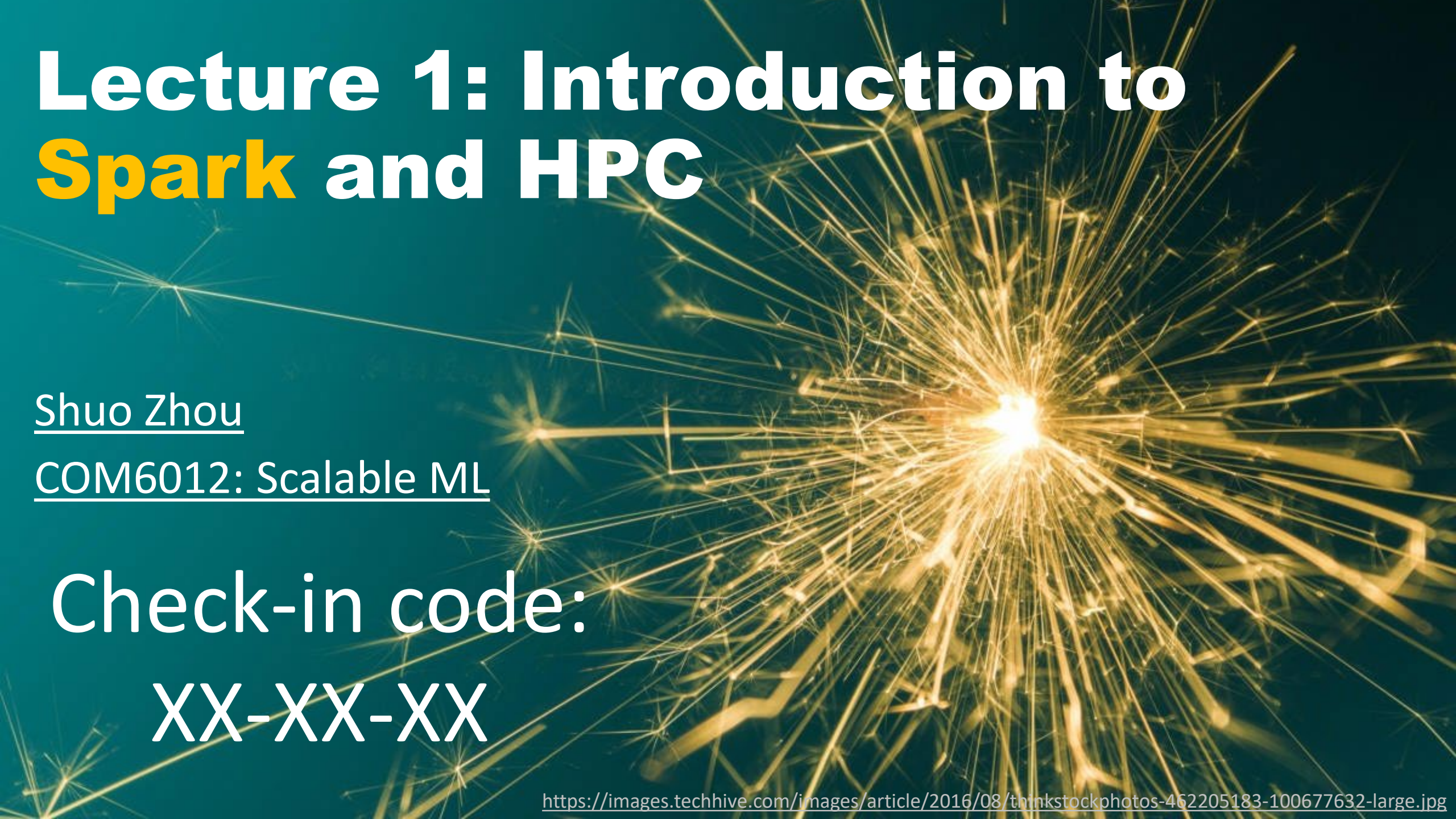
# Lecture 1: Introduction to Spark and HPC

Shuo Zhou

COM6012: Scalable ML

Check-in code:

XX-XX-XX



https://images.techhive.com/images/article/2016/08/thinkstockphotos-462205183-100677632-large.jpg

# Week 1 Contents / Objectives

- The Big Data Problem: Why Spark?
- What is Spark?: The Essentials
- An Example of Spark: Log Mining
- How to Use Spark: PySpark, HPC, Resources

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- **The Big Data Problem: Why Spark?**
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# Where Does Big Data Come From?

- All happening online, e.g. tracking of:
  - Clicks
  - Billing events
  - Server requests
  - Transactions
  - Network messages
  - Faults
  - …

https://th.bing.com/th/id/R.2ebddefd79cccedb3a4de28ba4601c99?rik=iMHqajO28%2bIvjw&pid=ImgRaw&r=0

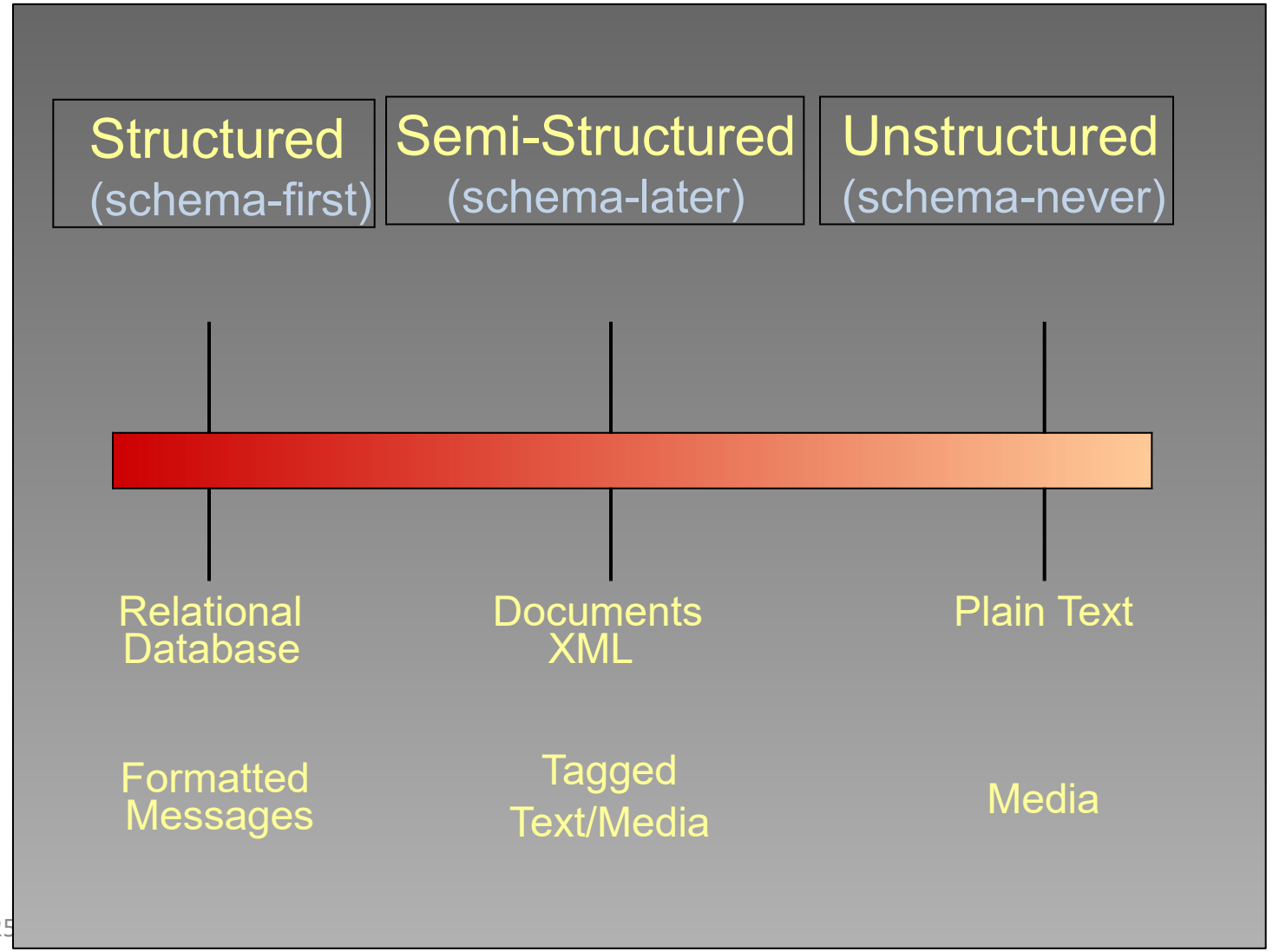
# Where Does Big Data Come From?

- User generated content: web + mobile

# Where Does Big Data Come From?

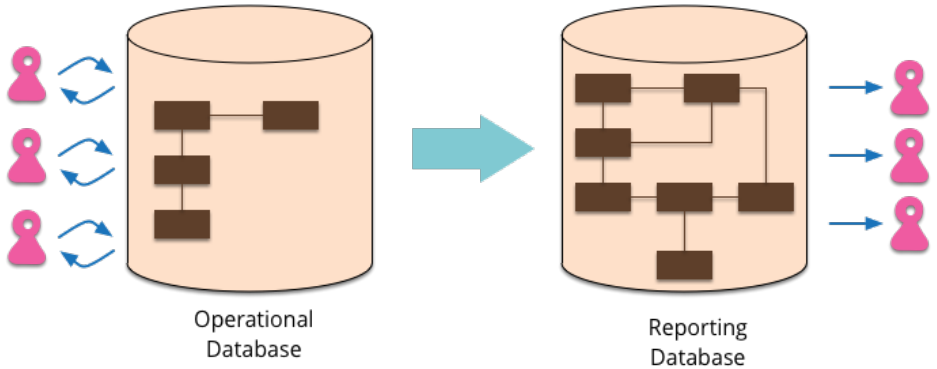
AI generated content


# Data Structure Spectrum



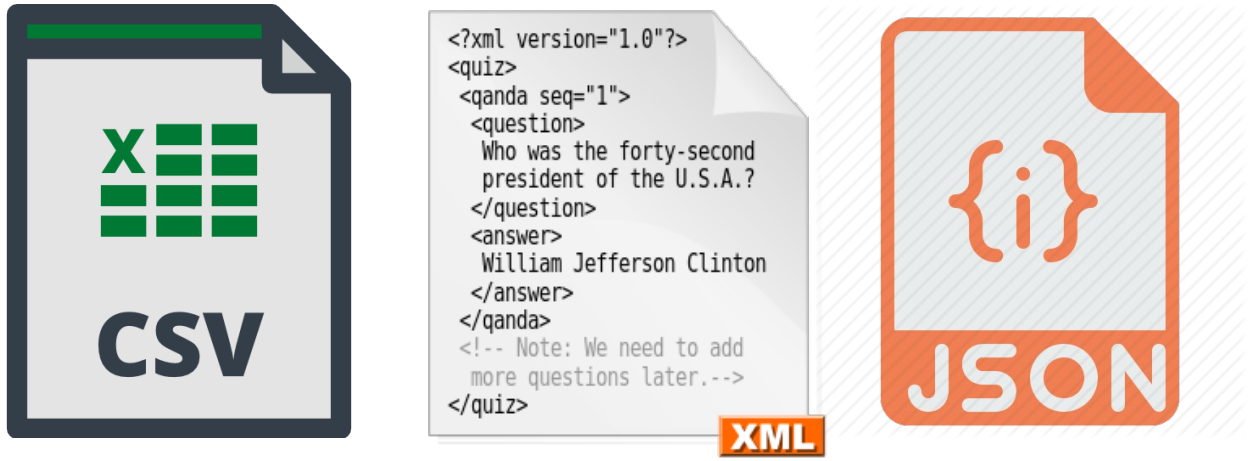
# Structured Data

- Database: relational data model → how a database is structured and used
- Schema: the organisation of data as a blueprint of how the database is constructed
  - The programmer must statically specify the schema
  - Decreasing ← consumer/media app, enterprise search
- SQL: Structured Query Language



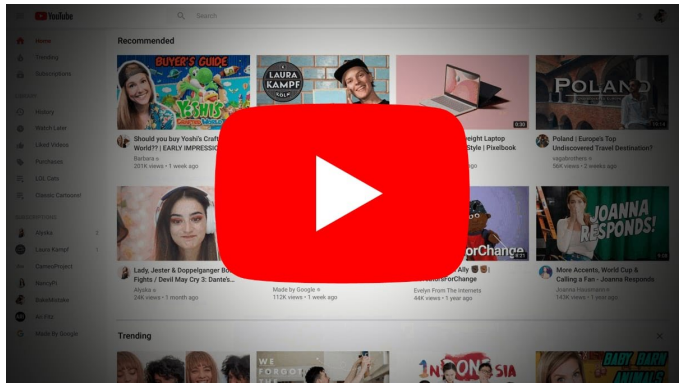

# Semi-Structured Data

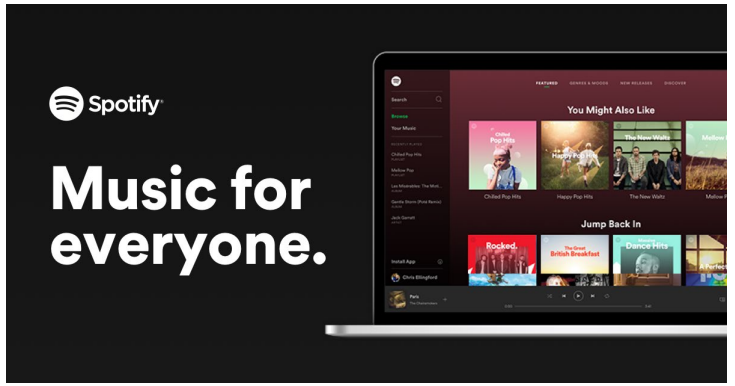
- Self-describing rather than formal structures, tags/markers to separate semantic elements
- The column types → the schema for the data
  - Spark dynamically infers the schema while reading each row
  - Programmer statically specifies the schema
- Examples:

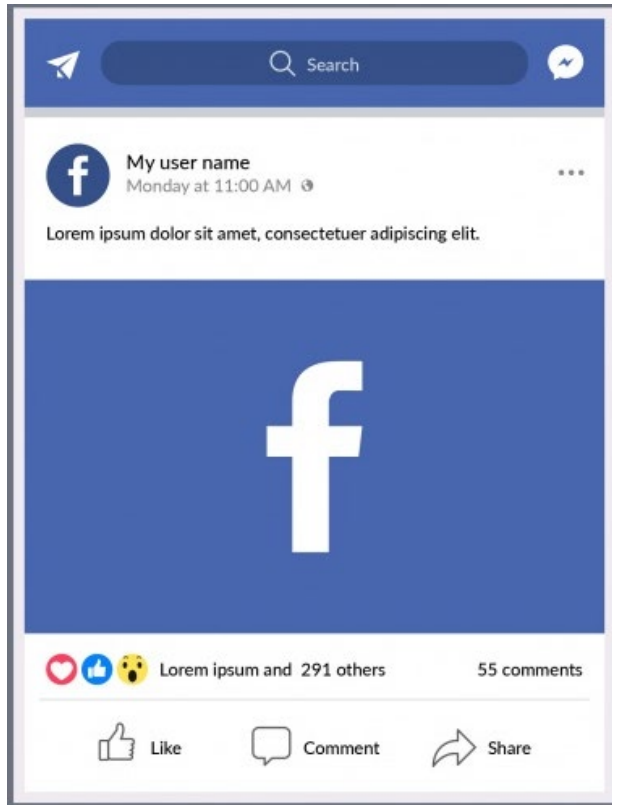


# Unstructured Data

- Only one column with string or binary type
- Examples



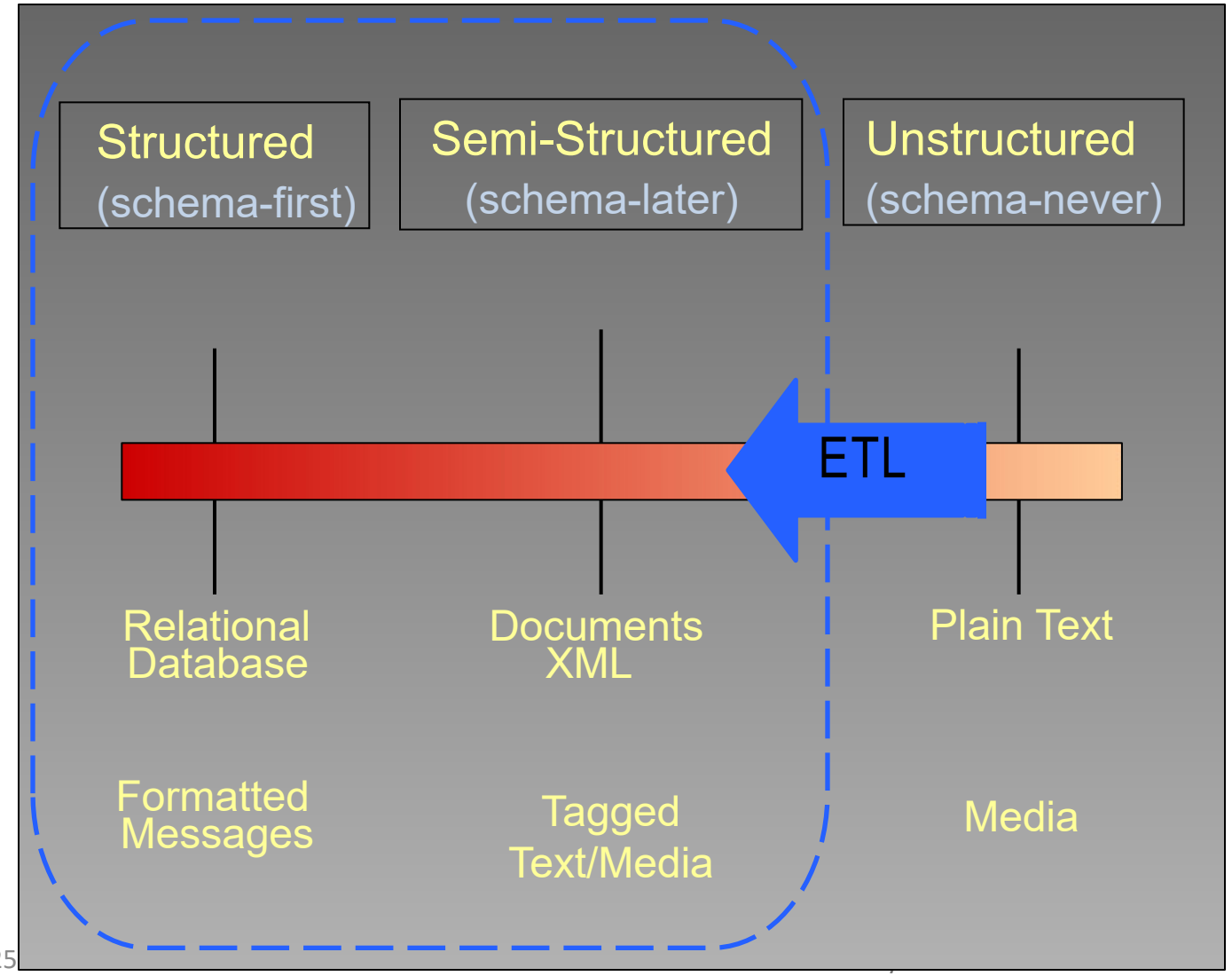




- Note: File formats ≠ data structure

https://cdn.wccftech.com/wp-content/uploads/2019/11/YouTube-Redesign-2019-768x432.jpg
https://th.bing.com/th/id/OIP.MNR8Ck5DWZb32tkqOfLuXAAAAA?rs=1&pid=ImgDetMain
https://files.codingninjas.in/article_images/preparation-guide-for-facebook-1-1662401488.webp

# Traverse the Data Structure Spectrum




- Impose structure on unstructured data
  - Extract
  - Transform
  - Load

# Traditional Analysis Tools

- Unix shell commands (awk, grep, ...)

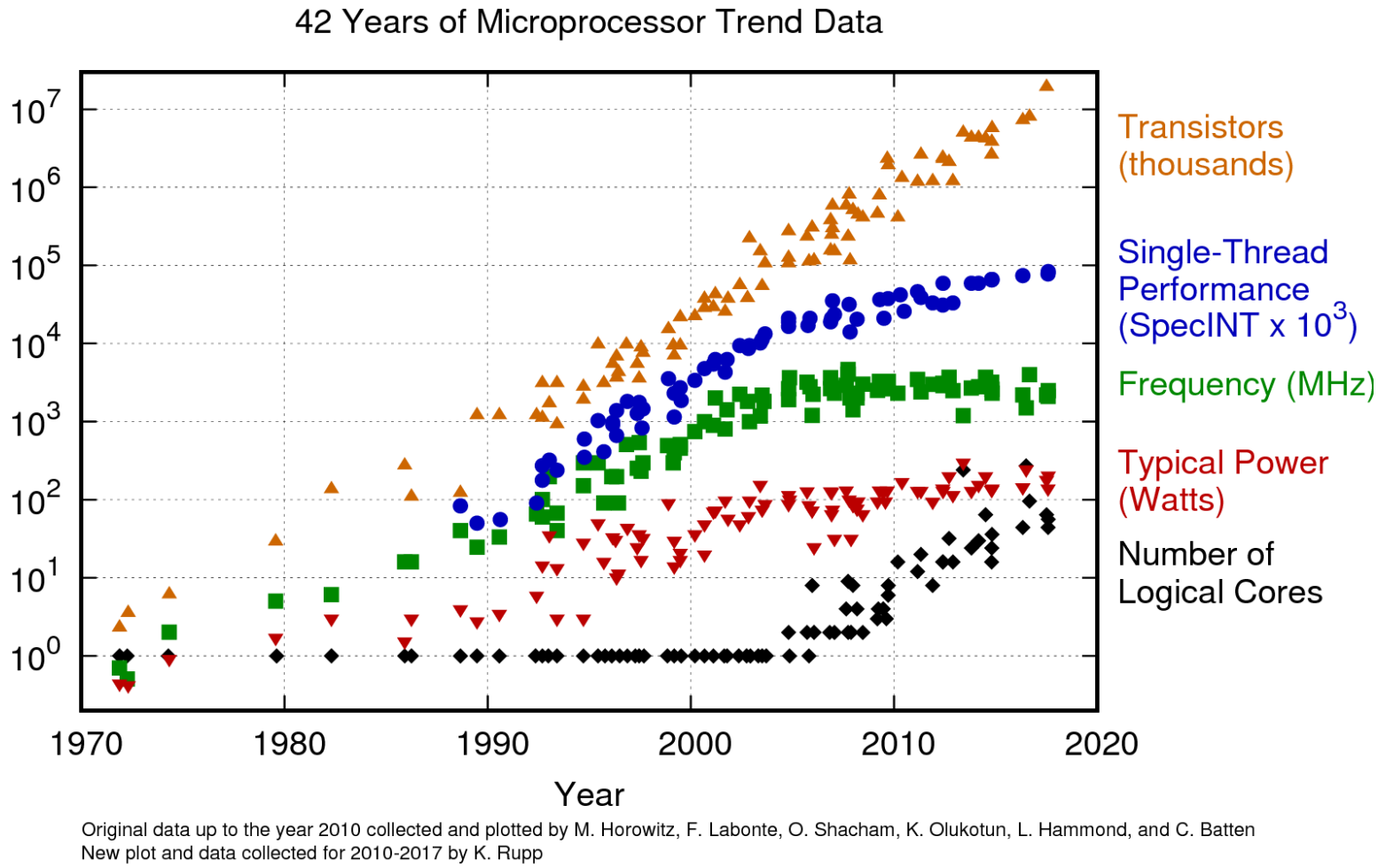
```
root@nginx:~# awk ' {print $0}' file.txt
Item    Model    Country          Cost

1       BMW      Germany          $25000
2       Volvo    Sweden           $15000
3       Subaru   Japan            $2500
4       Ferrari  Italy            $2000000
5       SAAB     USA              $3000
```

```
vulphere@arifuretaarch:~|⇒  grep root /etc/passwd
root:x:0:0:root:/root:/bin/zsh
vulphere@arifuretaarch:~|⇒  grep -n root /etc/passwd
1:root:x:0:0:root:/root:/bin/zsh
vulphere@arifuretaarch:~|⇒  grep -c false /etc/passwd
3
vulphere@arifuretaarch:~|⇒  _
```

All run on a single machine!

# The Big Data Problem

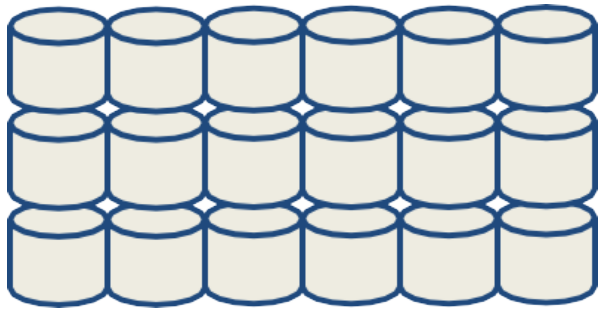
- Data growing faster than computation speeds
- Growing data sources
  - Web, mobile, scientific, …
- Storage getting cheaper
- But, stalling CPU speeds and storage bottlenecks



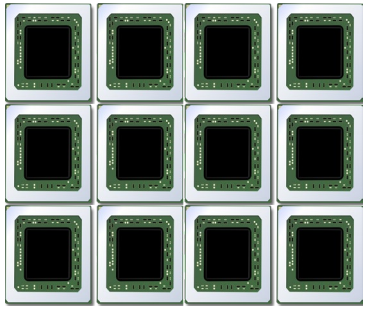

Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2017 by K. Rupp

# Solution for the Big Data Problem

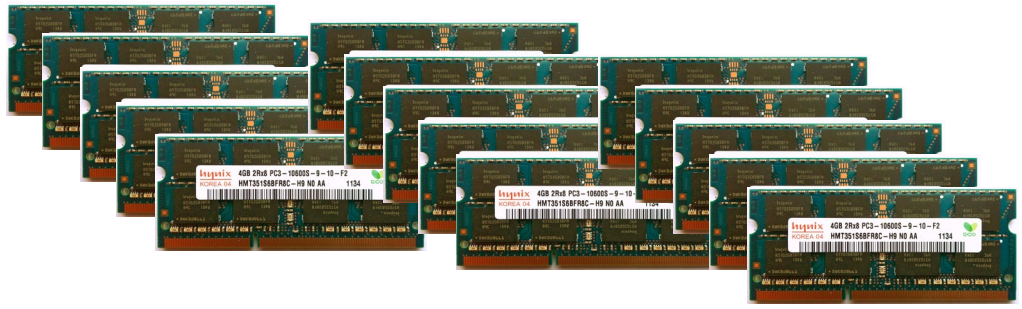
- One machine cannot process or *even store* all the data!
- Solution: **distribute** data over a **cluster** of machines



Lots of hard drives



… and CPUs



… and memory!

# Solution in this module


"Apache Spark is an industry-leading platform for distributed extract, transform, and load (ETL) workloads on large-scale data."

– NVIDIA Technical Blog, Jun 12, 2023

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# Apache Spark

- Fast and general cluster computing system
- Interoperable with

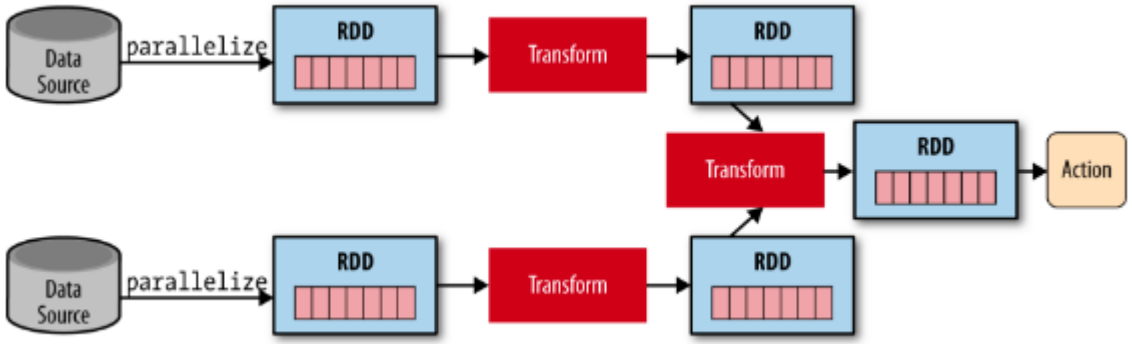

- Improves efficiency through:
  - In-memory computing primitives
  - General computation graphs
- Improves usability through:
  - Rich APIs in Scala, Java, Python
  - Interactive shell

→ Up to 100× faster (2-10× on disk)

→ 2-5× less code

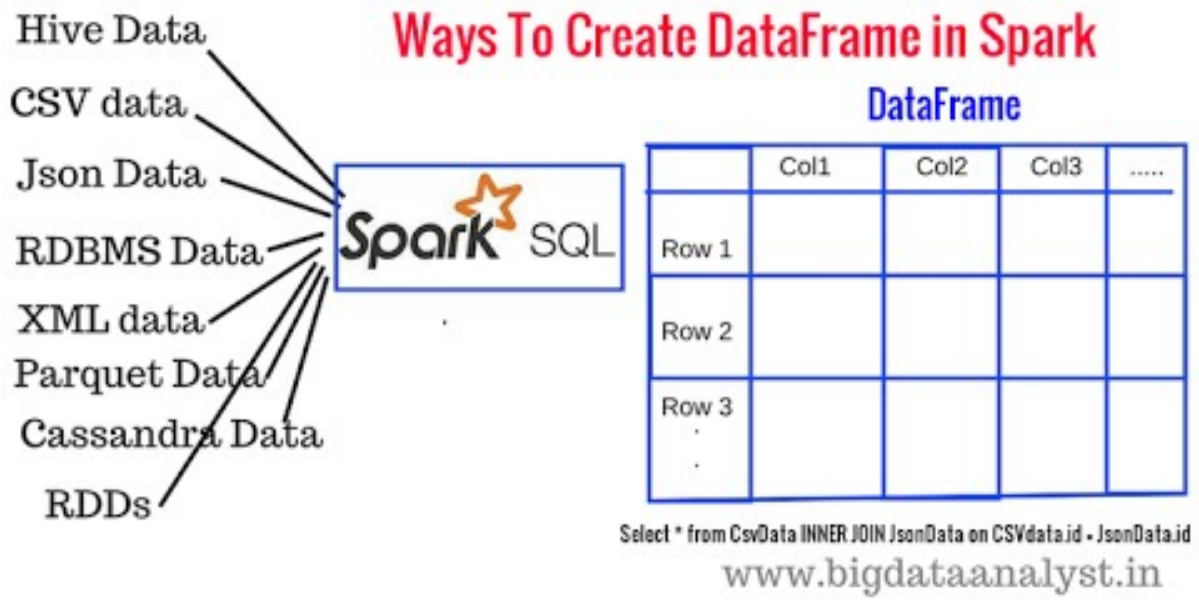
# Spark Model

- Write programs in terms of transformations on distributed datasets
- Resilient Distributed Datasets (RDDs)
  - Collections of objects that can be stored in memory or disk across a cluster
  - Parallel functional transformations (map, filter, …)
  - Automatically rebuilt on failure



# Spark for Data Science

- DataFrames
  - Structured data (SQL)
  - Familiar API based on R/Python Pandas
  - Distributed, optimised implementation




- Machine learning pipelines
  - Simple construction and tuning of ML workflows

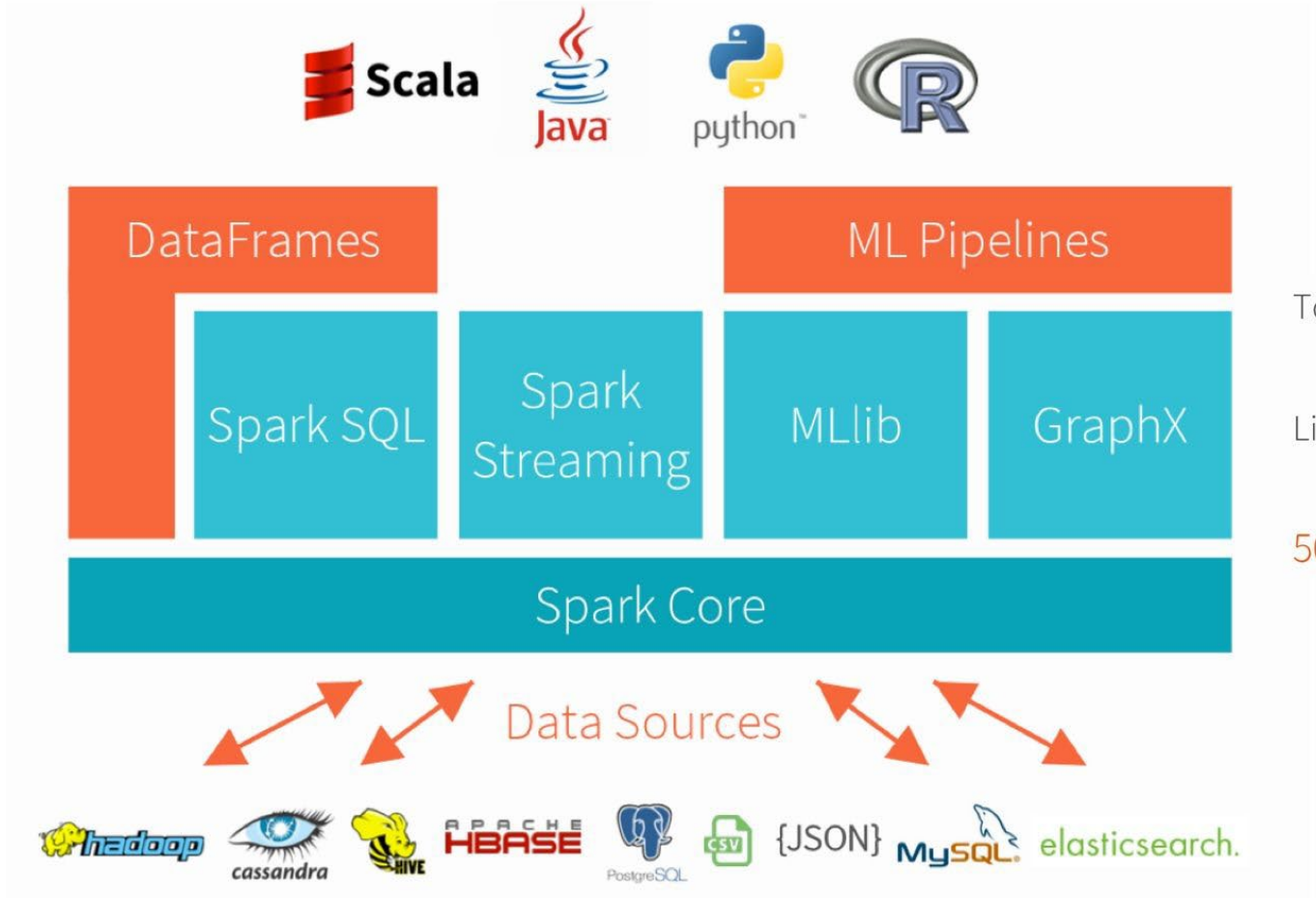
# Spark Computing Framework

- Programming abstraction and parallel runtime to hide complexities of **fault-tolerance** and **slow** machines

"Here's an operation, run it on all of the data"


- Don't care where it runs (you schedule that)
- In fact, feel free to run it twice on different nodes (e.g. when it fails)

# Apache Spark Ecosystem




Total contributors: 150 → 500

Lines of code: 190K → 370K

500+ active production deployments

https://i.pinimg.com/originals/e7/f3/2d/e7f32d041846a5938a09e192bdf3885d.jpg

## Data science and Machine learning


## SQL analytics and BI

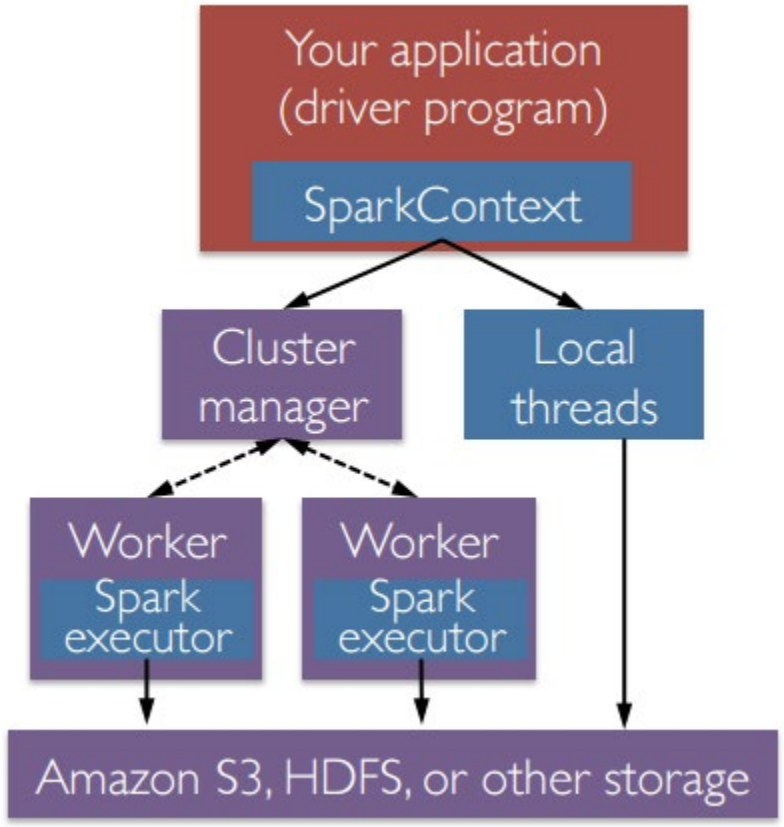

# Ecosystem

Apache Spark™ integrates with your favorite frameworks,
helping to scale them to thousands of machines.

## Storage and Infrastructure


https://spark.apache.org/

# Spark Components




- A Spark program first creates a **SparkSession** object as the driver (including **SparkContext**)
  - Tells Spark how/where to access a cluster
  - Connect to cluster managers
- Cluster managers
  - Allocate resources across applications
- Spark executor (worker):
  - Access data storage
  - Run computations

# SparkSession and SparkContext

- **SparkSession**
  - Entry point for DataFrame API, create DataFrames
  - PySpark shell automatically create SparkSession as spark
  - Programs: must create a new SparkSession first (see lab)
- **SparkContext**
  - Entry point for Spark functionality, create RDDs
  - Connect to a Spark cluster
  - Associated with a SparkSession
  - PySpark shell automatically create SparkContext as sc
  - Programs: sc = spark.sparkContext

# The '*Master*' Parameter for a SparkSession

- Determines cluster type and size

| Master Parameter | Description |
|---|---|
| local | run Spark locally with one worker thread (no parallelism) |
| local[K] | run Spark locally with K worker threads (ideally set to number of cores) |
| spark://HOST:PORT | connect to a Spark standalone cluster; PORT depends on config (7077 by default) |
| mesos://HOST:PORT | connect to a Mesos cluster; PORT depends on config (5050 by default) |

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# Spark Example: Log Mining (w/t RDD)

Load error messages from a log into memory, then interactively search for various patterns

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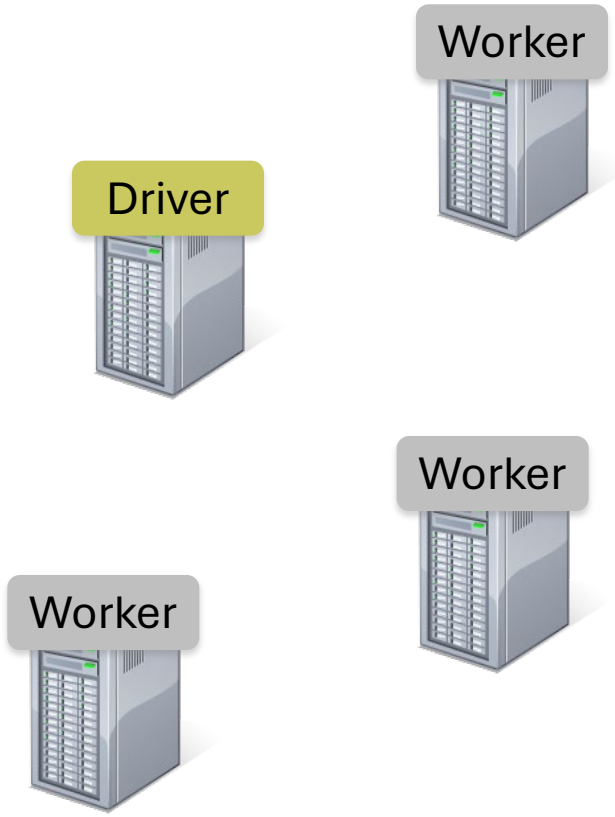

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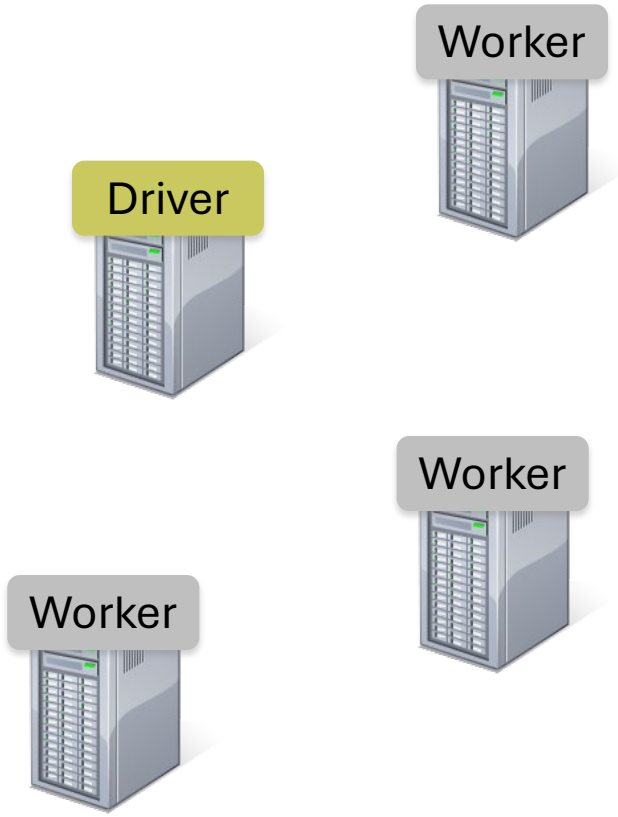

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Base RDD

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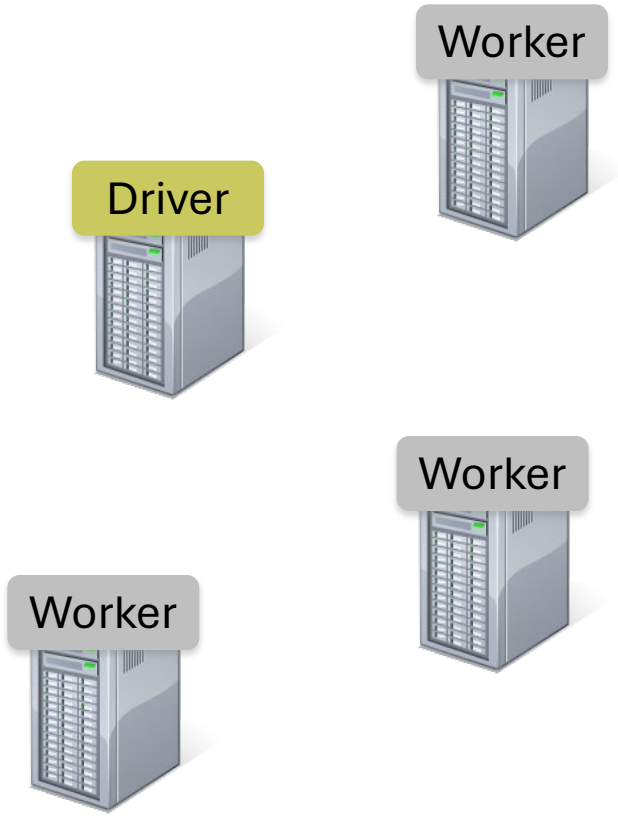

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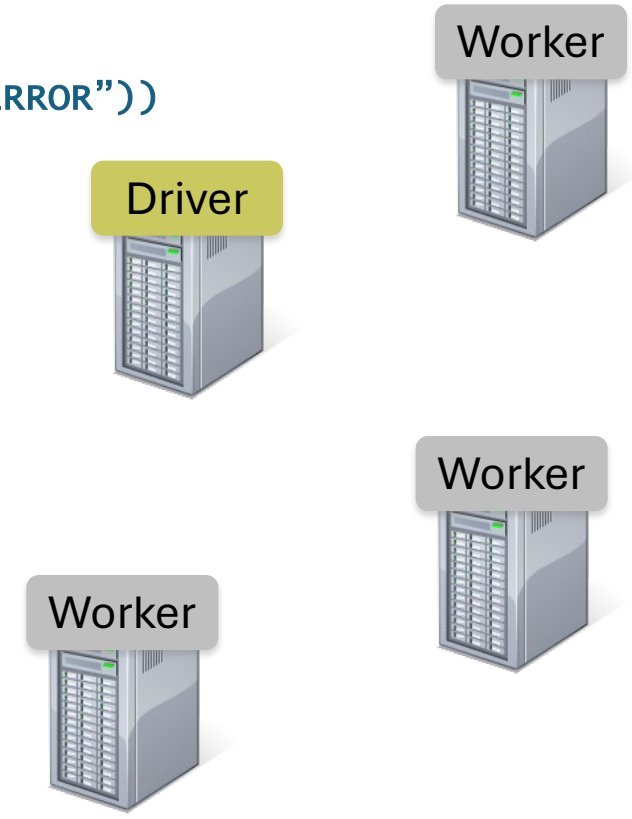

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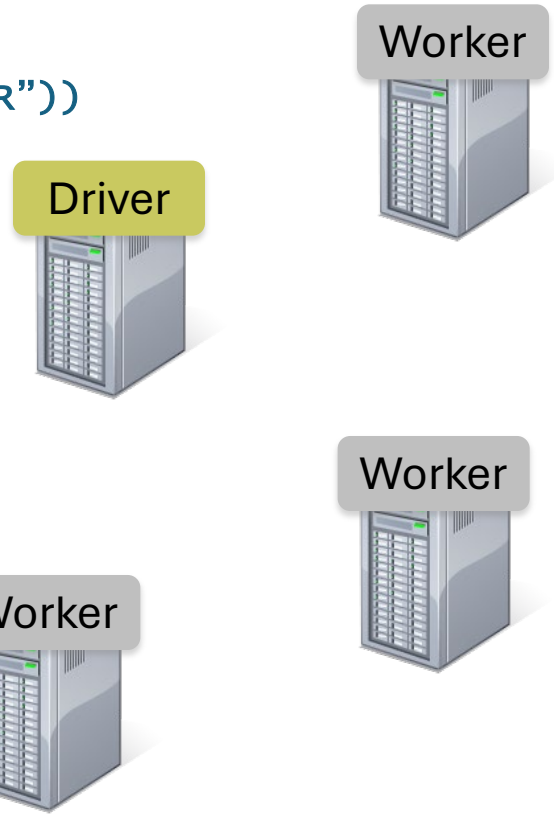
Load error messages from a log into memory, then interactively search for various patterns

Transformed RDD

```
lines = spark.textFile("hdfs://...")
errors = lines.filter(lambda s: s.startswith("ERROR"))
```



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messages.filter(lambda s: “mysql” in s).count()
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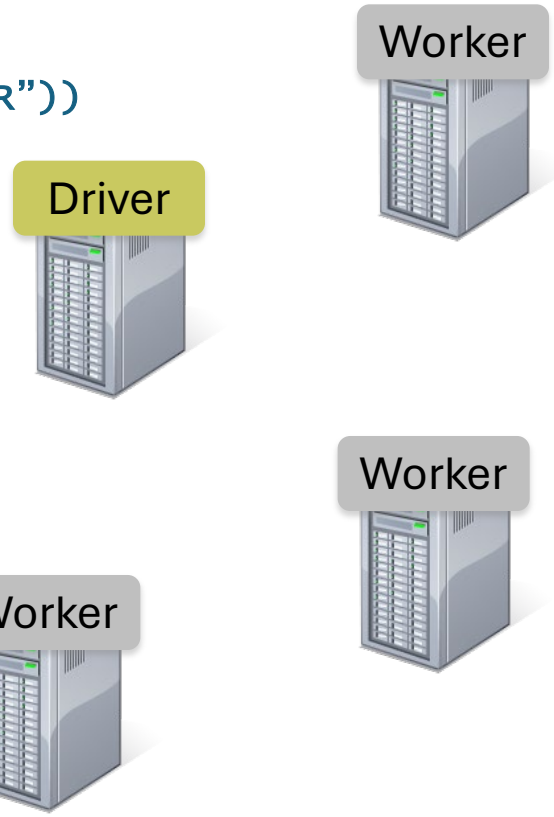

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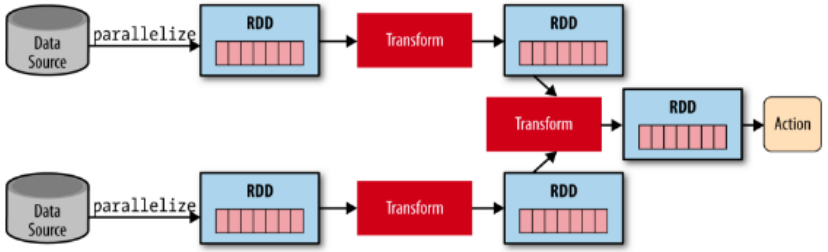


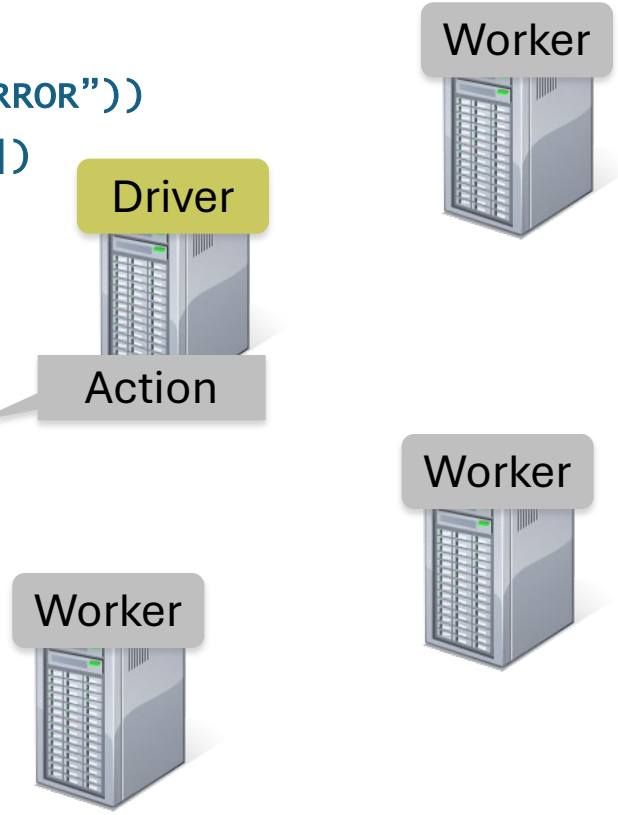

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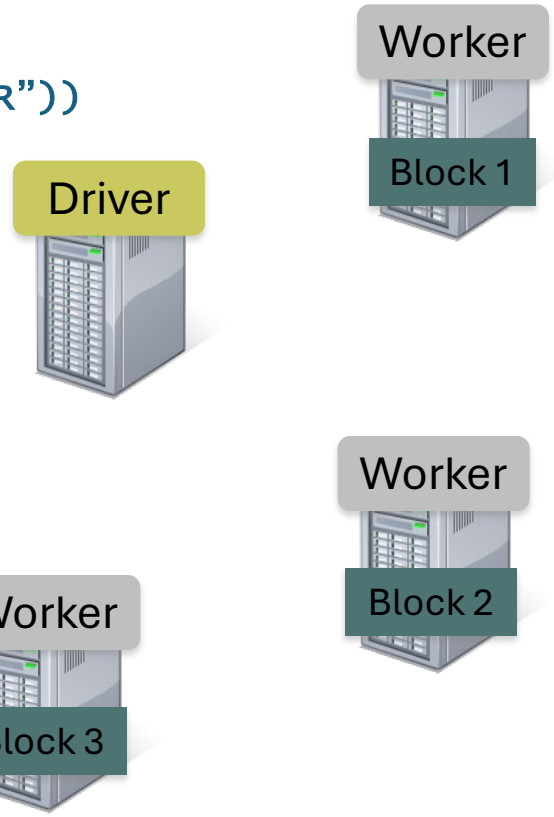

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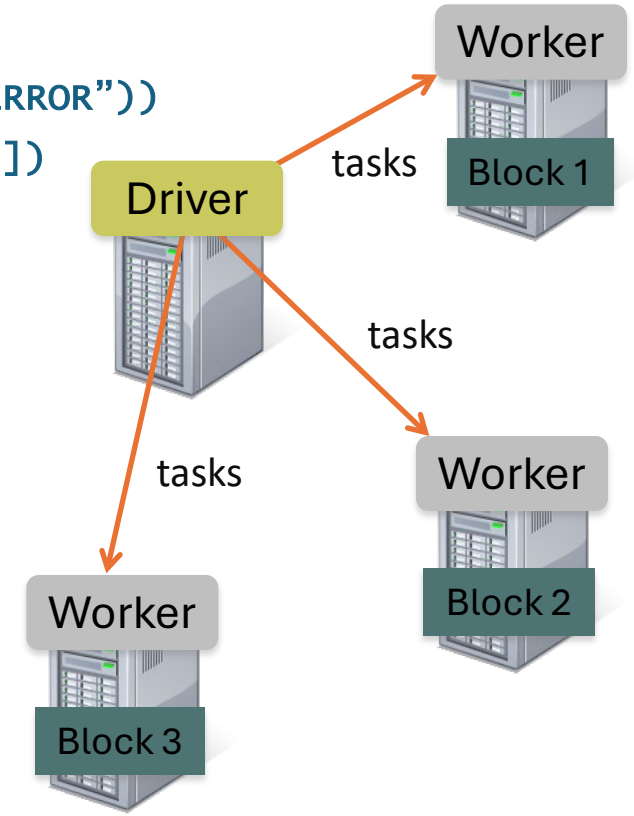

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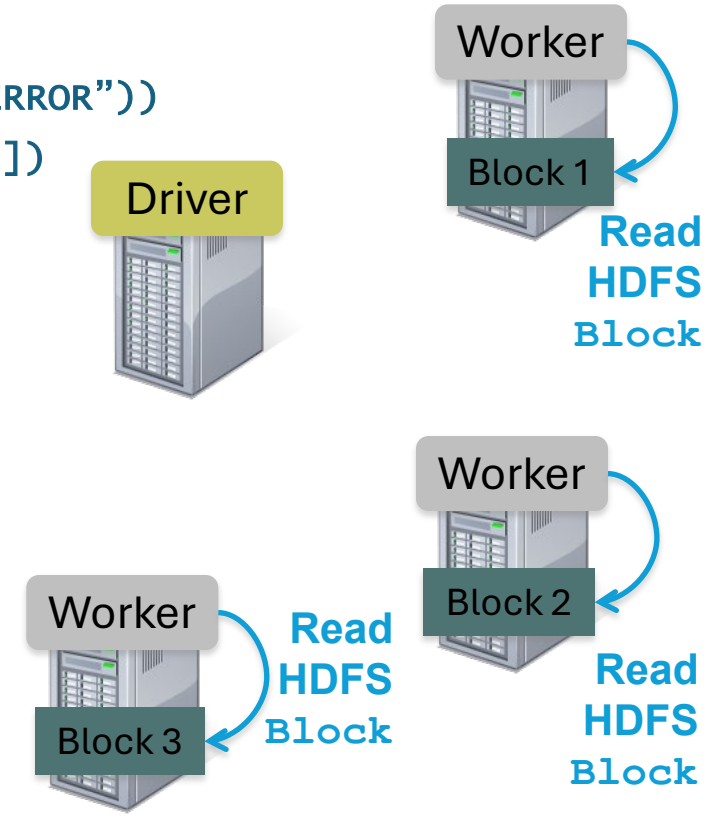

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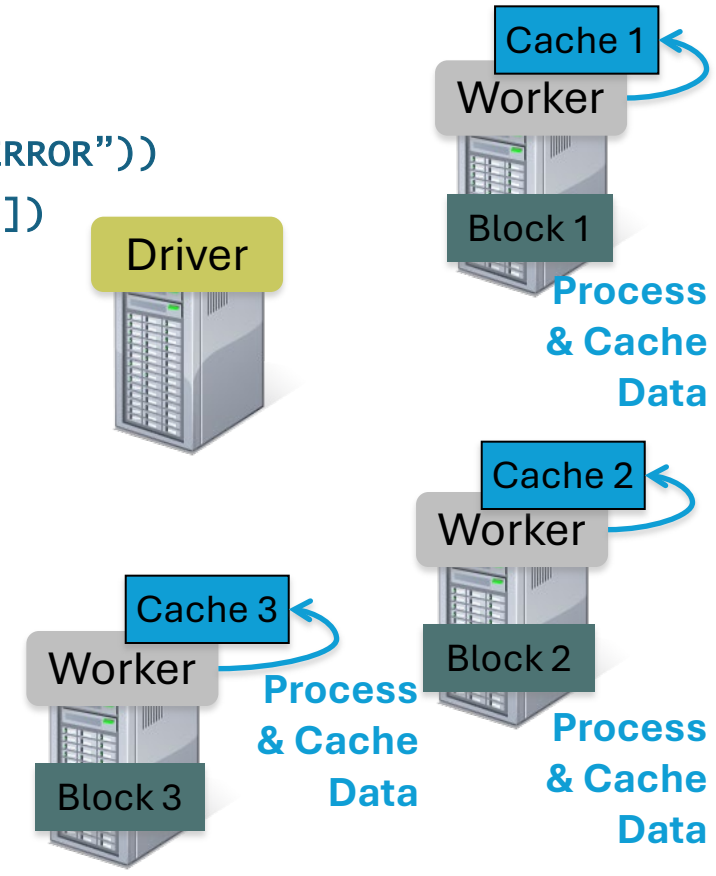

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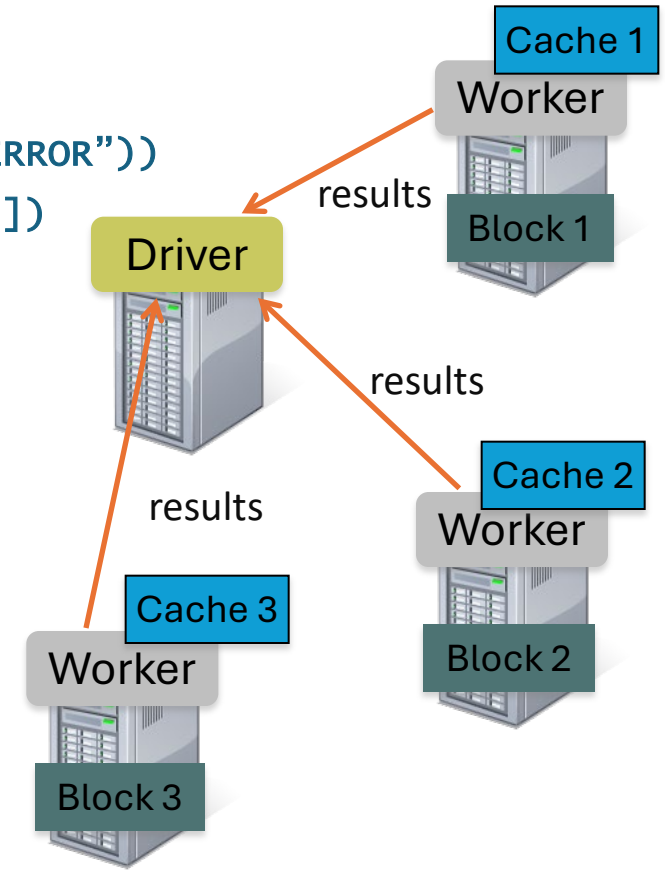

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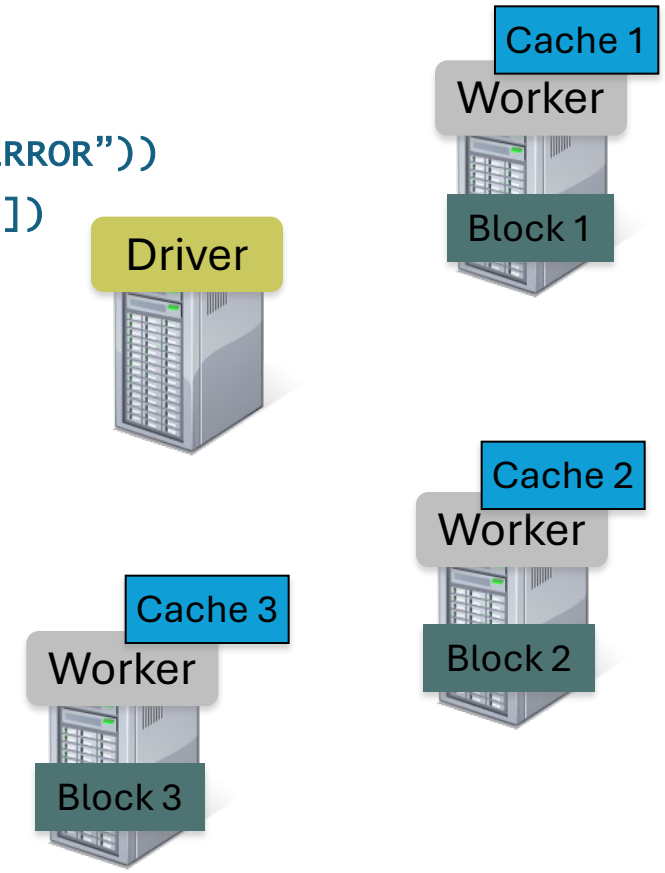

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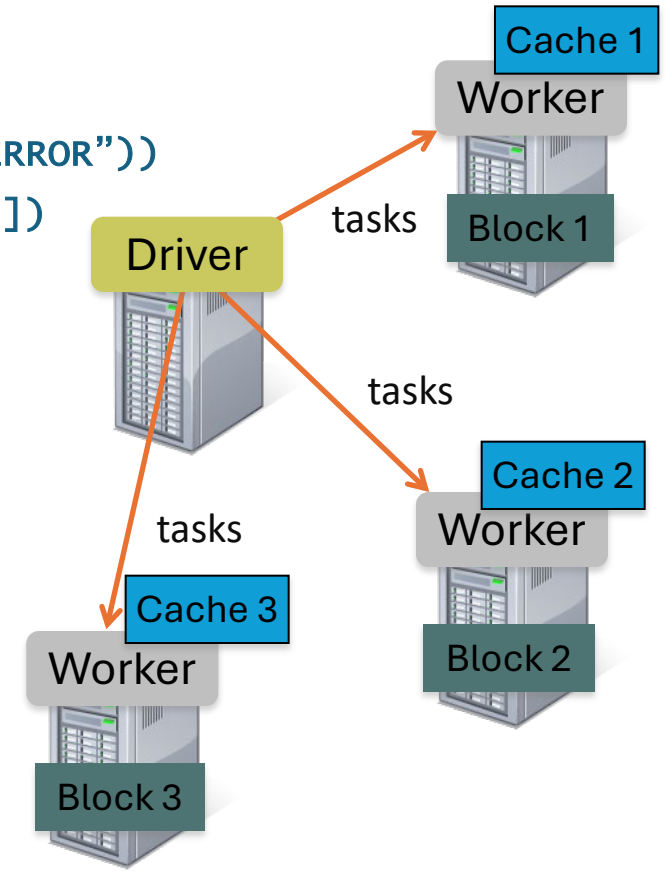

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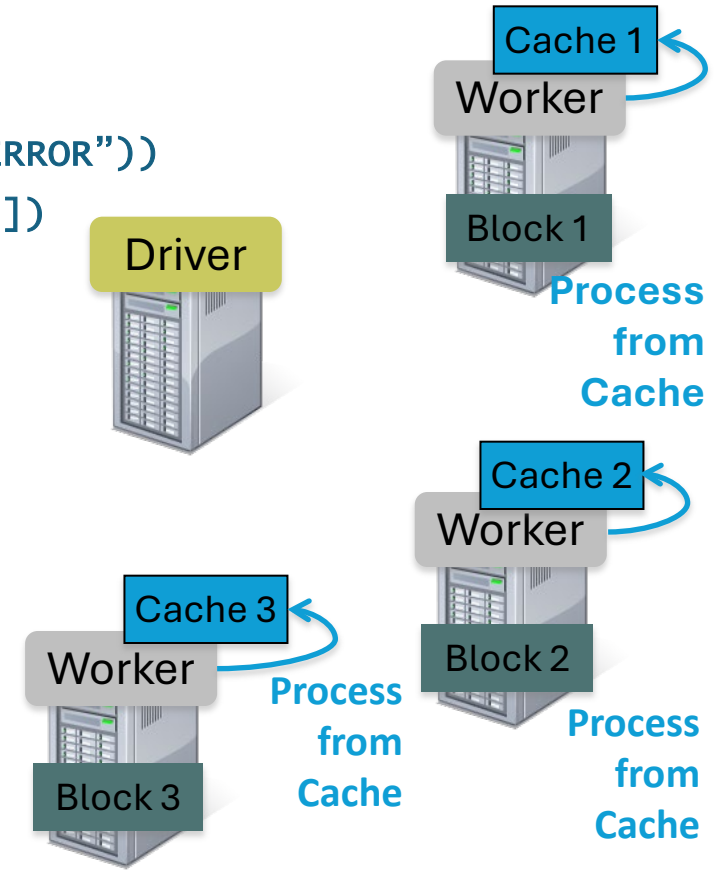

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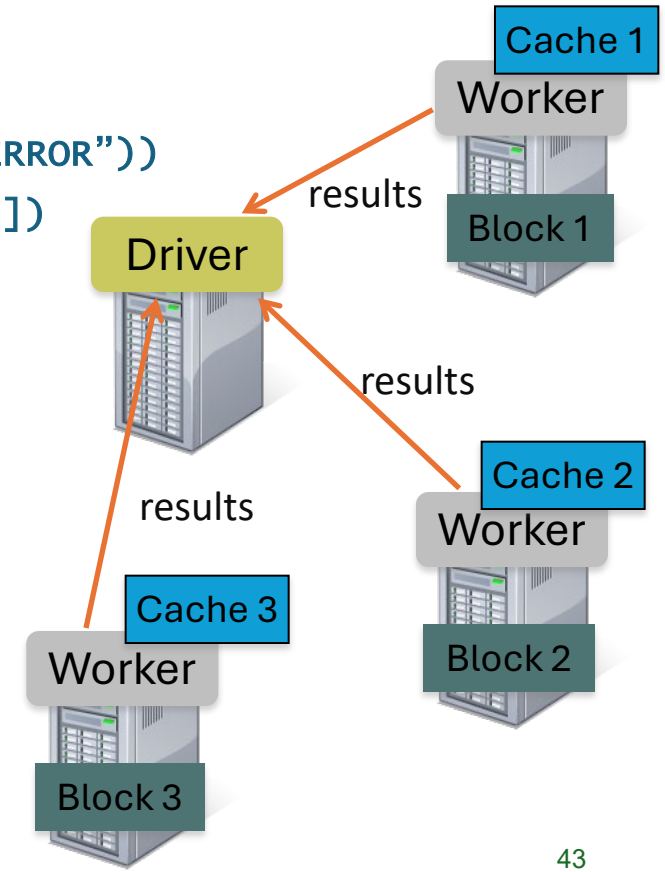

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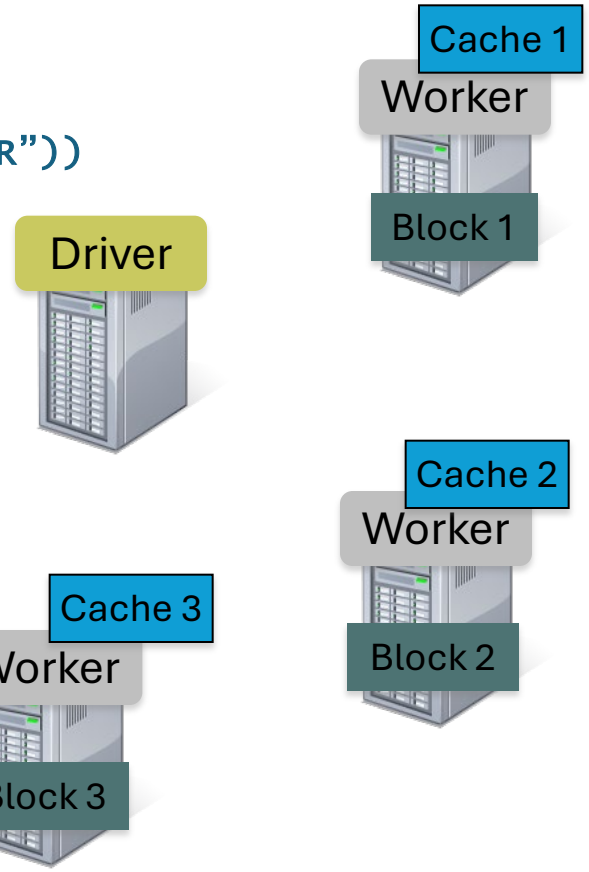
**Cache** your data ➔ Faster results
*Full-text search of Wikipedia*
- 60GB on 20 EC2 machines
- 0.5 sec from mem vs. 20s for on-disk



# Spark Program Lifecycle

- Create DataFrames from external data or create DataFrame from a collection in a driver program
- Lazily transform them into new DataFrames
- cache( ) some DataFrames for reuse
- Perform actions to execute parallel computation and produce results

Use Spark Transformations and Actions wherever possible: Search DataFrame reference API

# Week 1 Contents / Objectives

- The Big Data Problem: Why Spark?
- What is Spark?: The Essentials
- An Example of Spark: Log Mining
- **How to Use Spark: PySpark, HPC, Resources**

# Check-in code: XX-XX-XX

# PySpark 3.5.4

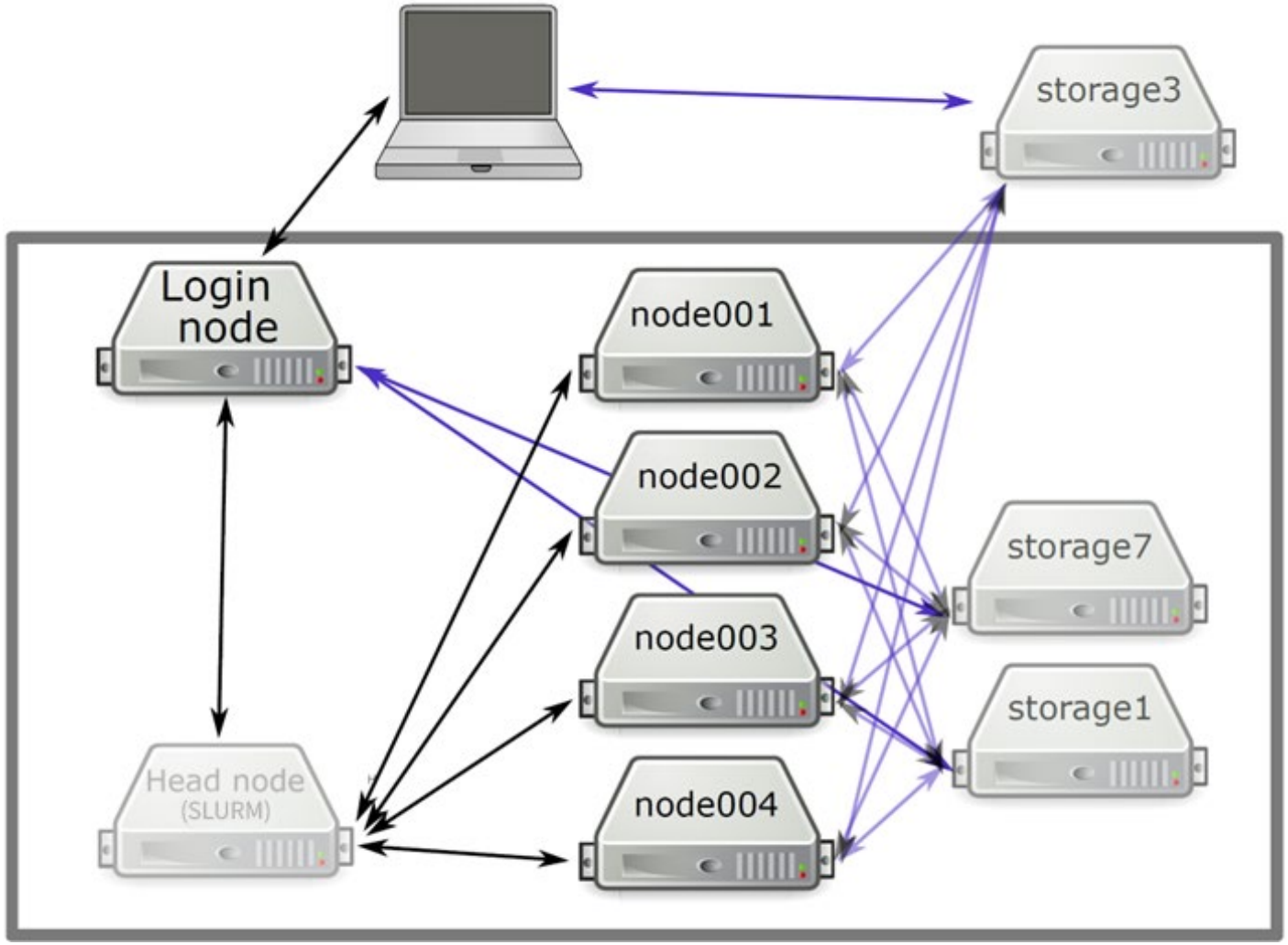
- Need: Java, Python, Spark
- See lab 1 on how to install on HPC
- To install on Windows (optional)
  - Lab 1 instructions: Install Java JRE, Python, Spark
  - Or pip install pyspark==3.5.4
- To install on Linux/Mac (optional): see lab references

# University of Sheffield's HPC

STANAGE

- Account created for you already!
- Training (due 13th Feb Thursday-AS0): HPC Driving License test
- SSH access via stanage.sheffield.ac.uk
  - Windows: MobaXTerm
  - Linux/MAC OS: terminal (command line)
- VPN: a **MUST** for when connecting on campus using Eduroam or off campus

# HPC Cluster Structure



# Storage

| Location | Quota | Speed | Suitable for? |
|---|---|---|---|
| /users/$USER | 50GB | > | Personal data |
| /mnt/parscratch/ | No limits | >>> | Temporary large files |
| /tmp | No limits | >>> | Temporary lots of small files |

More information available at: https://docs.hpc.shef.ac.uk/en/latest/hpc/filestore.html

# Interactive Session

```
Python 3.12.8 | packaged by Anaconda, Inc. | (main, Dec 11 2024, 16:31:09) [GCC 11.2.0
] on linux
Type "help", "copyright", "credits" or "license" for more information.
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLevel(newL
evel).
25/02/10 21:19:46 WARN NativeCodeLoader: Unable to load native-hadoop library for your
 platform...  using builtin-java classes where applicable
Welcome to
      ____              __
     / __/__  ___ _____/ /__
    _\ \/ _ \/ _ `/ __/  '_/
   /__ / .__/\_,_/_/ /_/\_\   version 3.5.4
      /_/

Using Python version 3.12.8 (main, Dec 11 2024 16:31:09)
Spark context Web UI available at http://node001.pri.stanage.alces.network:4040
Spark context available as 'sc' (master = local[*], app id = local-1739222387570).
SparkSession available as 'spark'.
>>>
```

# Batch Session – Shell Script xx.sh

Create a file `Lab1_SubmitBatch.sh`

```
#!/bin/bash
#SBATCH --time=00:30:00  # Change this to a longer time if you need more time
#SBATCH --nodes=1  # Specify a number of nodes
#SBATCH --mem=4G  # Request 4 gigabytes of real memory (mem)
#SBATCH --output=./Output/COM6012_Lab1.txt  # This is where your output and errors are logged
#SBATCH --mail-user=username@sheffield.ac.uk  # Request job update email notifications

module load Java/17.0.4
module load Anaconda3/2024.02-1

source activate myspark

spark-submit ./Code/LogMiningBig.py
```

# Batch Session: Submit & Relax

- sbatch your job (can run at the login node): see Lab 1
- Then?
  - Close the terminal and leave
  - Wait for pre-set email notification
  - Check status: squeue
  - Cancel job: scancel
- How much resources to request
  1. Run short test jobs
  2. View resource utilisation
  3. Extrapolate
  4. Submit larger jobs

https://assets.entrepreneur.com/content/3x2/2000/20150216153034-laptop-desk-glasses.jpeg?format=pjeg&auto=webp
https://th.bing.com/th/id/OIP.P2L5k-Z44bVifj1bnm6-SwAAAA?w=300&h=300&rs=1&pid=ImgDetMain

# Spark Resources

- Apache Spark Documentation
- PySpark tutorial
- Spark videos on YouTube
- Open-source code
- Suggested reading in labs

**Suggested reading**:

- Spark Overview
- Spark Quick Start (Choose **Python** rather than the default *Scala*)
- Chapters 2 to 4 of PySpark tutorial (several sections in Chapter 3 can be safely skipped)
- Reference: PySpark documentation
- Reference: PySpark source code

# Summary of key concepts

- Data structure spectrum
  - Structured, semi-structured, unstructured data, schema, ETL
- Spark's computing model and framework
  - RDDs, DataFrames, parallel transformation, fault-tolerance, …
- Components and lifecycle of a spark programme
  - SparkSession and SparkContext
  - Creating DataFrames, lazy transformations, caching, and actions
- Key features of the Stanage cluster
  - HPC structure, storage, interactive vs. batch session

# Acknowledgements


- Some slides (sec. 1) are modified from the "Introduction to Apache Spark" course by Prof. A. D. Joseph, University of California, Berkeley.
- This module benefits from many open resources. See the acknowledgement on our GitHub page.
- There are many other resources that I have consulted but may somehow lost track of the origins.



Thank-you-word-cloud.jpg (967×522) (wikimedia.org)

# Image sources for the logos

- Page 5:
  - https://upload.wikimedia.org/wikipedia/commons/thumb/b/b9/2023_Facebook_icon.svg/1024px-2023_Facebook_icon.svg.png
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