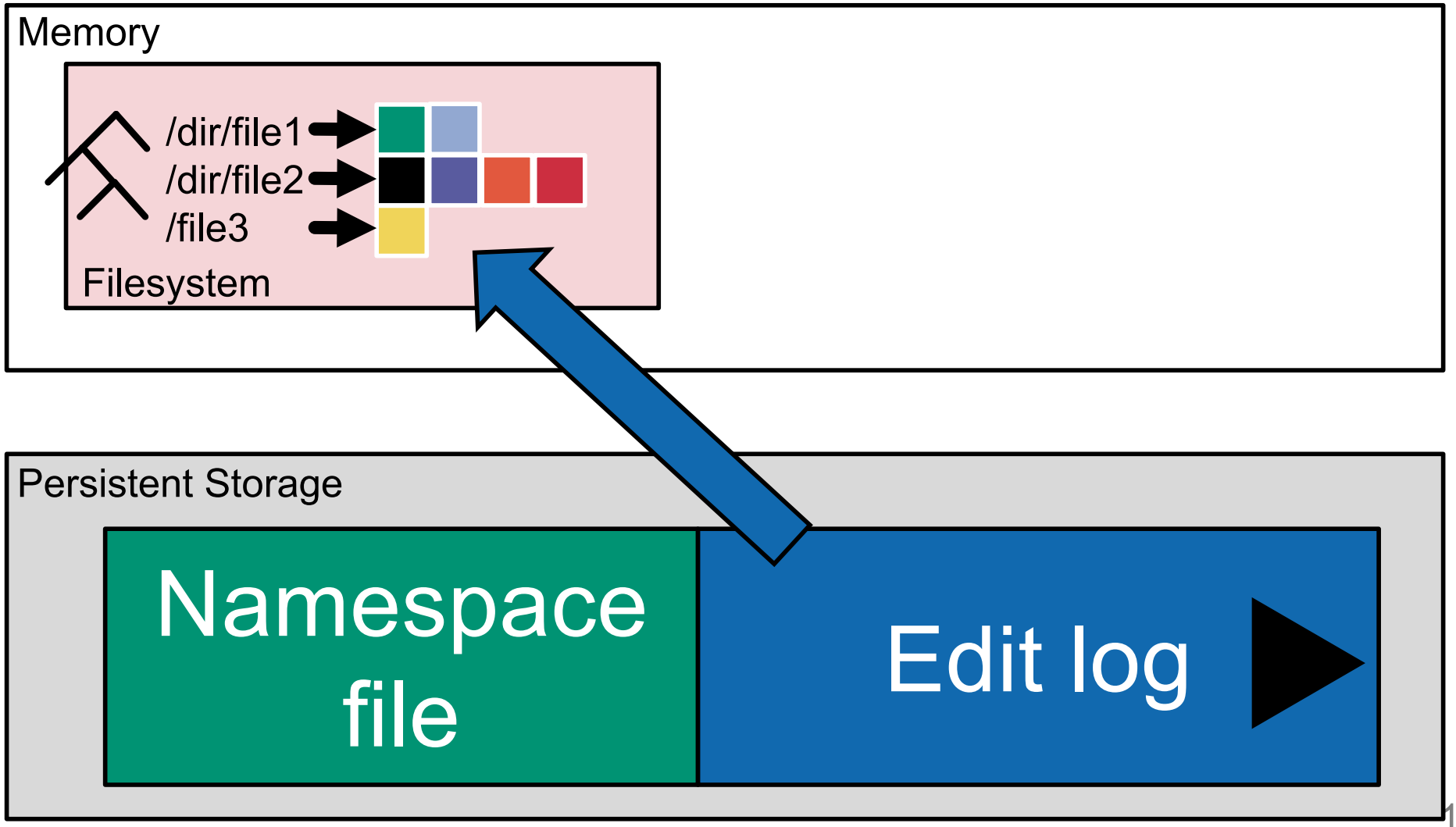
Namenodes: Startup



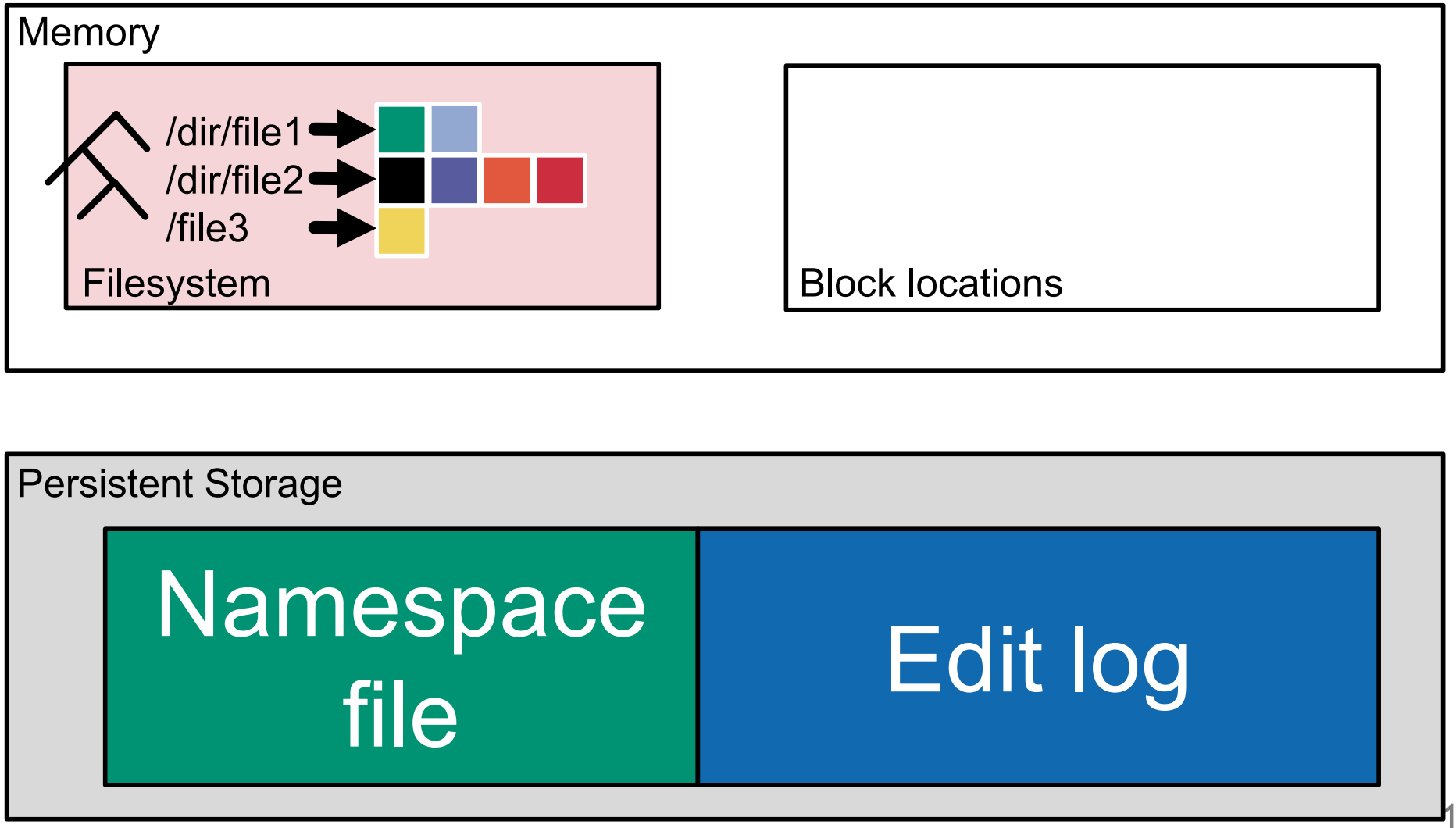
Namenodes: Startup



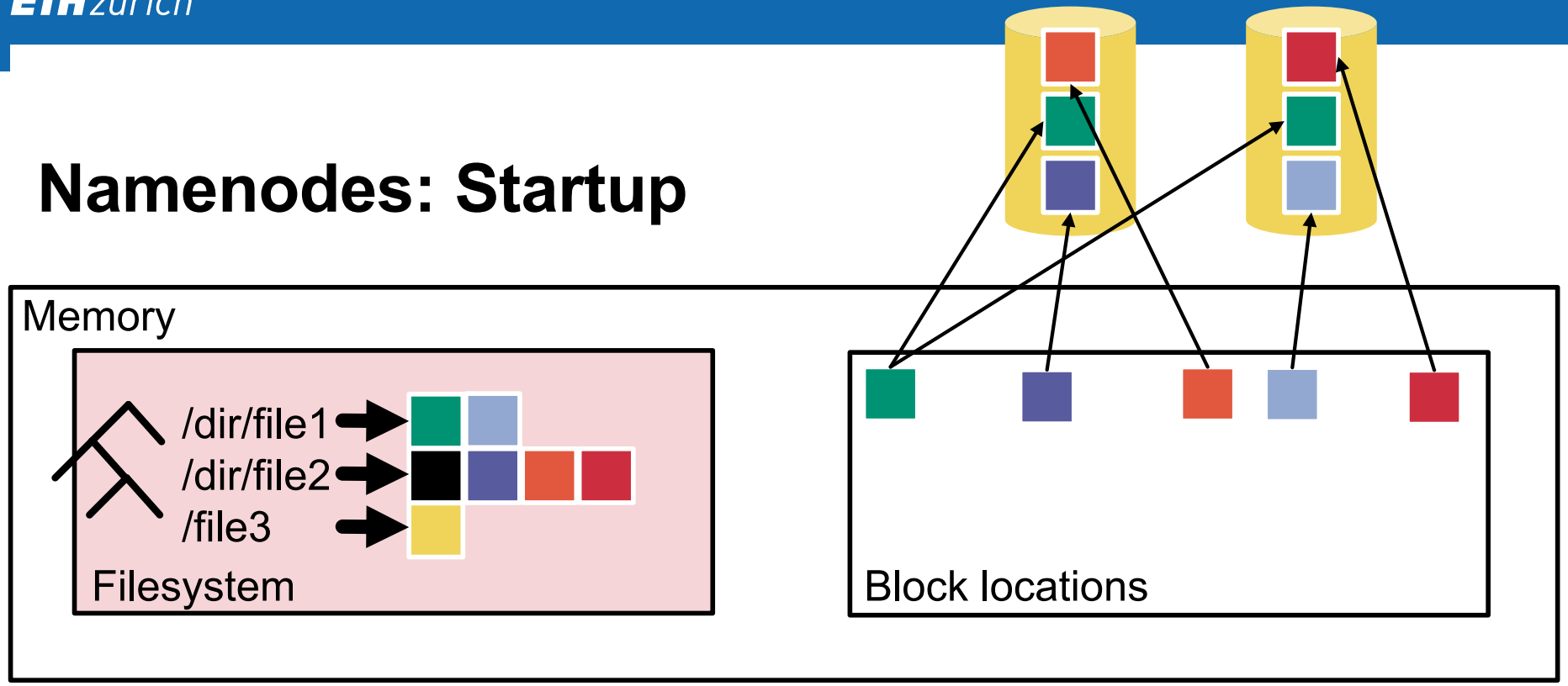
Namenodes: Startup



Namenodes: Startup



Namenodes: Startup



Starting a namenode...

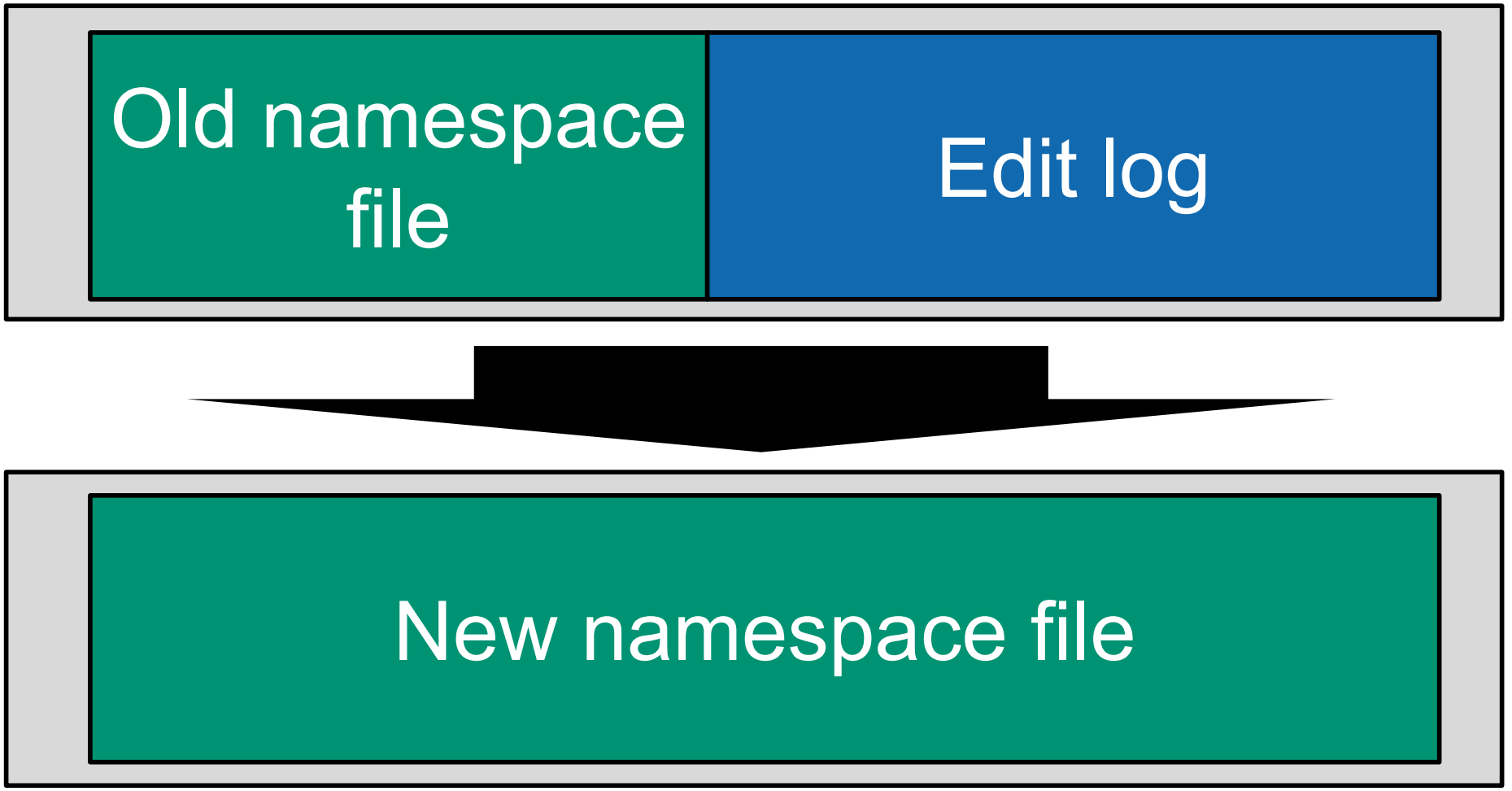
… takes

30 minutes!

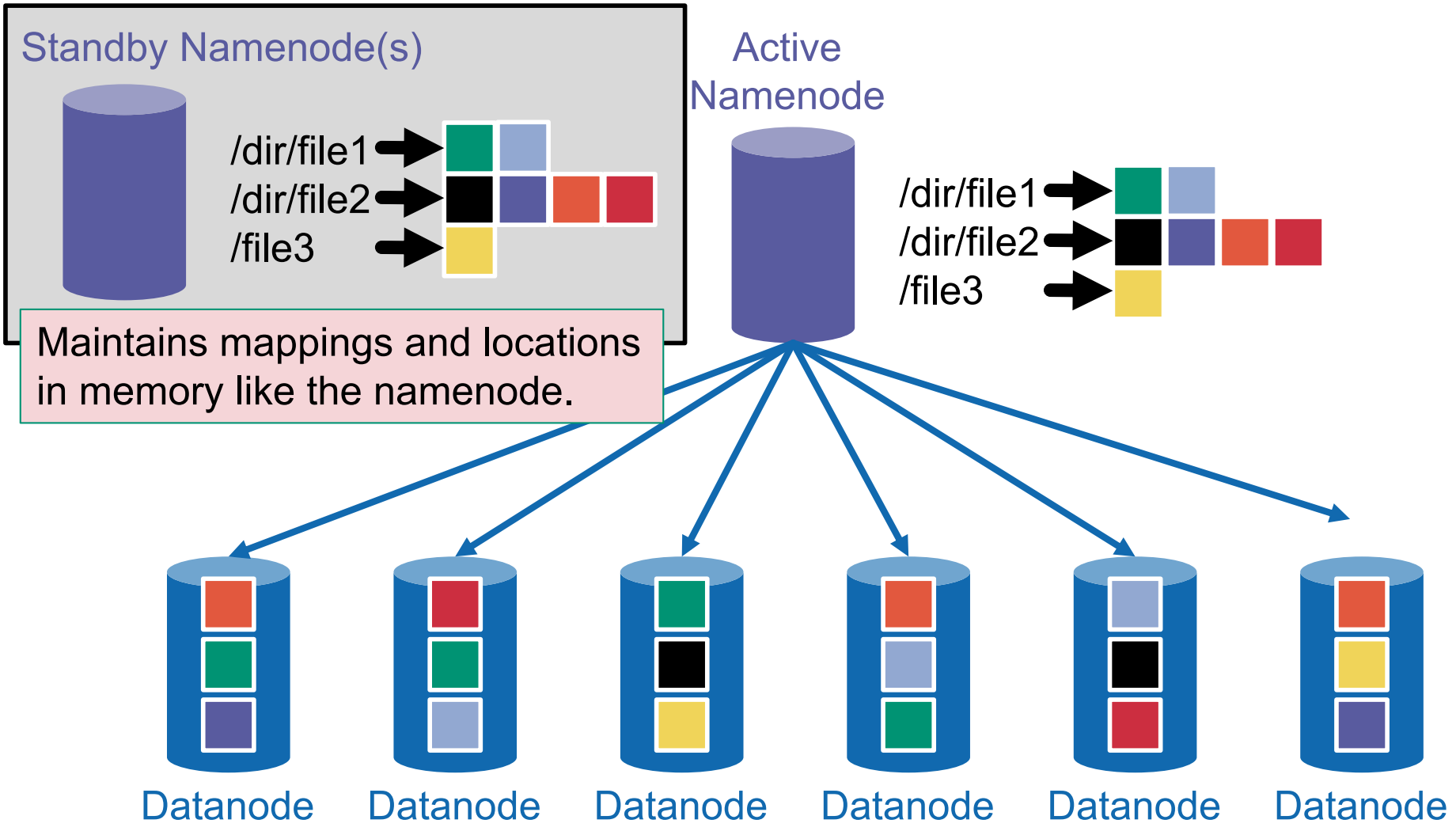
Starting a namenode...

Can we do **better?**

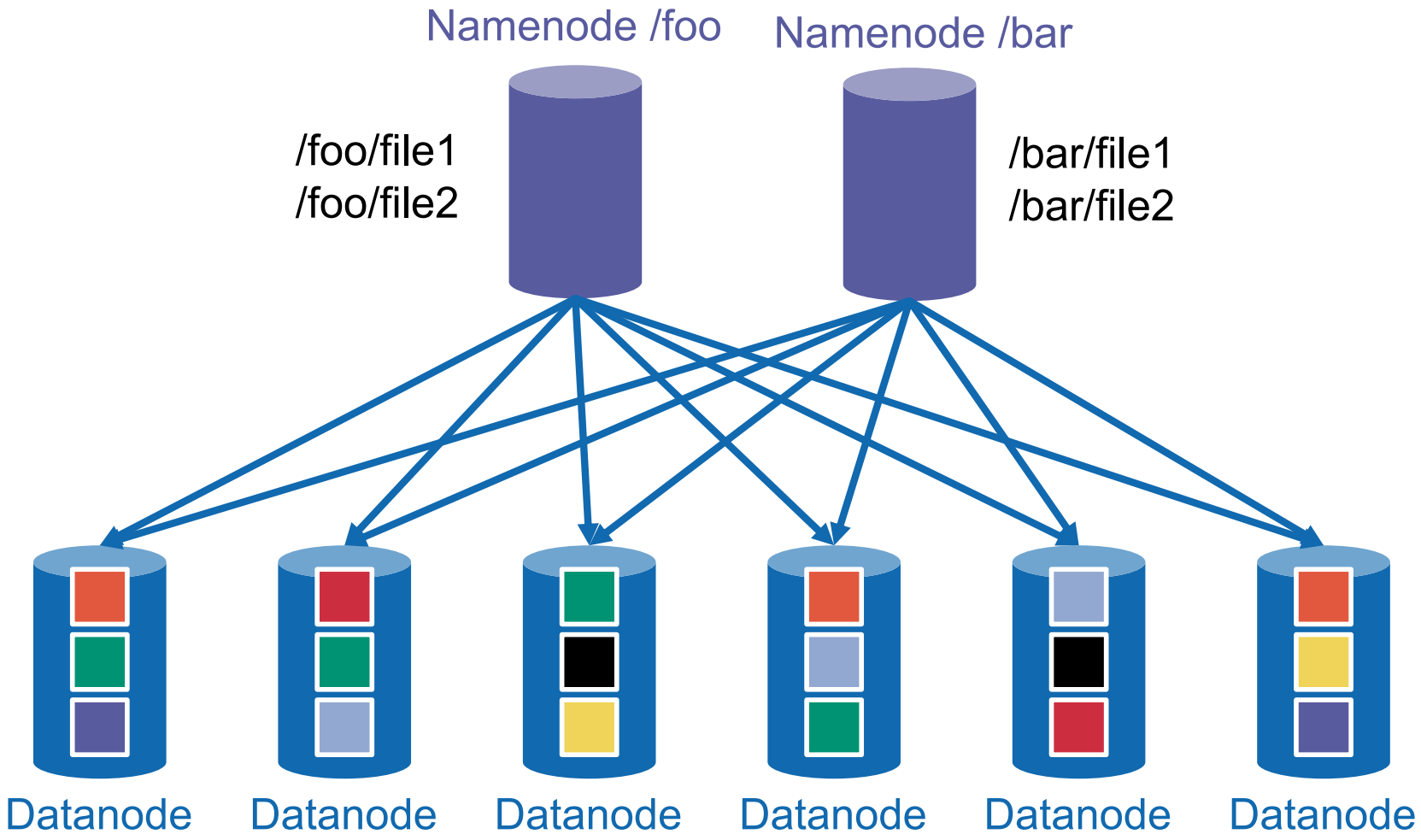
3. Checkpoints



4. High Availability (HA): Standby NameNodes



5. Federated DFS



Using HDFS

HDFS Shell: POSIX-like

```
$ hadoop fs -ls

$ hadoop fs -cat /dir/file

$ hadoop fs -rm /dir/file

$ hadoop fs -mkdir /dir
```

HDFS Shell: upload and download

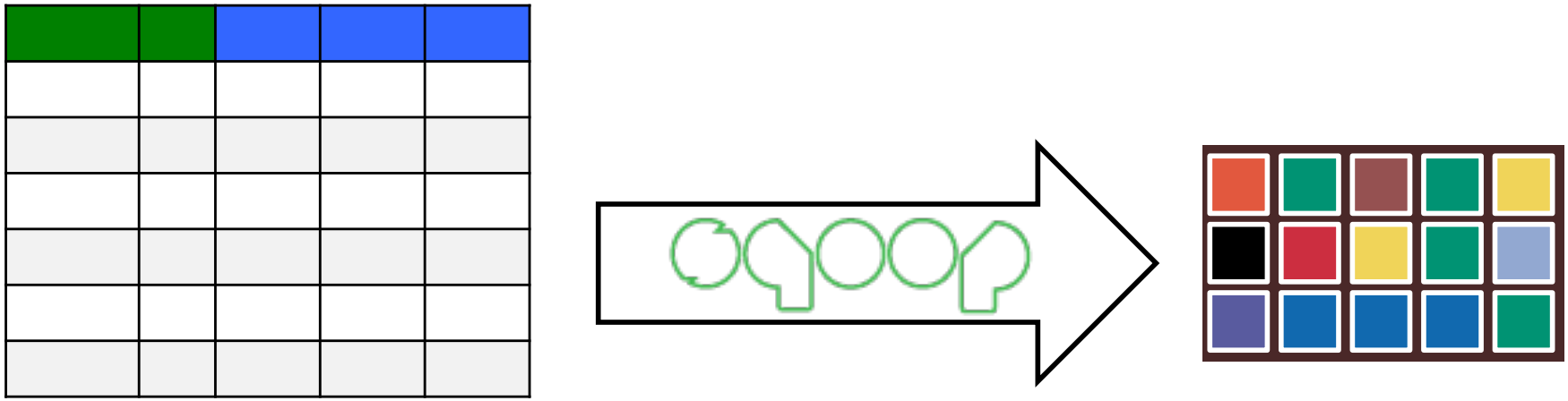
```
$ hadoop fs –copyFromLocal
        localfile1 localfile2
        /user/hadoop/hadoopdir
```

```
$ hadoop fs –copyToLocal /user/hadoop/file
                    localfile
```

Populating HDFS: Apache Flume

Collects, aggregates, moves log data (into HDFS)

Populating HDFS: Apache Sqoop



Imports from a relational database

Pointers

Official documentation
http://hadoop.apache.org/docs/r3.2.1/

GFS Paper
On course website

Java API
https://hadoop.apache.org/docs/r3.2.1/api/index.html