

# Lecture 1: Introduction to **Spark** and HPC

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COM6012: Scalable ML

# Week 1 Objectives

- Identify key data types across the **data structure spectrum** and describe the **Extract–Transform–Load** (ETL) process.
- Summarise the challenges of the **big data problem**.
- Explain the **architecture, components, and resource management** of a Spark application, and implement simple PySpark programs.
- Explain the structure of the University's **high-performance computing (HPC) cluster**, and request resources to execute computational tasks.

# Contents

- 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**

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# Where Does Big Data Come From?

- **Online** activities:

- Clicks
- Billing events
- Server requests
- Transactions
- Network messages
- Faults
- ...

- Data sharing platforms: web + mobile



YouTube



TikTok

amazon



Instagram



weibo



# Where Does Big Data Come From?

AI generated content



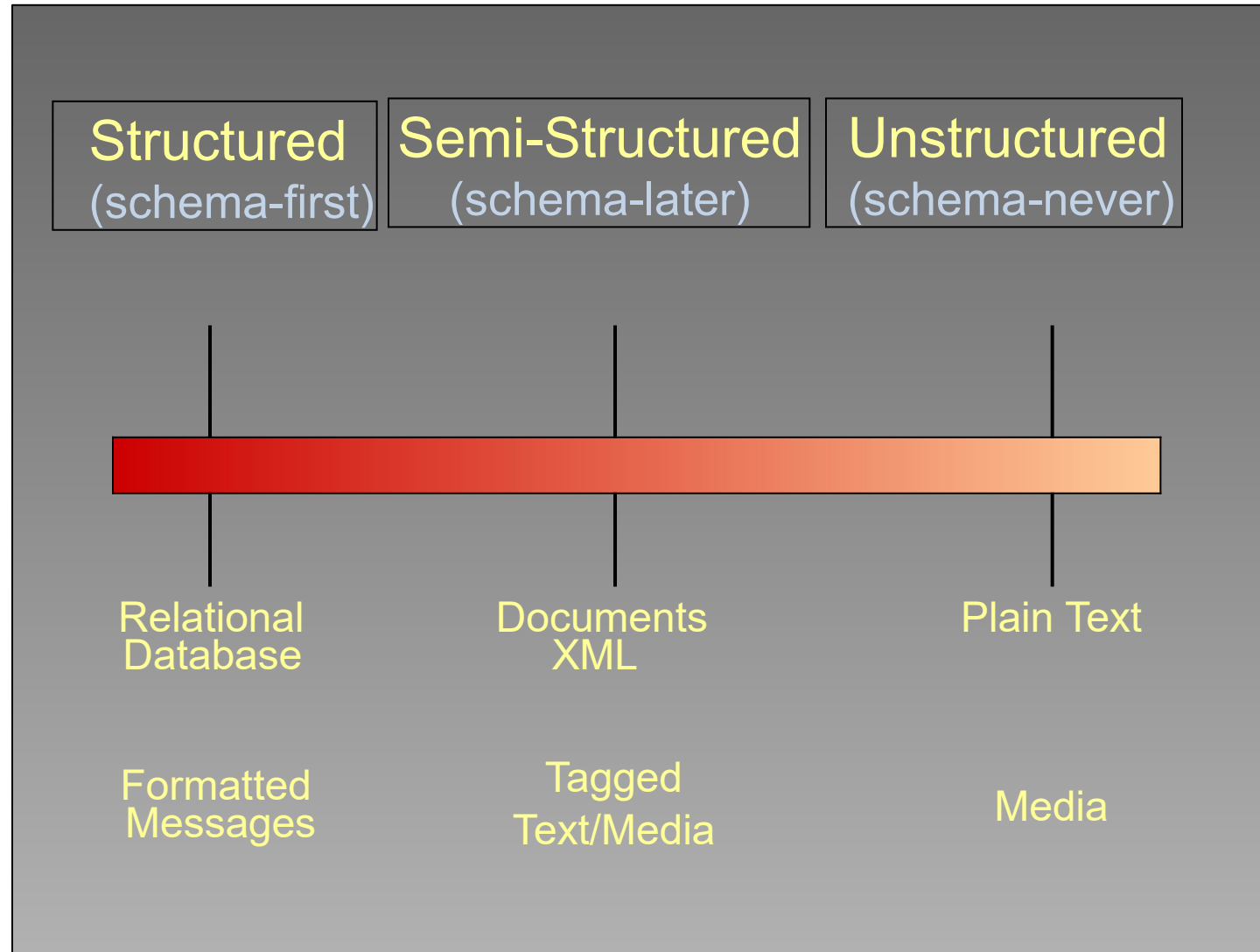
 Gemini

The Gemini logo, featuring a purple four-pointed star above the word "Gemini" in a blue-to-purple gradient font.

 deepseek

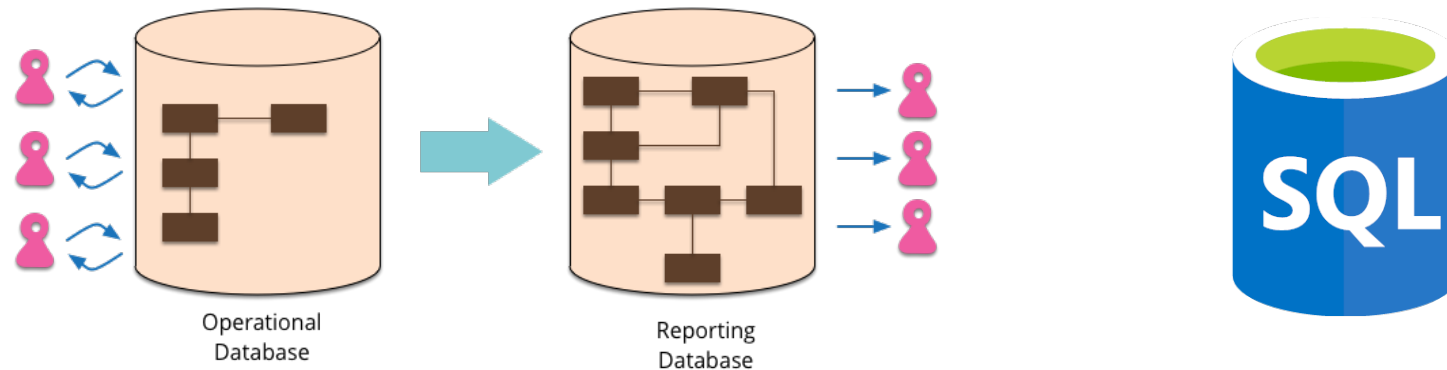
The Deepseek logo, featuring a blue whale icon above the word "deepseek" in a blue font.

# Data Structure Spectrum



# Structured Data

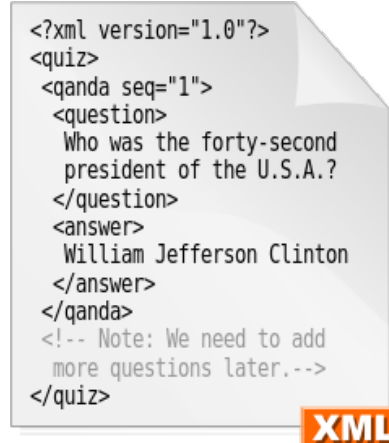
- **Database:** relational data model → how a database is structured and used
- **Schema:** the organisation of data as a blueprint of how the database is constructed
  - The programmer **must statically specify** the schema
- **SQL:** Structured Query Language





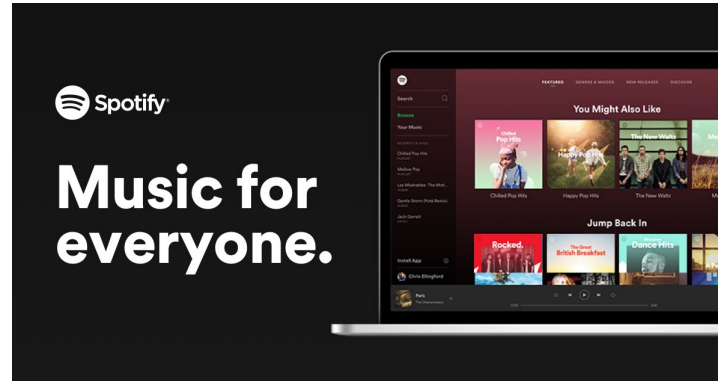
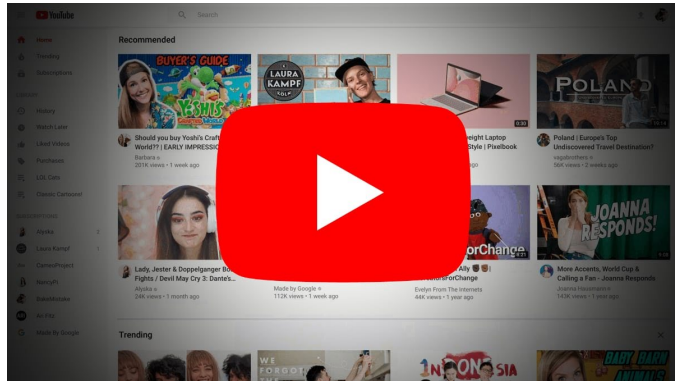
# Semi-Structured Data

- **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:

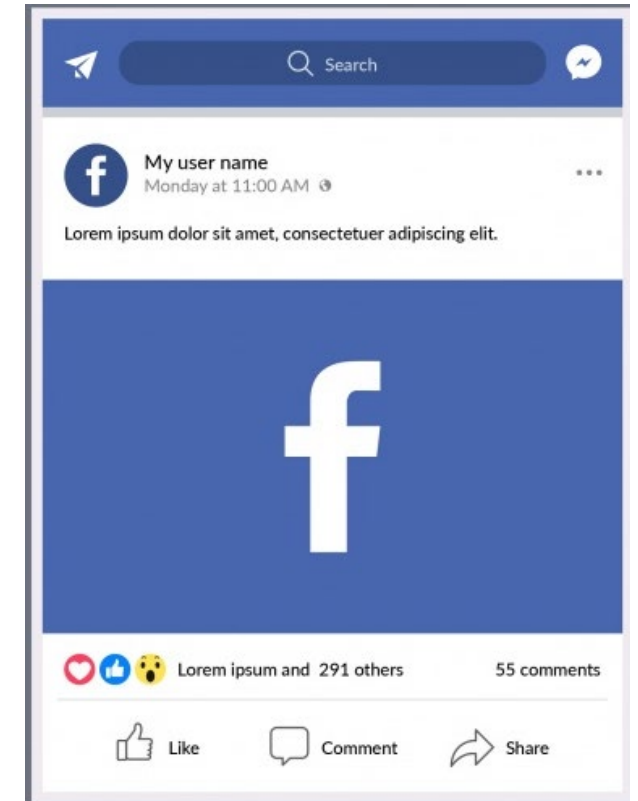


# Unstructured Data

- Only one column with string or binary type
- Examples

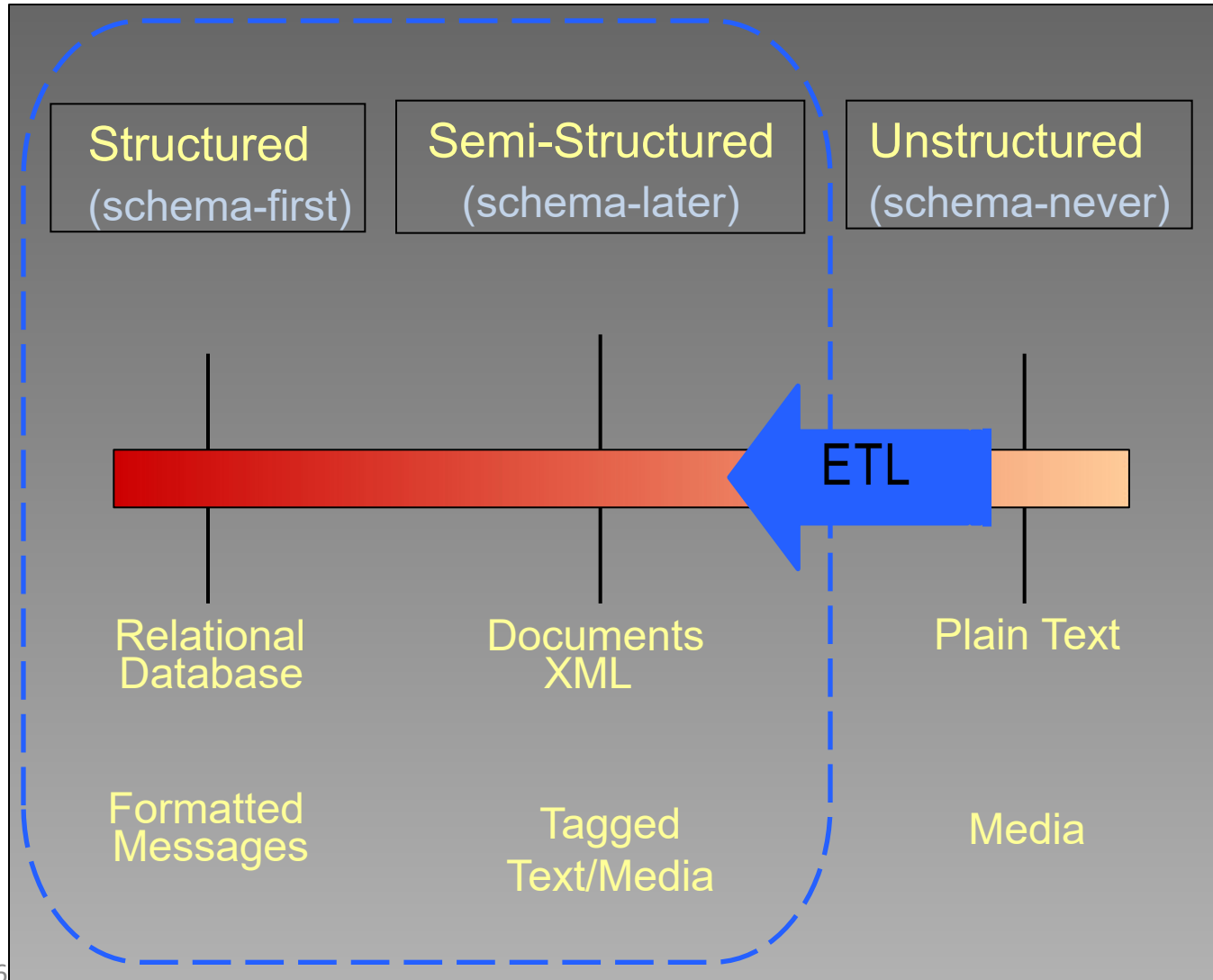


- Note: File formats  $\neq$  data structure



<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](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
```

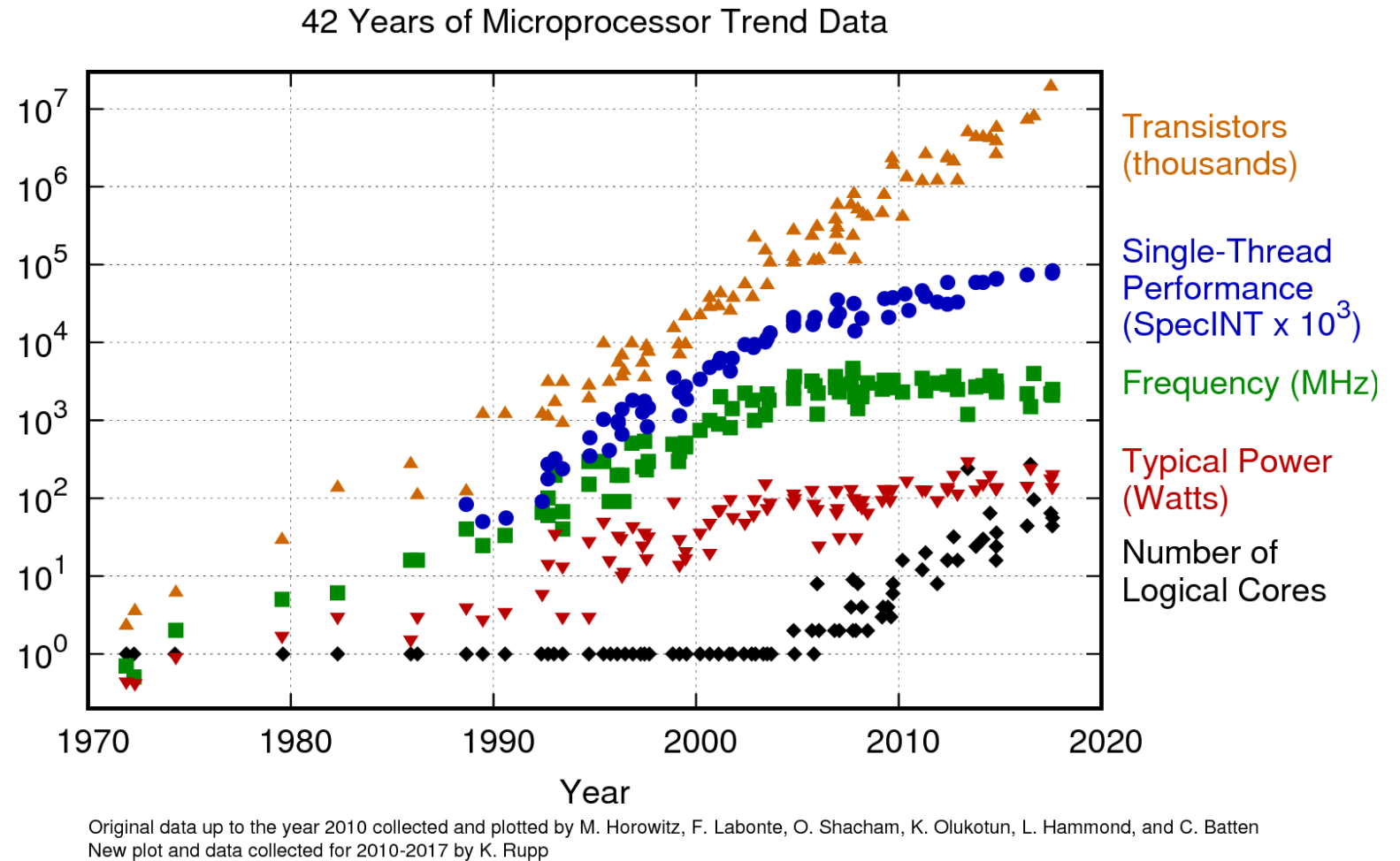
Item	Model	Country	Cost
1	BMW	Germany	\$25000
2	Volvo	Sweden	\$15000
3	Subaru	Japan	\$2500
4	Ferrari	Italy	\$2000000
5	SAAB	USA	\$3000

```
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!

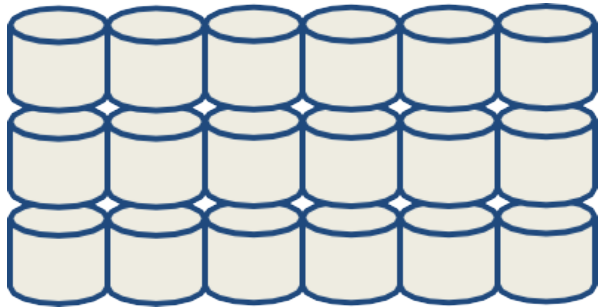
# The Big Data Problem

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

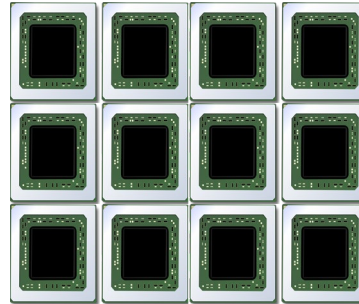


# Solution for the Big Data Problem

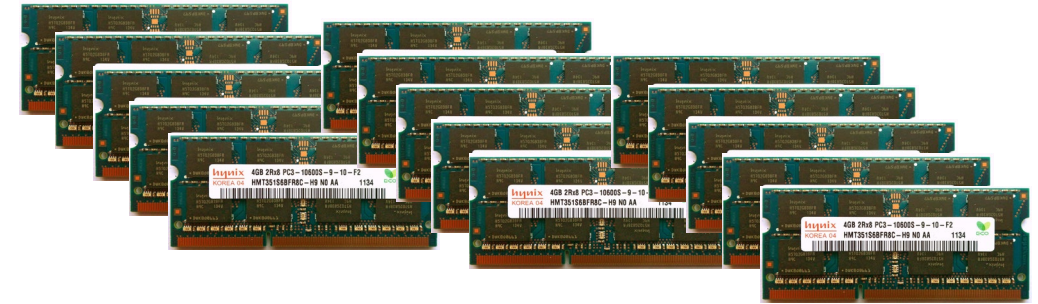
- **One machine** cannot process or *even store* all the data!
- Solution: **distribute** data over a **cluster** of machines



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



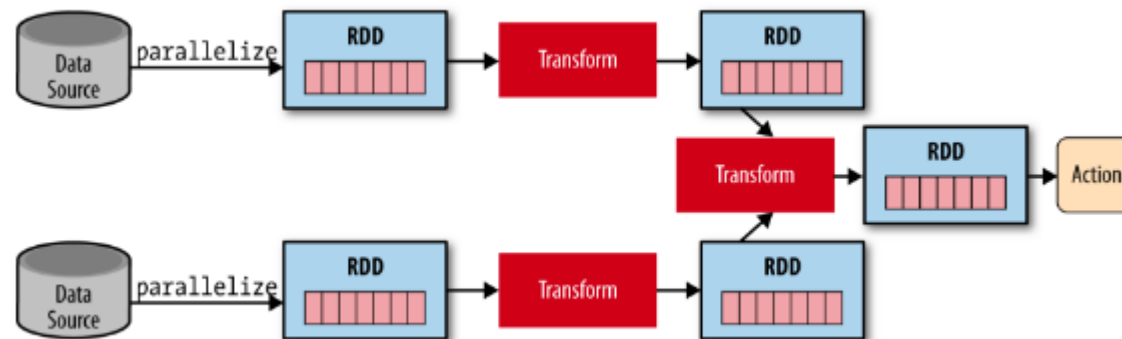
- Improves efficiency through:
  - **In-memory** computing primitives
  - General **computation graphs**
- Improves usability through:
  - Rich APIs in Scala, Java, **Python**
  - **Interactive shell**

→ Up to 100× faster  
(2-10× on disk)

→ 2-5× less code

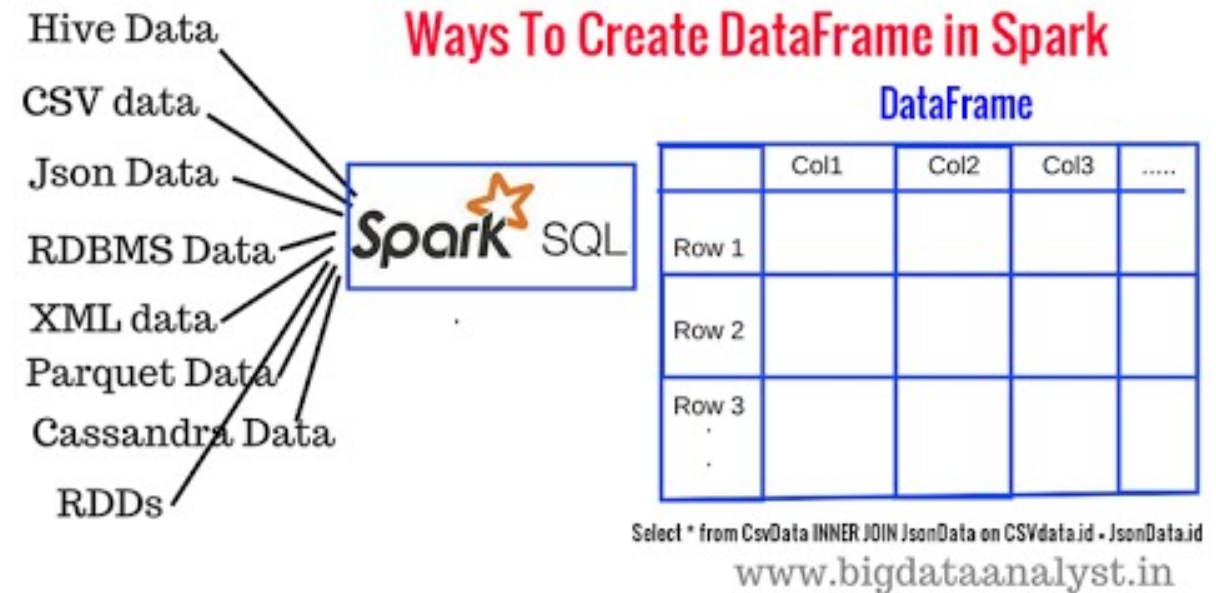
# Spark Model

- 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

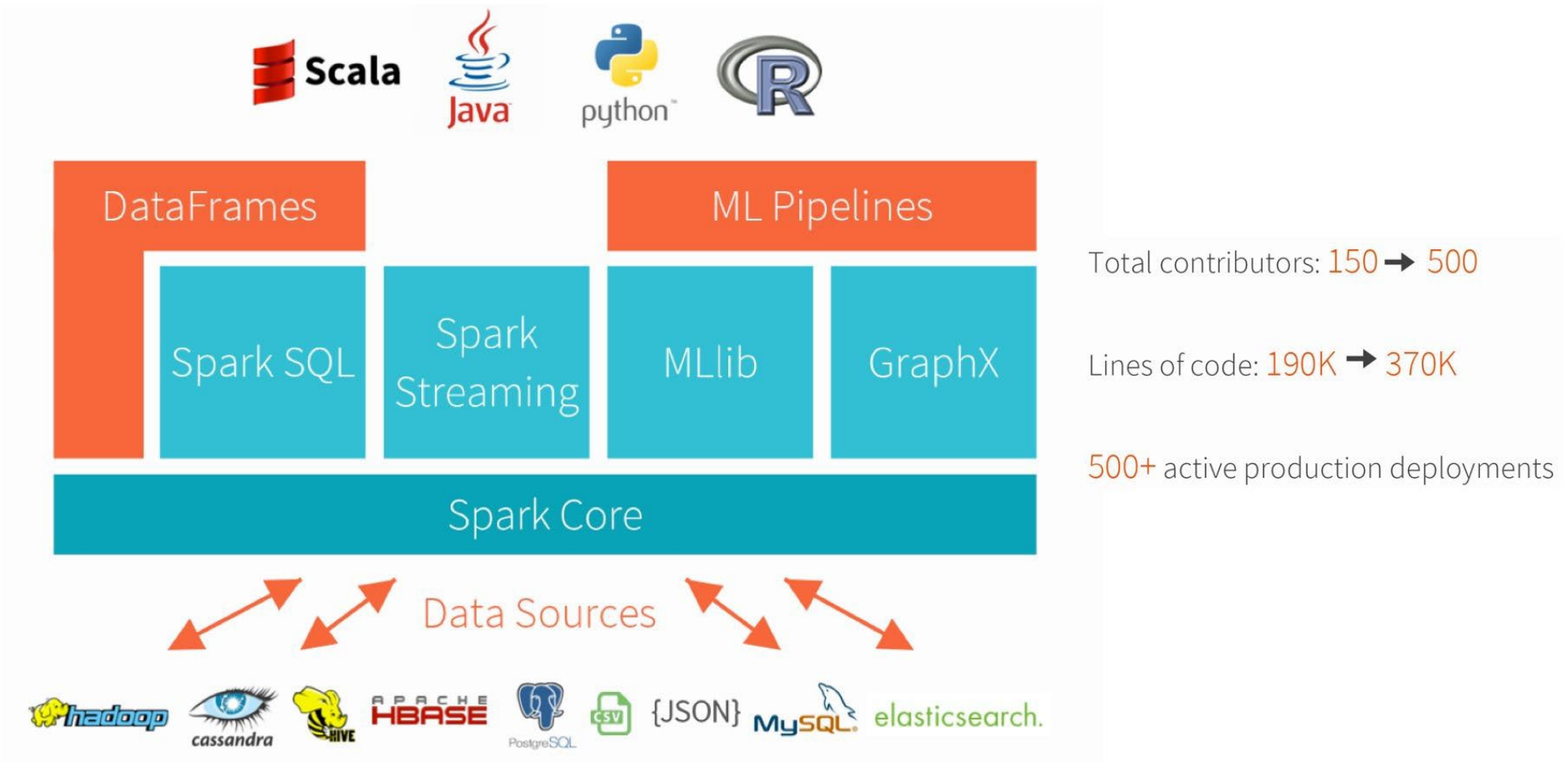
“Here’s an operation, run it on all of the data”

**JUST DO IT.**

- 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)

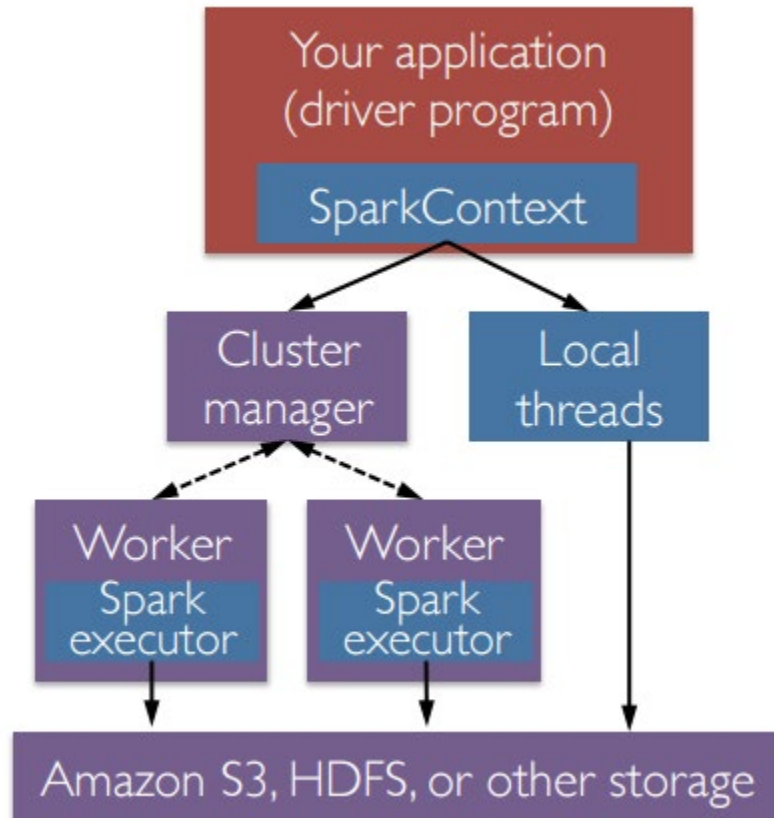


# Apache Spark Ecosystem



<https://i.pining.com/originals/e7/f3/2d/e7f32d041846a5938a09e192bdf3885d.jpg>

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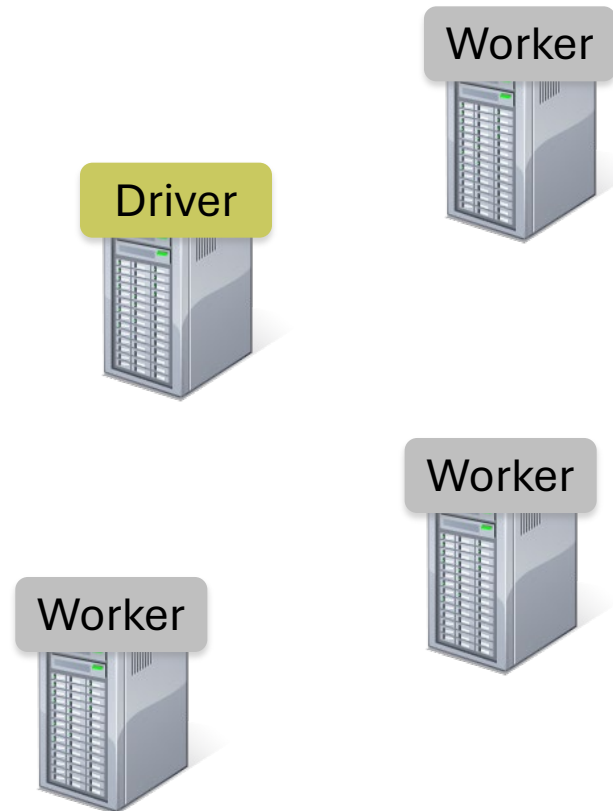
# Spark Example: Log Mining (w/t RDD)

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



# Spark Example: Log Mining

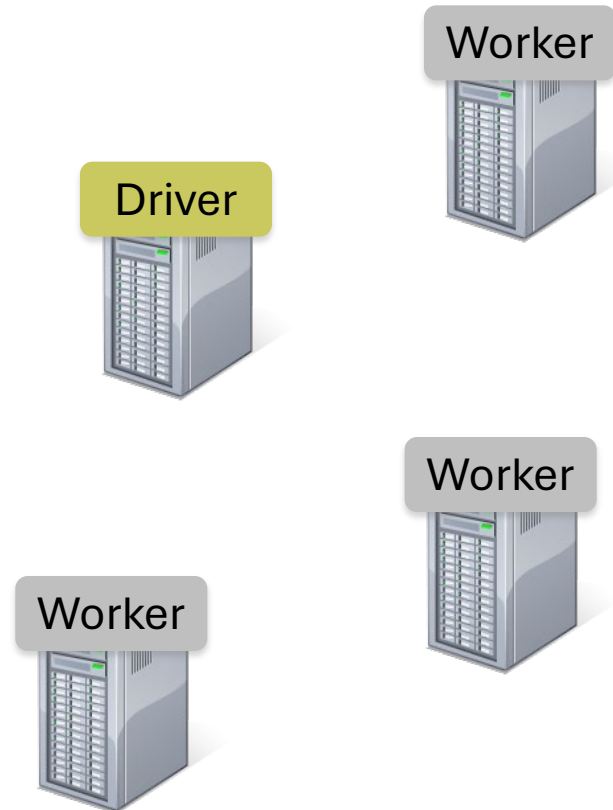
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# Spark Example: Log Mining

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

```
lines = spark.textFile("hdfs://...")
```



# Spark Example: Log Mining

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

Base RDD

```
lines = spark.textFile("hdfs://...")
```

Driver

Worker

Worker

Worker

# Spark Example: Log Mining

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

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

Driver

Worker

Worker

Worker

# Spark Example: Log Mining

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"))
```

Driver

Worker

Worker

Worker

# Spark Example: Log Mining

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

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lines = spark.textFile("hdfs://...")
errors = lines.filter(lambda s: s.startswith("ERROR"))
messages = errors.map(lambda s: s.split("\t")[2])
messages.cache()
```

```
messages.filter(lambda s: "mysql" in s).count()
```

Driver

Worker

Worker

Worker

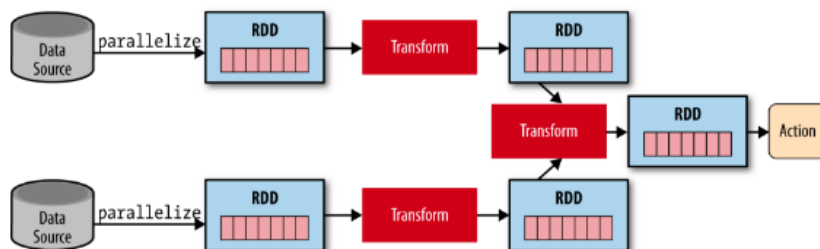


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Driver

Action

Worker

Worker

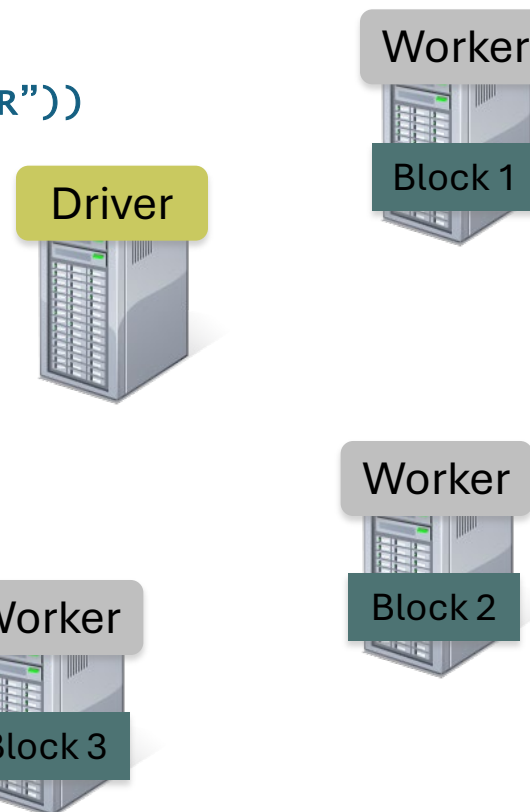
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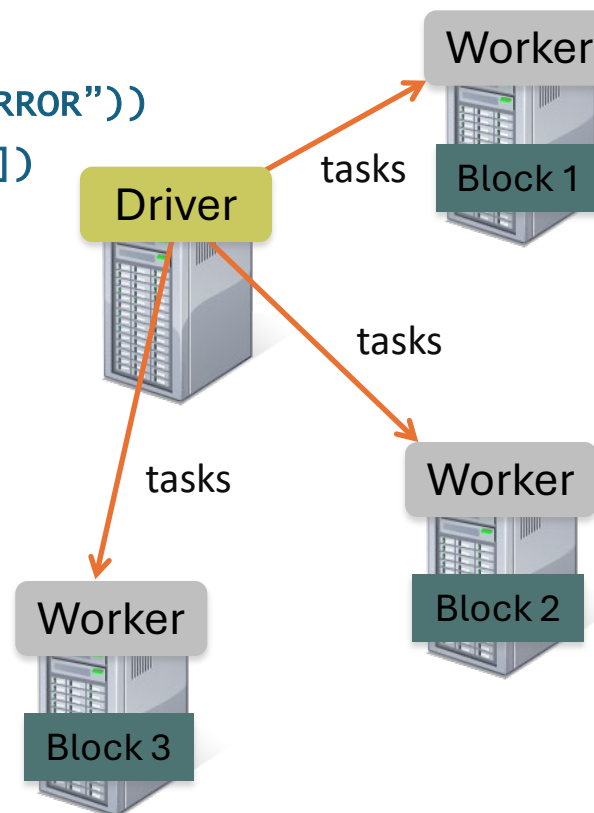


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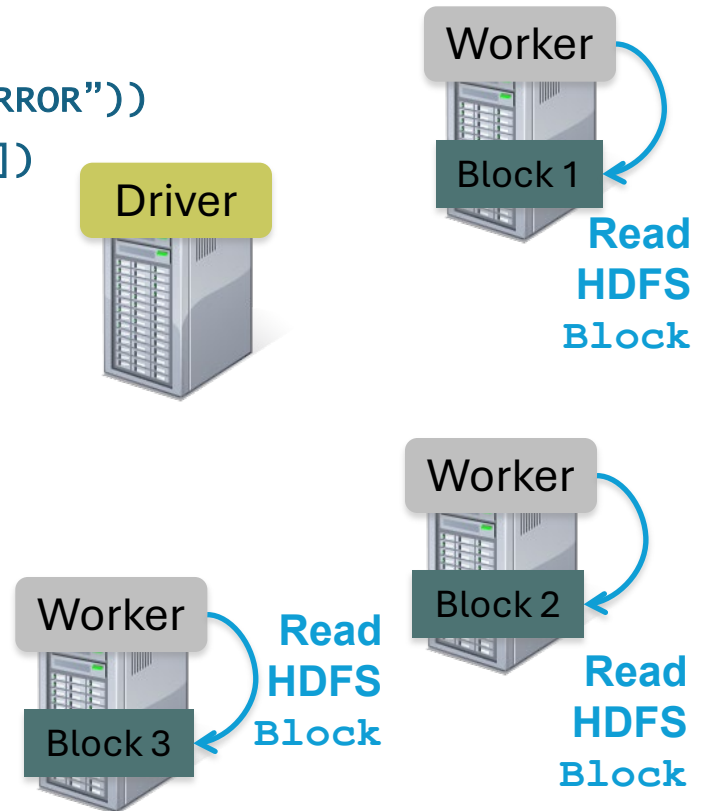


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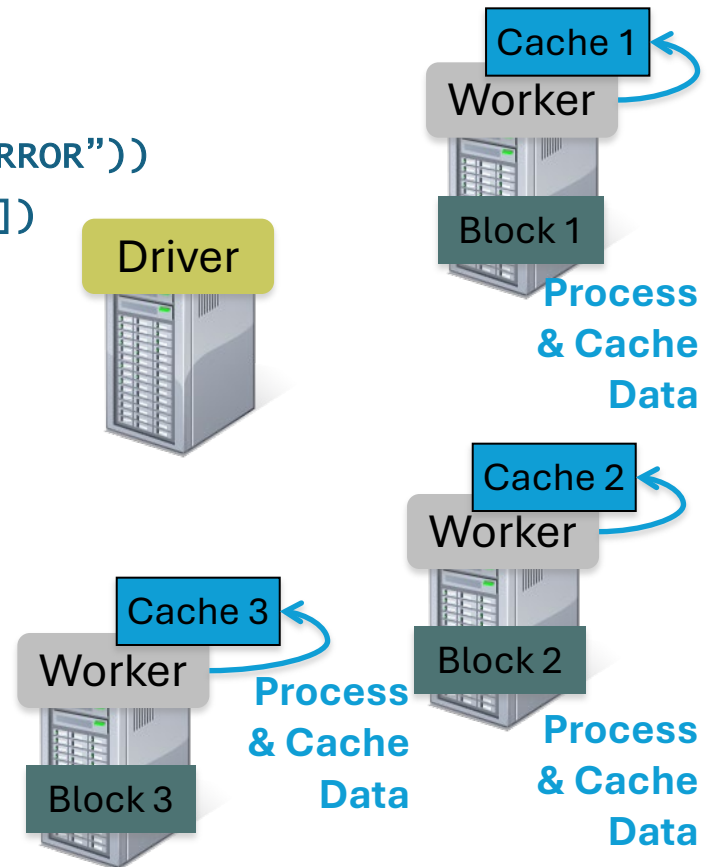


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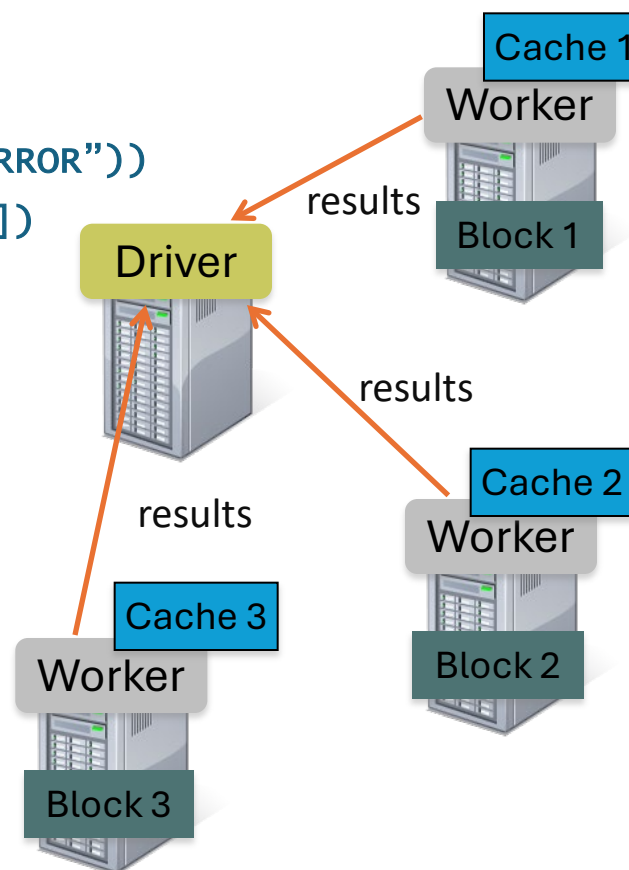


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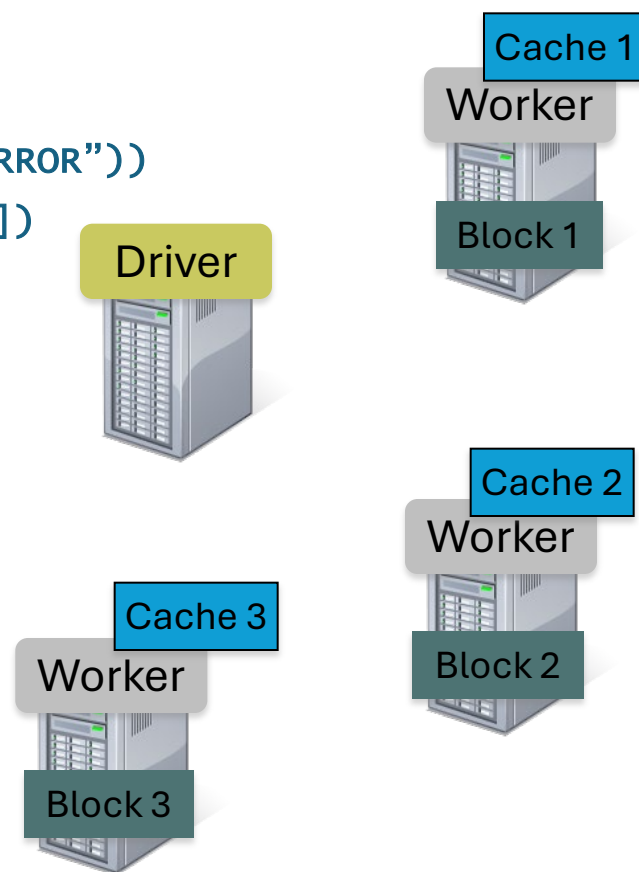


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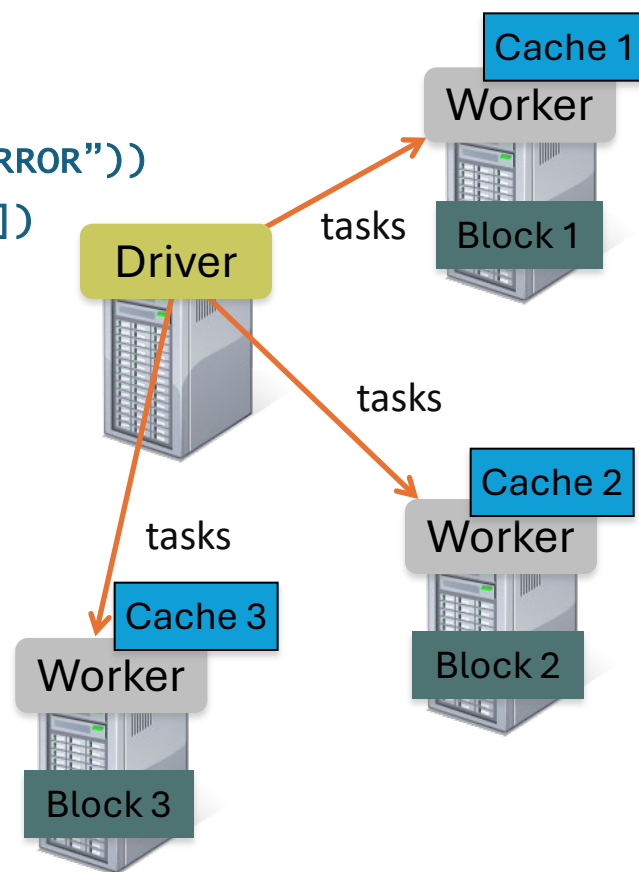


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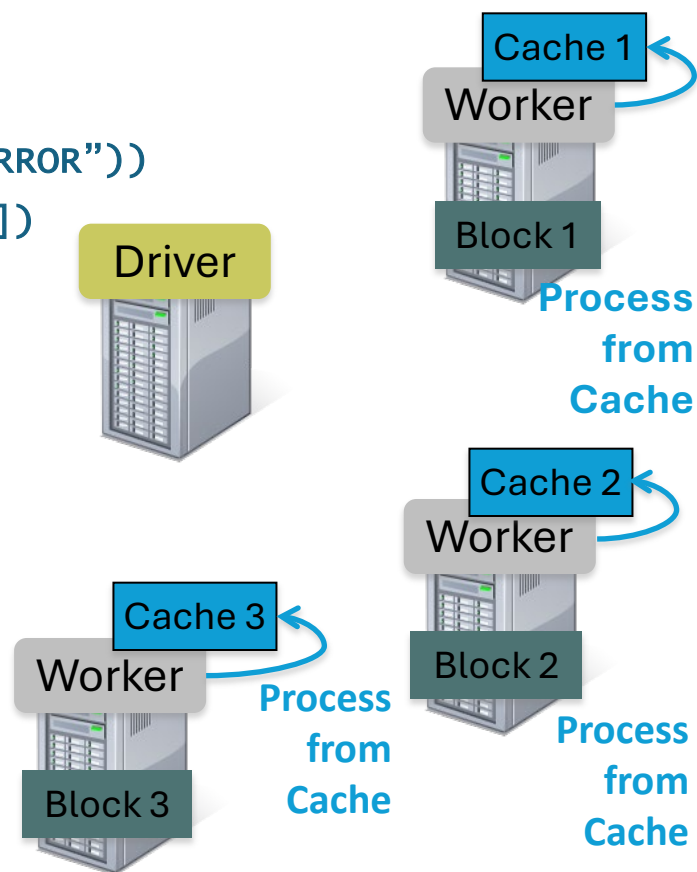


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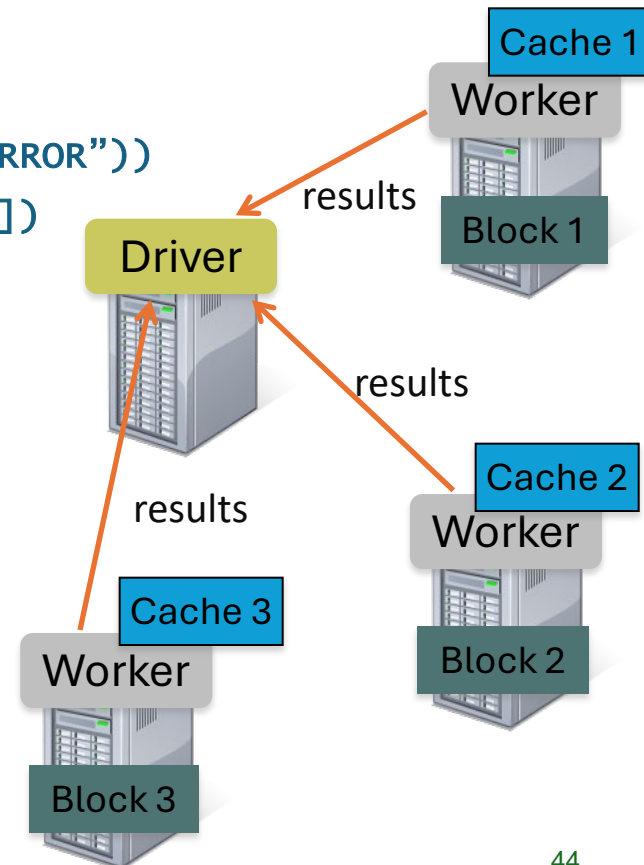


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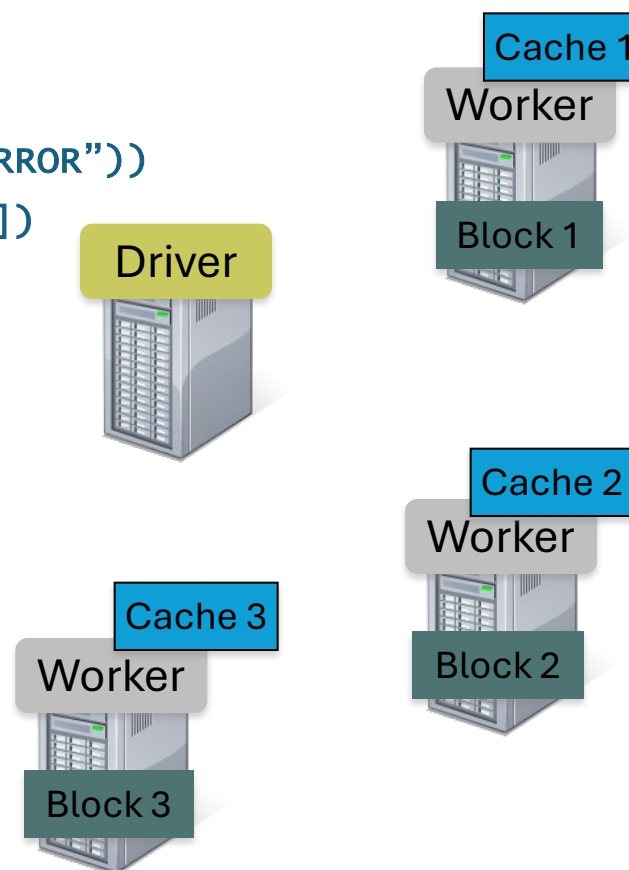
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```
messages.filter(lambda s: "mysql" in s).count()
messages.filter(lambda s: "php" in s).count()
```

**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](#)

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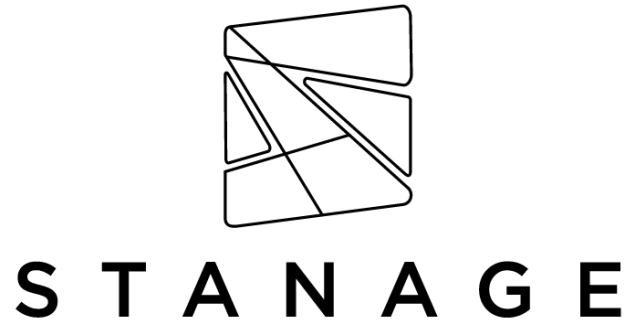
Check-in code:  
**XX-XX-XX**

# PySpark 4.1.0

- 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==4.1.0
- To install on Linux/Mac (optional): see lab references

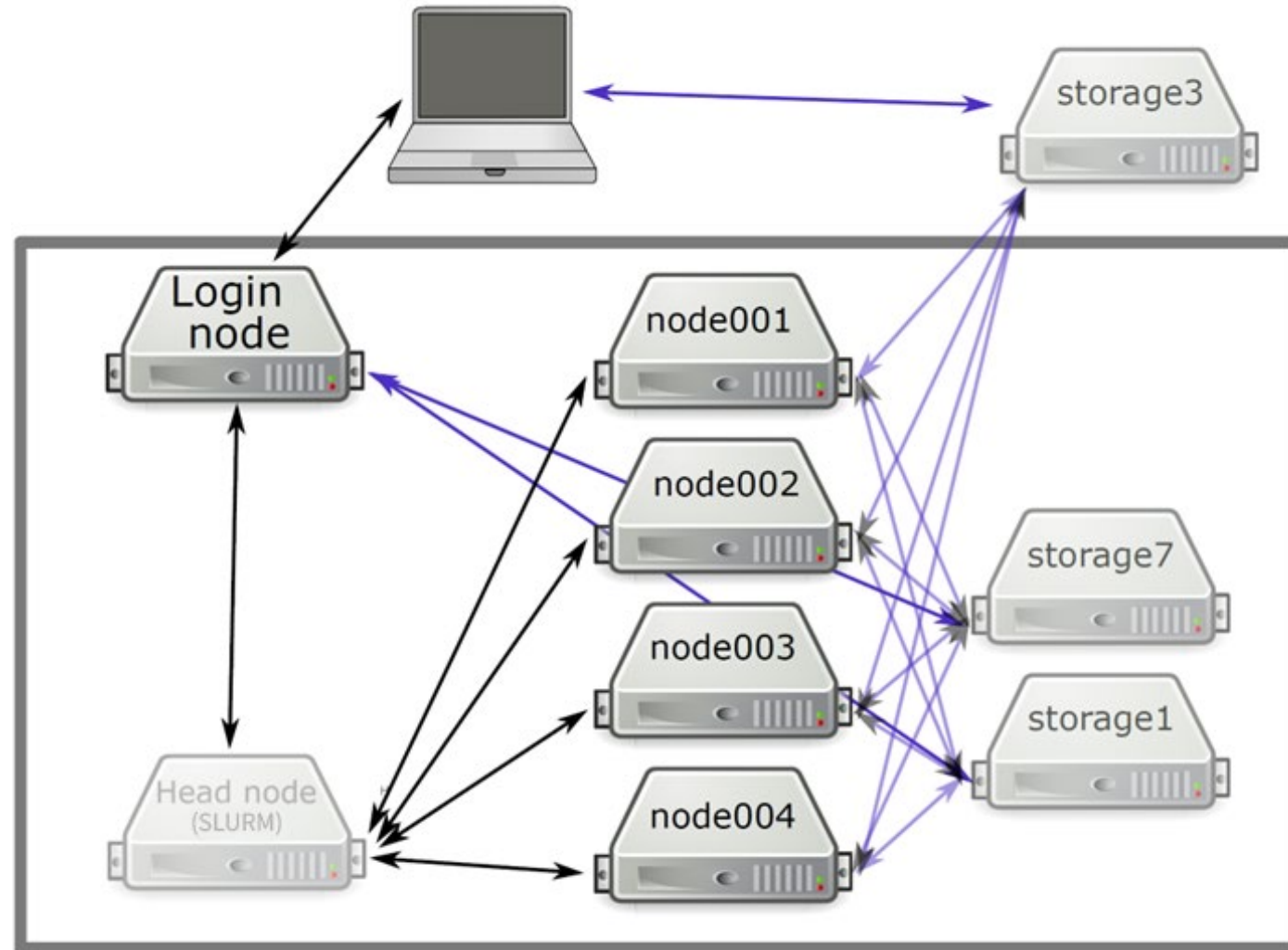


# University of Sheffield's HPC



- Account created for you already!
- Training (due 13<sup>th</sup> Feb Thursday-AS0): [HPC Driving License test](#)
- SSH access via [stanage.sheffield.ac.uk](https://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 3.13.5 | packaged by Anaconda, Inc. | (main, Jun 12 2025, 16:09:02) [GCC 11.2.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
WARNING: Using incubator modules: jdk.incubator.vector
Using Spark's default log4j profile: org/apache/spark/log4j2-defaults.properties
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLevel(newLevel).
26/02/03 14:52:48 WARN NativeCodeLoader: Unable to load native-hadoop library for your platform... us
ing builtin-java classes where applicable
Welcome to
```



version 4.1.0

```
Using Python version 3.13.5 (main, Jun 12 2025 16:09:02)
Spark context Web UI available at http://node001.pri.stanage.alces.network:4040
Spark context available as 'sc' (master = local[*], app id = local-1770130369562).
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=pjpeg&auto=webp>  
<https://th.bing.com/th/id/OIP.P2L5k-Z44bVifj1bnm6-SwAAAA?w=300&h=300&rs=1&pid=ImgDetMain>

# 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

# Spark Resources

- [Apache Spark open-source repository](#)
- [Apache Spark Documentation](#)
- [Learning Apache Spark with Python](#) (Chapters 2 and 4)
- 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 4.1.0 documentation](#)
- Reference: [PySpark source code](#)

# 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 (967x522) (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](https://upload.wikimedia.org/wikipedia/commons/thumb/b/b9/2023_Facebook_icon.svg/1024px-2023_Facebook_icon.svg.png)
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