

# Large-scale Data Systems

Lecture 1: Introduction

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# The zettabyte era





*"Every two days now we create as much information as we did from the dawn of civilization up until 2003, according to Schmidt. That's something like five exabytes of data, he says.*

*Let me repeat that: **we create as much information in two days now as we did from the dawn of man through 2003.***

Eric Schmidt, 2010.

# 1 Zettabyte (ZB) = 1 Trillion Gigabytes (GB)

We face an overwhelming amount of data in every industry

**>2.5 PB**

of customer data stored by Walmart **every hour.**

**292 exabytes**

of mobile traffic by 2019, **up from 30 exabytes** in 2014.

**1 TB**

of data produced by a cancer patient **every day.**

2010

2018

2025

Today

44 Zettabytes

Sensors & Devices

Images/ Multimedia

Text

Enterprise Data

Gap

Traditional

Source

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## **Exercise**

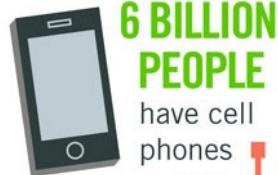
- How many iPads would you need to store 1 ZB?
- What distance and volume does that represent?

# The four V of big data

**40 ZETTABYTES**

[ 43 TRILLION GIGABYTES ]

of data will be created by 2020, an increase of 300 times from 2005



**6 BILLION PEOPLE**  
have cell phones



WORLD POPULATION: 7 BILLION



**2020**

**Volume**  
SCALE OF DATA

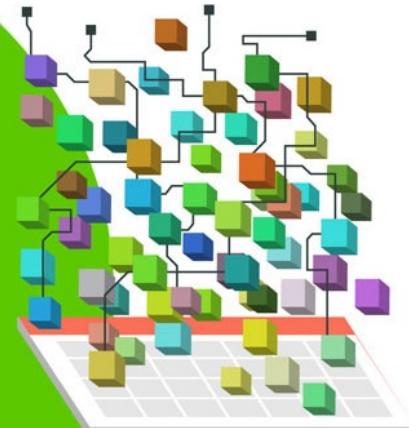


It's estimated that

**2.5 QUINTILLION BYTES**

[ 2.3 TRILLION GIGABYTES ]

of data are created each day



Most companies in the U.S. have at least

**100 TERABYTES**

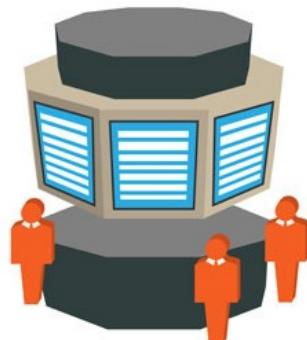
[ 100,000 GIGABYTES ]

of data stored

The New York Stock Exchange captures

## 1 TB OF TRADE INFORMATION

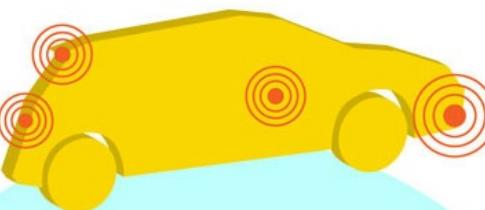
during each trading session



By 2016, it is projected there will be

## 18.9 BILLION NETWORK CONNECTIONS

– almost 2.5 connections per person on earth



Modern cars have close to **100 SENSORS** that monitor items such as fuel level and tire pressure

# Velocity

## ANALYSIS OF STREAMING DATA

As of 2011, the global size of data in healthcare was estimated to be

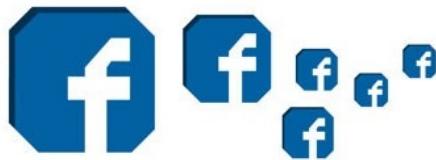
**150 EXABYTES**

[ 161 BILLION GIGABYTES ]



**30 BILLION  
PIECES OF CONTENT**

are shared on Facebook every month



## Variety

### DIFFERENT FORMS OF DATA

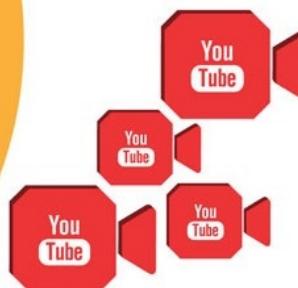
By 2014, it's anticipated there will be

**420 MILLION  
WEARABLE, WIRELESS  
HEALTH MONITORS**



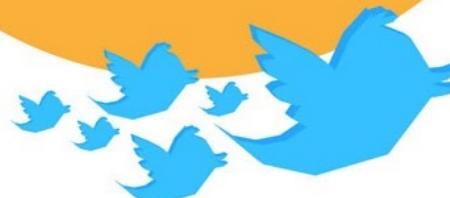
**4 BILLION+  
HOURS OF VIDEO**

are watched on YouTube each month



**400 MILLION TWEETS**

are sent per day by about 200 million monthly active users



## 1 IN 3 BUSINESS LEADERS

don't trust the information they use to make decisions



27% OF RESPONDENTS

in one survey were unsure of how much of their data was inaccurate

Poor data quality costs the US economy around

**\$3.1 TRILLION A YEAR**



## **Example: your own Facebook data**

How much data do you generate through your interactions with Facebook?

Let's check!

## What's new?

- our ability to **store machine generated data**, at unprecedented scale and rate.
- the broad understanding that we **cannot just manually get value out of data**.



The  
**F O U R T H**  
**P A R A D I G M**

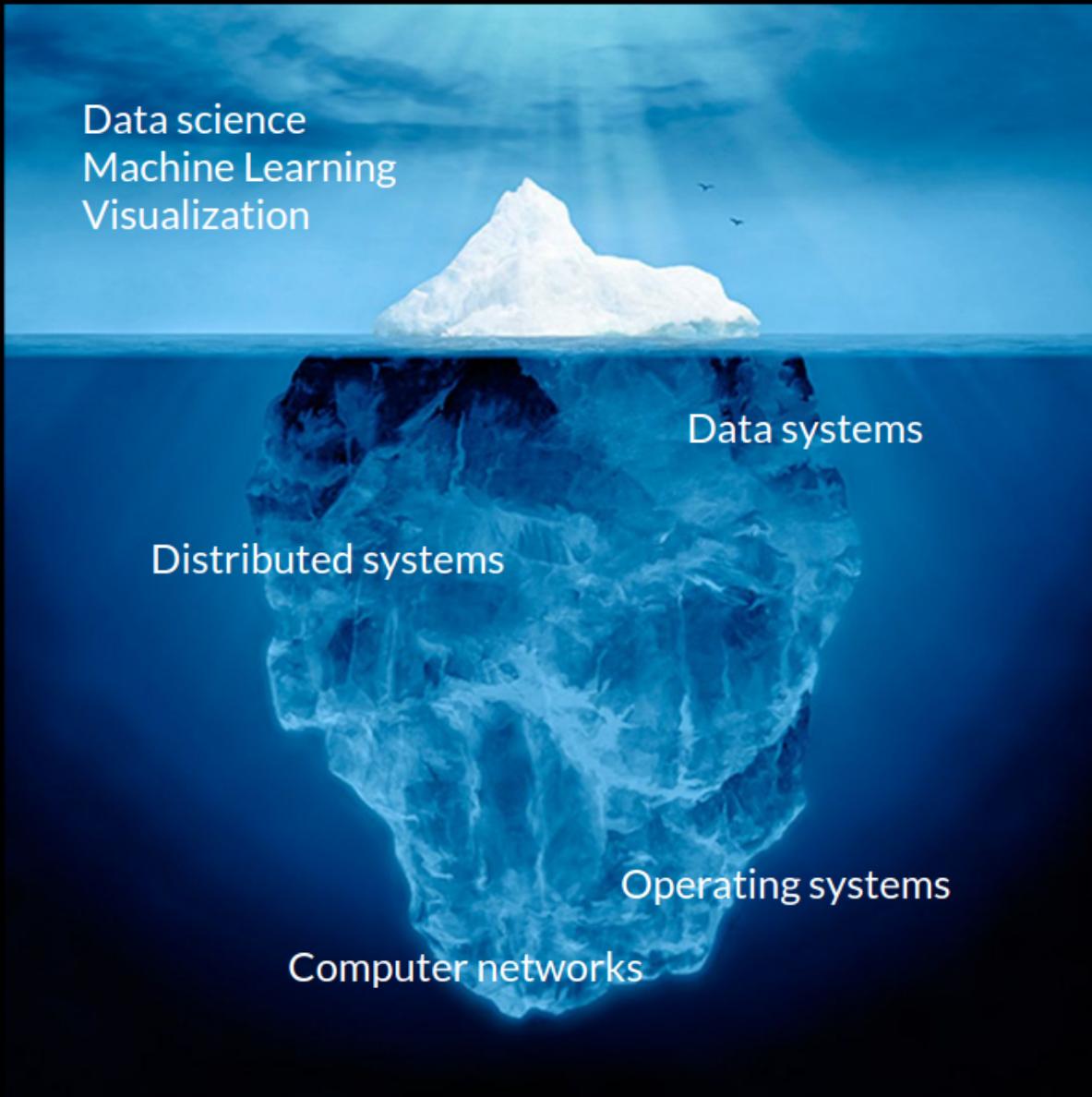
DATA-INTENSIVE SCIENTIFIC DISCOVERY

EDITED BY TONY HEY, STEWART TANSLEY, AND KRISTIN TOLLE

*"Increasingly, scientific breakthroughs will be powered by advanced computing capabilities that help researchers manipulate and explore massive datasets."*

*The speed at which any given scientific discipline advances will depend on how well its researchers collaborate with one another, and with technologists, in areas of eScience such as **databases**, **workflow management**, **visualization**, and **cloud computing technologies**."*

# Data systems



# Operating systems

Can you name examples of **operating systems**?

# Operating systems

Can you name examples of **operating systems**?

- Android
- Chrome OS
- FreeBSD
- iOS
- macOS
- OS/2
- RISC OS
- Solaris
- Windows
- ...

## **Definition**

The low-level software which handles the interface to peripheral hardware, schedules tasks, allocates storage, and presents a default interface to the user when no application program is running.

# Distributed systems

Can you name examples of [distributed systems](#)?

# Distributed systems

Can you name examples of **distributed systems**?

- A client/server system
- The web
- Wireless networks
- Telephone networks
- DNS
- Massively multiplayer online games
- Distributed databases
- BitTorrent (peer-to-peer overlays)
- A cloud, e.g. Amazon EC2/S3, Microsoft Azure
- A data center, e.g. a Google data center, AWS
- The bitcoin network

## Definition

A distributed system is a collection of entities with a common goal, each of which is **autonomous**, **programmable**, **asynchronous** and **failure-prone**, and which communicate through an **unreliable** communication medium.

- **Entity**: a process on a device.
- **Communication medium**: Wired or wireless network.

A distributed system appears to its users as a **single coherent** system.



**Internet:** What are the entities? What is the communication medium?



**Data center:** What are the entities? What is the communication medium?

## Why study distributed systems?

- Distributed systems are **everywhere**:
  - Internet
  - WWW
  - Mobile devices
  - Internet of Things
- **Technical importance**:
  - Improve **scalability**
    - Adding computational resources to a system is an easy way to scale its performance to many users.
  - Improve **reliability**
    - We want high availability and durability of the system.

- Distributed systems are **difficult** to build.
  - **Scale:** hundreds or thousands of machines.
    - Google: 4k-machine MapReduce cluster
    - Facebook: 60k machines providing the service
  - **Fault tolerance:** machines and networks do fail!
    - 50 machine failures out of 20k machine cluster per day (reported by Yahoo!)
    - 1 disk failure out of 16k disks every 6 hours (reported by Google)
  - **Concurrency:**
    - Nodes execute in parallel
    - Messages travel asynchronously
  - **Consistency:**
    - Distributed systems need to ensure user guarantees about the data they store.
    - E.g., all read operations return the same value, no matter where it is stored.
- But only a few **core problems** reoccur.

## Teaser: Two Generals' Problem

Two generals need to coordinate an attack.

- They must **agree** on time to attack.
- They will win only if they attack **simultaneously**.
- They communicate through **messengers**.
- Messengers may be **killed** on their way.

### Exercise

What should they do?



## The Two Generals Problem



Watch later Share



Let's try to solve the problem for generals  $g_1$  and  $g_2$ .

- $g_1$  sends time of attack to  $g_2$ .
- Problem: how to ensure  $g_2$  received the message?
- Solution: let  $g_2$  acknowledge receipt of message.
- Problem: how to ensure  $g_1$  received the acknowledgment?
- Solution: let  $g_1$  acknowledge receipt of acknowledgment.
- ...

This problem is provably **impossible** to solve!  
(Unless we make additional assumptions)

- Applicability to distributed systems:
  - Two nodes need to **agree** on a **value**.
  - They communicate by **messages** using an **unreliable channel**.
- **Agreement** is one of the core problems of distributed systems.

# Data systems

Can you name examples of **data systems**?

# Data systems

Can you name examples of **data systems**?

- A database
- A file system
- A ledger
- Search engines
- Data flow frameworks
- Social networks
- ...

## **Definition**

In this course, data systems will broadly refer to any kind of computer systems, distributed or not, that can be used to store, retrieve, organize or process data.

Our main focus will be on data systems for data science purposes.

BIG DATA & AI LANDSCAPE 2018



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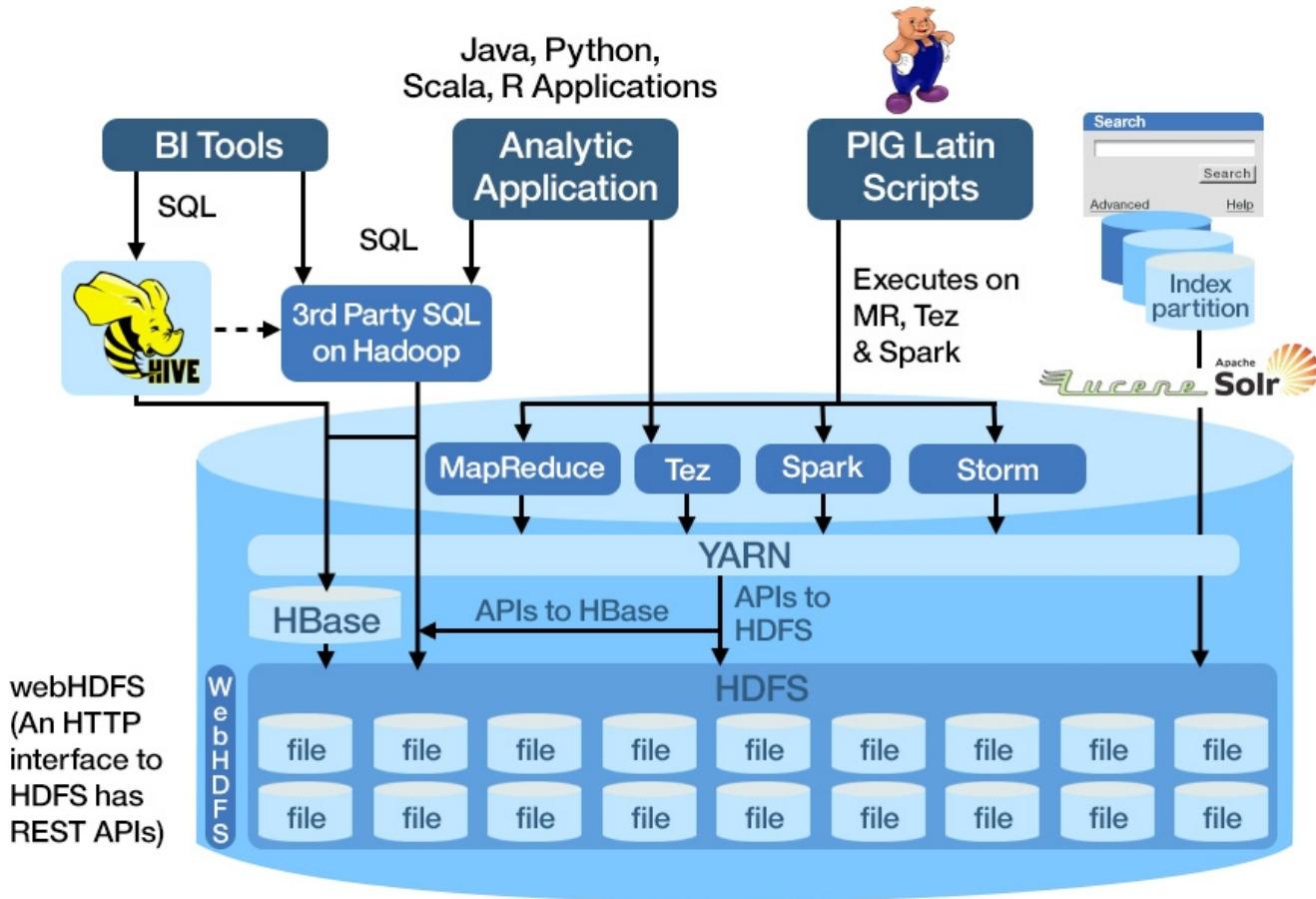
[mattturck.com/bigdata2018](http://mattturck.com/bigdata2018)

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## Cloud services

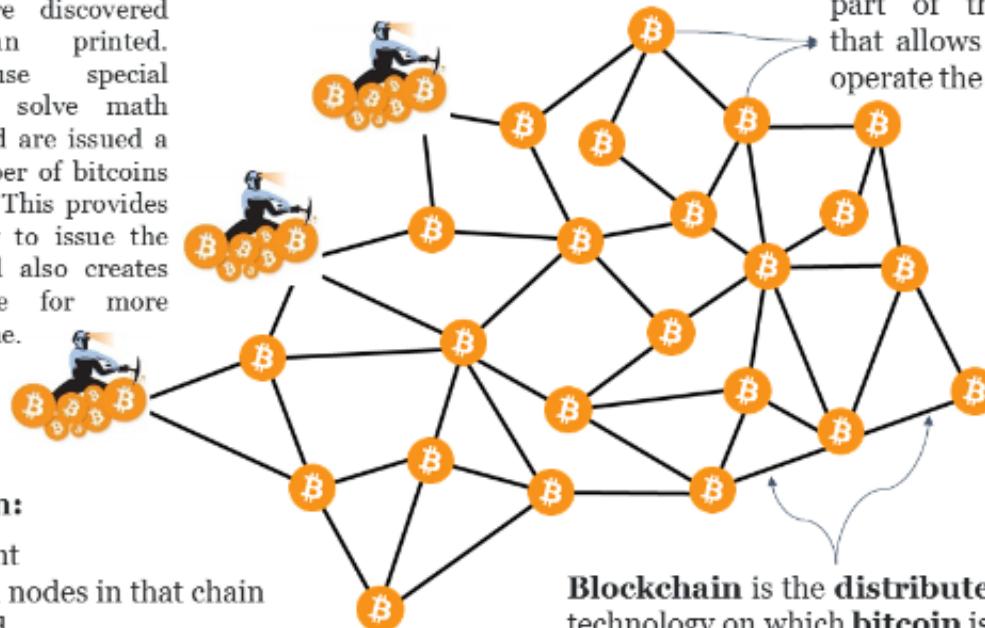


# The Hadoop ecosystem (less and less)



## A distributed ledger

**Bitcoins** are discovered rather than printed. **Miners** use special software to solve math problems and are issued a certain number of bitcoins in exchange. This provides a smart way to issue the currency and also creates an incentive for more people to mine.

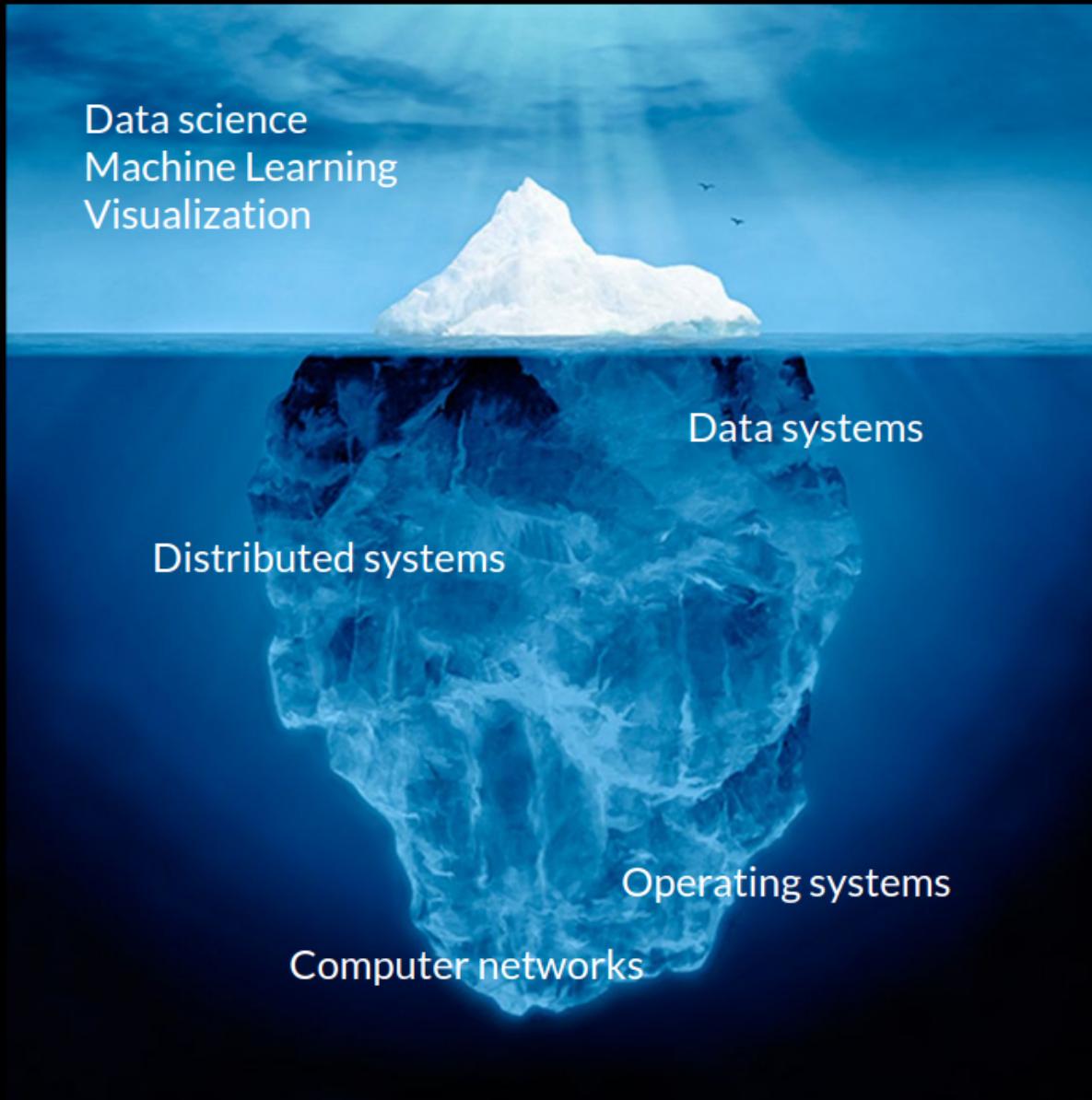


### Blockchain:

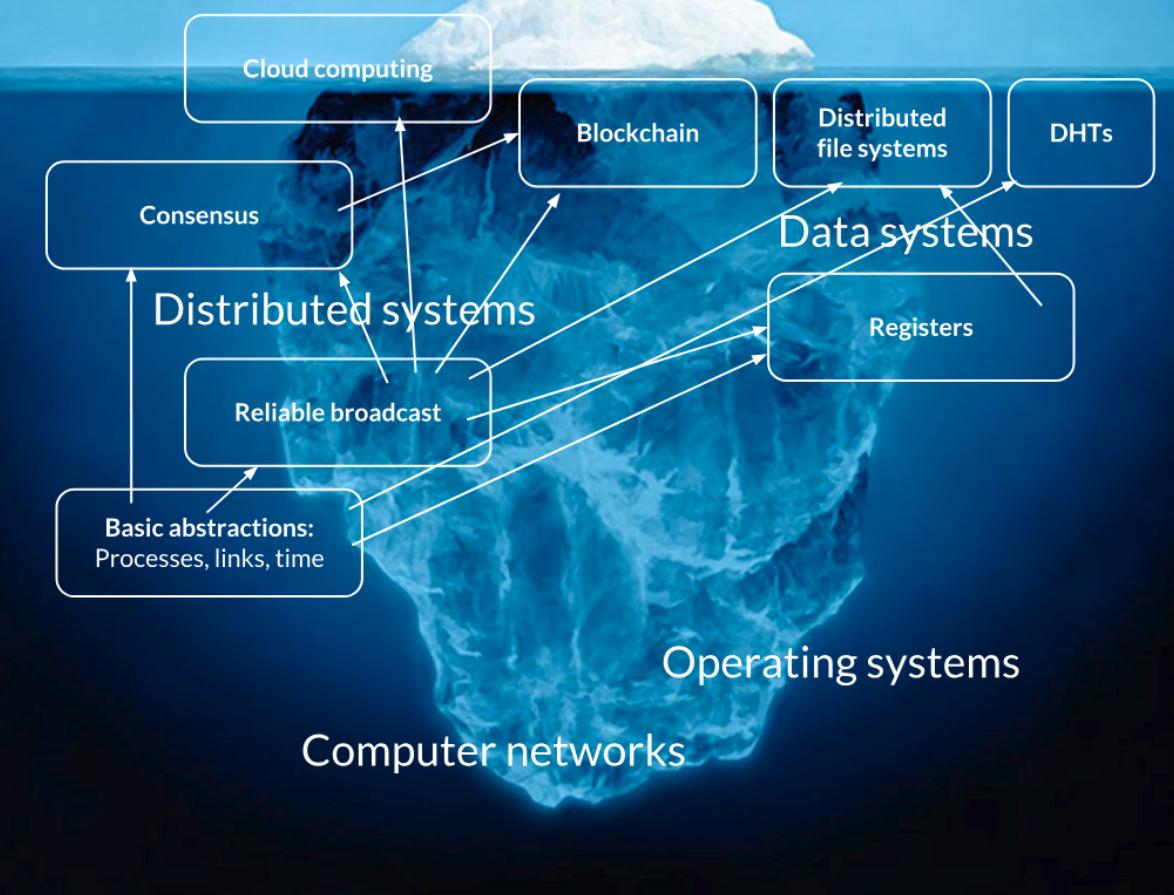
- Transparent
- Open to all nodes in that chain
- Distributed

**Blockchain** is the **distributed** ledger technology on which **bitcoin** is built

# Outline



# Data science Machine Learning Visualization



# Fundamentals of distributed systems

Understand the **foundational principles** required for the **design, implementation** and **maintenance** of distributed systems.

- Communications
- Failures
- Consistency
- Concurrency
- Consensus

## Communications

- How do you talk to another machine?
  - Reliable networking.
- How do you talk to multiple machines at once, with ordering guarantees?
  - Multicast, Gossiping.

## Failures and consistency

- How do you know if a machine has failed?
  - Failure detection.
- How do you program your system to operate continually even under failure?
  - Gossiping, replication.
- What if some machines do not cooperate?
  - Byzantine fault tolerance.

## Concurrency

- How do you control access to shared resources?
  - Distributed mutual exclusion, distributed transactions, etc.

## Consensus

- How do multiple machines reach an agreement?
  - Time and synchronization, global states, leader election, Paxos, proof of work, blockchain.
- **Bad news:** it is impossible!
  - The impossibility of consensus for asynchronous systems.

# Case studies

From these building blocks, understand how to build and architecture data systems for large volumes or data or for data science purposes.

## Distributed storage

- How do you locate where things are and access them?
  - Distributed file systems
  - Key-value stores
- How do you record and share sensitive data?
  - Proof of work, blockchain

## Distributed computing for data science

- What are the distributed computing systems for data science?
  - Map Reduce (Hadoop)
  - Computational graph systems (Spark, Dask)
- Is distributed computing always necessary?

