Data Management in Large-Scale Distributed Systems

Introduction

Thomas Ropars

thomas.ropars@univ-grenoble-alpes.fr

http://tropars.github.io/

2019
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\textsuperscript{1}
• 40K search queries on Google every second\textsuperscript{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

\textsuperscript{1}https://www.slideshare.net/BernardMarr/big-data-25-facts
\textsuperscript{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

The challenges of Big Data

Distributed and Parallel Systems

Cloud Computing

Running at scale
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
• Cluster of commodity servers

Pros and Cons
😎 Often requires modifying applications
😊 Less expensive (nodes can be turned off when not needed)
😊 Infinite scalability

The solution studied in this course
Large scale infrastructures

**Figure:** Google Data-center

**Figure:** Barcelona Supercomputing Center

**Figure:** Amazon Data-center
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. How to take advantage of a large number of distributed resources?
2. 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?

1Read Chapter 1 of Designing Data-Intensive Applications for further details
Distributed computing: Challenges

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?

\[1\text{Read Chapter 1 of }\ Designing\ Data-Intensive\ Applications\ for\ further\ details\]
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 \(\approx\) 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

The challenges of Big Data

Distributed and Parallel Systems

Cloud Computing

Running at scale
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

Switch

- : storage
- : memory
- : processor
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

The challenges of Big Data

Distributed and Parallel Systems

Cloud Computing

Running at scale
Running at scale

How to distribute data?

- Partitioning
- Replication

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

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

Client 1

read A

Switch

Client 2

write A = 1

write A = 2
Replication

Client 1 reads A

Switch

Client 2 writes A=1

Client 2 writes A=2

Client 1 reads A
Replication

Client 1

Switch

read A

write A

write A = 1

write A = 2
Replication

Client 1

Switch

read A

write A

write A=1

write A=2

??
Replication

Client 1

read A

Switch

write A

Client 2

write A=1

write A=2

read A
Replication

write A
Client 1

Switch

Client 2

read A
write A
write A=1
write A=2
Replication

write A=1
Client 1

Switch

write A=2
Client 2

A

A

A

A

A

A

A

A

A

A
Replication

write A=1
Client 1

write A=2
Client 2

Switch
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

Client 1

Switch

Client 2

A

B

C

D

read A
read C
write A
write C
read A-D
Partitioning

Client 1
- read A

Client 2
- read C

Switch

A
B
C
D
Partitioning

write A
Client 1

write C
Client 2

Client 1
read A
write A
read A-D

Client 2
read C
write C

Switch

A
B
C
D
Partitioning

Client 1 reads A and A-D. Switch is connected to clients A, B, C, and D. Client 1 writes to A and C.
Partitioning + Replication

Switch

B  C
D  A

B
A

C  D

C  B
D  A
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 Army¹

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