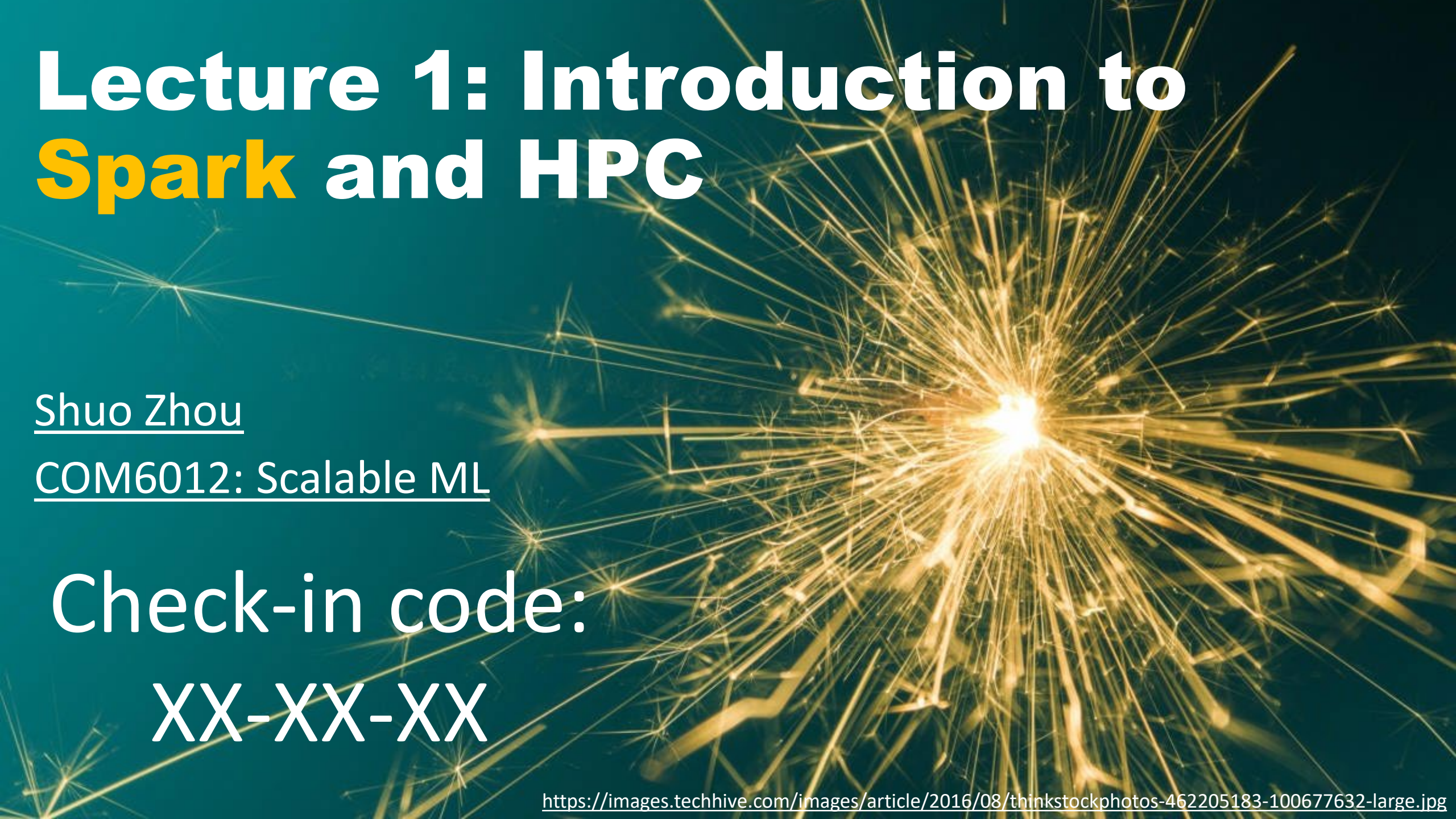
Lecture 1: Introduction to Spark and HPC

Shuo Zhou

COM6012: Scalable ML

Check-in code:

XX-XX-XX



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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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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

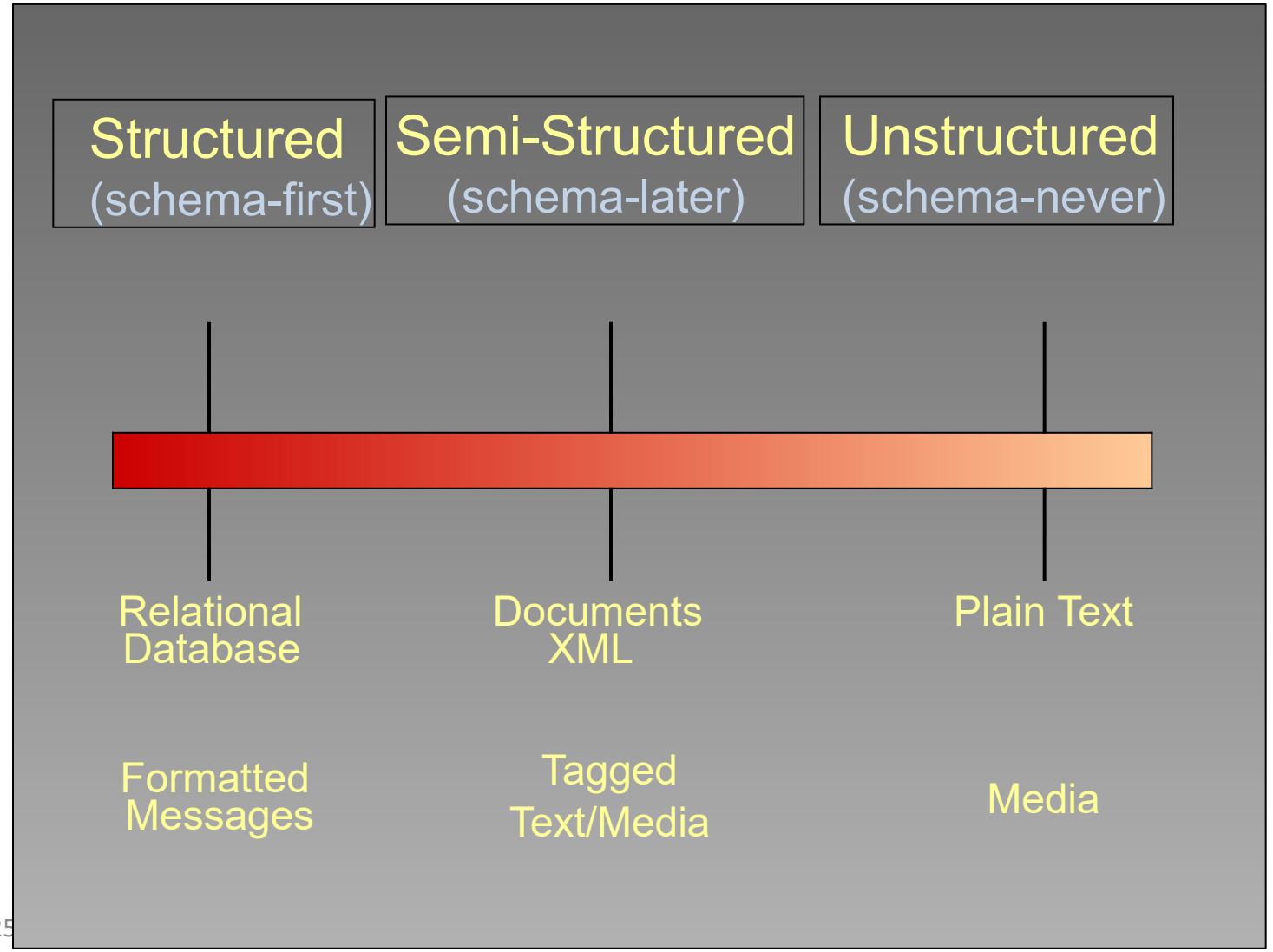
Where Does Big Data Come From?

- User generated content: web + mobile

Where Does Big Data Come From?

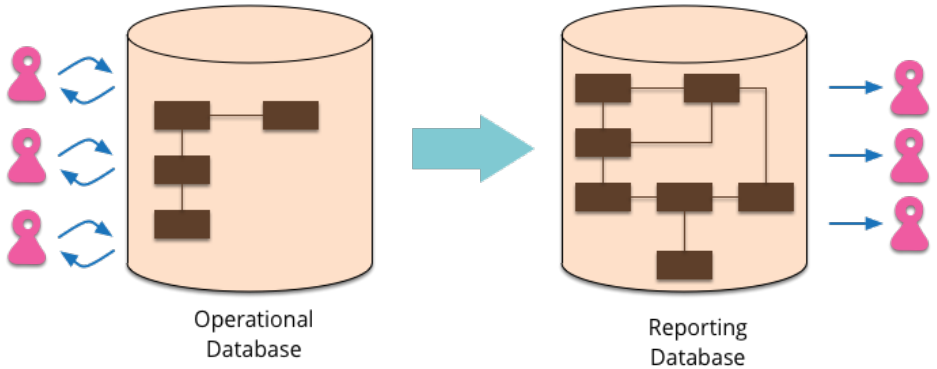
AI generated content

Data Structure Spectrum



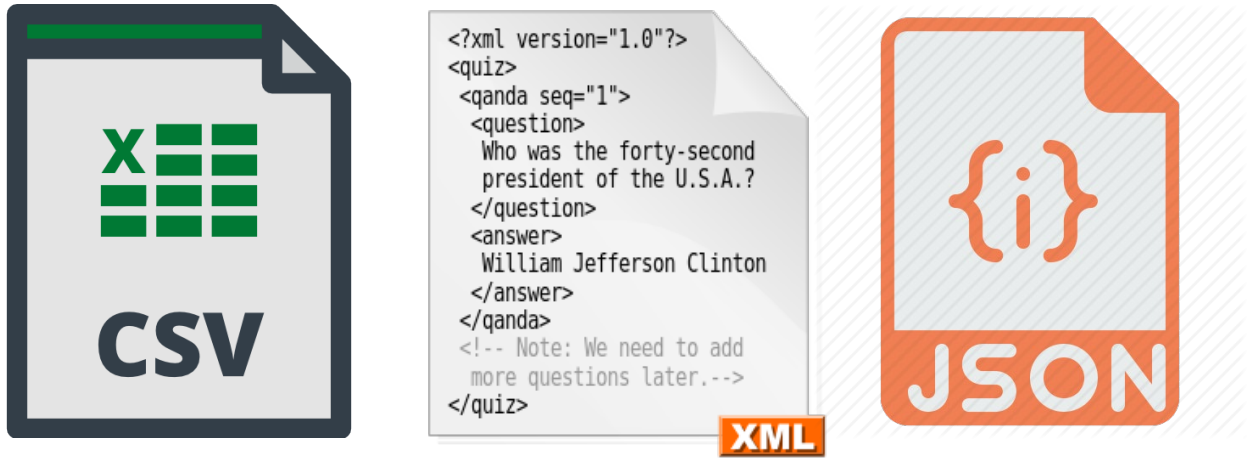
Structured Data

- 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



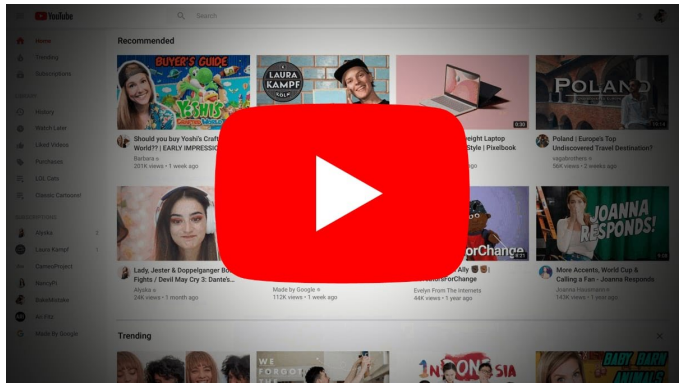
Semi-Structured Data

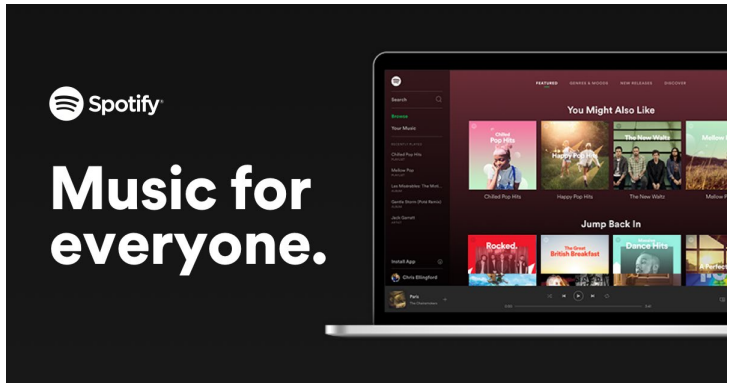
- Self-describing rather than formal structures, tags/markers to separate semantic elements
- The column types → the schema for the data
  - Spark dynamically infers the schema while reading each row
  - Programmer statically specifies the schema
- Examples:

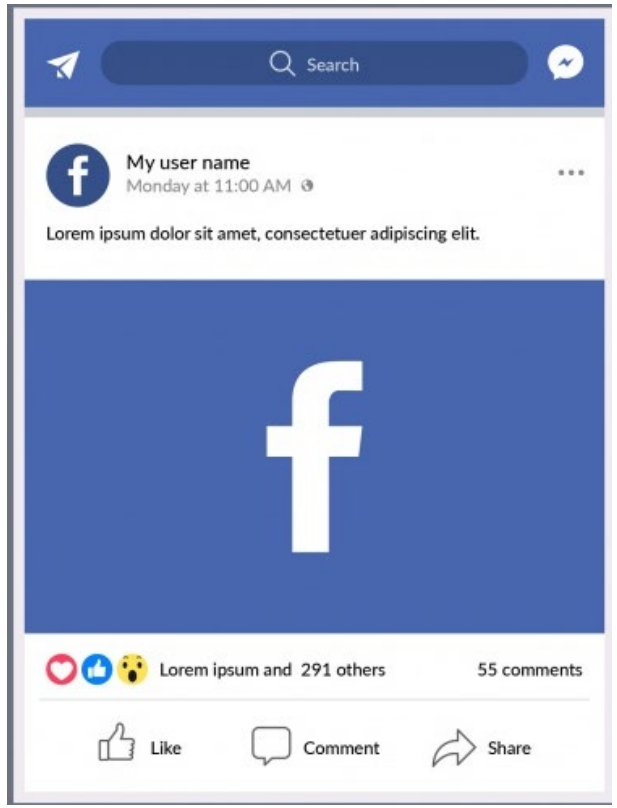


Unstructured Data

- Only one column with string or binary type
- Examples







- Note: File formats ≠ data structure

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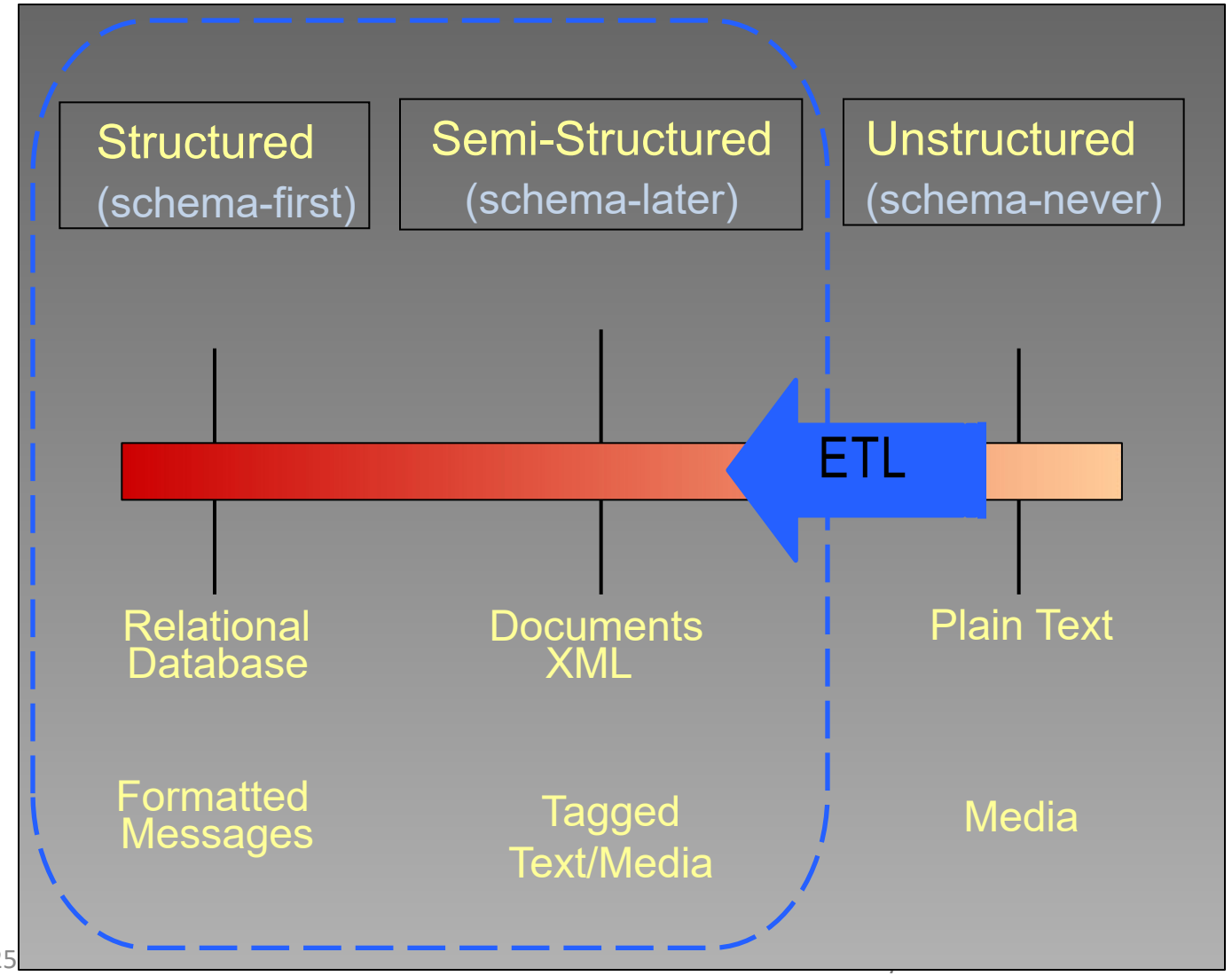
https://files.codingninjas.in/article_images/preparation-guide-for-facebook-1-1662401488.webp

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

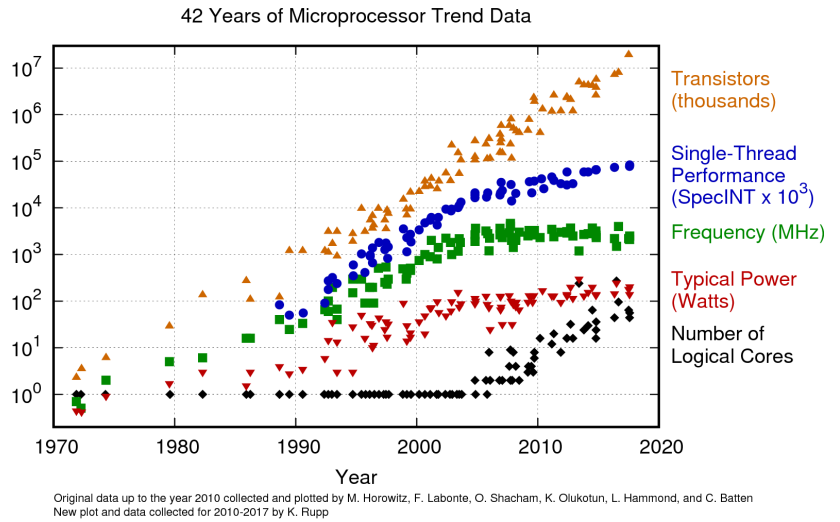
1       BMW      Germany          $25000
2       Volvo    Sweden           $15000
3       Subaru   Japan            $2500
4       Ferrari  Italy            $2000000
5       SAAB     USA              $3000
```

```
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!

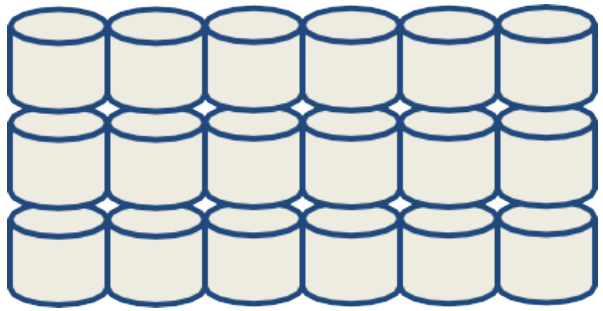
The Big Data Problem

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

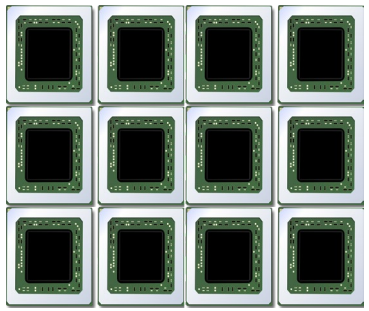


Solution for the Big Data Problem

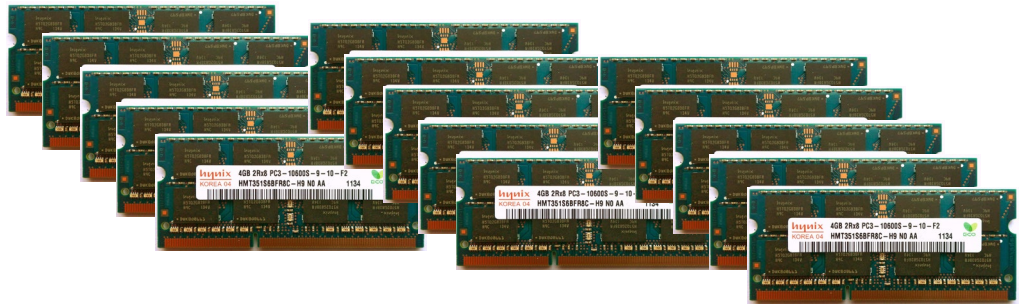
- One machine cannot process or even store all the data!
- Solution: **distribute** data over a **cluster** of machines



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

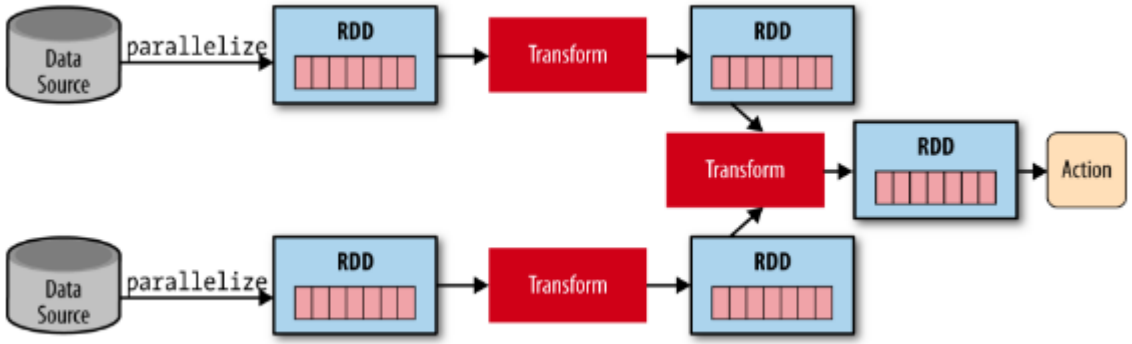
- Improves efficiency through:
  - In-memory computing primitives
  - General computation graphs
- Improves usability through:
  - Rich APIs in Scala, Java, Python
  - Interactive shell

→ Up to 100× faster (2-10× on disk)

→ 2-5× less code

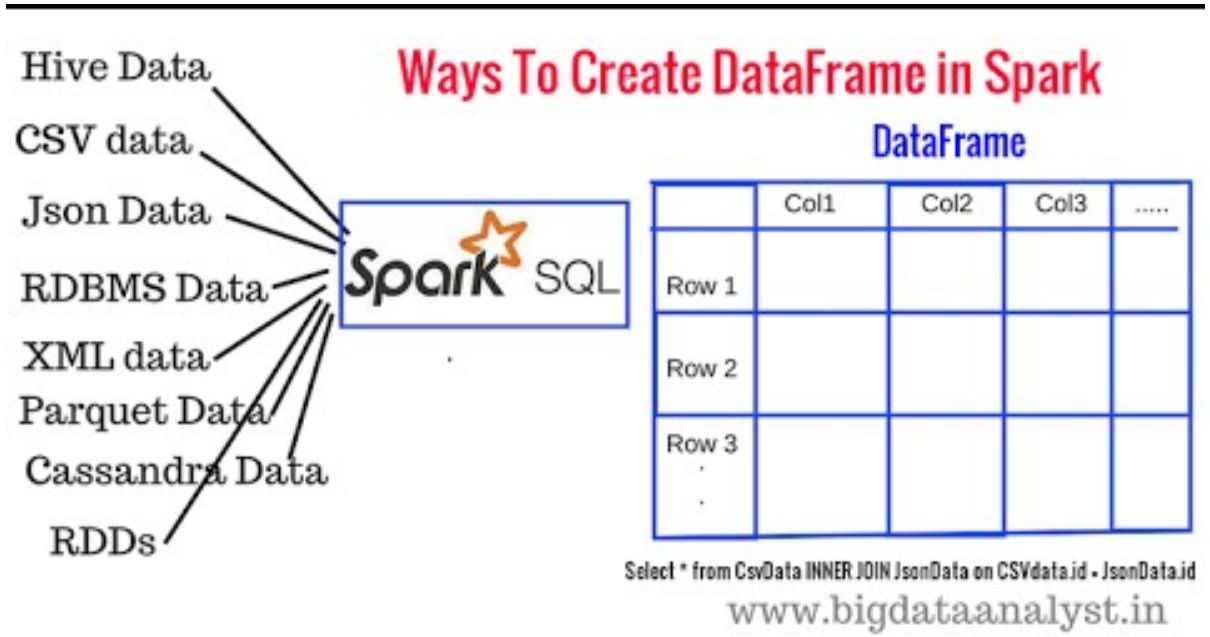
Spark Model

- 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

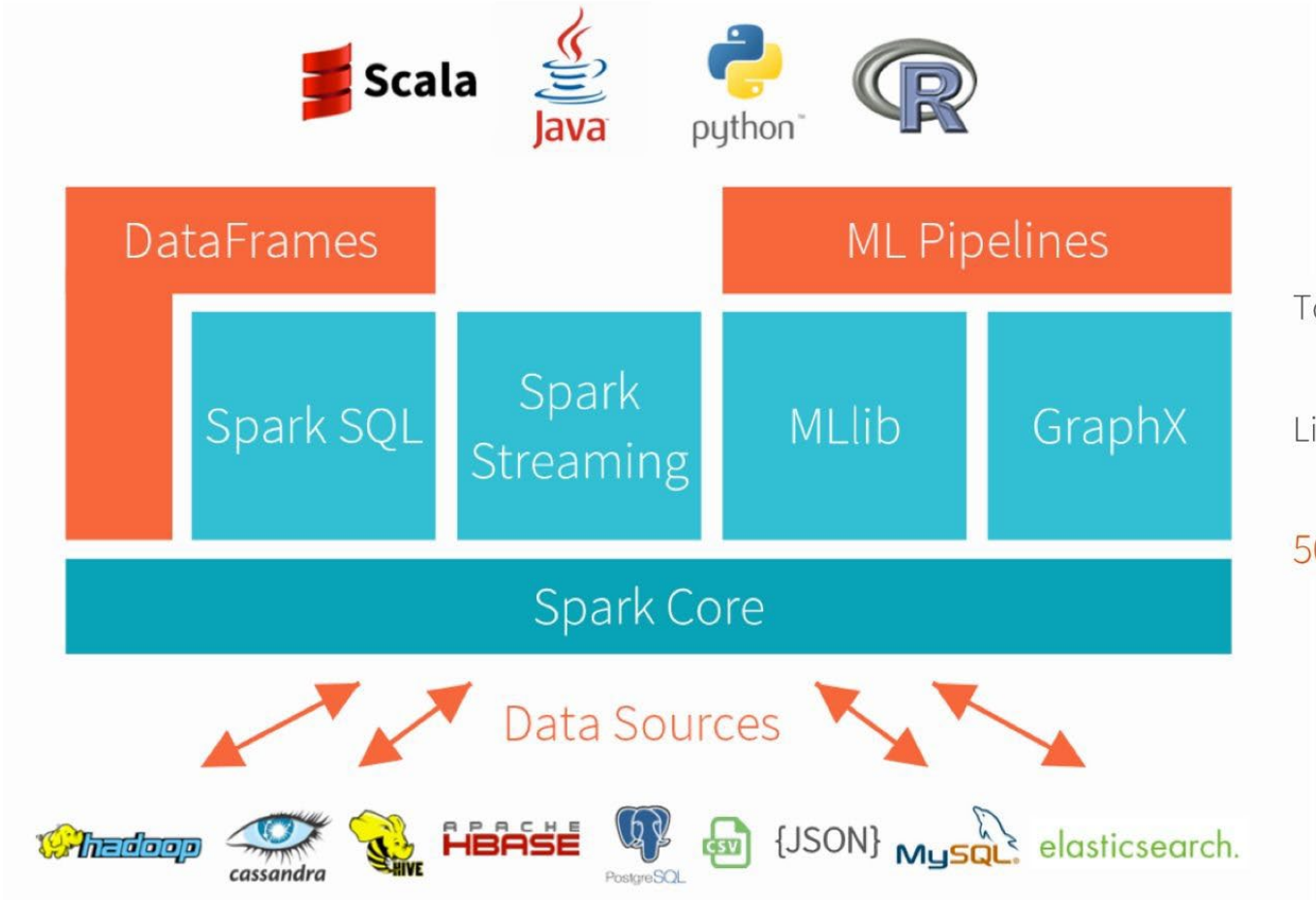
Spark Computing Framework

- 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"

- 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

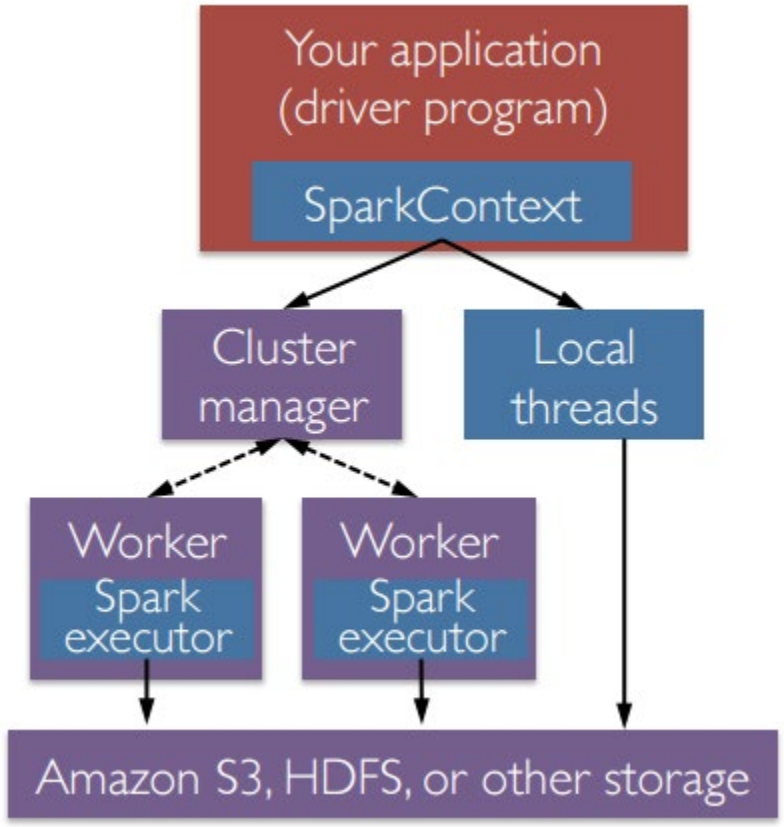
Ecosystem

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):
  - Run computations
  - Access data storage

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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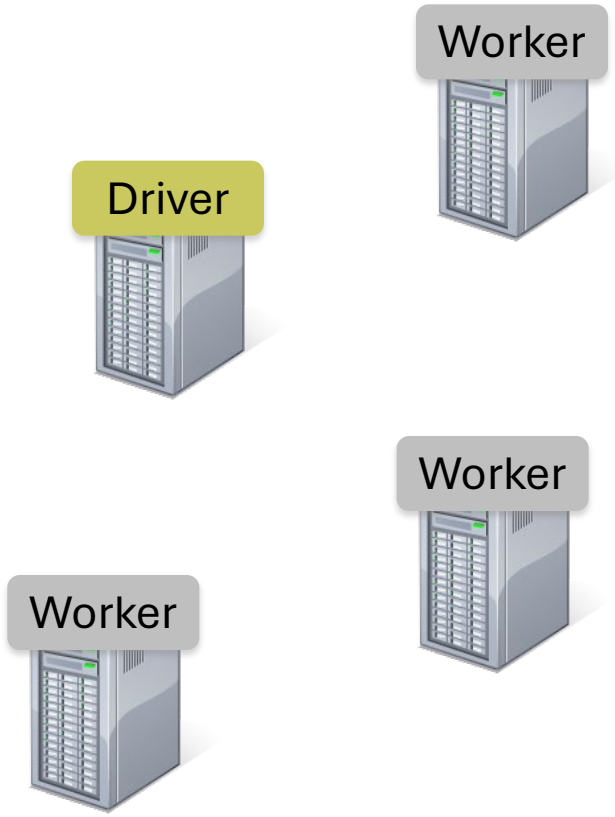

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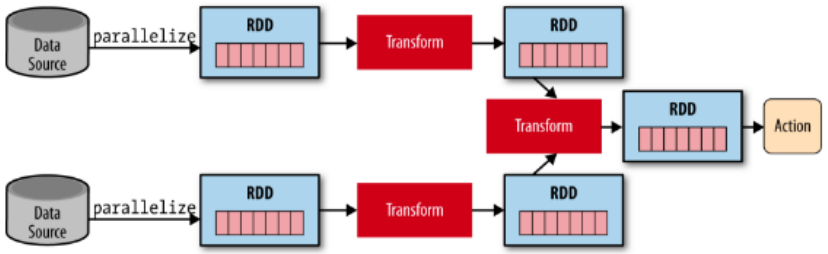

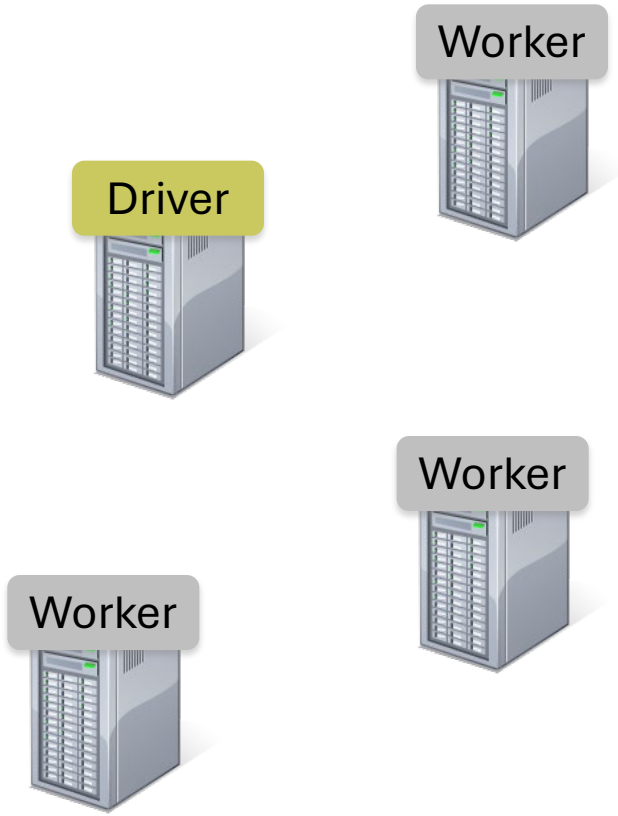

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Base RDD

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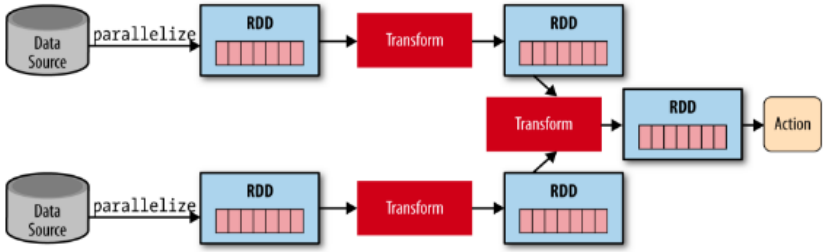

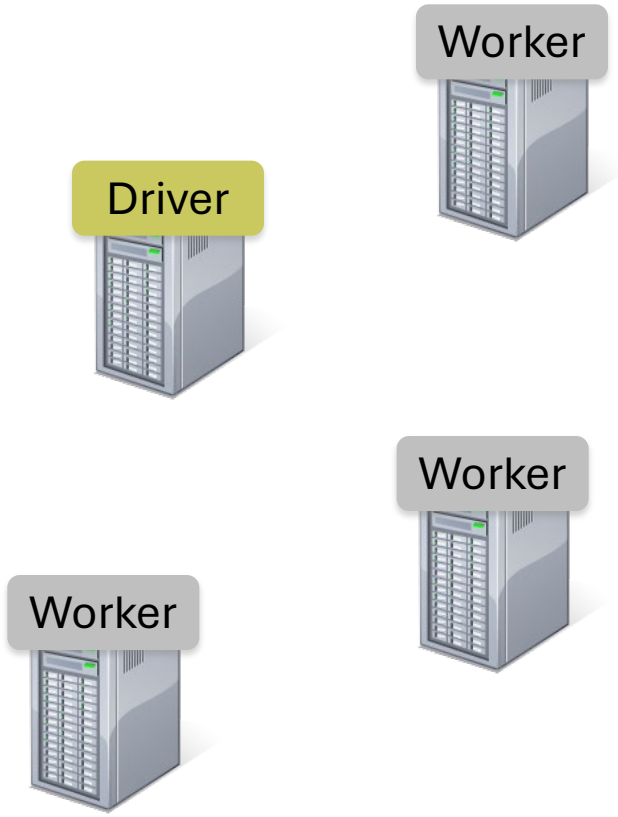

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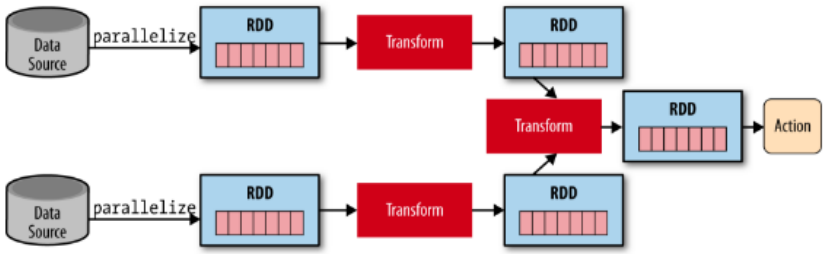

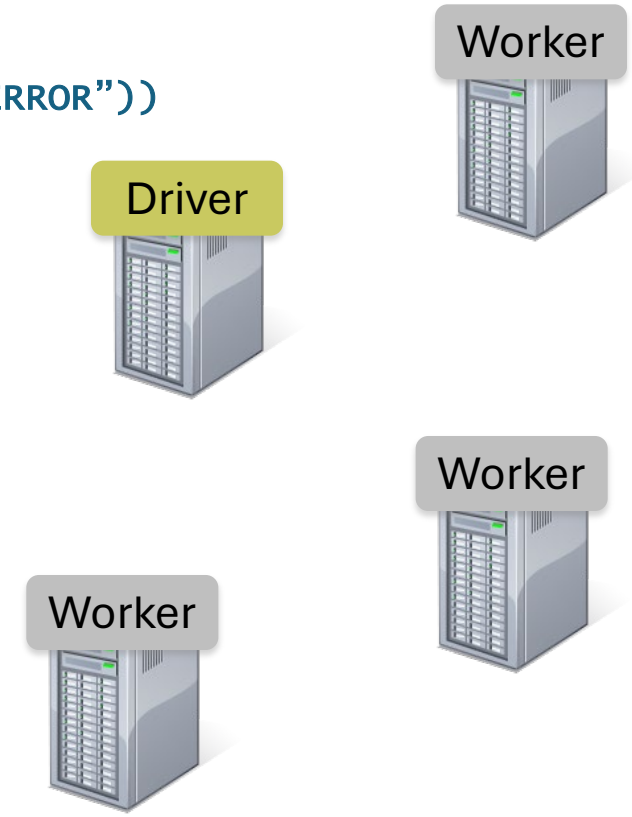

Spark Example: Log Mining

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

Transformed RDD

```
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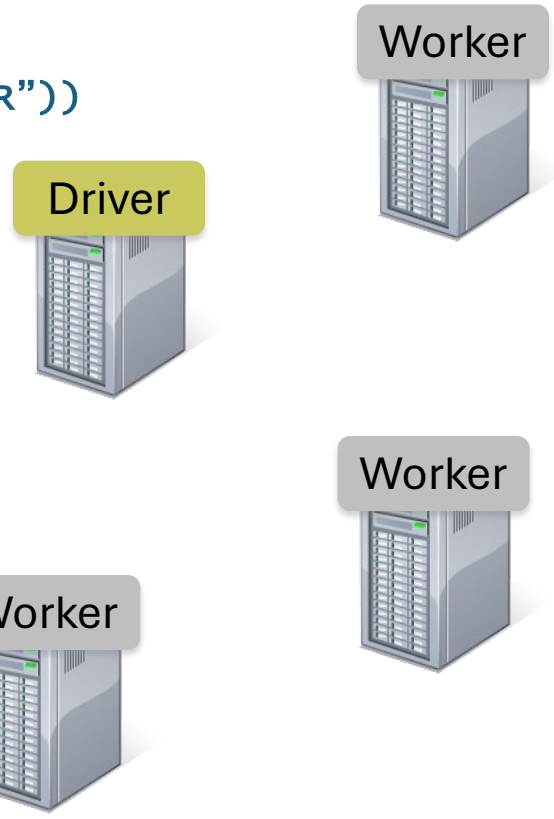
```



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messages.cache()


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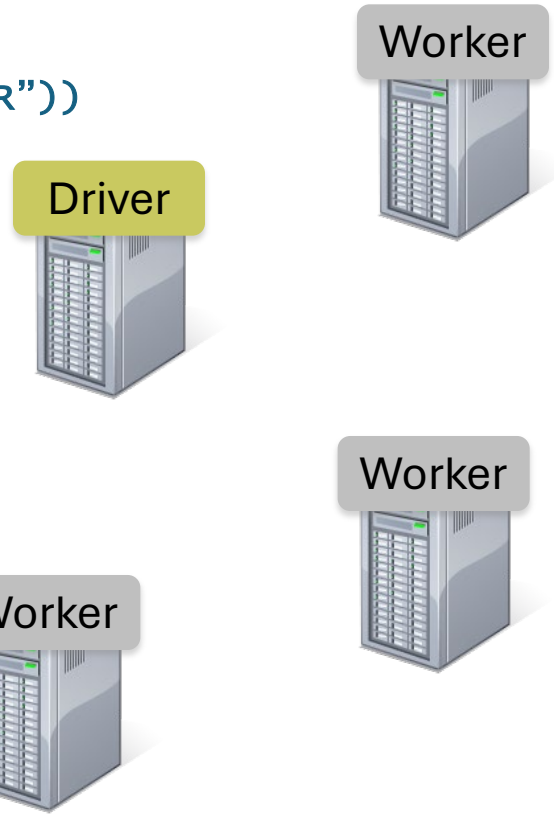

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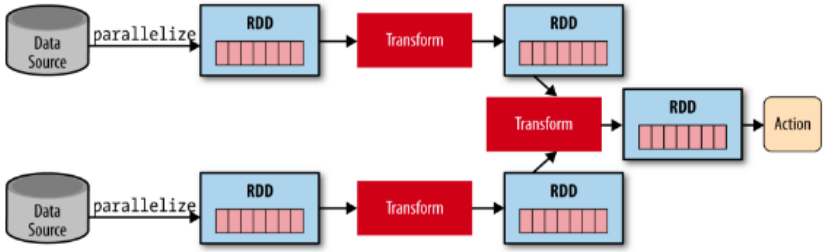

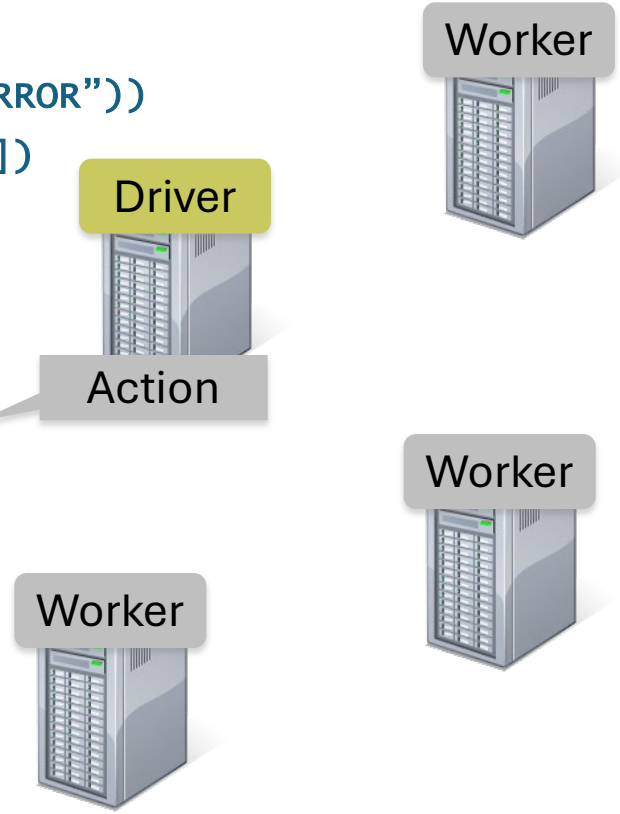

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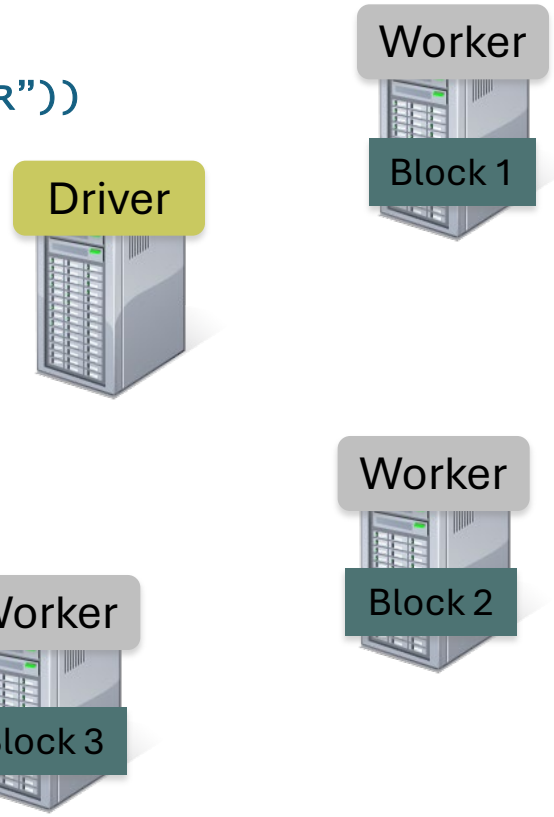

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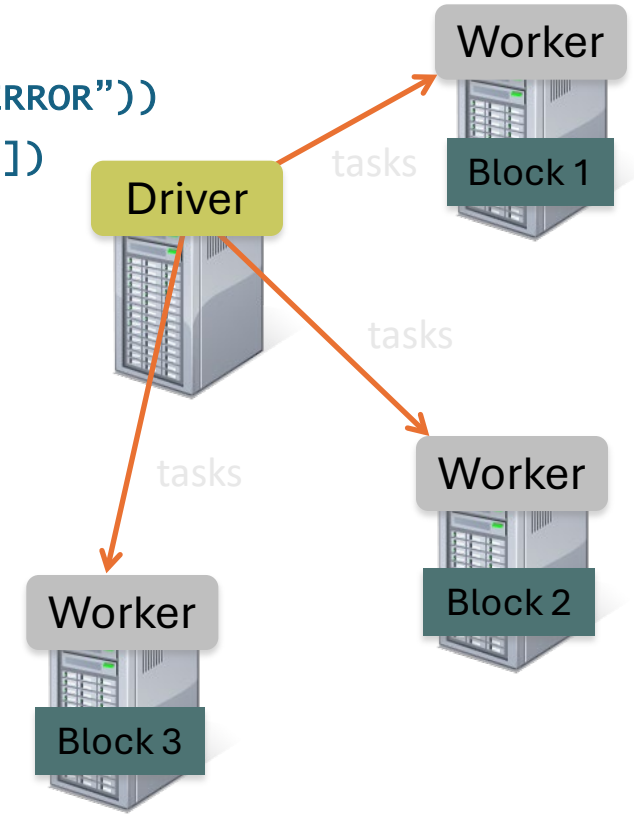

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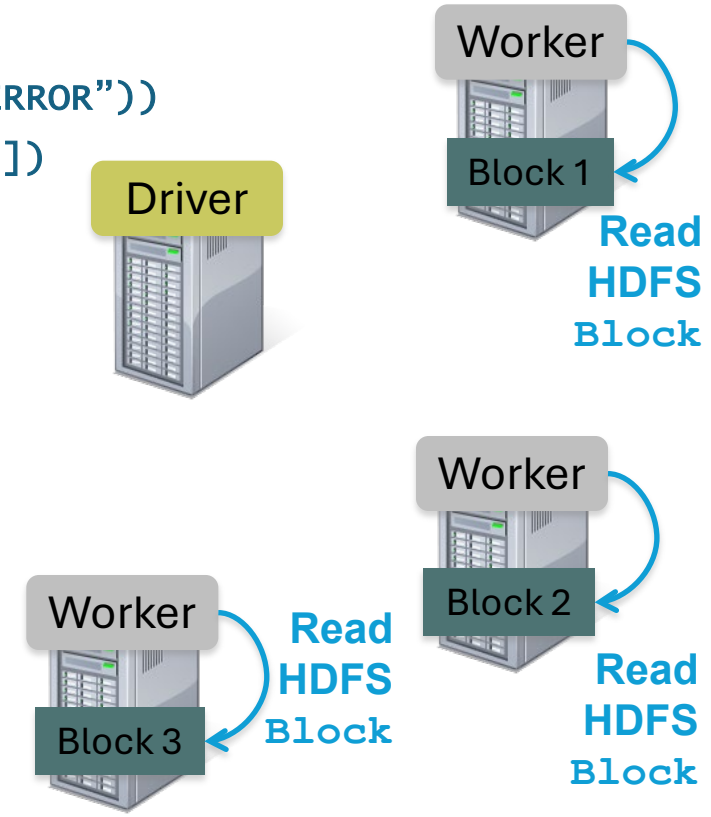

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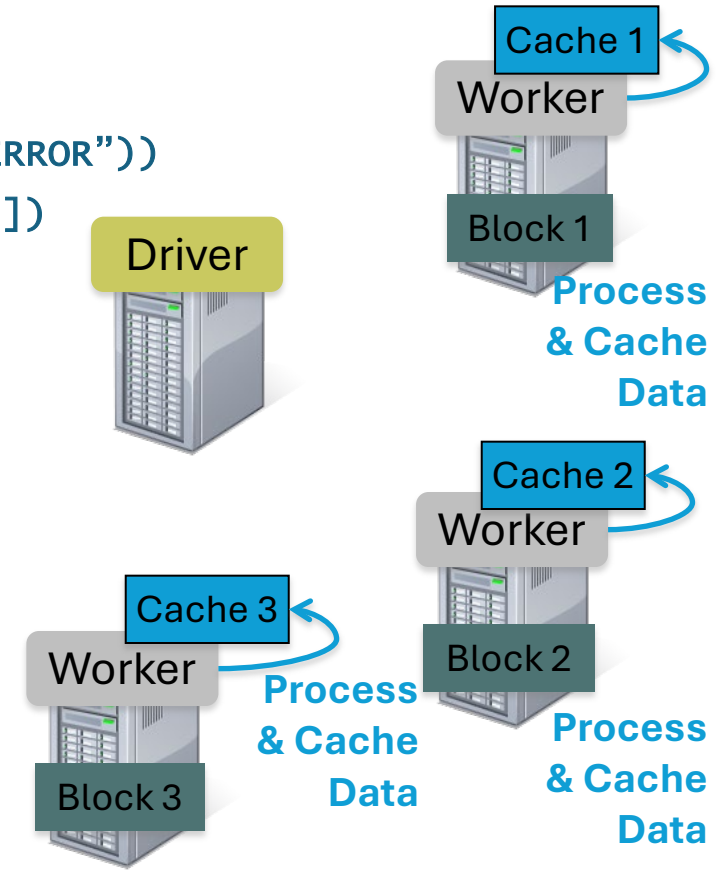

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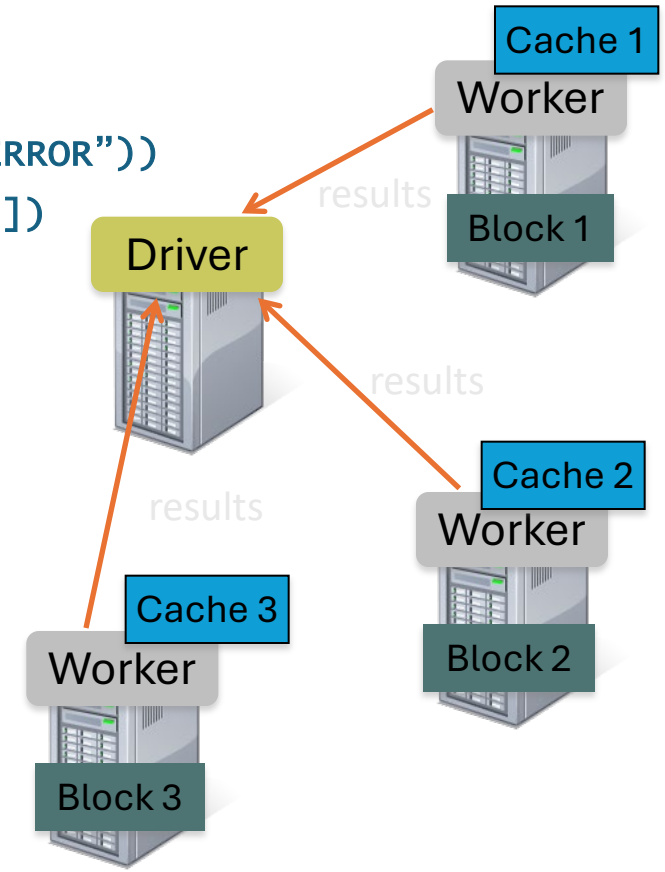

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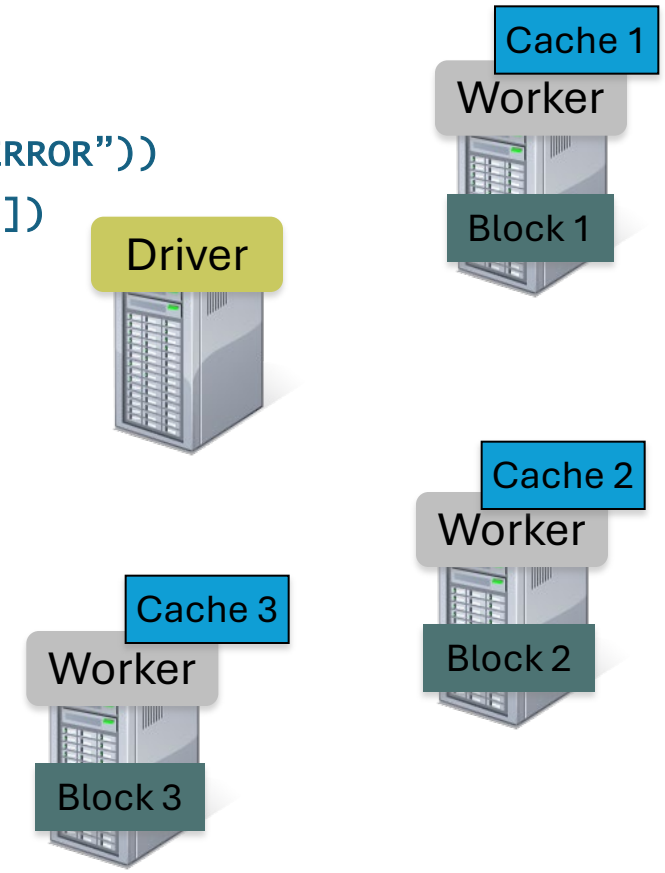

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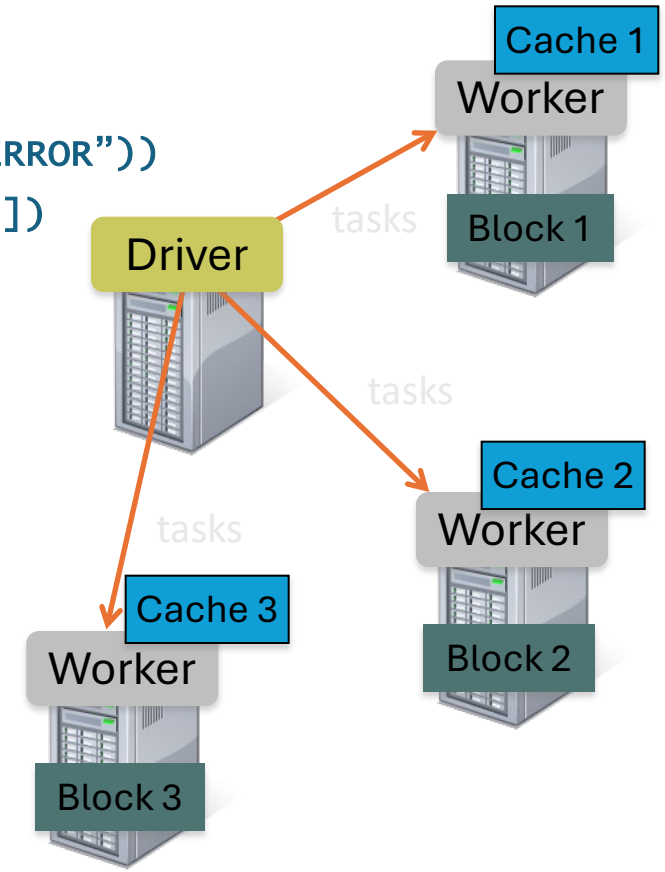

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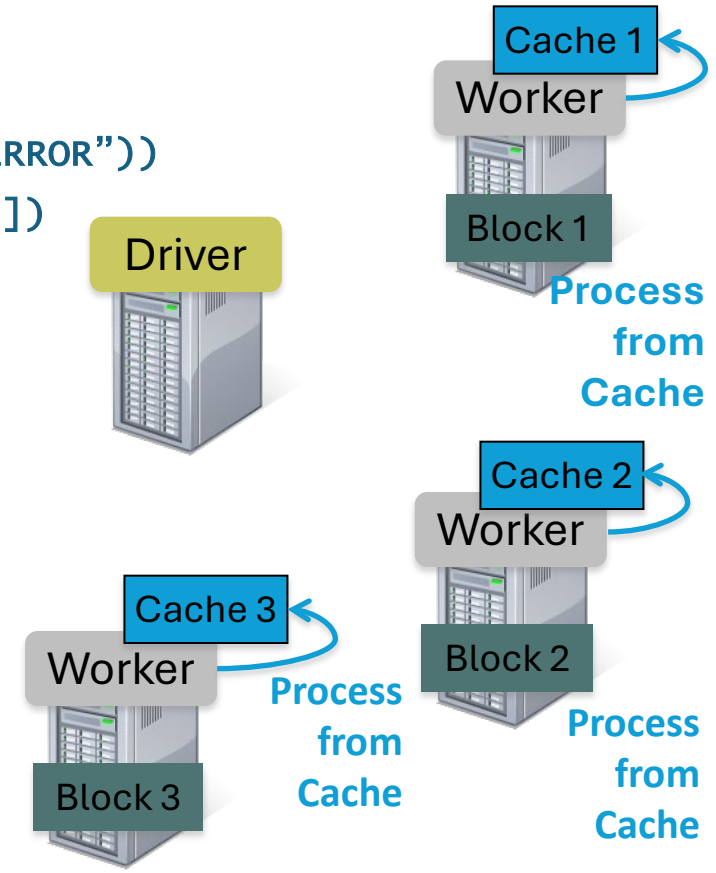

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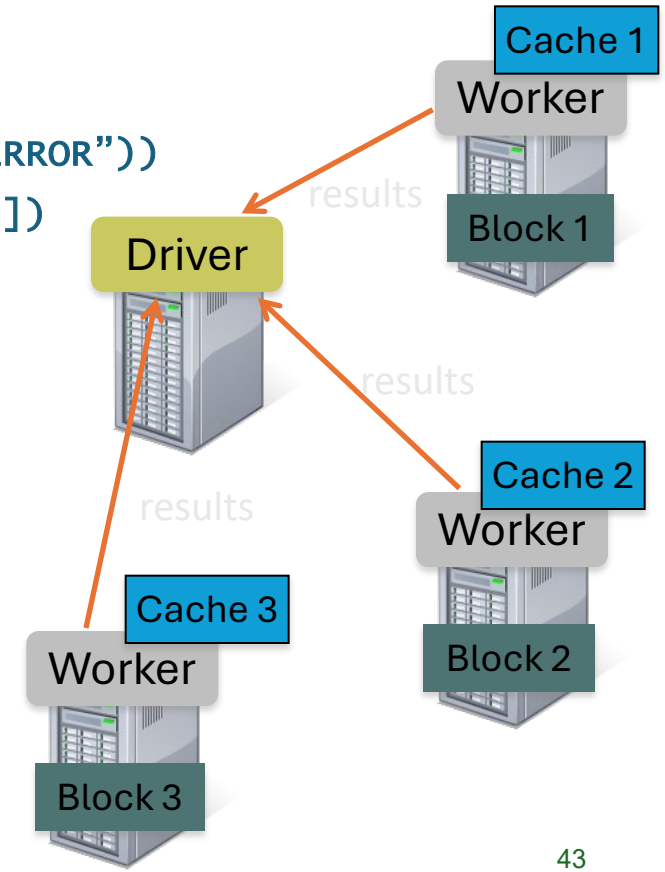
messages.filter(lambda s: “php” in s).count()
```



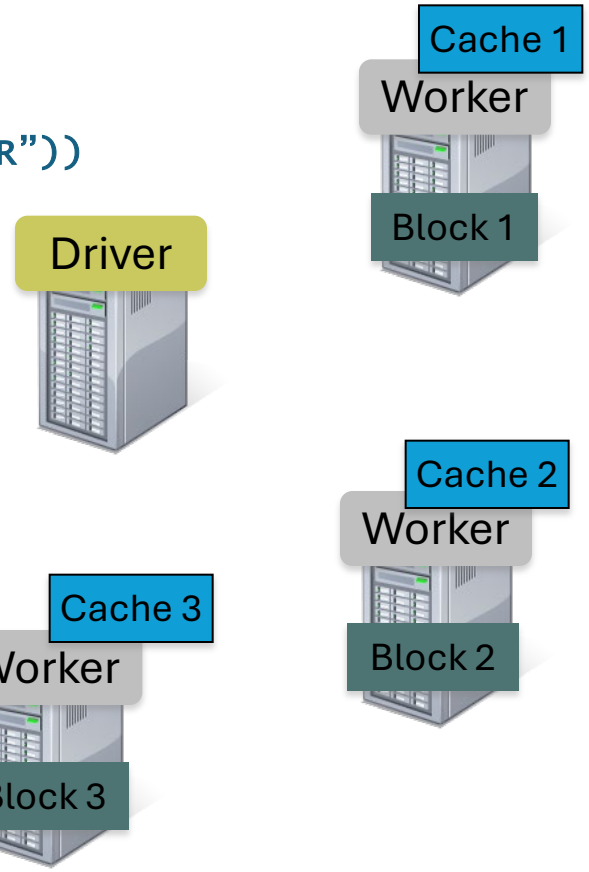
Spark Example: Log Mining

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"))
messages = errors.map(lambda s: s.split("\t")[2])
messages.cache()
```

```
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



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

Spark Program Lifecycle

- Create DataFrames from external data or createDataFrame 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

PySpark 3.5.4

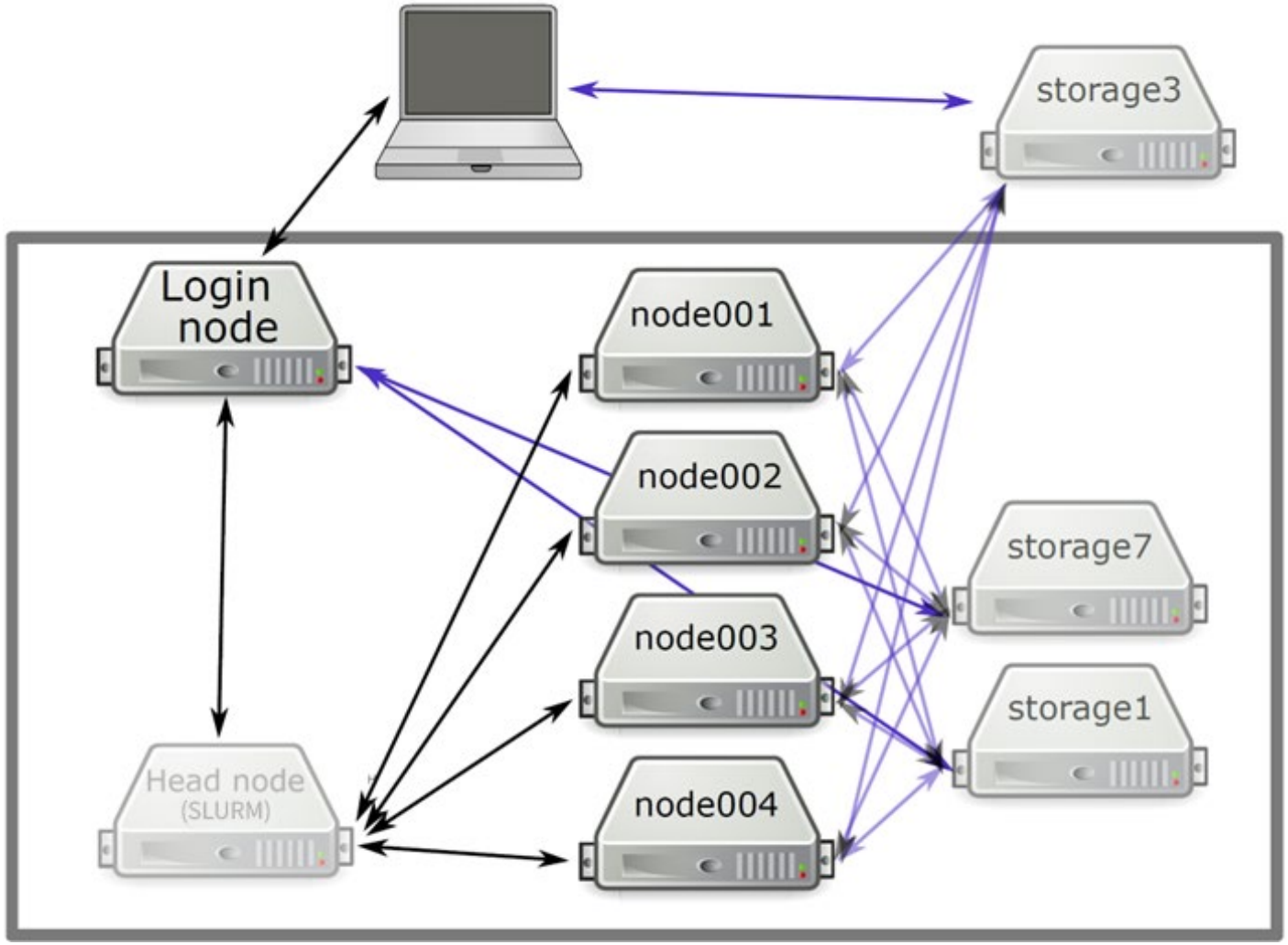
- Need: Java, Python, Spark
- See lab 1 on how to install on HPC
- To install on Windows (optional)
  - Lab 1 instructions: Install Java JRE, Python, Spark
  - Or pip install pyspark==3.5.4
- To install on Linux/Mac (optional): see lab references

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 while 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 5 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

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:
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