DISTRIBUTED SYSTEMS

LECTURE 1

INTRODUCTION

OUTLINE

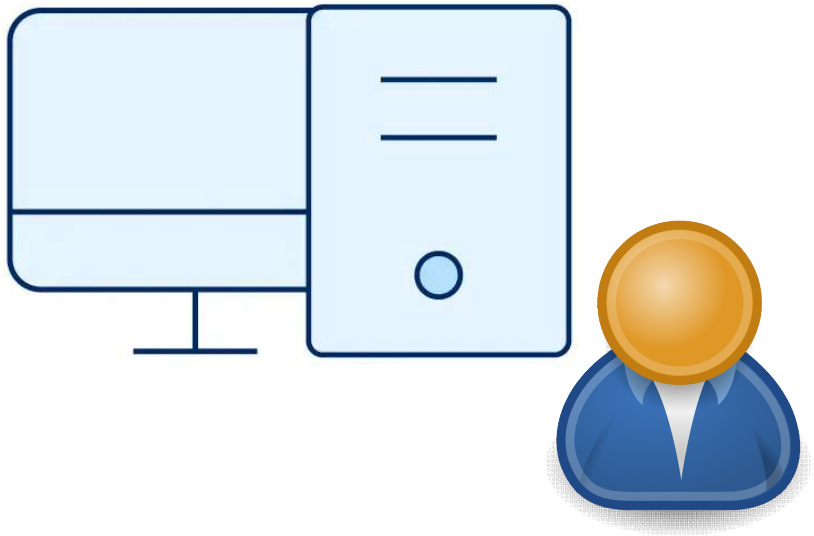
- Introduction
- Concepts and use-cases
- Challenges
- Trends in distributed systems
- Summary
- Discussion
- References

INTRODUCTION

WHY DO DISTRIBUTED SYSTEMS MAKE SENSE?

A FILE SHARING SYSTEM

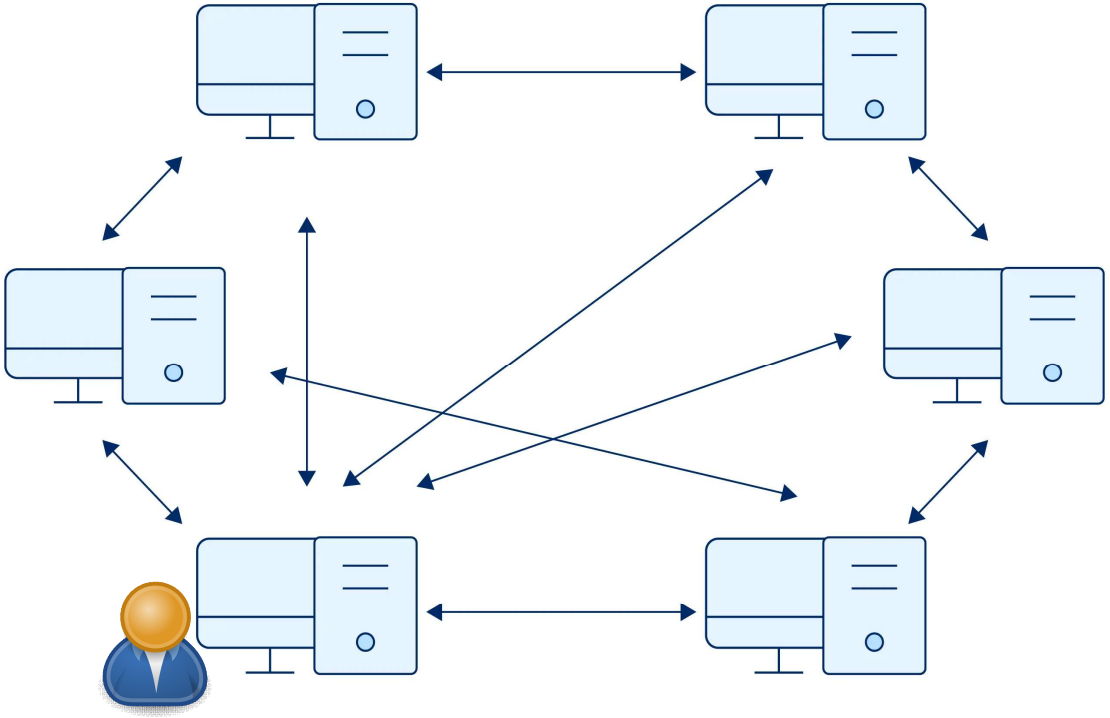
- Bob wants to share his movies to his friends
- Bob also wants to get other movies from his friends



https://www.scaler.in/p2ppeer-to-peer-file-sharing/

A FILE SHARING SYSTEM

- Giving a computer network



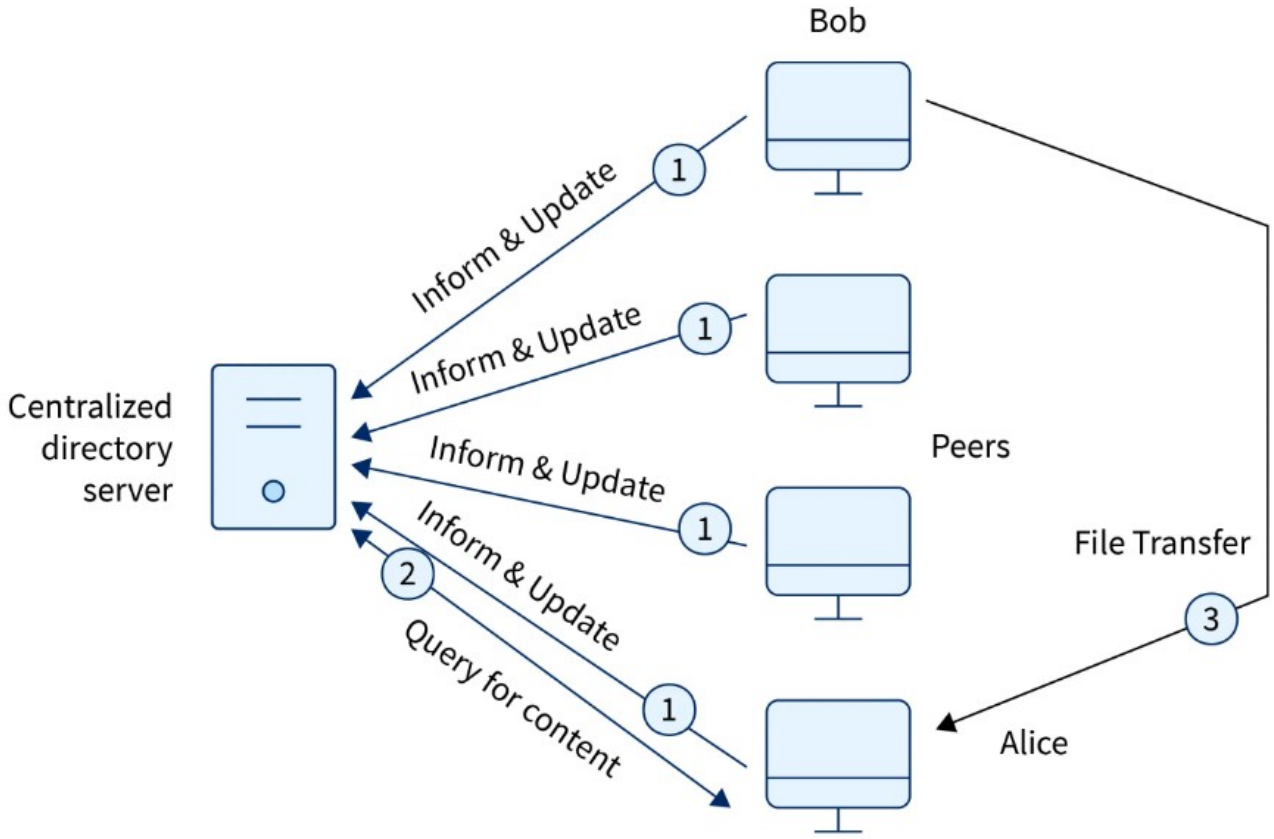
https://www.scaler.in/p2ppeer-to-peer-file-sharing/

A FILE SHARING SYSTEM

- Main research questions
  - How to store files in the network?
  - How to search for a file?
  - How to download that file?

A FILE SHARING SYSTEM

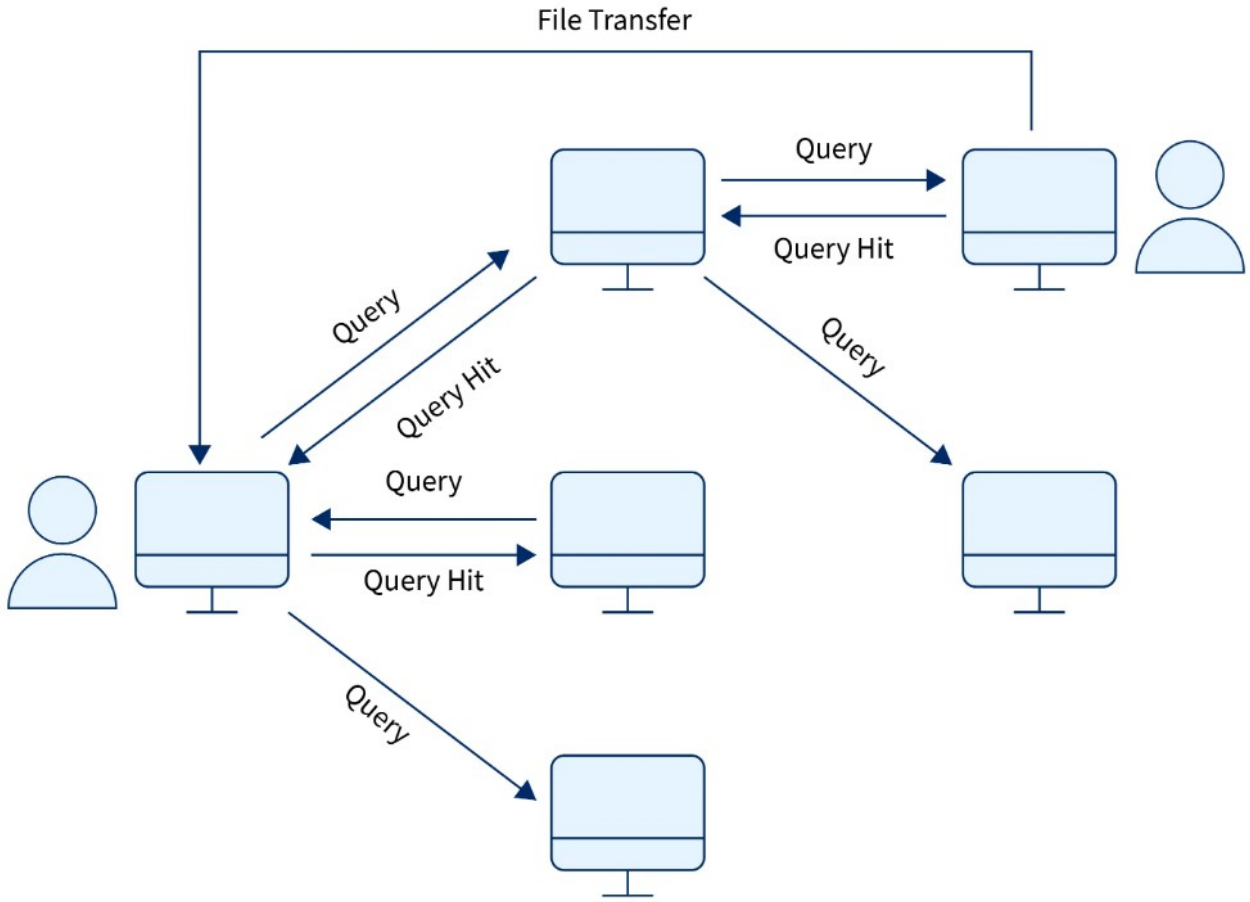
- A client-server architecture



https://www.scaler.in/p2ppeer-to-peer-file-sharing/

A FILE SHARING SYSTEM

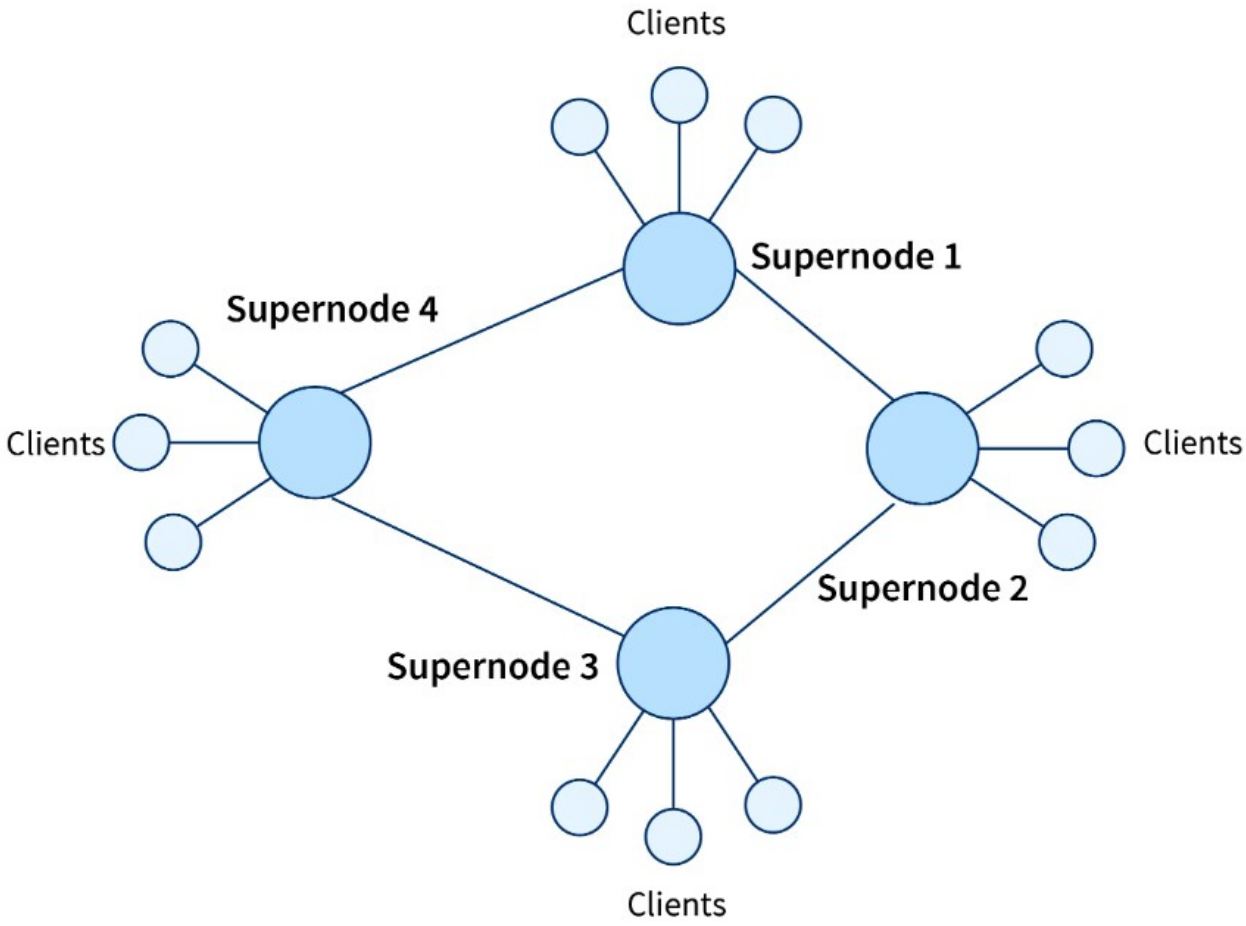
- A peer-to-peer architecture



https://www.scaler.in/p2ppeer-to-peer-file-sharin

A FILE SHARING SYSTEM

- A cluster architecture



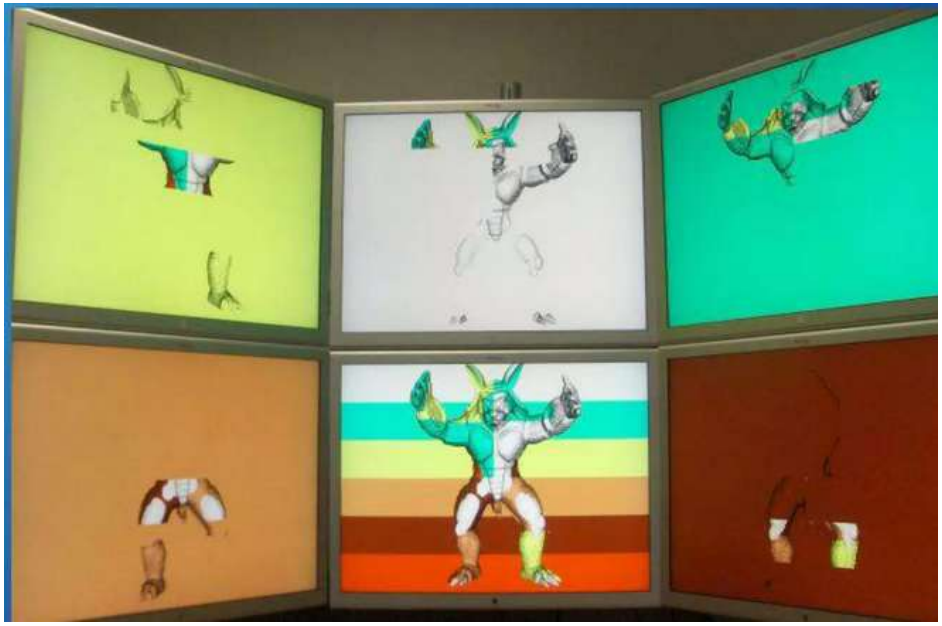
https://www.scaler.in/p2ppeer-to-peer-file-sharing/

A FILE SHARING SYSTEM

- Other challenges
  - Performance
  - Failure Tolerance
  - Big data
  - Scalability
  - Load balancing
  - Security
  - Etc.

OTHER SCENARIOS

- Games like StarCraft II, Diablo III, and World of Warcraft
- High Performance Computing
- Database systems
- Windows 10 update
- Blockchain
- Etc.

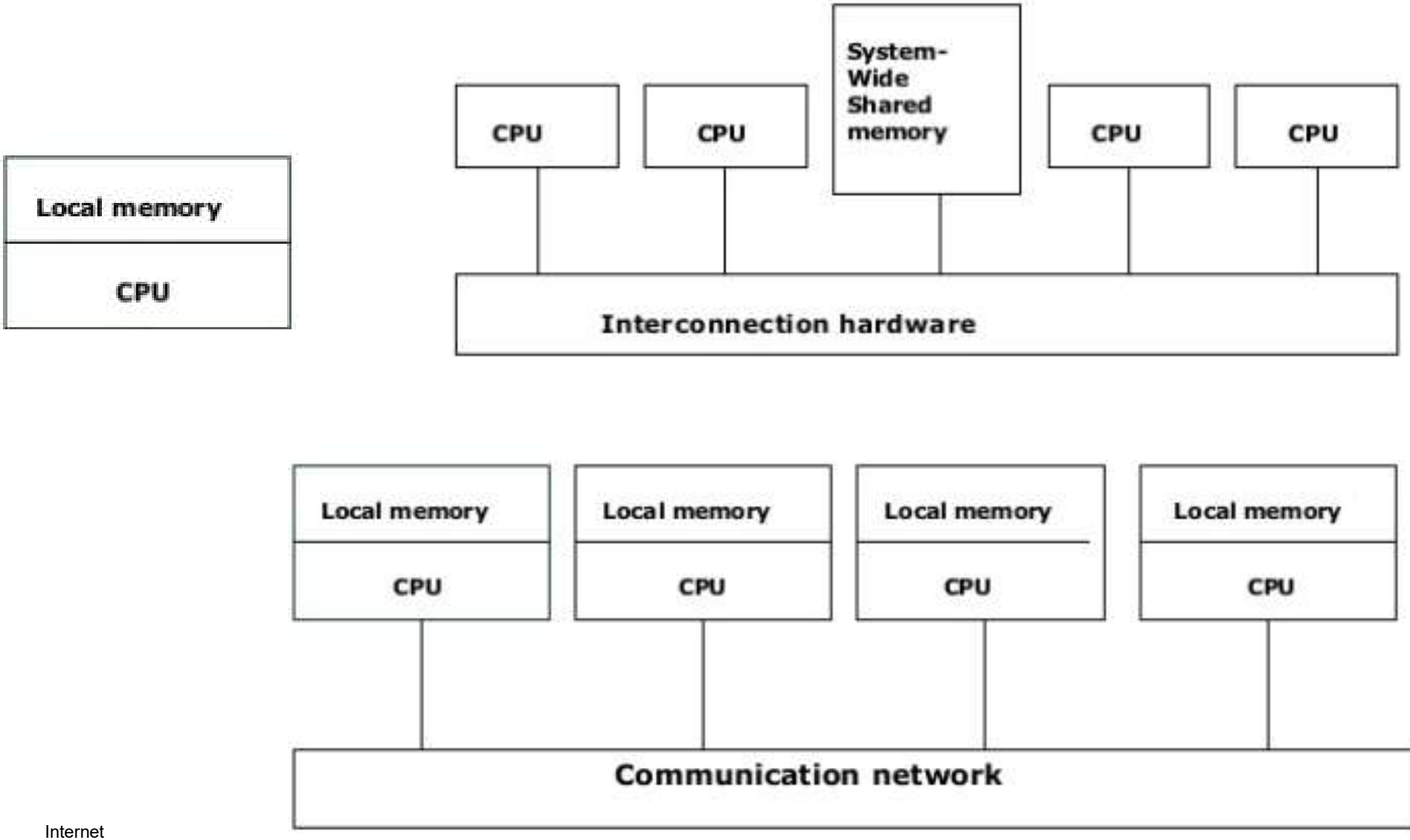


https://www.slideshare.net/AmanSrivastava20/distributed-systems-real-life-applications-53246784

CASE STUDIES

- Big data storage
- Similarity search with large dataset
- Large Language Model
- Smart traffic
- Cloud services
- Etc.

STANDALONE TO MULTIPLE MACHINES



BONEMET: AN OPEN LARGE-SCALE MULTI-MODAL MURINE DATASET FOR BREAST CANCER BONE METASTASIS DIAGNOSIS AND PROGNOSIS

Tiankuo Chu[1], **Fudong Lin**[2], **Shubo Wang**[1], **Jason Jiang**[3], **Wiley J.W. Gong**[1], **Xu Yuan**[2*], **Liyun Wang**[1†]

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[3]Department of Computer Science, University of Maryland

ABSTRACT

Breast cancer bone metastasis (BCBM) affects women's health globally, calling for the development of effective diagnosis and prognosis solutions. While deep learning has exhibited impressive capacities across various healthcare domains, its applicability in BCBM diseases is consistently hindered by the lack of an open, large-scale, deep learning-ready dataset. As such, we introduce the Bone Metastasis (BoneMet) dataset, the first large-scale, publicly available, high-resolution medical resource, which is derived from a well-accepted murine BCBM model. The *unique advantage* of BoneMet over existing human datasets is repeated sequential scans per subject over the entire disease development phases. The dataset consists of over *67 terabytes* of multi-modal medical data, including 2D X-ray images, 3D CT scans, and detailed biological data (*e.g.*, medical records and bone quantitative analysis), collected from more than five hundreds mice spanning from 2019 to

WHAT WE STUDY

- In this course, we discuss about
  - Distributed systems in overview
    - Concepts
    - Characteristics
    - Models
  - Popular and modern techniques for the implementation of distributed systems
    - Remote Procedure Call
    - Socket Programming
    - Message Queue Telemetry Transport
    - Web service
    - MapReduce paradigm

CONCEPTS AND USE-CASES

DISTRIBUTED AND PARALLEL COMPUTING

- Distributed Computing
  - A process of accomplishing a bigger task through splitting it into multiple subtasks.
  - Goal is to solve heavy computing problems with low cost.
- Parallel Computing
  - A type of computation in which many calculations or processes are carried out simultaneously.
  - Goal is to solve many computing problems at the same time (better throughput).

BEFORE DISTRIBUTED SYSTEMS

- Parallel computing during 70s and 80s
- Earlier distributed systems started dominating in the 1990s
  - The WWW
  - Airline reservation systems
  - Banking systems

DISCUSSION

“DISTRIBUTED SYSTEMS”
GUESS WHAT?

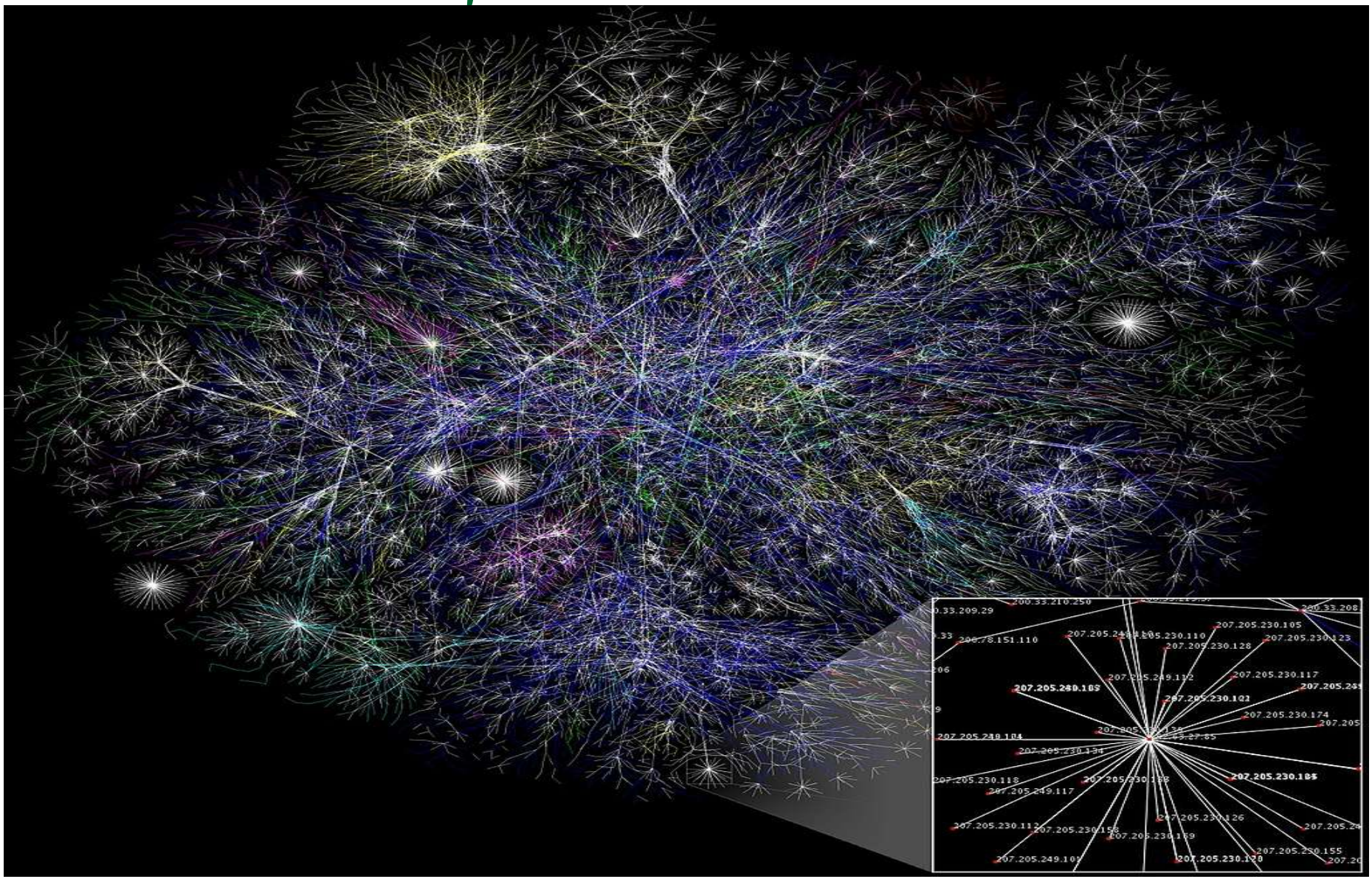
DISTRIBUTED SYSTEM

- "A distributed system as one in which hardware or software components located at networked computers communicate and coordinate their actions only by passing messages."
- A distributed system is a collection of independent computers (nodes) that work together, sharing resources like data or processing power and appearing to users as a single coherent system.

DISCUSSION

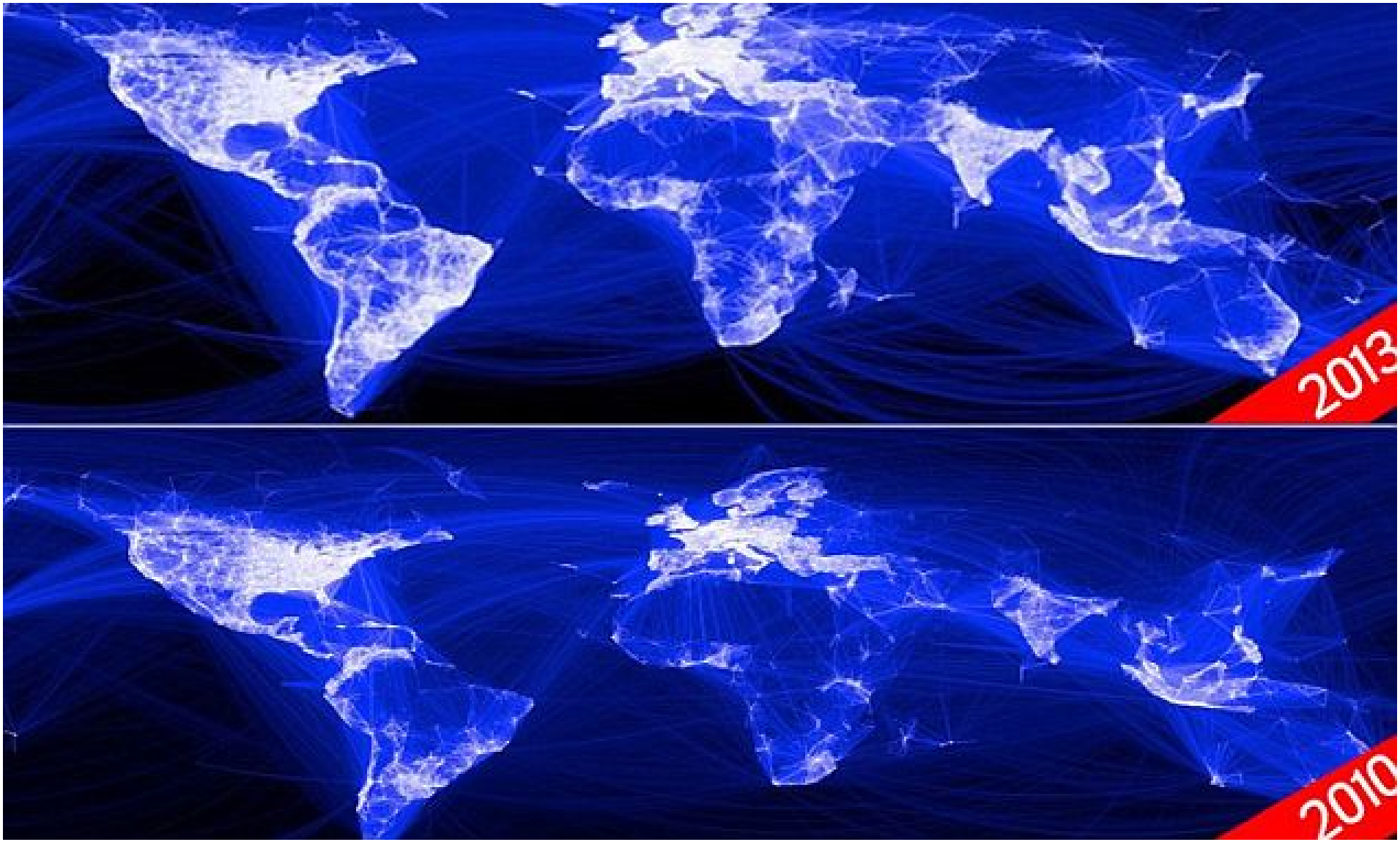
CAN YOU FIND EXAMPLES OF NETWORK OF COMPUTERS?

OPTE PROJECT 2005



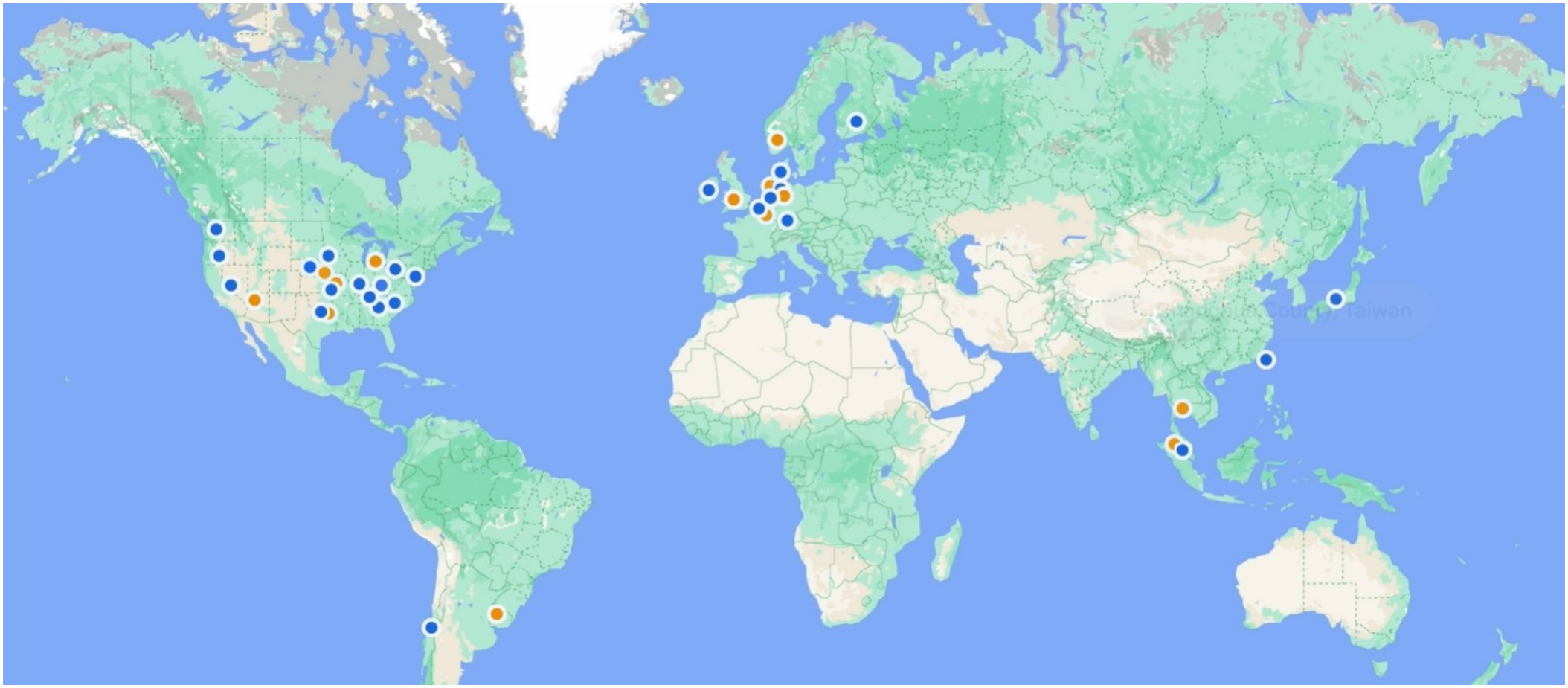
www.opte.org

FACEBOOK MAP



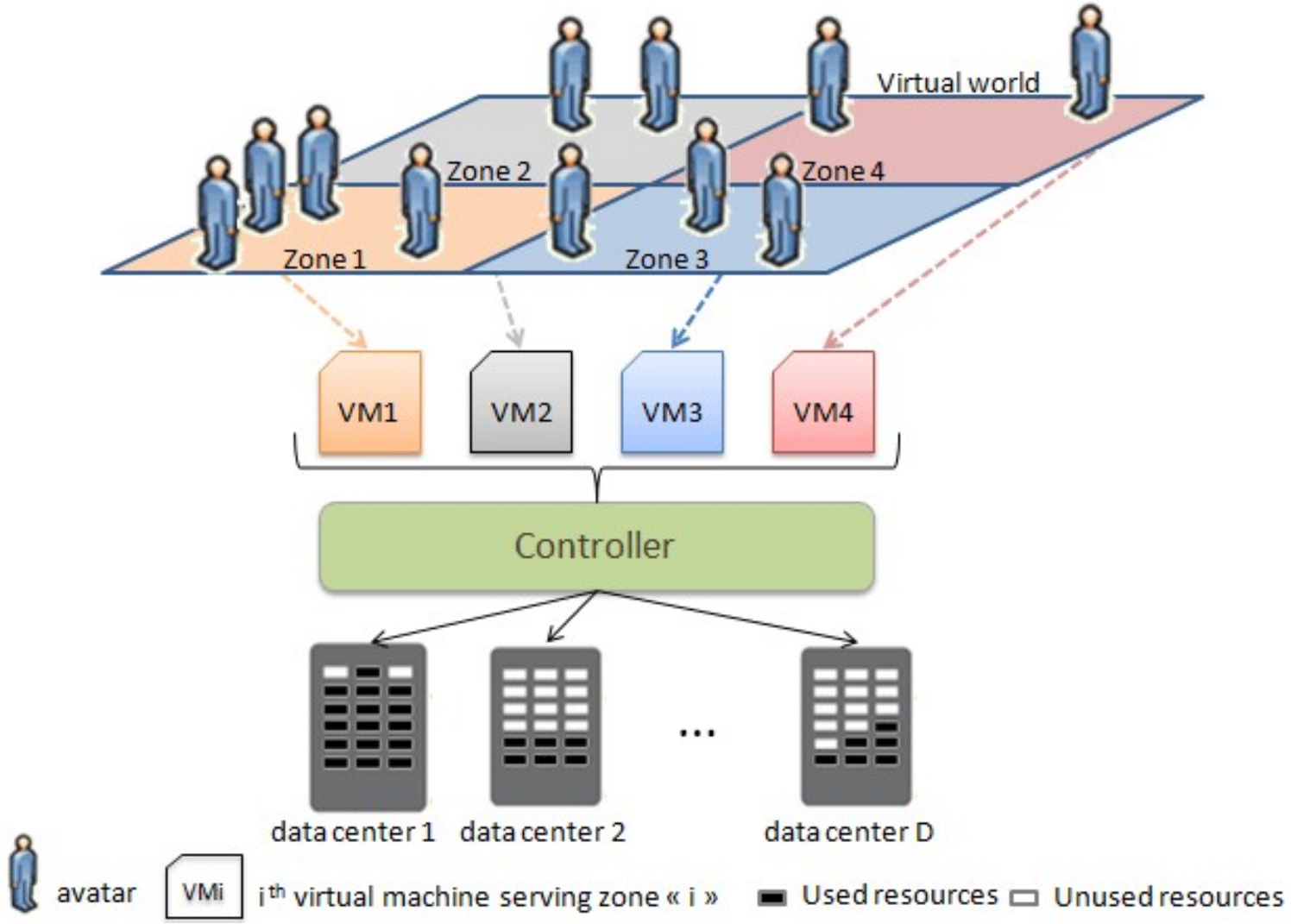
https://www.dailymail.co.uk/news/article-2431452/Blue-planet-New-Facebook-map-depicts-worlds-interconnected-friendships--unmistakable-black-hole-China.html

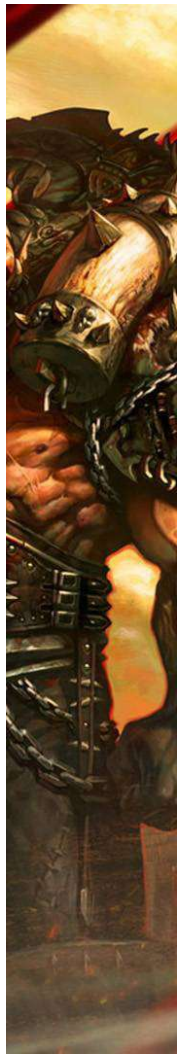
WEB SEARCH



https://datacenters.google/

MMOG



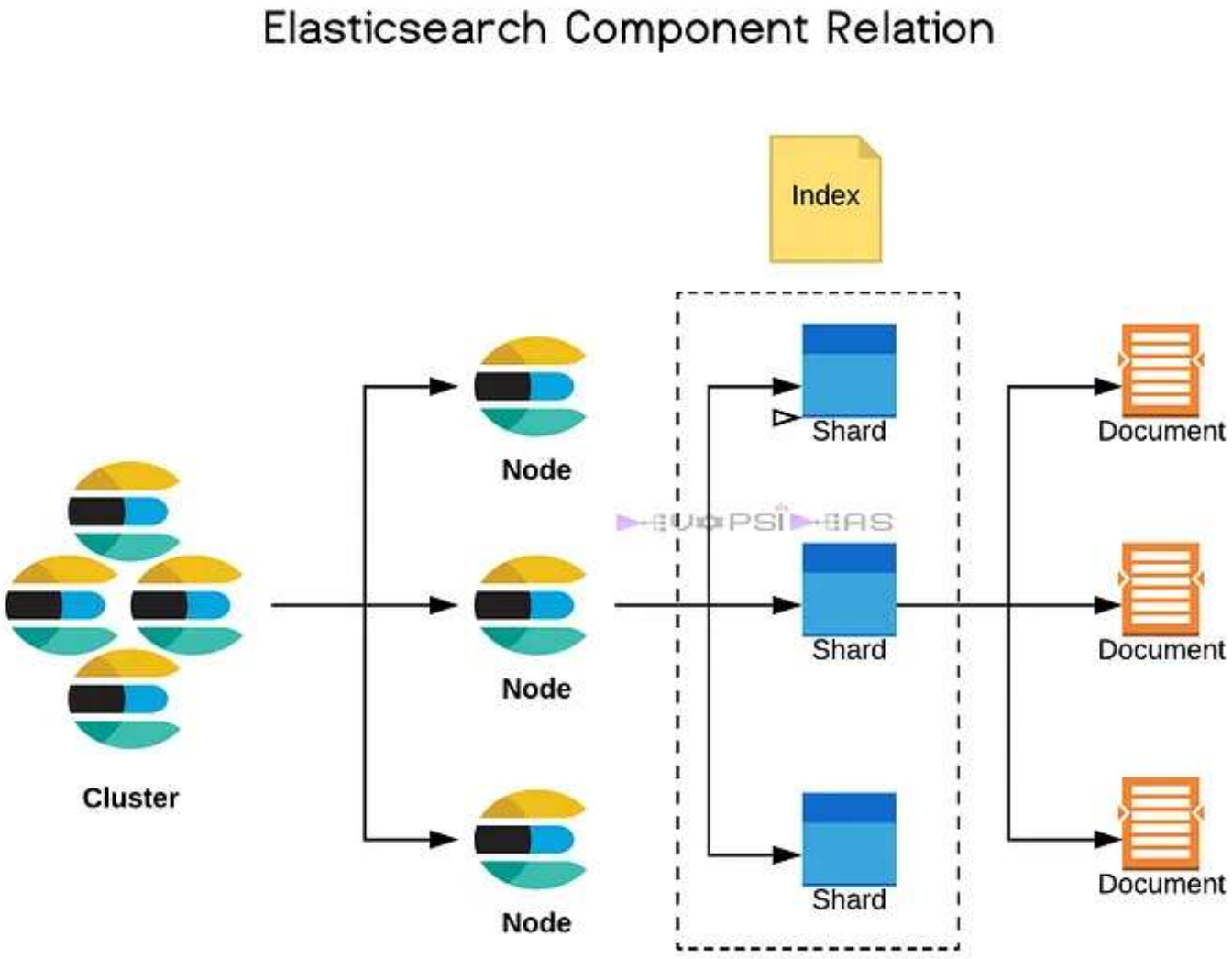


Internet; https://www.researchgate.net/figure/Distibuted-MMOG-architecture_fig2_337210529

EBAY

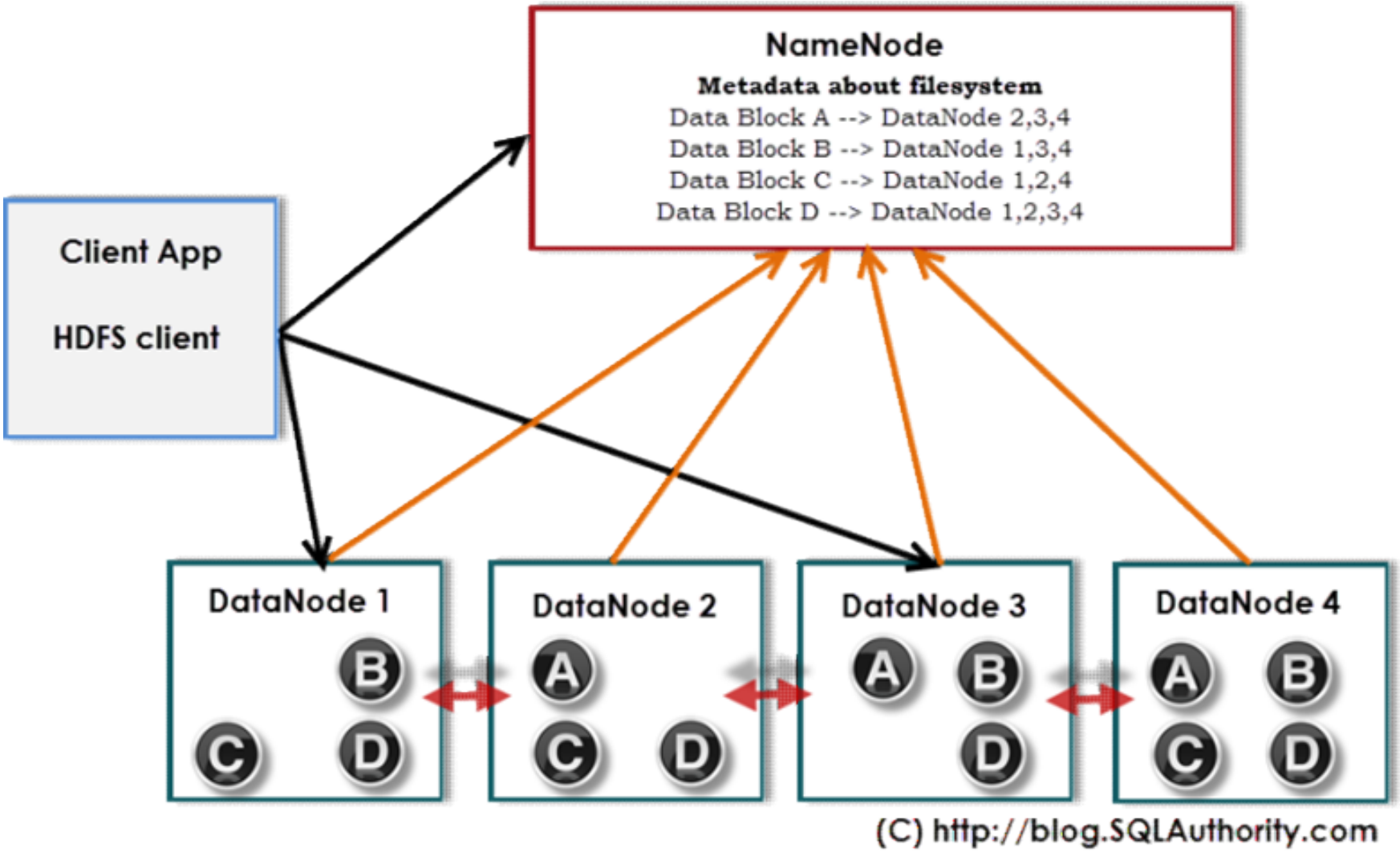
https://lh3.googleusercontent.com/XIrKX_wt5koHZvCuWwm8LazJo0lHXe1aSy_IrJWu6EzUbZTv1XZx3L0IJN9UOO7md7V5_F_7cg=w640-h400-e365;
https://computer.howstuffworks.com/internet/basics/ebay2.htm

ELASTIC SEARCH



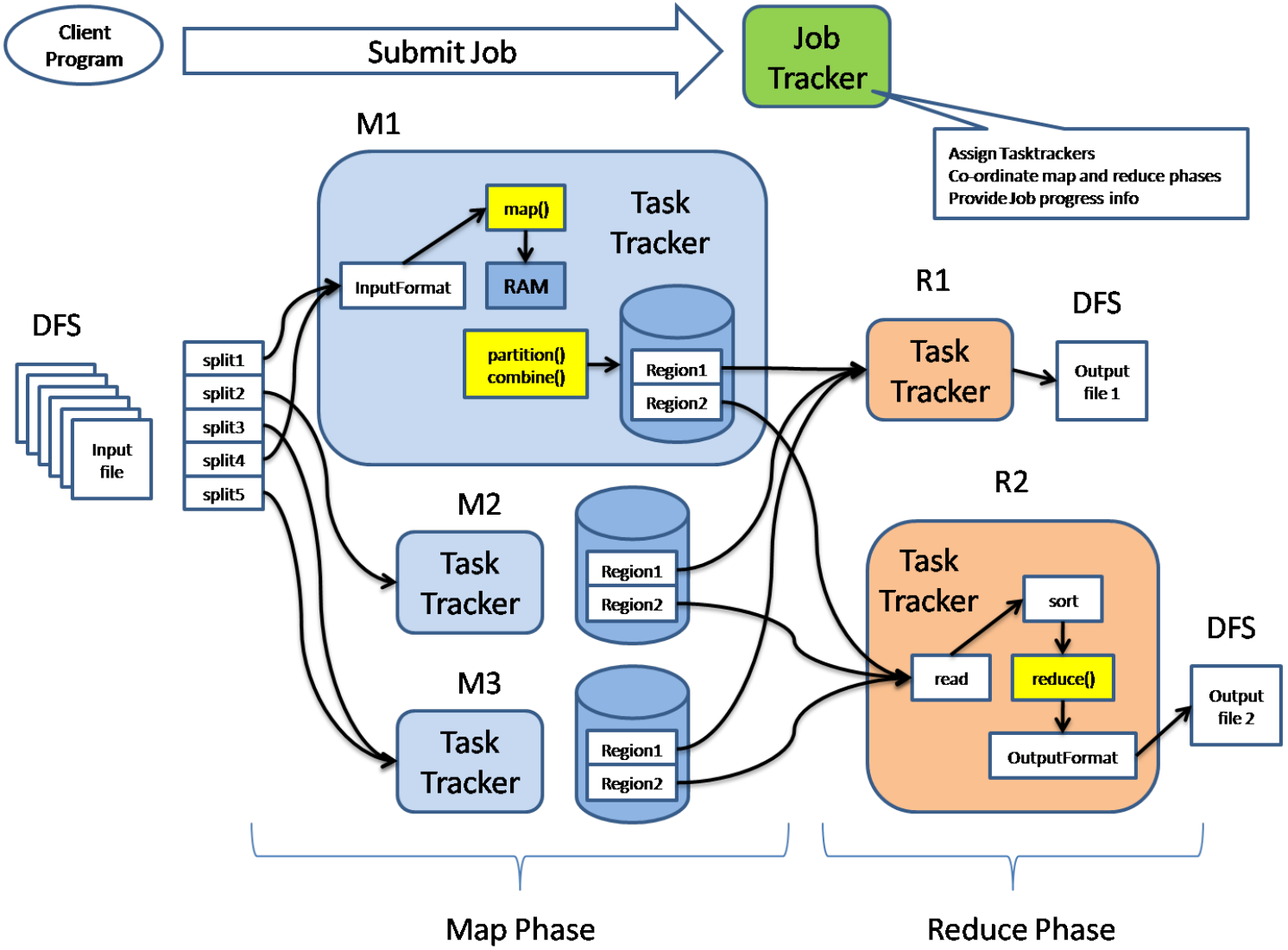
https://medium.com/geekculture/elasticsearch-architecture-1f40b93da719

HADOOP DISTRIBUTED FILE SYSTEM



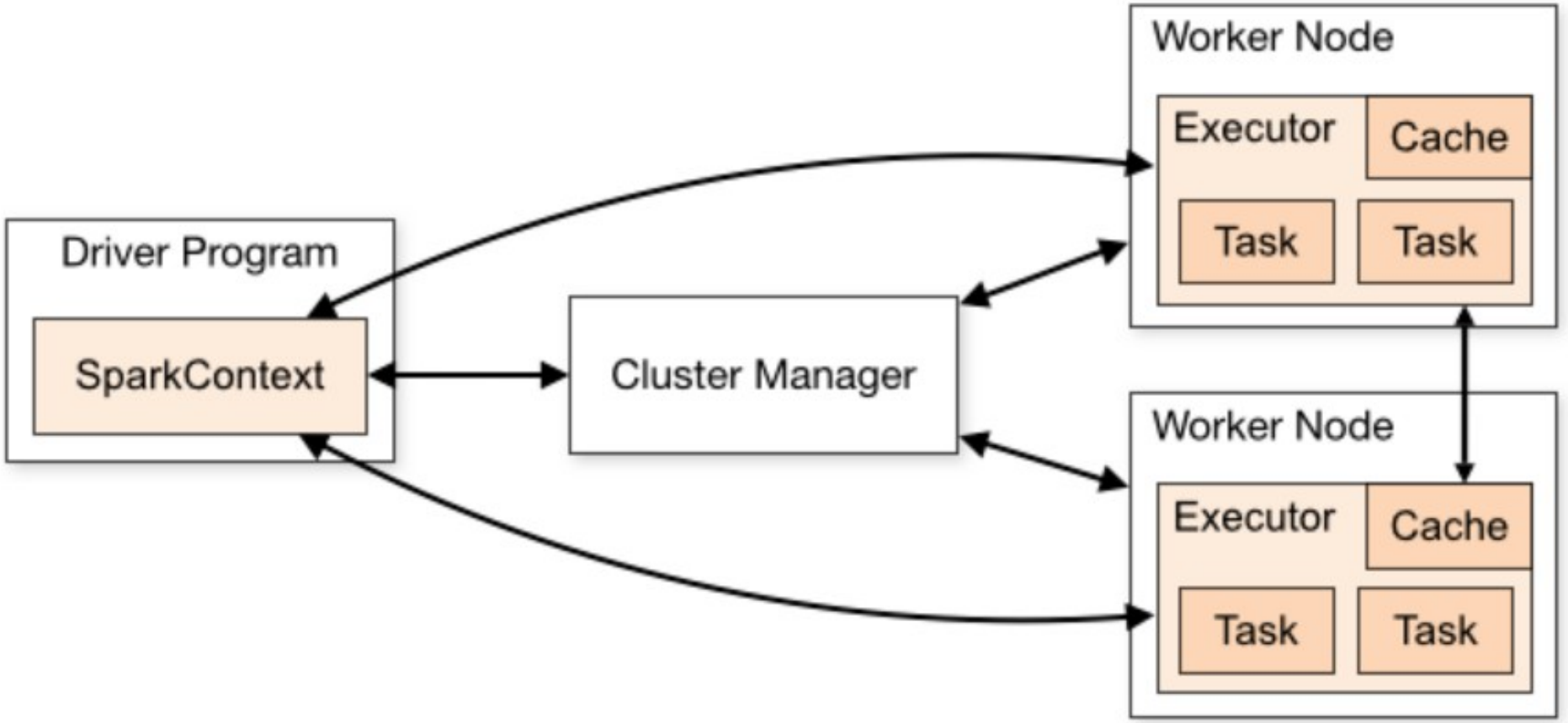
https://expressmagazine.net/posts/view/3674/ngay-8-hoc-hdfs-la-viet-tat-cua-hadoop-distributed-file-system

HADOOP MAPREDUCE



https://www.pluralsight.com/guides/getting-started-with-hadoop-mapreduce

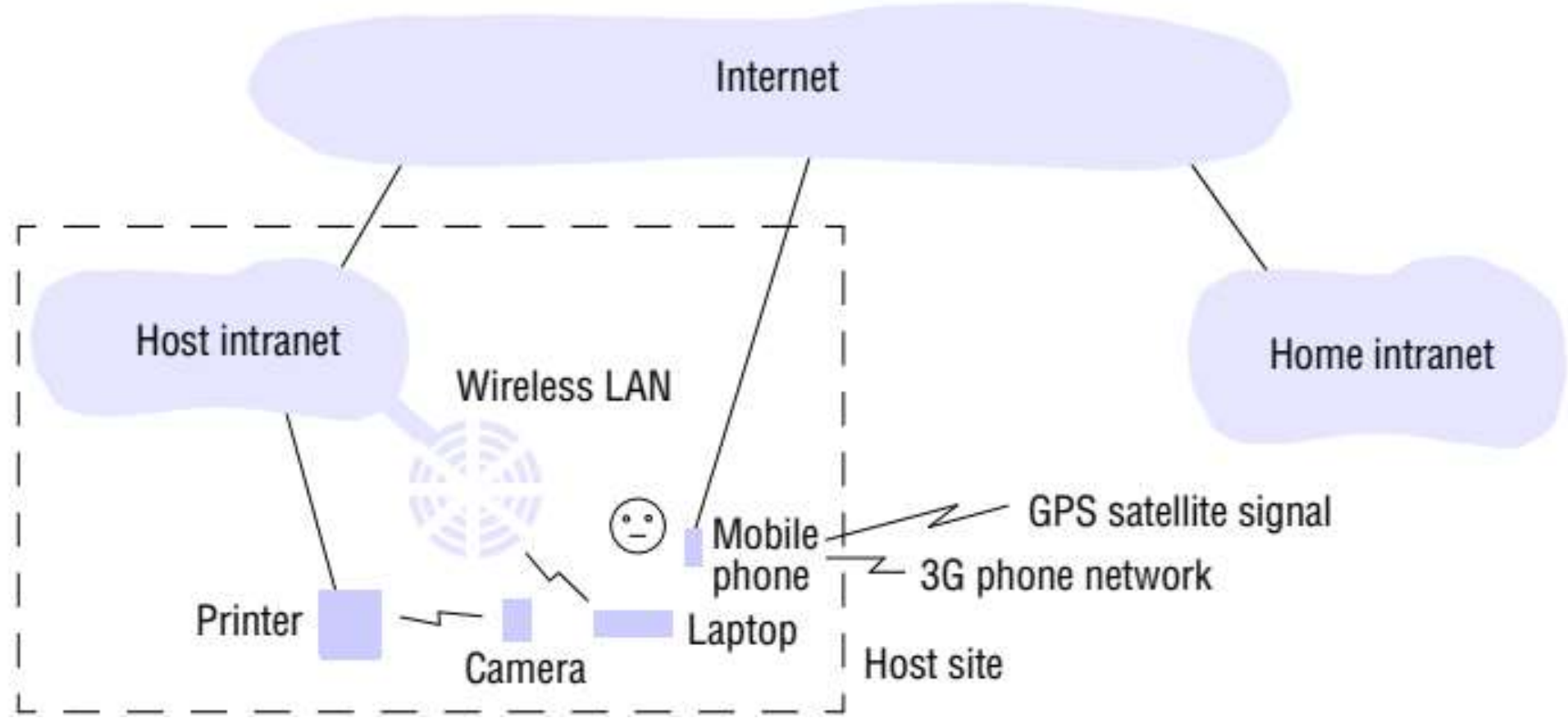
APACHE SPARK



https://spark.apache.org/docs/latest/cluster-overview.html

SUPPORTING TECHNOLOGY (1/3)

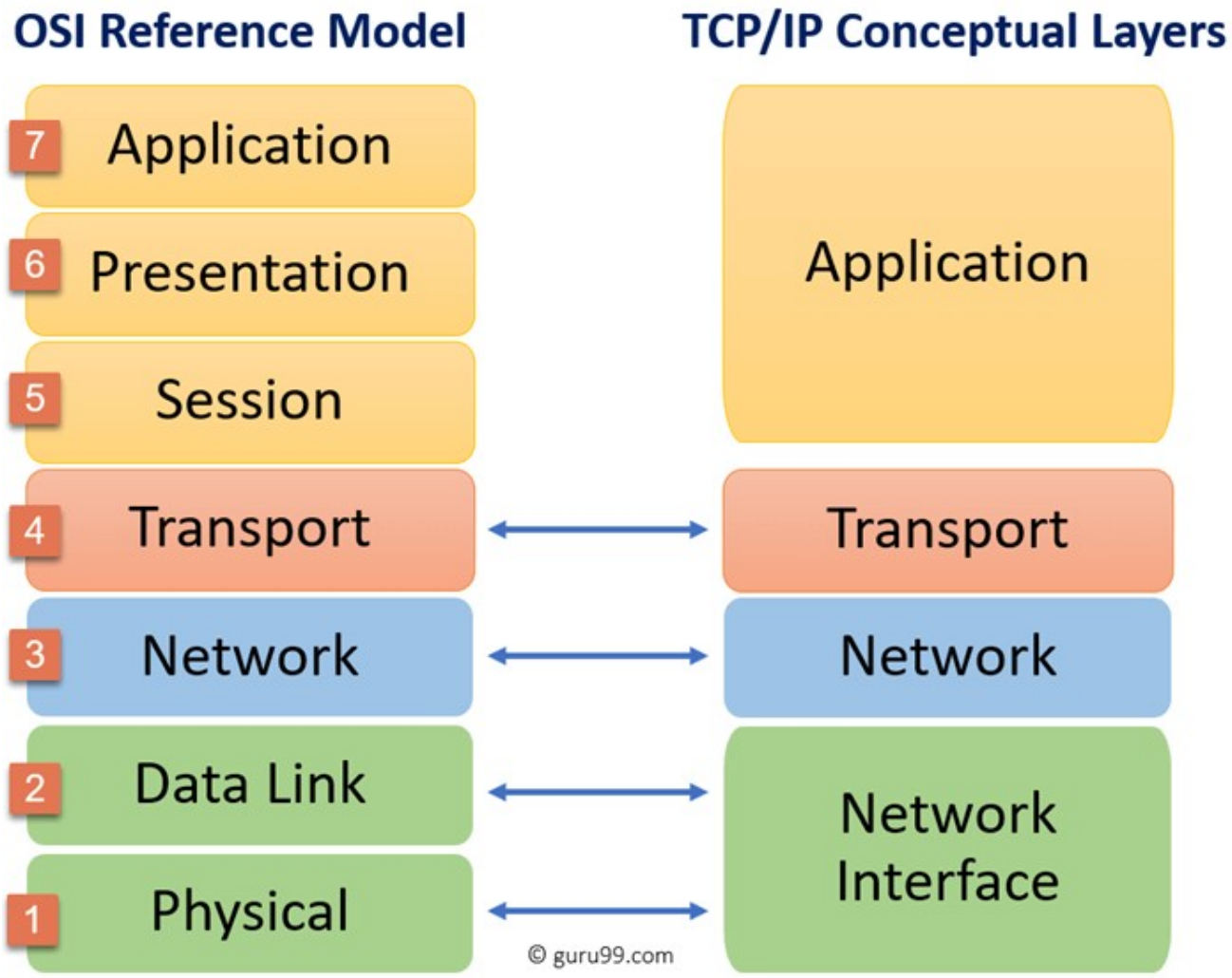
- Internet & IoT



[1]

SUPPORTING TECHNOLOGY (2/3)

- Internet



SUPPORTING TECHNOLOGY (3/3)

- Message Exchange Protocols
  - Java RMI
  - Socket Programming
  - Message Queue Telemetry Transport
  - Web service
  - MapReduce paradigm
  - Etc.

WHY IS IT USEFUL?

- Resource sharing with heterogeneity
  - Hardwares
  - Softwares
  - Data and database
- Performance
- Availability
- Reliability
- Scalability

➔ Utility, economy, and mobility

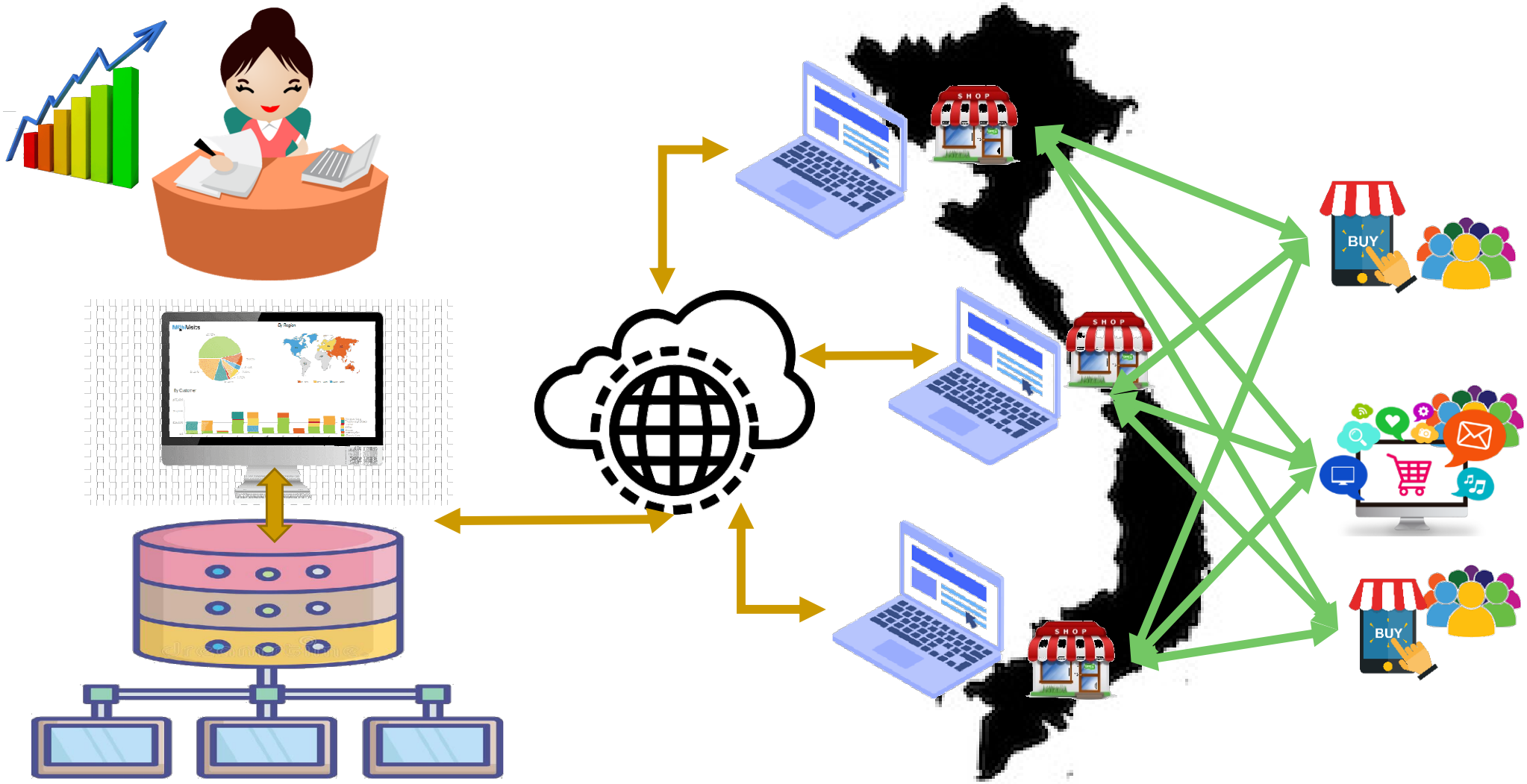
DISCUSSION

DISTRIBUTED SYSTEM IS GOOD, BUT …

DISTRIBUTED SYSTEMS LEAD TO…

- Concurrency
  - Concurrent program execution (accesses to the same resource at the same time)
- No global clock
  - Limits to the accuracy with which the computers in a network can synchronize their clocks
- Independent failures
  - Each component of the system can fail independently, leaving the others still running
- No global state

WHAT IS THE PROBLEM?



- http://www.dinh.vip/small-store-icon-psd-free-psd; https://iconbug.com/data/06/512/f91d30a37d1b631de0005b1402442924.png; https://static.pakwheels.com/2015/06/graph.gif; https://image.shutterstock.com/image-vector/high-detailed-vector-map-vietnam-260nw-150472901.jpg; https://encrypted-tbn0.gstatic.com/images?q=tbn%3AANd9GcQeeOZor21HxfRcdDaFqBdsNqBknZoYjo1b1h8Lv0FAmwXwLjqr&usqp=CAU; https://st2.depositphotos.com/1001911/7684/v/450/depositphotos_76840879-stock-illustration-depressed-emoticon.jpg; https://www.onlinewebfonts.com/icon/504308; https://encrypted-tbn0.gstatic.com/images?q=tbn%3AANd9GcRxN_w4kEKxFlrNl_P7sJrrlaKDbPgnxeleV3aZO7uCuRPPibJ8&usqp=CAU; https://telegramchannels.me/stickers/s-thevirus; https://thumbs.dreamstime.com/b/centralized-database-fill-vector-icon-which-can-easily-modify-edit-centralized-database-fill-vector-icon-which-can-easily-185306424.jpg; https://e7.pngegg.com/pngimages/56/552/png-clipart-dashboard-business-intelligence-report-analytics-computer-icons-analysis-company-display-advertising.png

CHALLENGES

CHALLENGES (1/9)

Heterogeneity

Openness

Scalability

Security

Failure handling

Concurrency

Transparency

Quality of service

CHALLENGES (2/9)

- Heterogeneity (variety and difference)
  - Networks;
  - Computer hardware;
  - Operating systems;
  - Programming languages;
  - Implementations by different developers.

CHALLENGES (3/9)

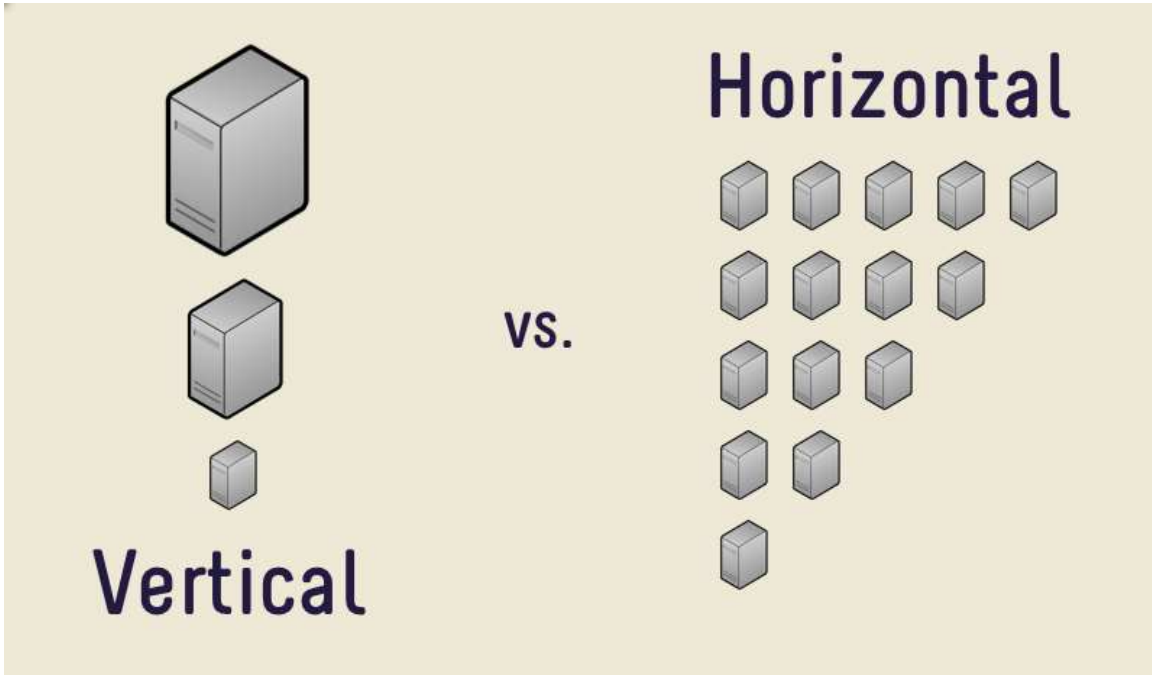
- Openness
  - The characteristic that determines whether the system can be extended and reimplemented in various ways.
  - At the hardware level
  - At the software level

CHALLENGES (4/9)

- Scalability
  - A system is described as scalable if it will remain effective when there is a significant increase in the number of resources and the number of users.
  - Effectiveness
    - Reasonable cost
    - Performance
    - Little bottleneck
- Do you know two major types of scalability?

TWO MAJOR TYPES OF SCALABILITY

- Vertical scaling
  - Scale up
- Horizontal scaling
  - Scale out



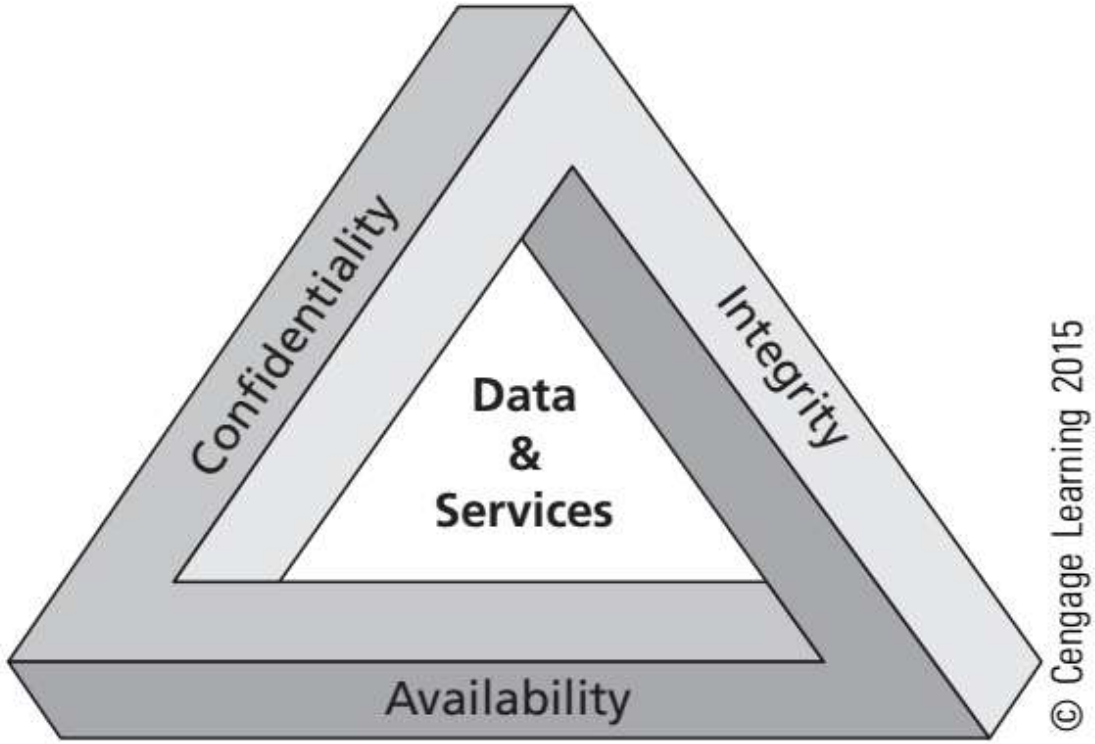
https://1.bp.blogspot.com/-58qlT6bSnC0/VoTvX08YByI/AAAAAAAAGF8/aTJM7229jfA/s1600/horizontal-vs-vertical-scaling-vertical-and-horizontal-scaling-explained-diagram.png

SOME FACTS

Date	*Computers*	*Web servers*	*Percentage*
1993, July	1,776,000	130	0.008
1995, July	6,642,000	23,500	0.4
1997, July	19,540,000	1,203,096	6
1999, July	56,218,000	6,598,697	12
2001, July	125,888,197	31,299,592	25
		42,298,371	

CHALLENGES (5/9)

- Security
  - Confidentiality
  - Integrity
  - Availability

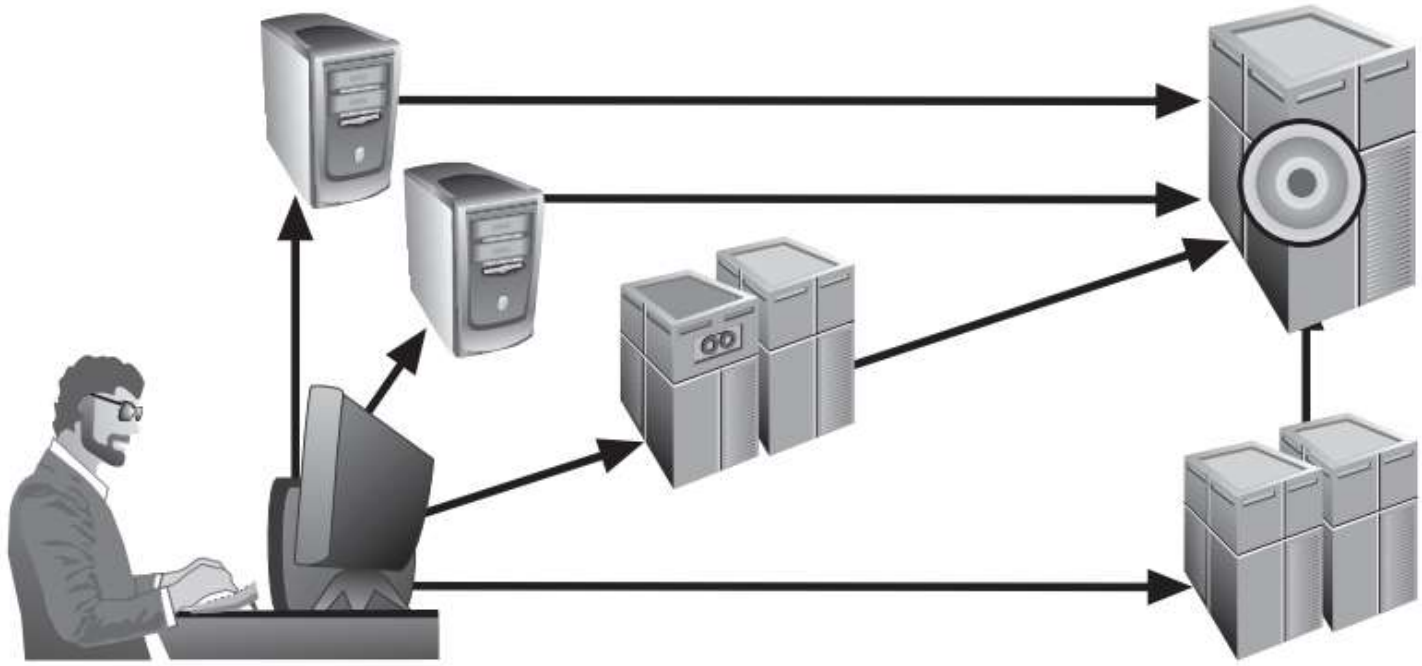


Michael E. Whitman, Herbert J. Mattord. Principles of Information Security, 6th Edition, Cengage Learning, pp. 656, 2017

DDOS

In a denial-of-service attack, a hacker compromises a system and uses that system to attack the target computer, flooding it with more requests for services than the target can handle.

In a distributed denial-of-service attack, dozens or even hundreds of computers (known as zombies) are compromised, loaded with DoS attack software, and then remotely activated by the hacker to conduct a coordinated attack.



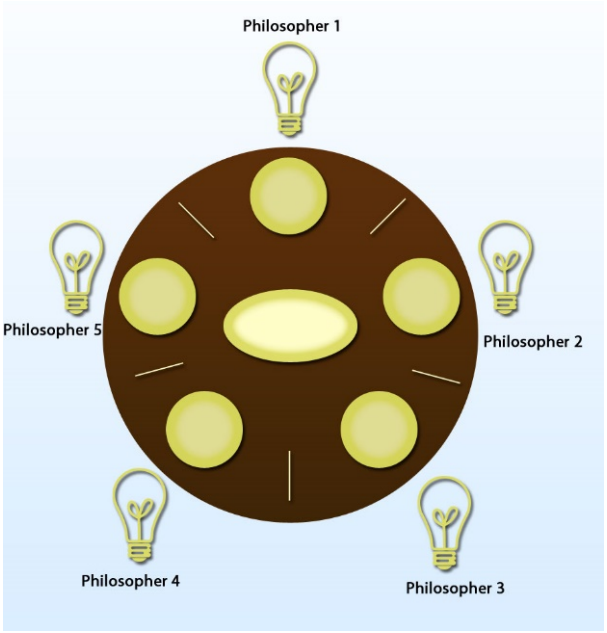
Michael E. Whitman, Herbert J. Mattord. Principles of Information Security, 6th Edition, Cengage Learning, pp. 656, 2017

CHALLENGES (6/9)

- Failure handling
  - Failures in a distributed system are partial – that is, some components fail while others continue to function.
    - Process
    - Channel
    - Computer
    - Part of computer
- What are other failures you may know?

CHALLENGES (7/9)

- Concurrency
  - Both services and applications provide resources that can be shared by clients in a distributed system.
  - Several clients will attempt to access a shared resource at the same time.
- Dining Philosophers
  - How to solve the deadlock?



https://commons.wikimedia.org/wiki/File:Dining-philosophers.jpg

CHALLENGES (8/9)

- Transparency
  - The concealment from the user and the application programmer of the separation of components in a distributed system, so that the system is perceived as a whole rather than as a collection of independent components.
    - Access transparency
    - Location transparency
    - Concurrency transparency
    - Replication transparency
    - Failure transparency
    - Mobility transparency
    - Performance transparency
    - Scaling transparency

CHALLENGES (9/9)

- Quality of service
  - Guarantees regarding the qualities associated with such service access.
    - Performance (e.g., reducing latency)
    - Security (e.g., improving CIA)
    - Reliability (e.g., reducing packet loss)

FALLACIES OF DISTRIBUTED COMPUTING (1/9)

1. The network is reliable
2. Latency is zero
3. Bandwidth is infinite
4. The network is secure
5. Topology doesn't change
6. There is one administrator
7. Transport cost is zero
8. The network is homogeneous

Developing distributed systems is HARD!

FALLACIES OF DISTRIBUTED COMPUTING (2/9)

- The network is reliable?
  - Reliability as the degree to which a product or service conforms to its specifications when in use, even in the case of failures.
  - Hardware and software may fail
  - E.g., powerloss, network errors, attacks
- Implications
  - Building fault-tolerance and redundancy
  - Having a reliable messaging such as message retry, message acknowledgement, message integrity verification, message order, message deduplication, etc.

FALLACIES OF DISTRIBUTED COMPUTING (3/9)

- Latency is Zero?
  - How much time it takes for data to move from one place to another (measured in time).
  - LAN vs. Internet
- Implications
  - Traffic proximity to clients

```
Pinging google.com [74.125.24.138] with 32 bytes of data:
Reply from 74.125.24.138: bytes=32 time=58ms TTL=58
Reply from 74.125.24.138: bytes=32 time=60ms TTL=58
Reply from 74.125.24.138: bytes=32 time=59ms TTL=58
Reply from 74.125.24.138: bytes=32 time=57ms TTL=58

Ping statistics for 74.125.24.138:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 57ms, Maximum = 60ms, Average = 58ms
```

  - Caching, event-driven protocol (e.g., WebSocket), server performance (e.g., processing speed, available RAM)

FALLACIES OF DISTRIBUTED COMPUTING (4/9)

- Bandwidth is infinite?
  - How much data you can transfer over a period of time (may be measured in bits/second).
  - High volume of data leads to queuing delays, bottlenecks, and network congestion
- Implications
  - Multiplexing
  - Lighweight data formats (e.g., JSON)
  - Network traffic control and monitoring

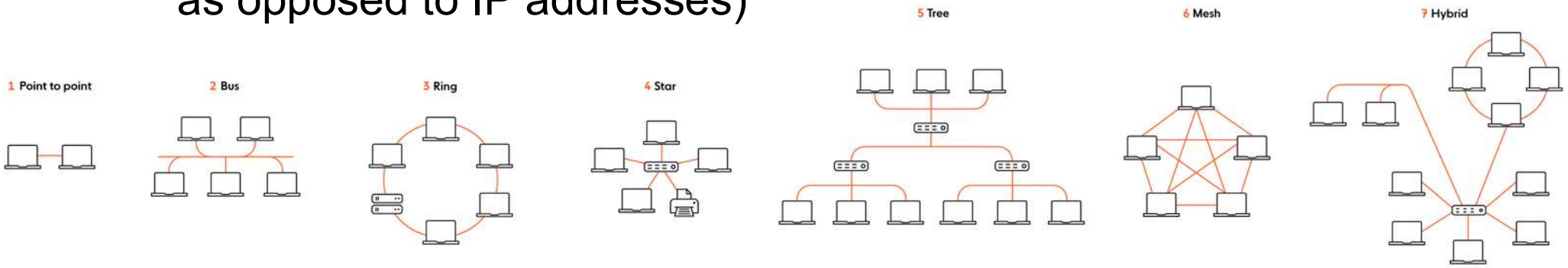
```
C:\Users\Lenovo>netsh wlan show interface

There is 1 interface on the system:

    Name                   : Wi-Fi
    Description            : Qualcomm Atheros AR956x Wireless Network Adapter
    GUID                   :
    Physical address       :
    State                  :
    SSID                   :
    BSSID                  :
    Network type           :
    Radio type             :
    Authentication         :
    Cipher                 :
    Connection mode        :
    Channel                : 11
    Receive rate (Mbps)    : 72.2
    Transmit rate (Mbps)   : 72.2
    Signal                 : 98%
    Profile                : HappyFamily2_4G

    Hosted network status  : Not available
```

FALLACIES OF DISTRIBUTED COMPUTING (5/9)

- The network is secure?
  - Security features are CIA
  - They are not naturally built in the network
  - Security attacks: bugs, unauthorized access, unencrypted communication, DDOS, etc.
- Basic security
  - Cryptography
  - Access control

FALLACIES OF DISTRIBUTED COMPUTING (6/9)

- Topology doesn't change?
  - Topology defines the structure of the network of how all the components are interconnected to each other.
  - E.g., point-to-point, bus, ring, tree, star, mesh, hybrid
  - Machines are added or removed quite often
- Implications
  - Quickly adjust to topology changes without affecting service availability
  - Abstract the physical structure of the network (e.g., DNS names as opposed to IP addresses)



https://ably.com/blog/8-fallacies-of-distributed-computing

FALLACIES OF DISTRIBUTED COMPUTING (7/9)

- There is one administrator?
  - Different administrators associated with the network with different degrees of expertise
  - E.g., many services developed and managed by different teams
- Implications
  - Decouple system components (e.g., pub/sub pattern)
  - Make troubleshooting easy

FALLACIES OF DISTRIBUTED COMPUTING (8/9)

- Transport cost is zero?
  - Networking infrastructure has a cost (e.g., servers, network switches, load balancers, proxies, firewalls, operation and maintenance, security)
  - It takes time and CPU resources to go from the application layer to the transport layer (e.g., marshalling)
- Implications
  - Use lightweight format (e.g., JSON, MessagePack, Protocol Buffers)

FALLACIES OF DISTRIBUTED COMPUTING (9/9)

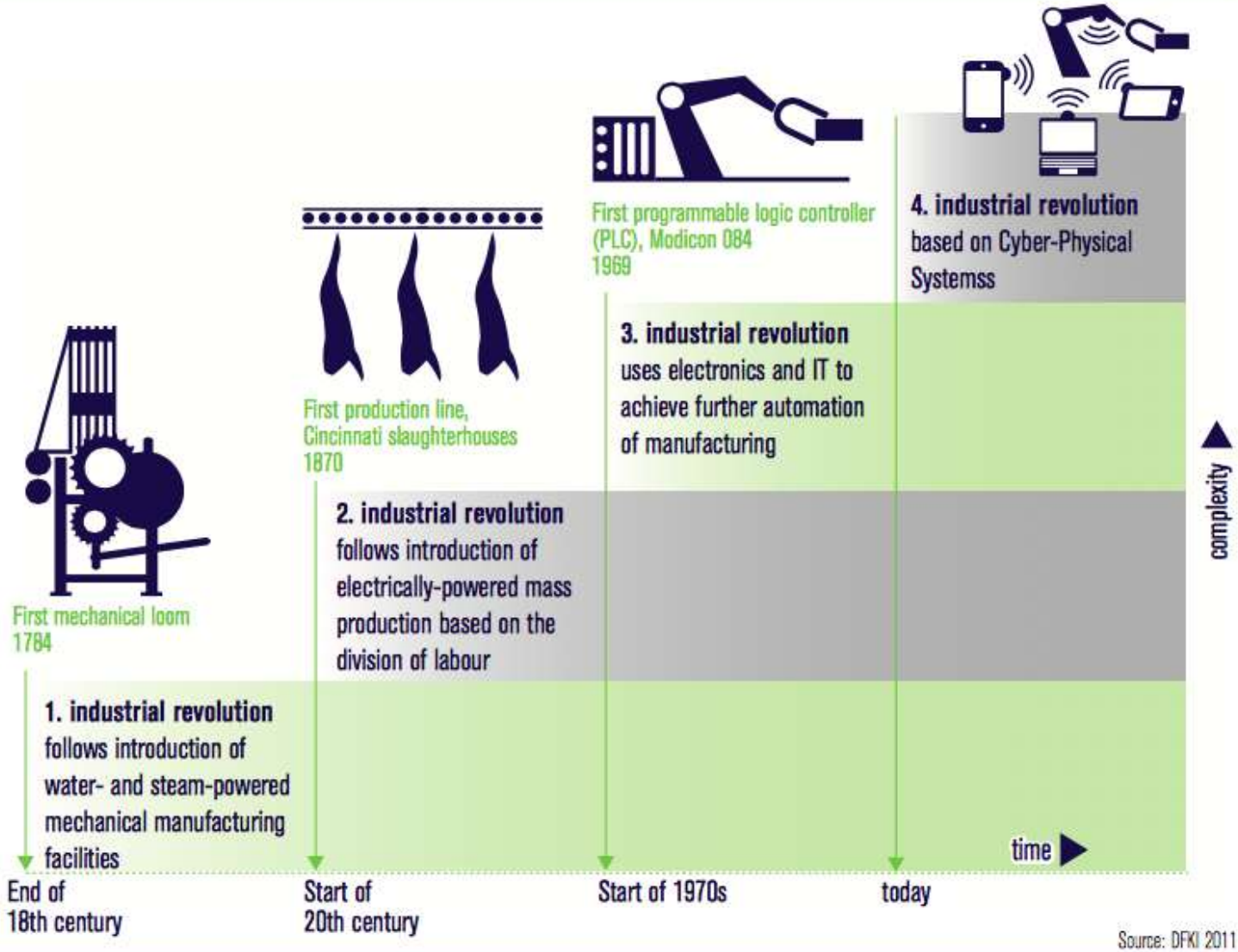
- The network is homogenous?
  - Network connects different types of devices (e.g., laptop, mobile)
  - Most distributed systems need to integrate with multiple types of devices, adapt to various operating systems, work with different browsers, and interact with other systems.
- Implications
  - Interoperability is needed (e.g., all these components can “talk” to each other, despite being different).
  - Where possible, use open and standard protocols such as HTTP, WebSockets, Server-Sent Events, MQTT.
  - Use lightweight format (e.g., JSON, MessagePack, Protocol Buffers)

TRENDS IN DISTRIBUTED SYSTEMS

- Utility
- Mobility
- Pervasive networking technology
- Multimedia technology and demands

INDUSTRY 4.0

Figure 1:
The four stages of
the Industrial Revolution



IoT

(Timothy Chou)

Do

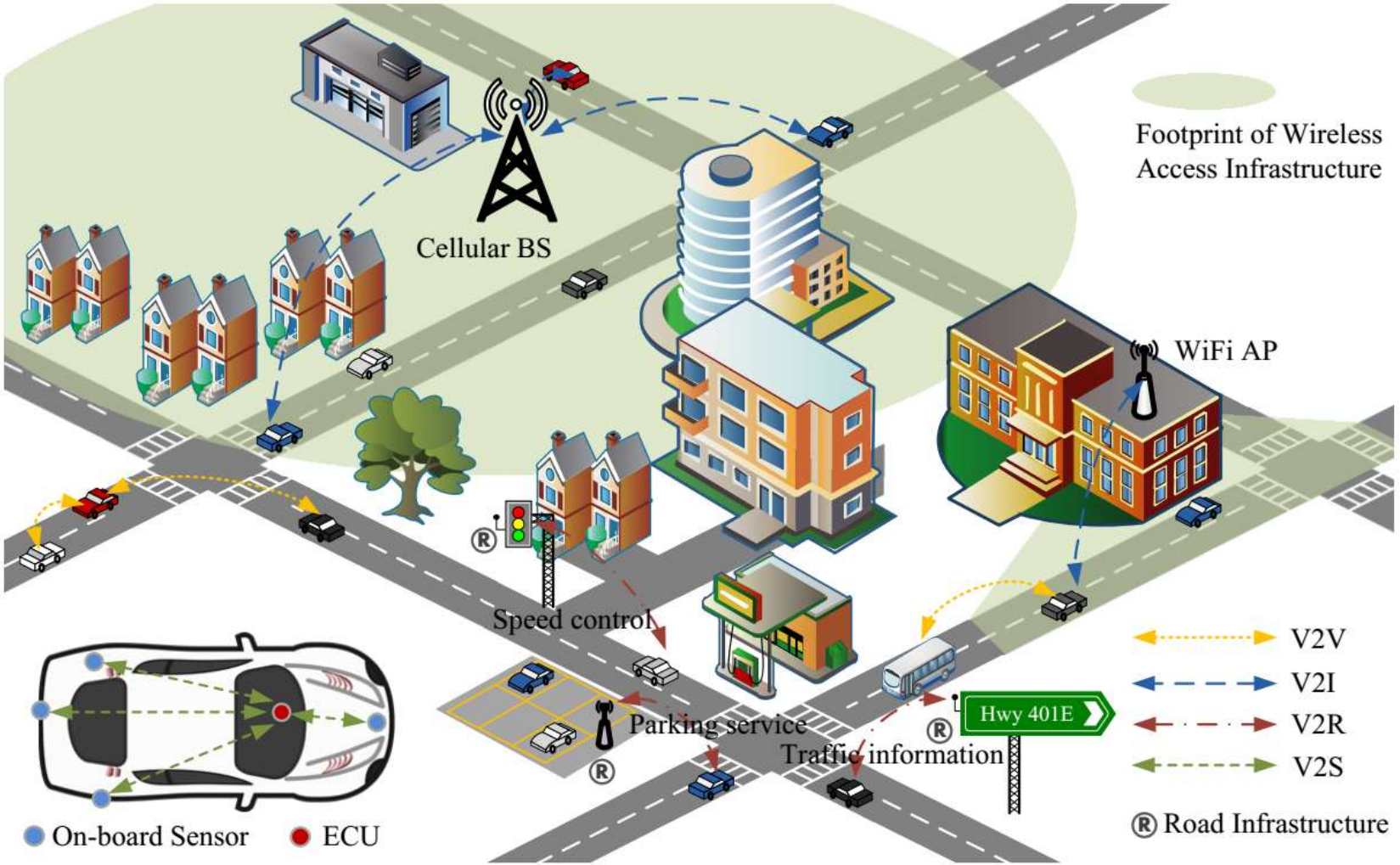
Learn

Collect

Connect

Things

V2V NETWORK



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IoT ECOSYSTEMS

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SUMMARY

- Overview in distributed systems
  - Concepts
  - Use-cases
  - Benefits
- Main challenges when implementing the distributed systems
- Trends in distributed systems

DISCUSSION

DISCUSSION

- Which of the followings describing the concept of distributed systems?
  1. Multiple connected CPUs working together.
  2. A collection of independent computers that appears to its users as a single coherent system.
  3. One in which components located at networked computers communicate and coordinate their actions by only message passing.

DISCUSSION

- What should not we expect in distributed systems when we design them?

DISCUSSION

- What should we know about the characteristics of each process in distributed systems?

DISCUSSION

- Which of the followings are the type of distributed systems?
  1. Local area network
  2. World-Wide-Web
  3. ATM system
  4. Cluster
  5. Grid
  6. Cloud

DISCUSSION

- What are the pros and cons of distributed systems?

DISCUSSION

- Can you differentiate the two systems below? Justify your answer.
  - Parallel processing systems
  - Distributed systems

DISCUSSION

- Can you differentiate the three systems below? Justify your answer.
  - Centralized systems
  - De-centralized systems
  - Distributed systems

DISCUSSION

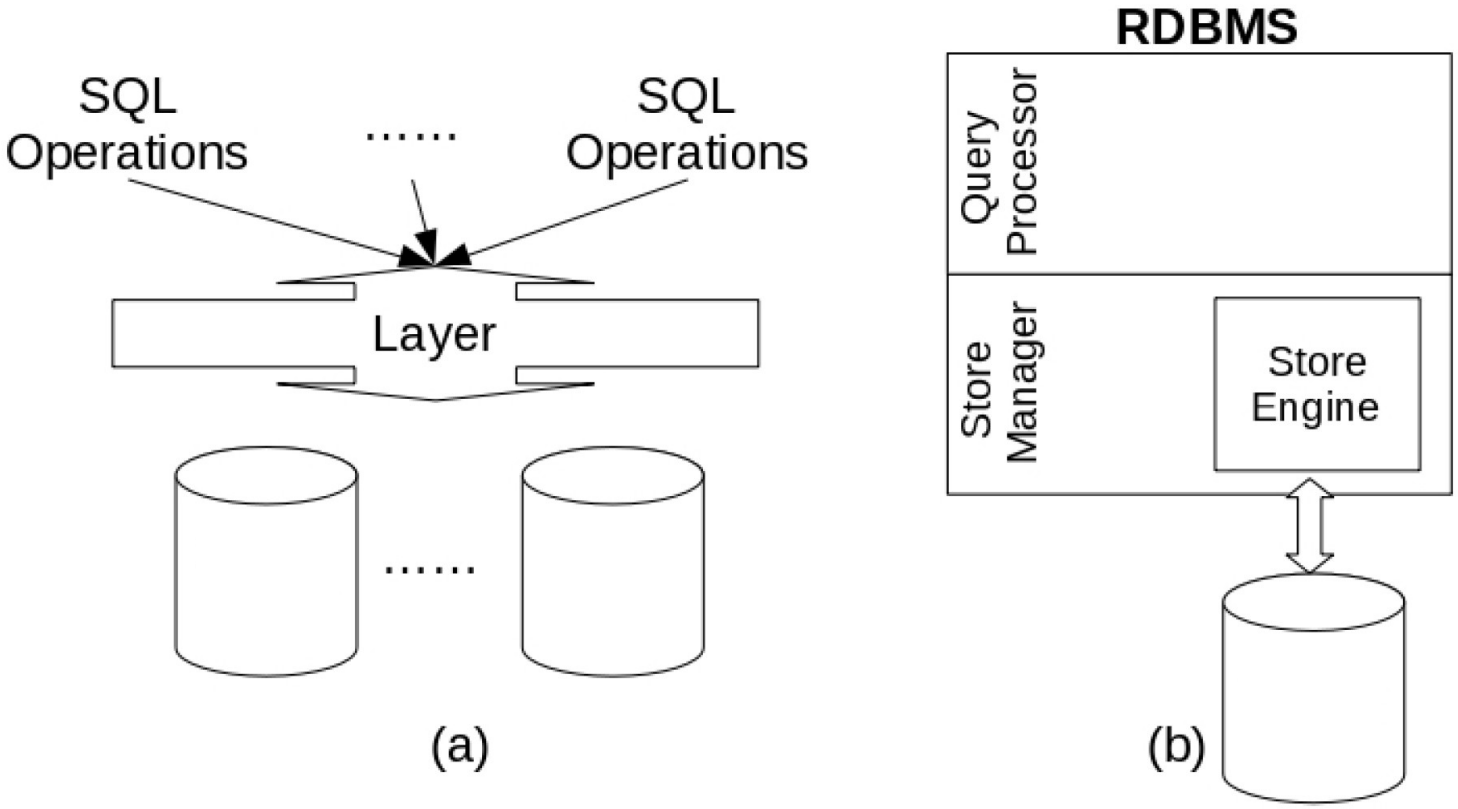
- Can you recognize the transparency features of those cases below? Show your demonstrations.
  1. File system operations in Network File System
  2. Navigation on the web
  3. SQL queries
  4. Pages on the web
  5. Tables in the distributed databases
  6. Network file system
  7. Database management system
  8. Mirror sites

DISCUSSION

HOW ABOUT OTHER REAL WORLD DISTRIBUTED APPLICATIONS YOU MAY FIND?

FOR INSTANCE

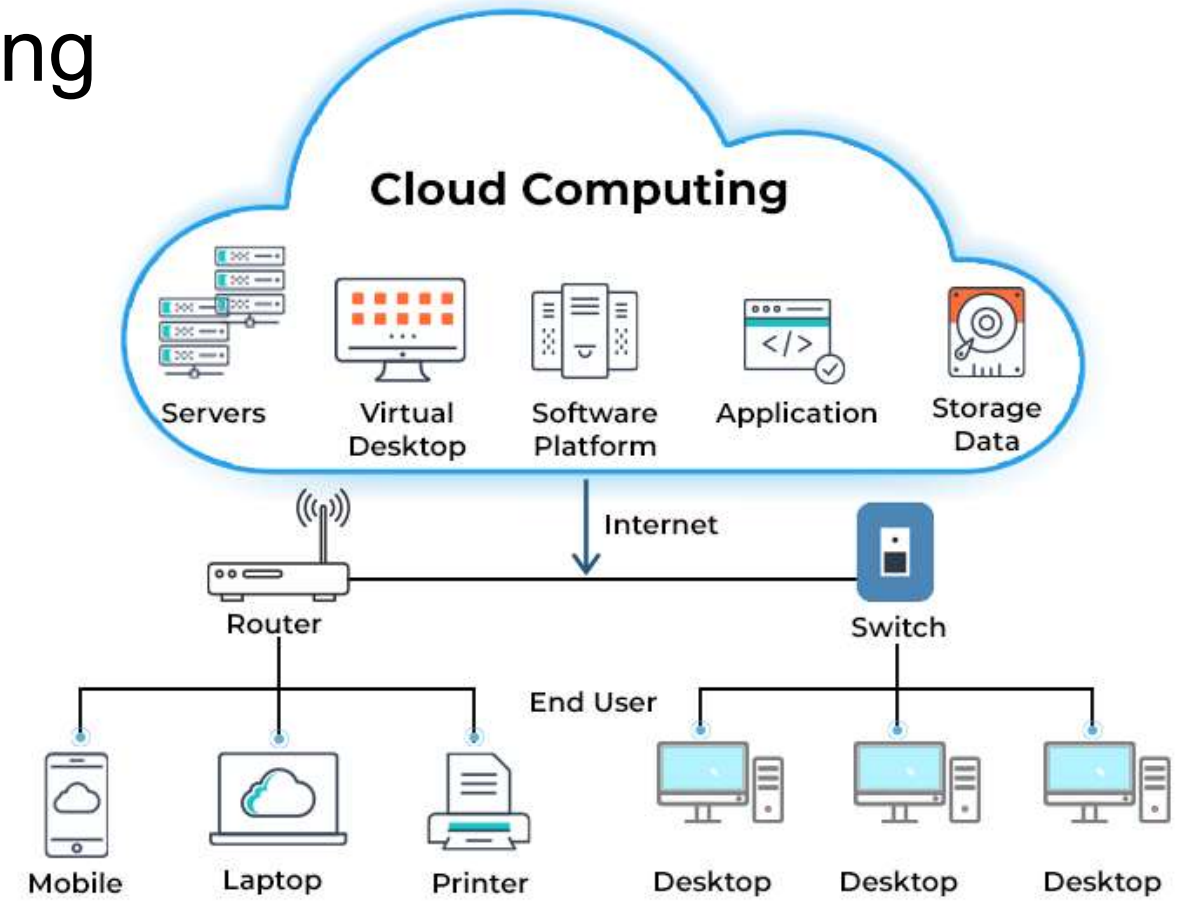
- SQL DBMS vs. NoSQL DBMS



https://www.mdpi.com/2078-2489/10/7/241

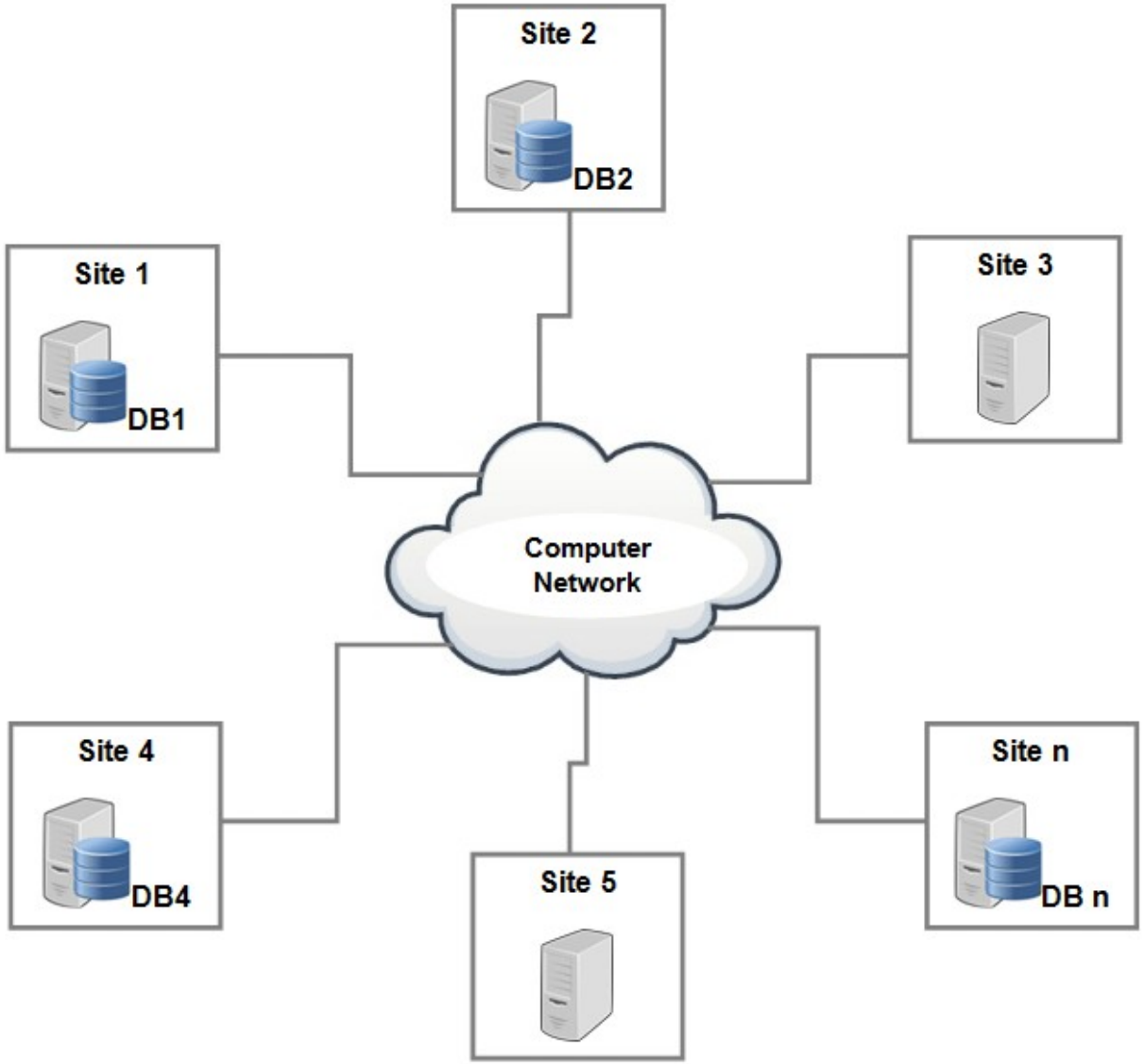
FOR INSTANCE

- Cloud computing



https://www.spiceworks.com/tech/cloud/articles/what-is-cloud-computing/

USE-CASE 1



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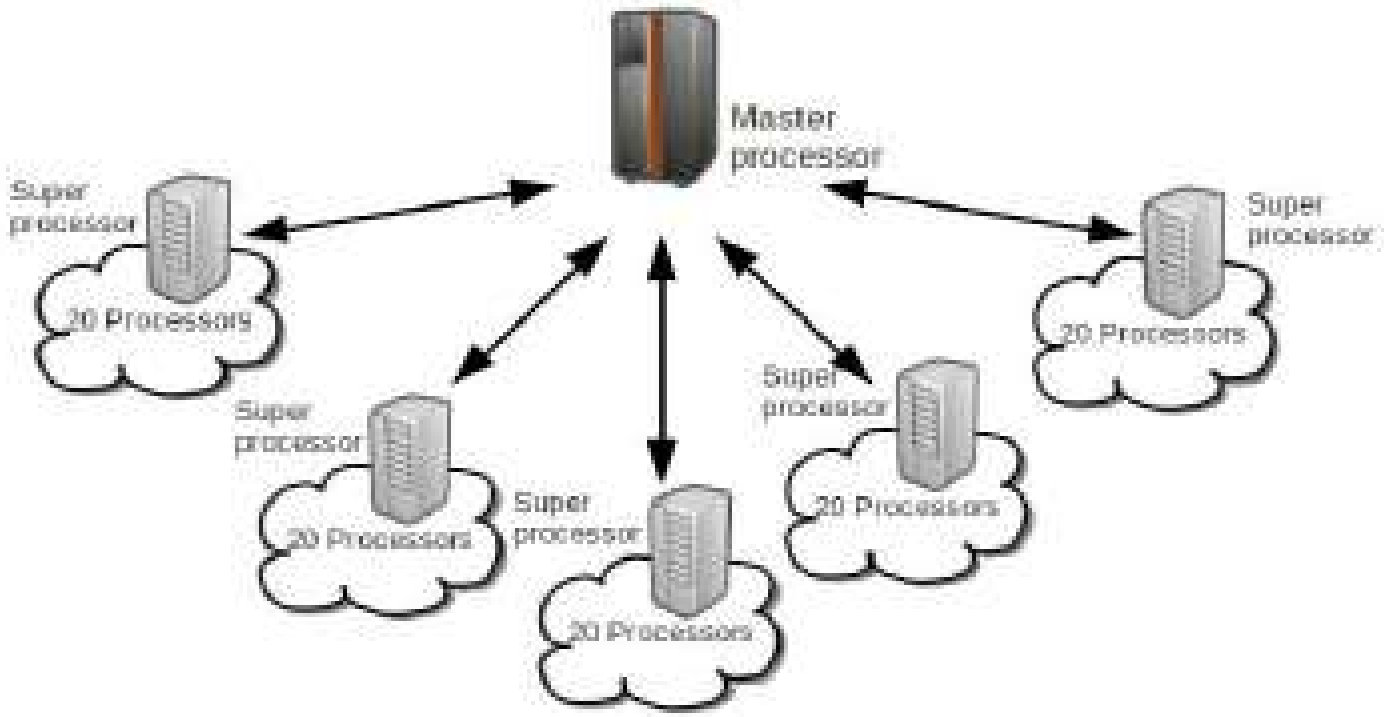
USE-CASE 2



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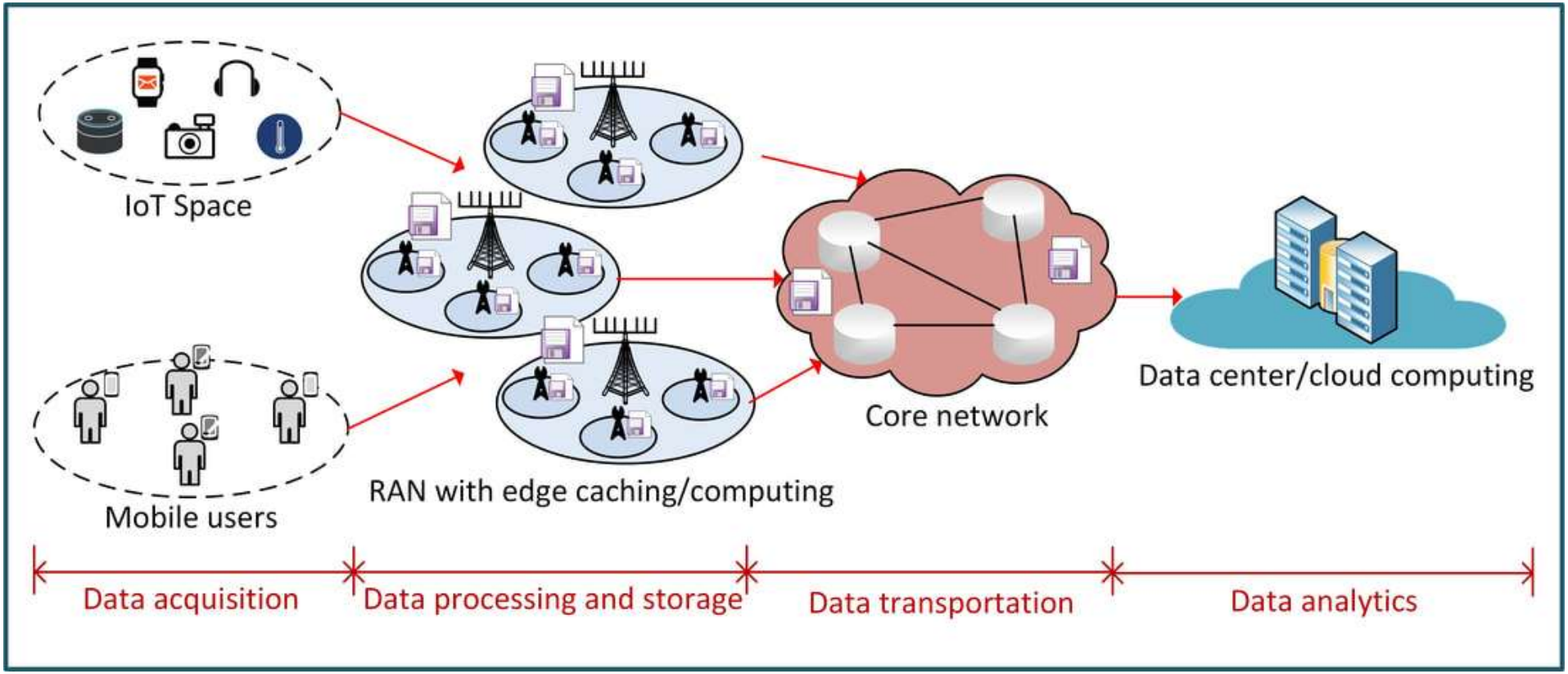
USE-CASE 3



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QUESTIONS AND ANSWERS