Data Management in Large-Scale Distributed Systems

Introduction

Thomas Ropars

thomas.ropars@univ-grenoble-alpes.fr

http://tropars.github.io/

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Organization of the course

18 hours

- 12 hours of lectures
- 6 hours of practical sessions

Grading

- Graded Lab (30% of the final grade)
- Written exam (70% of the final grade)

Covered topics

- The challenges of Big Data and distributed data processing
- The Map/Reduce programming model
- Batch and stream processing systems
- Distributed databases
- Performance of distributed data processing

Overview of this lecture

- Introduction to the Big Data challenges
- Challenges of distributed computing
- Introduction to Cloud Computing
- Scalability techniques

Agenda

The challenges of Big Data

Distributed and Parallel Systems

Cloud Computing

Running at scale

References

- Coursera – *Big Data*, University of California San Diego
- The lecture notes of V. Leroy
- The lecture notes of R. Lachaize
- Designing Data-Intensive Applications by Martin Kleppmann

The data deluge

Many sources of data

The data deluge

Many sources of data

- Sensors
- Social media
- Scientific experiments
- Industry activity
- Etc.

Some numbers

- Every 2 days, we create as much information as we did since 2013[1]
- 40K search queries on Google every second[2]
- 30M messages posted on Facebook every minute
- 6.1 Billions of smartphone users by 2020 (and 50 Billions connected devices)
- 570 new web sites every minute
- Largest database: 3.2 Trillions rows (AT&T)
- 40 TB of data every second during an experiment at the Large Hadron Collider

[1] https://www.slideshare.net/BernardMarr/big-data-25-facts

[2] https://www.newgenapps.com/blog/big-data-statistics-predictions-on-the-future-of-big-data

Hardware capacity

Storage

- All the music of the world stored for 500$
- Large Amazon EC2 instance: 768GB of RAM, 3.6TB of SSD

Computing resources

- Google data-centers: more than 2.5M servers (2016)
- Amazon capacity increase each day = size of Amazon in 2005

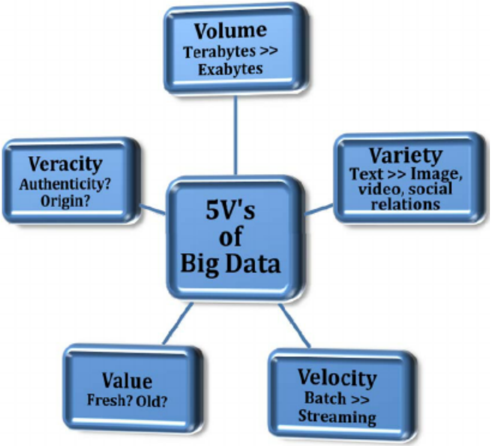
Huge opportunities for storing and processing data

Big data challenges: The V's

source: Big Data for Modern Industry: Challenges and Trends

Big data challenges: The V's

source: Big Data for Modern Industry: Challenges and Trends



Big data challenges: The V's

- Volume: Amount of data generated
- Variety: all kinds of data are generated (text, image, voice, time series, etc.)
- Velocity: Rate at which data are produced and should be processed
- Veracity: Noise/anomalies in data, truthfulness
- Value: How do we extract/learn valuable knowledge from the data

Big data challenges: The V's

In this course we are going to deal with:

- **Volume**
- **Velocity**
- Variety

Questions to be answered:

- How to build a system and algorithms that can process huge amount of data?
- How to build a system and algorithms that can process data in a timely manner?
- (Bonus questions) How to build software that can deal with the variety of data?

Agenda

Motivation

The solution to process large amount of data:

Using large amount of resources

Note that:

- Different strategies can be used to leverage these resources
- Using large amount of resources presents new challenges

Increasing the processing power and the storage capacity

Goals

- Increasing the amount of data that can be processed (weak scaling)
- Decreasing the time needed to process a given amount of data (strong scaling)

Two solutions

- Scaling up
- Scaling out

Vertical scaling (scaling up)

Idea

Increase the processing power by adding resources to existing nodes:

- Upgrade the processor (more cores, higher frequency)
- Increase memory volume
- Increase storage volume

Pros and Cons

Vertical scaling (scaling up)

Idea

Increase the processing power by adding resources to existing nodes:

- Upgrade the processor (more cores, higher frequency)
- Increase memory volume
- Increase storage volume

Pros and Cons

☺ Performance improvement without modifying the application

☹ Limited scalability (capabilities of the hardware, cf *The end of Moore's law*)

☹ Expensive (non linear costs)

Horizontal scaling (scaling out)

Idea

Increase the processing power by adding more nodes to the system

- Cluster of commodity servers

Pros and Cons

Horizontal scaling (scaling out)

Idea

Increase the processing power by adding more nodes to the system

- Cluster of commodity servers

Pros and Cons

☹ Often requires modifying applications

☺ Less expensive (nodes can be turned off when not needed)

☺ *Infinite* scalability

Horizontal scaling (scaling out)

Idea

Increase the processing power by adding more nodes to the system

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The solution studied in this course

Large scale infrastructures

Figure: Google Data-center

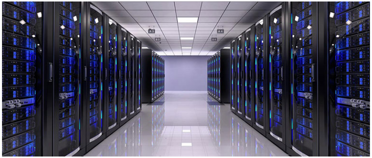


Figure: Amazon Data-center

Figure: Barcelona Supercomputing Center

Distributed computing: Definition

A distributed computing system is a system including several computational entities where:

- Each entity has its own local memory
- All entities communicate by message passing over a network

Each entity of the system is called a node.

Distributed computing: Challenges[1]

[1] Read Chapter 1 of *Designing Data-Intensive Applications* for further details

Distributed computing: Challenges[1]

Scalability

- How to take advantage of a large number of distributed resources?

Performance

- How to take full advantage of the available resources?
- Moving data is costly
  - How to maximize the ratio between computation and communication?
- How to ensure that the latency of requests processing remains below some upper bound?

[1] Read Chapter 1 of *Designing Data-Intensive Applications* for further details

Distributed computing: Challenges

Fault tolerance

- The more resources, the higher the probability of failure
- MTBF (Mean Time Between Failures)
  - MTBF of one server = 3 years
  - MTBF of 1000 servers $\simeq$ 19 hours (beware: over-simplified computation)
- How to ensure computation completion?
- How to ensure that results are correct?

Programmability

- How to provide programming models that hide the complexity of distributed computing? (while remaining efficient)
- What high level services should be made available to ease life of programmers?

A warning about distributed computing

> *You can have a second computer once you've shown you know how to use the first one. (P. Braham)*

Horizontal scaling is very popular.

- But not always the most efficient solution (both in time and cost)

Examples

- Processing a few 10s of GB of data is often more efficient on a single machine that on a cluster of machines
- Sometimes a single threaded program outperforms a cluster of machines (F. McSherry et al. "Scalability? But at what COST!". 2015.)

Agenda

Where to find computing resources?

Cloud computing

- A service provider gives access to computing resources through an internet connection.

Pros and Cons

Where to find computing resources?

Cloud computing

- A service provider gives access to computing resources through an internet connection.

Pros and Cons

☺ Pay only for the resources you use

☺ Get access to large amount of resources

- Amazon Web Services features millions of servers

☹ Volatility

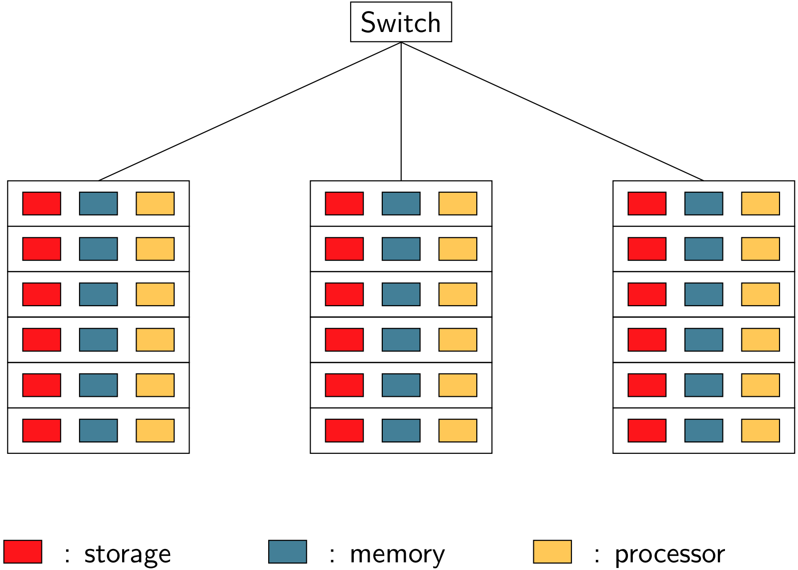
- Low control on the resources
- Example: Access to resources based on bidding
- See "The Netflix Simian Army"

☹ Performance variability

- Physical resources shared with other users

Architecture of a data center

Simplified



Architecture of a data center

A shared-nothing architecture

- Horizontal scaling
- No specific hardware

A hierarchical infrastructure

- Resources clustered in racks
- Communication inside a rack is more efficient than between racks
- Resources can even be geographically distributed over several datacenters

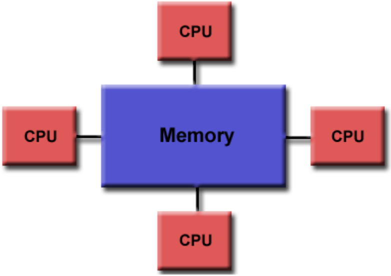
A hybrid system

Two paradigms for communicating between computing entities:

- Shared memory
- Message passing

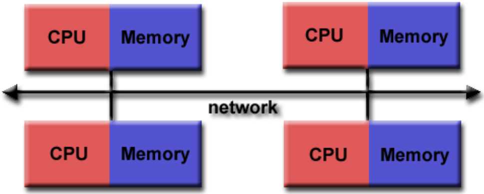
Shared memory

- Entities share a global memory
- Communication by reading and writing to the globally shared memory
- Communication between threads inside one node



Message passing

- Entities have their own private memory
- Communication by sending/receiving messages over a network
- Communication between nodes



Agenda

Running at scale

How to distribute data?

- Partitioning
- Replication

Running at scale

How to distribute data?

- Partitioning
- Replication

Replication

- Several nodes host a copy of the data
- Main goal: Fault tolerance
  - No data lost if one node crashes

Partitioning

- Splitting the data into partitions
- Partitions are assigned to different nodes
- Main goal: Performance
  - Partitions can be processed in parallel

Replication

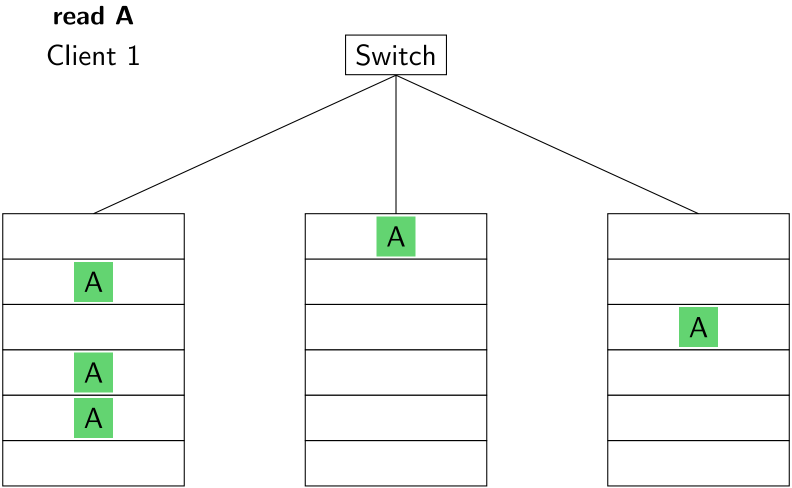
Purposes

- Continuing to serve requests when parts of the system fail
- Keep data close to the users
- Having multiple servers able to answer read requests

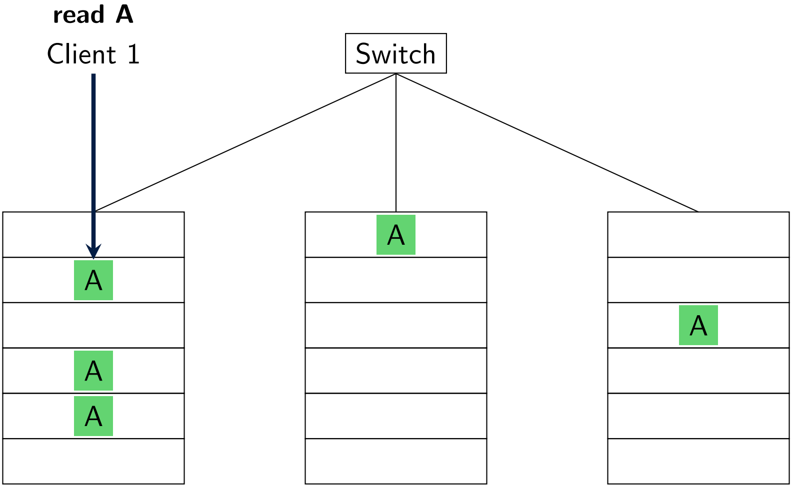
Challenges

- How to handle operations that modify data? (write operations)
  - Consistency (Consensus in a distributed system is a very difficult problem)
  - Performance

Replication



Replication



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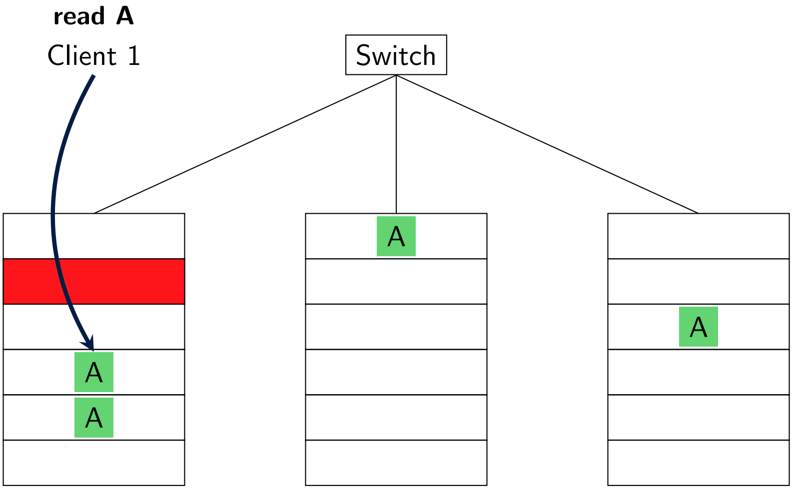

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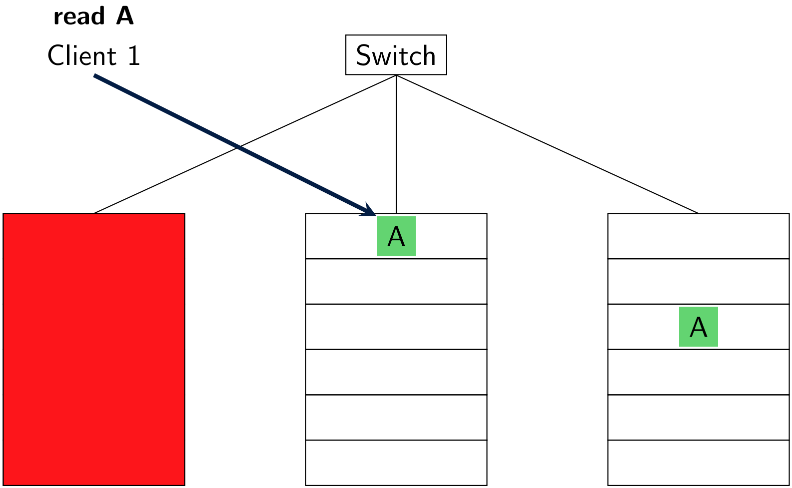

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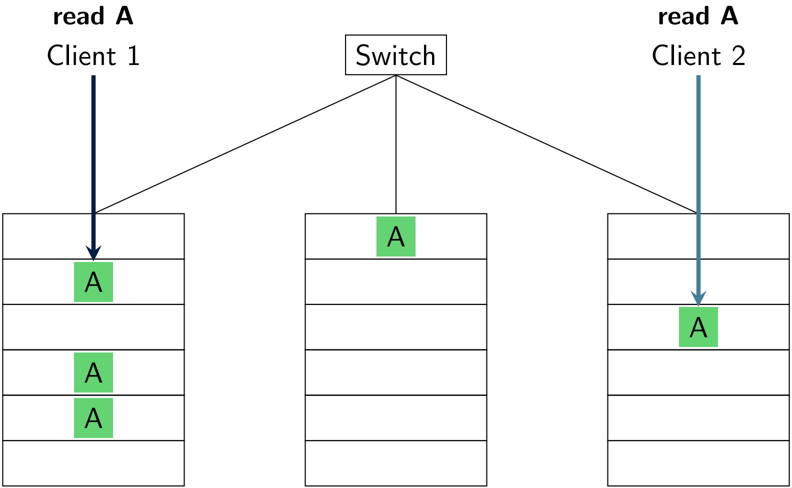

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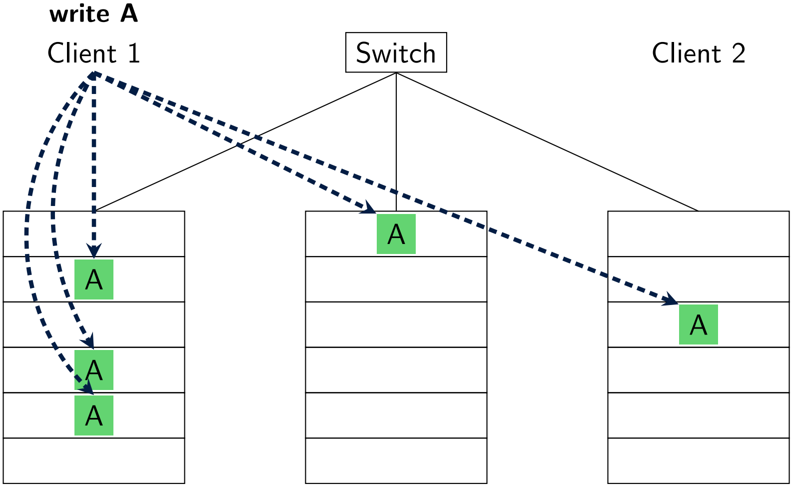

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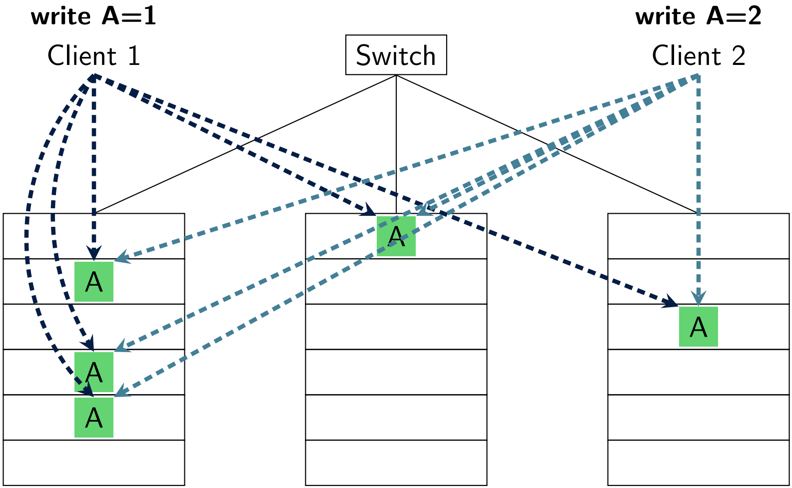

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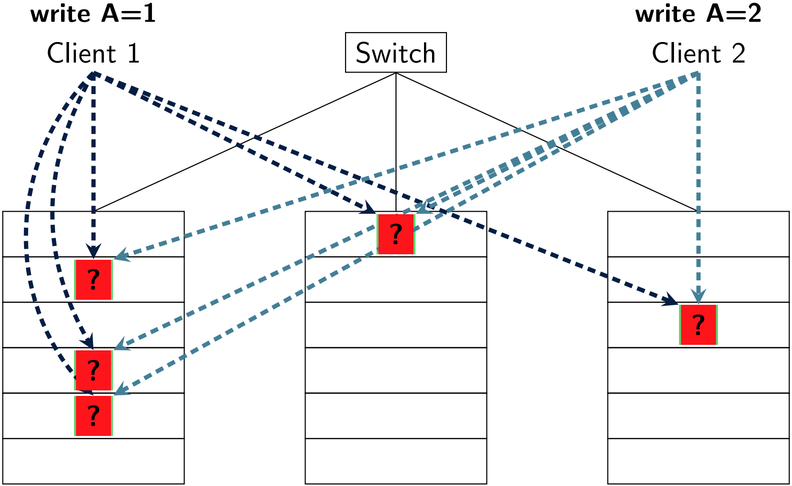


Partitioning
Sharding

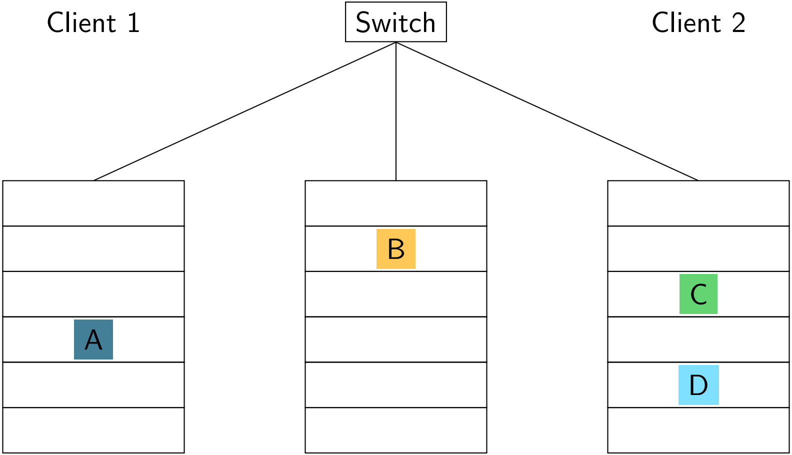
Purposes

- Performance
  - Distributing the load over several nodes

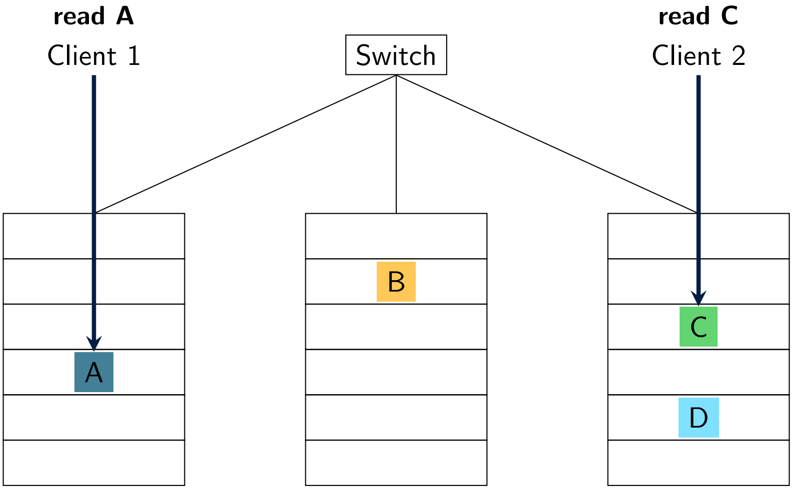
Challenges

- How to partition the data?
  - Evenly distributed load (even for skewed workloads)
  - Range queries

Partitioning



Partitioning



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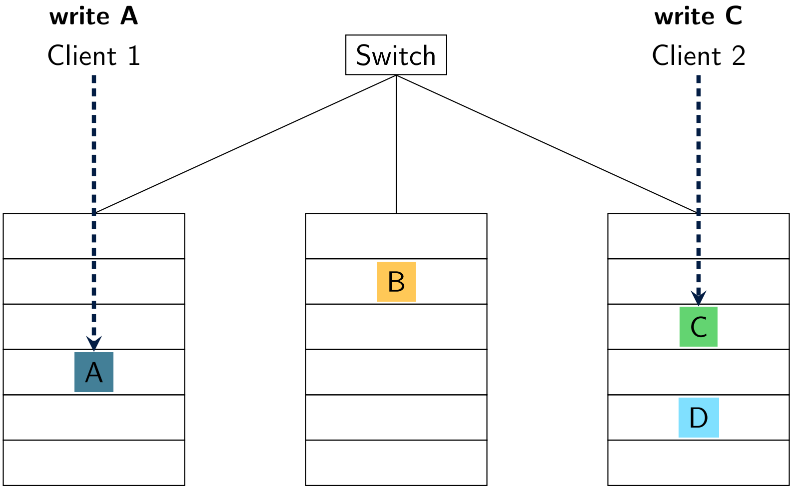
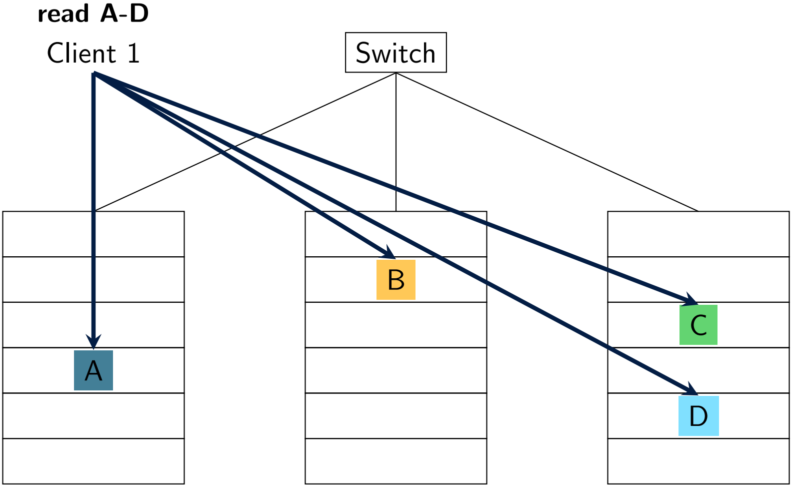
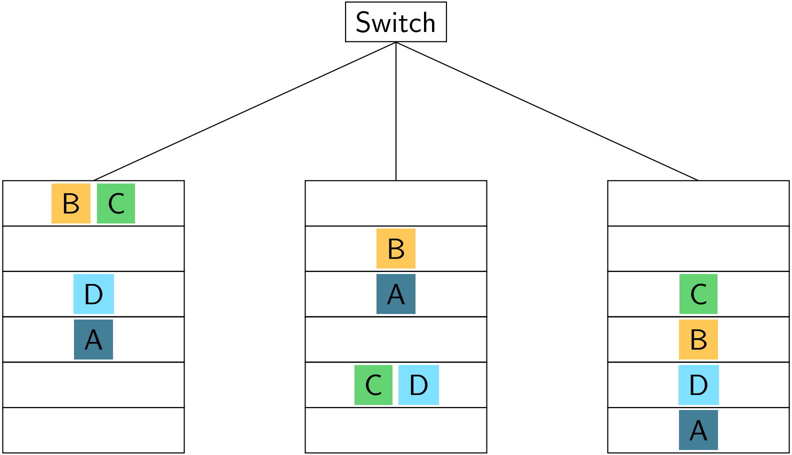


Partitioning



Partitioning + Replication



More references

Mandatory reading

- *Big data and its technical challenges*, by Jagadish et al, CACM 2014.

Suggested reading

- Chapter 1 of *Designing Data-Intensive Applications* by Martin Kleppmann
- The Netflix Simian Army[1]

[1] https://medium.com/netflix-techblog/the-netflix-simian-army-16e57fbab116