

Big Data – Challenges of Distributed Data-Systems: Replication

*Winter Semester 2025/2026,
Cooperative State University Baden-Wuerttemberg*



Agenda – 20.10.2025

01

Presentation and Discussion: Exercise Of Last Lecture

HiveServer2, HiveQL via JDBC, Partitioning with HDFS and Hive

02

Introduction To The Challenges Of Distributed Data-Systems: Replication

Basics of Replication, Master-based, Multi-Master-based and Masterless replication, Consistency Issues and Quorums

03

HandsOn – Spark, PySpark and Jupyter. Working on IMDb Dataset.

Quick Introduction To Apache Spark, especially Spark-Shell, PySpark Shell and Jupyter Notebooks. Use PySpark Shell and/or Jupyter to solve certain problems.

04

Exercise – Use PySpark and Jupyter to work with Partitions on IMDb dataset.

Using PySpark to read/Write DataFrames and Spark Tables from/to HDFS, work with Spark DataFrames, Join and aggregate DataFrames, Plot Data



Schedule

			Lecture Topic	HandsOn
29.09.2025	13:15-15:45	Ro. N/A	About This Lecture, Introduction to Big Data	Setup Google Cloud, Create Own Hadoop Cluster and Run MapReduce
06.10.2025	13:15-15:45	Ro. N/A	(Non-)Functional Requirements Of Distributed Data-Systems, Data Models and Access	Hive and HiveQL
13.10.2025	13:15-15:45	Ro. N/A	Challenges Of Distributed Data Systems: Partitioning	HiveQL via JDBC, Data Partitioning (with HDFS and Hive)
20.10.2025	13:15-15:45	Ro. N/A	Challenges Of Distributed Data Systems: Replication	Spark and Scala
27.10.2025	13:15-15:45	Ro. N/A	ETL Workflow and Automation	PySpark and Notebooks (Jupyter)
03.11.2025	13:15-15:45	Ro. N/A	Batch and Stream Processing	Airflow
10.11.2025	13:15-15:45	Ro. N/A	Practical Exam	Work On Practical Exam
17.11.2025	13:15-15:45	Ro. N/A	Practical Exam	Work On Practical Exam
24.11.2025	13:15-15:45	Ro. N/A	Practical Exam Presentation	
01.12.2025	13:15-15:45	Ro. N/A	Practical Exam Presentation	



Solution – Exercise IV

HiveServer 2, HiveQL via JDBC,
Partitioning with HDFS and Hive



Solution

Prerequisites:

- Start Gcloud instance
- Pull and start Docker image (`marcelmittelstaedt/hiveserver_base:latest`)
- Start Hadoop Cluster
- Start HiveServer2
- Download, Install and Configure JDBC Rich-client:
 - e.g. DBeaver,
 - SquirrelSQL,
 - ...
- Execute all preparation and example tasks of previous HandsOn slides of last lecture



Solution

Exercise IV:

2.1 Create table **name_basics_partitioned** partitioned by column **partition_is_alive**:

```
CREATE EXTERNAL TABLE IF NOT EXISTS name_basics_partitioned (
    nconst STRING,
    primary_name STRING,
    birth_year INT,
    death_year STRING,
    primary_profession STRING,
    known_for_titles STRING
) PARTITIONED BY (partition_is_alive STRING)
STORED AS PARQUET LOCATION '/user/hadoop/imdb/actors_partitioned';
```



Solution

Exercise IV:

2.2 Use **static** partitioning to create and fill partition 'alive'

```
INSERT OVERWRITE TABLE name_basics_partitioned
partition(partition_is_alive='alive')
SELECT
    a.nconst,
    a.primary_name,
    a.birth_year,
    a.death_year,
    a.primary_profession,
    a.known_for_titles
FROM name_basics a WHERE a.death_year IS NULL
```



Solution

Exercise IV:

2.3 Use **static** partitioning to create and fill partition 'dead'

```
INSERT OVERWRITE TABLE name_basics_partitioned
partition(partition_is_alive='dead')
SELECT
    a.nconst,
    a.primary_name,
    a.birth_year,
    a.death_year,
    a.primary_profession,
    a.known_for_titles
FROM name_basics a WHERE a.death_year IS NOT NULL
```



Solution

Exercise IV:

2.4 Check Results:

```
hadoop fs -ls /user/hadoop/imdb/actors_partitioned
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:16 /user/hadoop/imdb/actors_partitioned/partition_is_alive=alive
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:16 /user/hadoop/imdb/actors_partitioned/partition_is_alive=dead
```



Solution

Exercise IV:

2.4 Check Results:

SELECT * FROM name_basics_partitioned WHERE partition_is_alive = 'dead' LIMIT 100

Result

SELECT * FROM name_basics_partitioned WHERE Geben Sie einen SQL-Ausdruck ein, um die Ergebnisse zu filtern (verwenden Sie Strg+Leertaste).

	nconst	primary_name	birth_year	death_year	primary_profession	known_for_titles	partition_is_alive
1	nm0000001	Fred Astaire	1.899	1987	soundtrack,actor,miscellaneous	tt0072308,tt0053137,tt0050419,tt0031983	dead
2	nm0000002	Lauren Bacall	1.924	2014	actress,soundtrack	tt0037382,tt0071877,tt0038355,tt0117057	dead
3	nm0000004	John Belushi	1.949	1982	actor,soundtrack,writer	tt0072562,tt0080455,tt0077975,tt0078723	dead
4	nm0000005	Ingmar Bergman	1.918	2007	writer,director,actor	tt0069467,tt0050976,tt0050986,tt0060827	dead
5	nm0000006	Ingrid Bergman	1.915	1982	actress,soundtrack,producer	tt0038787,tt0077711,tt0034583,tt0038109	dead
6	nm0000007	Humphrey Bogart	1.899	1957	actor,soundtrack,producer	tt0042593,tt0037382,tt0033870,tt0034583	dead
7	nm0000008	Marlon Brando	1.924	2004	actor,soundtrack,director	tt0047296,tt0068646,tt0078788,tt0070849	dead
8	nm0000009	Richard Burton	1.925	1984	actor,soundtrack,producer	tt0057877,tt0059749,tt0061184,tt0087803	dead
9	nm0000010	James Cagney	1.899	1986	actor,soundtrack,director	tt0031867,tt0035575,tt0042041,tt0029870	dead
10	nm0000011	Gary Cooper	1.901	1961	actor,soundtrack,producer	tt0027996,tt0044706,tt0035896,tt0034167	dead



Solution

Exercise IV:

3.1 Create table `imdb_movies_and_ratings_partitioned` partitioned by column `partition_year` using fields of table `title_basics` and `title_ratings`:

```
CREATE TABLE IF NOT EXISTS imdb_movies_and_ratings_partitioned (
    tconst STRING,
    title_type STRING,
    primary_title STRING,
    original_title STRING,
    is_adult DECIMAL(1,0),
    start_year DECIMAL(4,0),
    end_year STRING,
    runtime_minutes INT,
    genres STRING,
    average_rating DECIMAL(2,1),
    num_votes BIGINT
) PARTITIONED BY (partition_year int) STORED AS PARQUET LOCATION '/user/hadoop/imdb/
movies_and_ratings_partitioned';
```



Solution

Exercise IV:

3.2 Use **dynamic partitioning** to create and fill partition `partition_year`:

```
SET hive.exec.dynamic.partition.mode=nonstrict;
INSERT OVERWRITE TABLE imdb_movies_and_ratings_partitioned partition(partition_year)
SELECT
    tb.tconst,
    tb.title_type,
    tb.primary_title,
    tb.original_title,
    tb.is_adult,
    tb.start_year,
    tb.end_year,
    tb.runtime_minutes,
    tb.genres,
    tr.average_rating,
    tr.num_votes,
    tb.start_year
FROM title_basics tb JOIN title_ratings tr ON (tb.tconst = tr.tconst)
```



Solution

Exercise IV:

3.3 Check Results:

```
hadoop fs -ls /user/hadoop/imdb/movies_and_ratings_partitioned
[...]
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1874
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1878
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1881
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1883
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1885
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1887
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1888
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1889
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1890
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1891
drwxr-xr-x  - hadoop supergroup          0 2021-02-27 17:24 /user/hadoop/imdb/movies_and_ratings_partitioned/partition_year=1892
[...]
```



Solution

Exercise IV:

3.3 Check Results:

```
SELECT tconst, primary_title, start_year, genres, average_rating, num_votes
FROM imdb_movies_and_ratings_partitioned
WHERE partition_year = 2020 AND title_type = 'movie' AND num_votes > 25000 ORDER BY average_rating DESC LIMIT 100
```

Result

SELECT tconst, primary_title, start_year, genres, average_ | Geben Sie einen SQL-Ausdruck ein, um die Ergebnisse zu filtern (verwenden Sie Strg+ Leertaste).

	tconst	primary_title	start_year	genres	average_rating	num_votes
1	tt10189514	Soorarai Pottru	2.020	Drama	8,6	55.837
2	tt8503618	Hamilton	2.020	Biography,Drama,History	8,5	57.348
3	tt2948372	Soul	2.020	Adventure,Animation,Comedy	8,1	179.805
4	tt8110330	Dil Bechara	2.020	Comedy,Drama,Romance	7,9	111.891
5	tt1070874	The Trial of the Chicago 7	2.020	Drama,History,Thriller	7,8	98.179
6	tt10288566	Another Round	2.020	Comedy,Drama	7,8	40.297
7	tt11464826	The Social Dilemma	2.020	Documentary,Drama	7,7	65.207
8	tt7212754	Ludo	2.020	Action,Comedy,Crime	7,6	28.350
9	tt6723592	Tenet	2.020	Action,Sci-Fi,Thriller	7,5	296.730
10	tt9620292	Promising Young Woman	2.020	Crime,Drama,Thriller	7,5	34.475
11	tt7146812	Onward	2.020	Adventure,Animation,Comedy	7,4	102.711
12	tt9484998	Palm Springs	2.020	Comedy,Fantasy,Mystery	7,4	81.009
13	tt10618286	Mank	2.020	Biography,Comedy,Drama	7,1	38.884
14	tt9686708	The King of Staten Island	2.020	Comedy,Drama	7,1	39.349
15	tt7395114	The Devil All the Time	2.020	Crime,Drama,Thriller	7,1	93.645
16	tt1051906	The Invisible Man	2.020	Drama,Horror,Mystery	7,1	169.172





Introduction To The Challenges Of Distributed Data-Systems: Replication

Basics of Replication, Master-based, Multi-Master-based and
Masterless replication, Consistency Issues and Quorums



Why Replication (and Partitioning)?

Availability and Redundancy: Even if some parts or nodes fail the whole data-system is able to continue working, as it can make of another replica.

Scalability and Performance: Using multiple replicas, for instance increases read performance and throughput as read queries can be distributed to any node of a replica set or even be handled concurrently by multiple nodes of the same replica set.

Reliability: Using multiple replicas stored in different data centers and locations, the data-system even continues to run during a catastrophe like an earthquake, typhoon or just a construction worker, having a bad day and cutting of the power link of one of your data-centers.

Low Latency: Keeping replicas of a data-system geographically close to users or consuming applications reduces latency (e.g. in case of a multi-national webshop, having a replica in every country).



Replication vs Partitioning

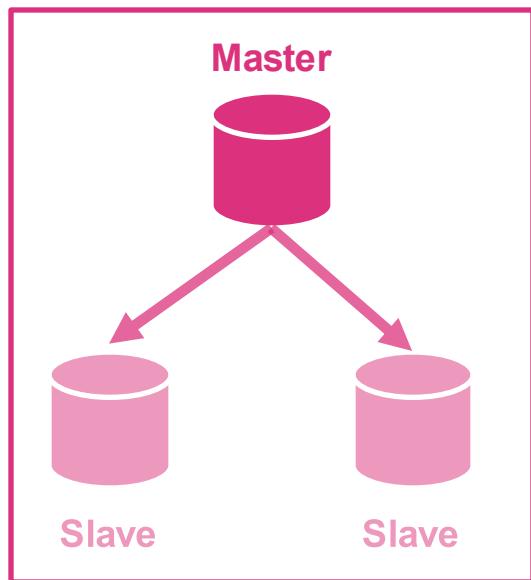
		Replication	Partitioning
stores:	copies of the same data on multiple nodes	subsets (<i>partitions</i>) on multiple nodes	
introduces:	redundancy	distribution	
scalability:	parallel IO	memory consumption , certain parallel IO	
availability:	nodes can take load of failed nodes		node failures affect only parts of the data

Different purposes, but usually used together



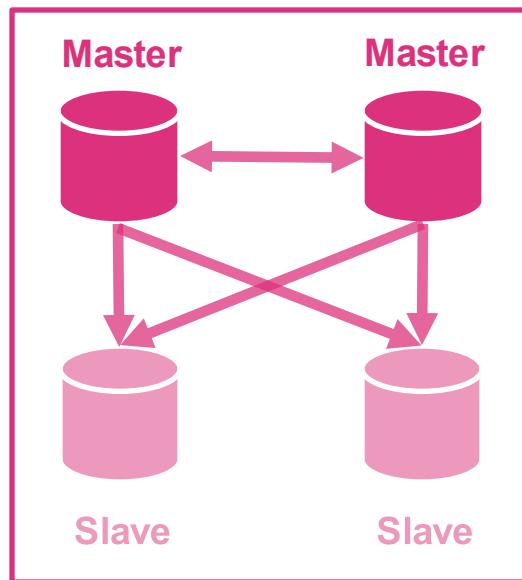
Approaches For Replication

Master-based



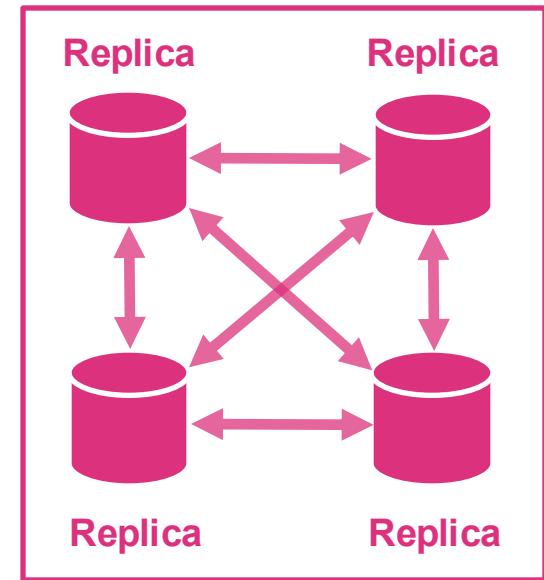
e.g. Oracle, PostgreSQL,
MySQL...

Multi-Master-based



e.g. CouchDB, PostgreSQL,
MySQL...

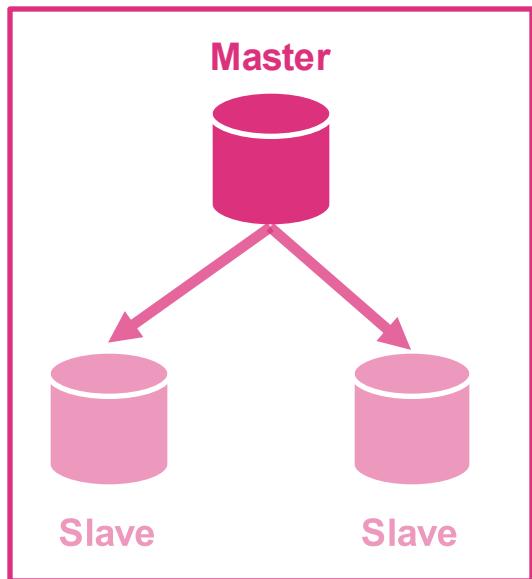
Masterless



e.g. Cassandra, Riak, Vol
demortDB, DynamoDB...

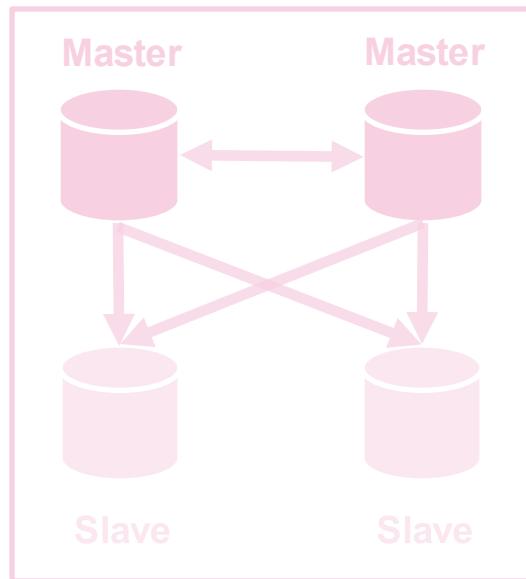
Master Replication

Master-based



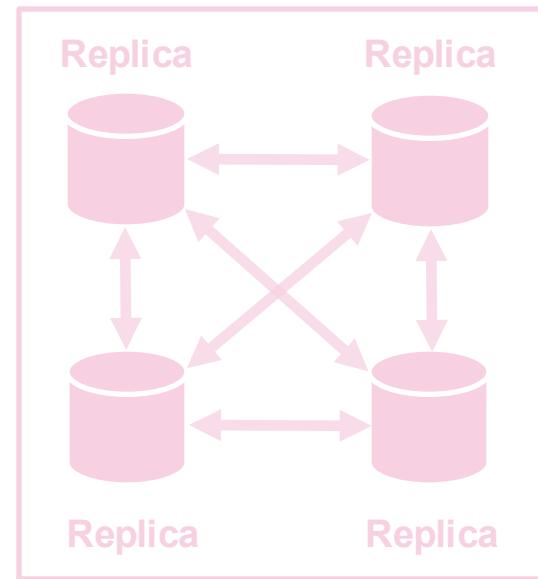
e.g. Oracle, PostgreSQL,
MySQL...

Multi-Master-based



e.g. CouchDB, PostgreSQL,
MySQL...

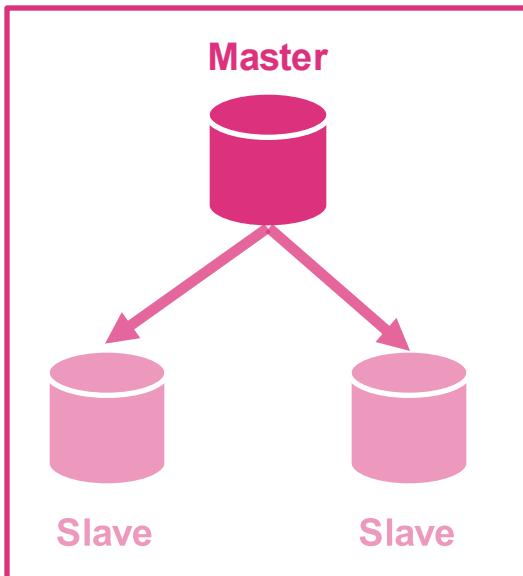
Masterless



e.g. Cassandra, Riak, Vol
demortDB, DynamoDB...

Master Replication

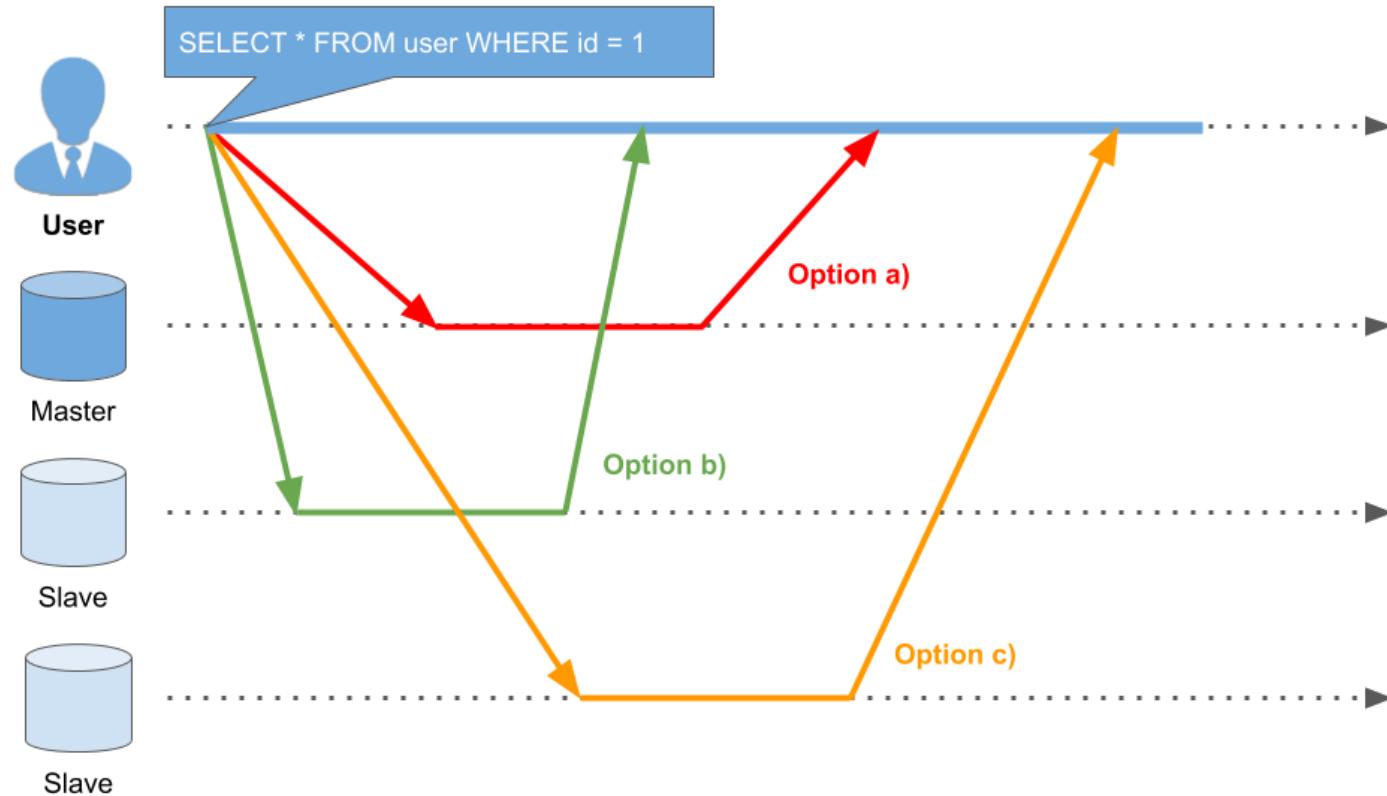
Also known as: Primary/Secondary, Master/Slave or Single-Leader Replication



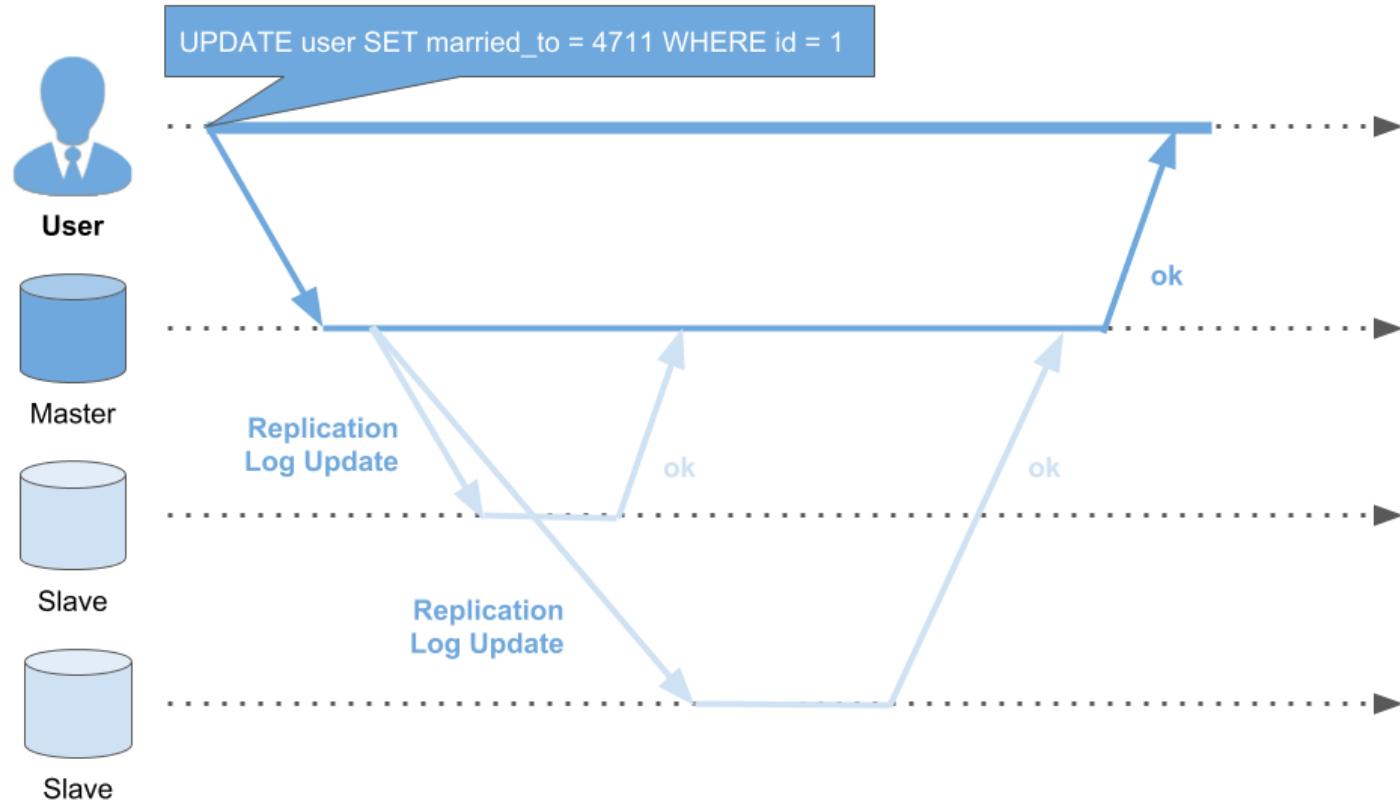
Master: (also known as *leader* or *primary*) dedicated processing node, usually also a replica and also known as primary or leader. The master node serves read as well as write queries, is responsible for persisting changes locally and propagates changes (e.g. by using replication logs or change streams) to slave nodes.

Slave: (also known as *secondary*, *follower* or *hot-standby*) are dedicated for serving read queries only. They receive changes from the master node and update their local replica accordingly to and in the same order as the replication log provided by the master.

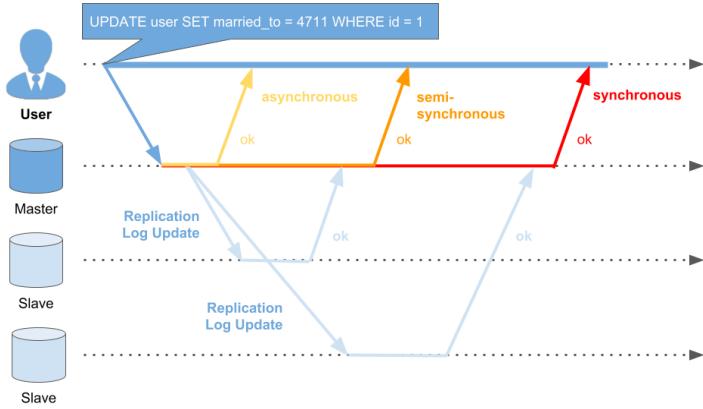
Master Replication - Read



Master Replication - Write



Master Replication – Write Synchrony



1. Synchronous:

- **master waits for all slaves** to succeed before reporting success to the user

→ all slaves have up-to-date copy of master

→ any slave can take over, if *master* crashes

→ Latency (like network) will directly effect write performance of the data-system, as the master waits for all slaves

- even if everything is running fine, it's slow, as slaves add additional processing time to write queries

2. Semi-Synchronous:

- the **master waits for one slave** to report success before reporting success to the user

→ one slave runs synchronous to master, all other slaves asynchronous

→ If synchronous slave gets slow or crashes, another slave becomes synchronous

→ it is guaranteed, that at least two nodes store a replica which is up-to-date

3. Asynchronous:

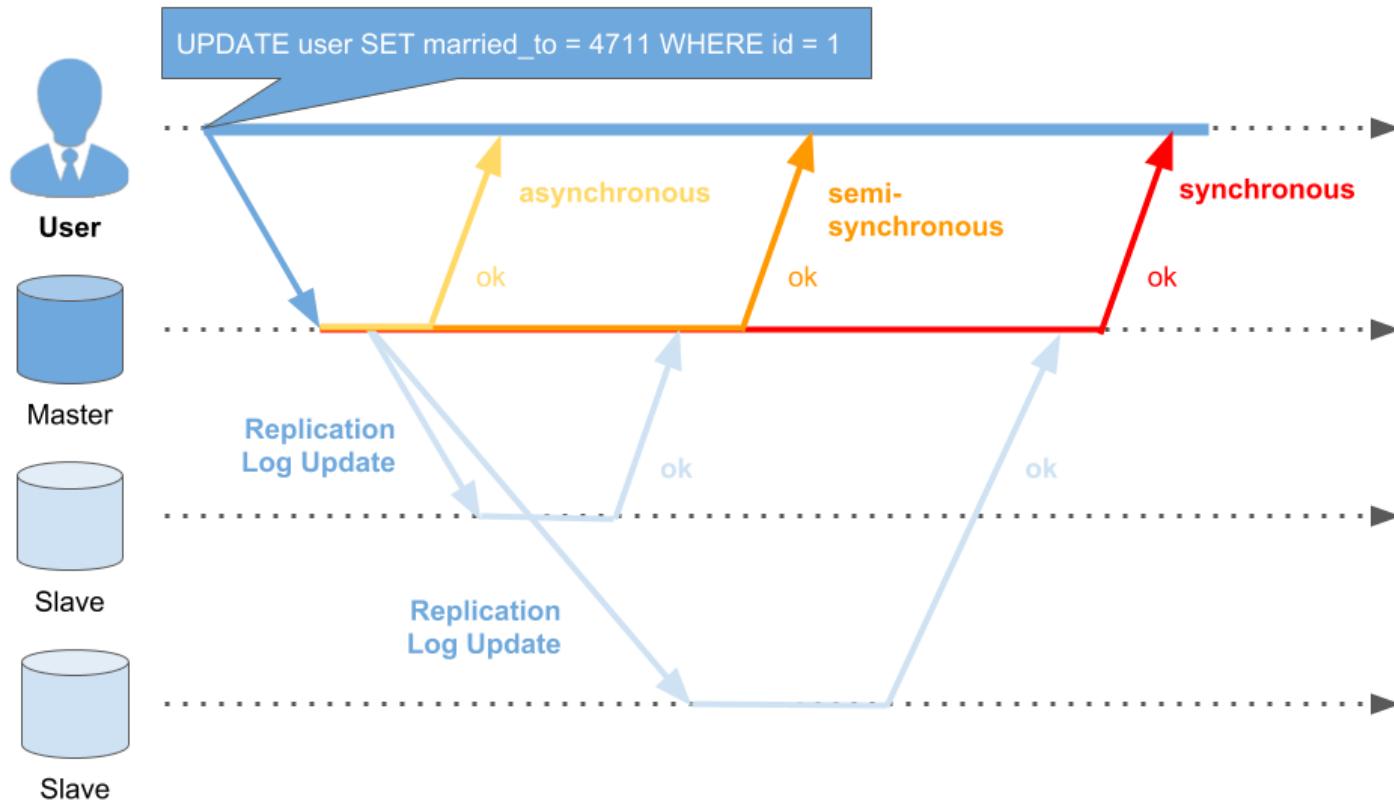
- the **master does not wait for any slaves** to report success, before reporting success to a user

→ not guaranteed to ensure durability

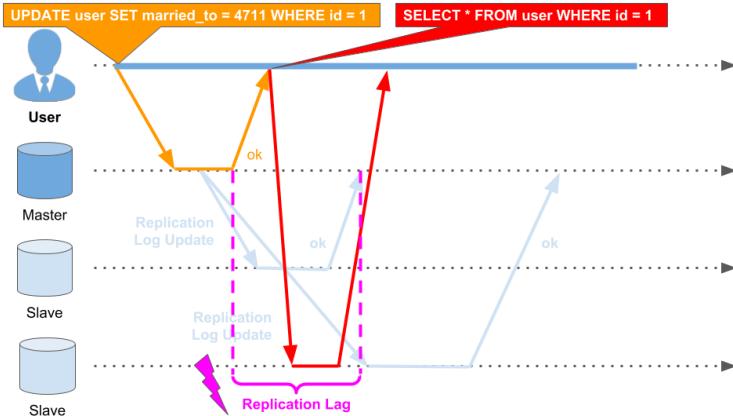
→ If the master crashes and cannot be re-covered, any write requests processed but not replicated to slaves, are lost

→ write-performance is incredibly fast

Master Replication - Synchrony



Master Replication – Replication Lag



Asynchronous and **semi-synchronous replication** are great for scalability of read-intensive data-systems/applications

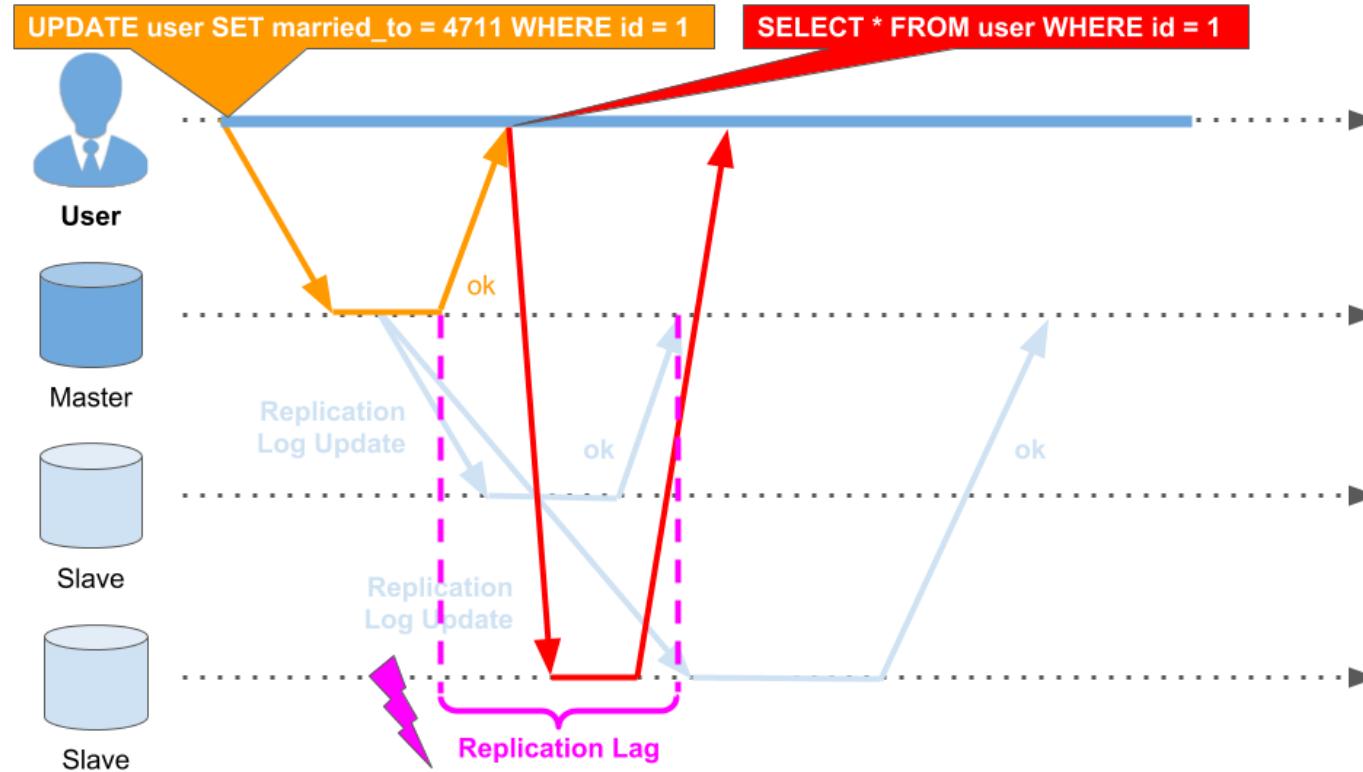
- Distribute and scale read requests by „just“ adding more slaves
- **Data locality** = put slaves geographically close to user/client-applications
- But: **vulnerable to replication lag** (timeframe when master and slaves are inconsistent, as the slaves have not yet processed the most recent write requests)

→ **replication lag** = **temporary inconsistency** (usually just fractions of seconds)

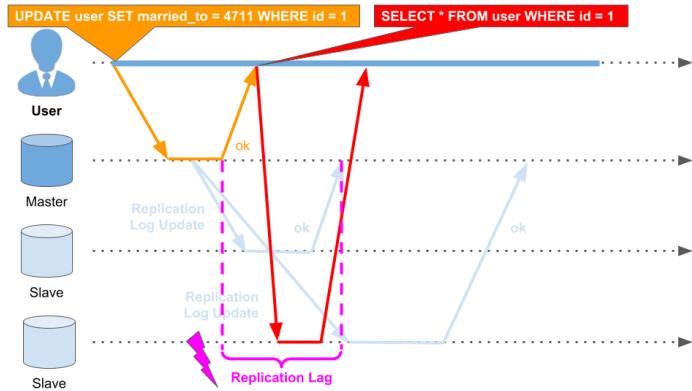
- Examples of replication lag causing a data-system to be inconsistent:

- **Reading Your Own Writes**
- **Monotonic Reads**

Master Replication – Replication Lag



Master Replication – Read-Your-Own-Writes



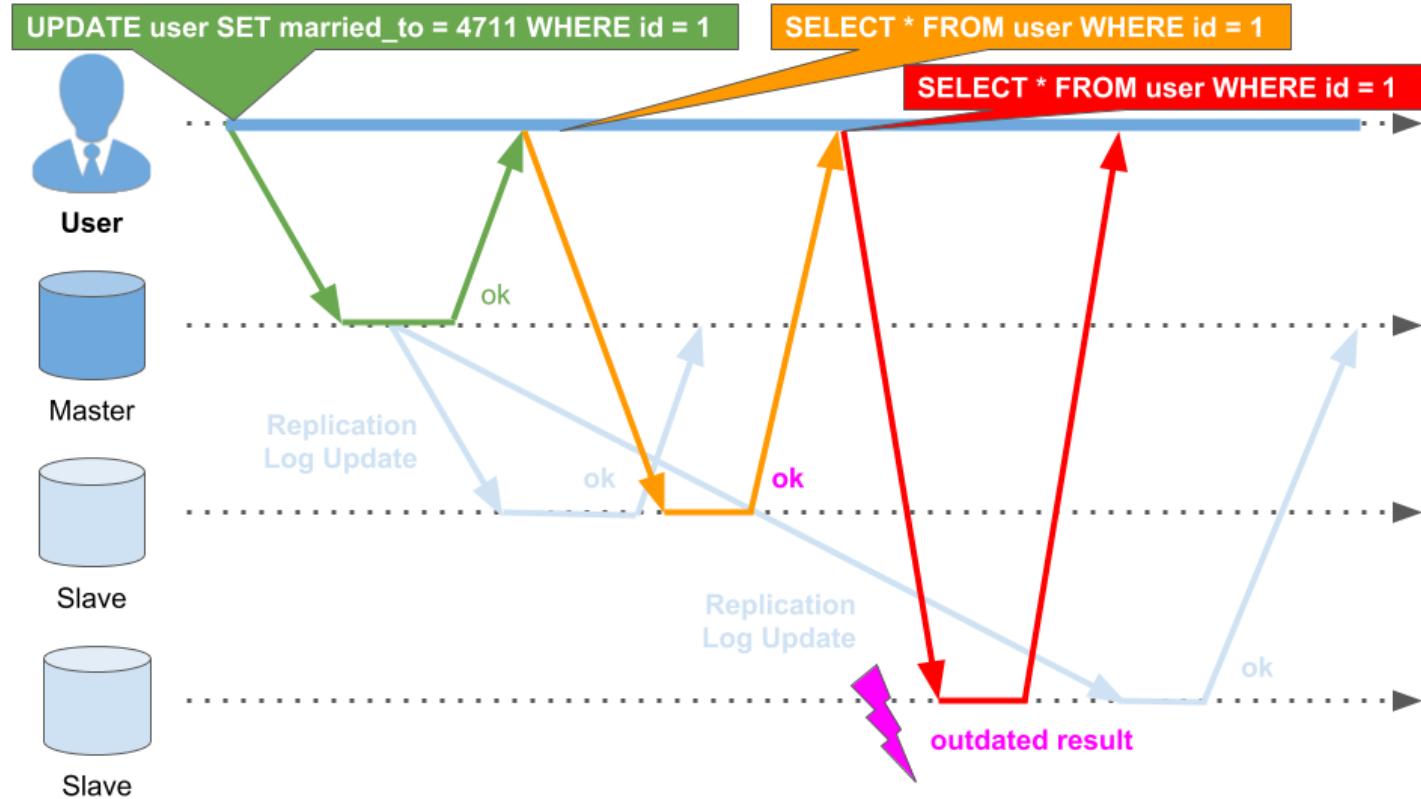
Read-Your-Writes Consistency:

ensures that any write requests submitted by a user will directly be seen on any further read requests (by the same user, guaranteeing a user his write request has been processed successfully).

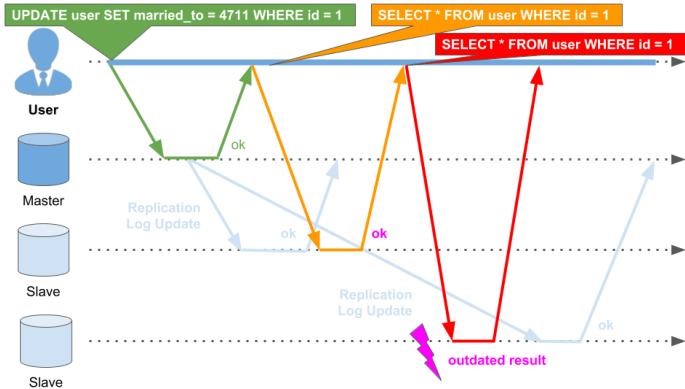
Approaches for achieving Read-Your-Writes consistency:

- **Read data, a user may have modified, from the master**, otherwise make use of a slave.
E.g. Xing/LinkedIn/Facebook Profile profiles → those profiles can only be edited by the user itself.
 - The previous approach does not work very well for data-systems where a user is able to edit almost anything of a data-system, as this would cause any read request to end up on the master.
Time or replication state could be a valuable criteria to decide whether use of the master or a slave is appropriate, e.g. if an update request is newer than X seconds or less than the replication lag, **read from master** node **otherwise** make use of a **slave node**.

Master Replication – Monotonic Reads



Master Replication – Monotonic Reads



Monotonic Reads Consistency:

A user is reading from 2 different slaves, one with less and one with more replication lag, whereas the last one is still missing a replication update. Monotonic Reads Consistency ensures that this kind of divergence does not happen - a user will not read less recent data after reading new data .

Approaches for achieving Monotonic Reads consistency:

- a user needs to always read from same replica (master or slave) within a session
- (different user can read from different replica nodes)
- E.g. determine replica by *user id modulo the number of replica nodes*



Master Replication – Adding New Slave Nodes

1. Create Snapshot

- take a snapshot of a master or slave node
- usually achieved by tools of a data system (e.g. *Ops Manager* in case of *MongoDB*) or Ops storage system tool like *LVM* or *Amazon EBS* in case of *EC2* instances
 - last one requires stop of data-system
 - plain snapshots require a lot of space as they contain indices, storage padding and fragmentation

2. Copy Snapshot

- copy Snapshot to new replica slave node
- for instance automatically by using tools of the data-system or in a lot of cases even `rsync` or `cp` is used and recommended (e.g. MySQL).



Master Replication – Adding New Slave Nodes

3. Process Replication Log

- the new slave node connects to the master node and processes all dataset changes happened since the snapshot used, was created.
- this is usually done by using a *replication log* of the *master node*
- oldest entry within the *replication log* needs to be less recent than or equal to the creation time of the snapshot
- a *slave* which is too far behind the replication log (*stale slave*) would lead to data loss

4. Go-Live

- as soon as the new slave successfully processed the replication log and is up-to-date, it can start working again like any slave node
- serve read requests and processing changes from the master as they happen



Master Replication – Outages Of Nodes

Slave Outage:

- slave nodes make use of **replication logs** to stay in-sync with the master
- Those replication logs and processing state (usually
 - timestamp,
 - number or
 - position of event within replication log)
- stored on the slave, e.g as
 - **OpLog** collection *local.oplog.rs* in case of MongoDB)
 - **relay logs** in case of MySQL relay logs
- If a slave node crashes and gets back up again or recovers from a network issue, it:
 - can just start right away using the **replication log** where it stopped
 - **connect to the master** and **request all dataset changes** that have happened during the time of outage
- As soon as the new slave successfully processed all missing data changes and is up-to-date, it works like before



Master Replication – Outages Of Nodes

Master Outage:

1. Determining Master Failure

- e.g. done by defining and using timeouts (*heartbeat*)
→ if a node does not respond within a defined timeframe, it is supposed to be dead

2. Evaluating New Master

- several approaches, most common: choose new master by the majority of the remaining nodes or a controller node (e.g. an *Arbiter* node in case of MongoDB)
- best candidate: node containing most-recent updates of old master node
- vulnerable to *split-brain scenario* (if node failure was caused by network outage)

3. Reconfiguration

- as soon as *new master* node is elected, all clients need to send their write requests to the *new master*
- all *slave nodes* need to receive the replication log from the new master as well



Master Replication – Replication Logs

Statement Based:

- most-simple approach
- master node processes each query and afterwards adds them to the replication log (e.g. *INSERT*, *UPDATE*, *DELETE*...)
- statements are later executed by slave nodes
- Pitfalls:
 - How to handle **non-deterministic** functions within a write request (like *RAND()*, *USER()* or *NOW()* used in an SQL query) or external functions like StoredProcedures, Triggers or user-defined functions?
→ The master node would need to **replace** those **non-deterministic functions** with deterministic values (like the return value of the called function).
 - What if statements depend on other data, like in an *UPDATE ... WHERE ...* statement.
→ This requires all statements to be executed **within the exact same order**, otherwise they will end up in different results.
- For instance previously used by MySQL and still supported in a mixed-approach (with row-based replication)



Master Replication – Replication Logs

WAL (Write-Ahead-Log):

- the master logs all IO data changes to a **WAL** (e.g. (re-)writes of disk blocks, appends to files, etc.), writes the WAL to disk and sends it to all slaves
 - when a slave processes this log file, it builds an exact same copy of the data structures as found at the master.
- **significantly reduces IO** (disk writes) → only the log file needs to be flushed to disk to guarantee that a transaction is committed, rather than every statement or data file changed by the transaction
- Highly dependent on storage engine (which byte has changed within which disk block)
 - different versions of a data-system or storage engine on master and slave nodes impossible
 - increases complexity of maintenance tasks, especially rolling-upgrades of single nodes within a data-system are not possible any more
 - makes downtimes inevitable
- For instance used by ArangoDB or PostgreSQL

Master Replication – Replication Logs

Logical Log Replication

- logical row-based replication (decoupled from storage engine)
- Replication log contains records describing changes of a dataset in a row-based way,
e.g.:
 - **INSERT**: The log contains one record with all values for each inserted row.
 - **UPDATE**: The log contains one record for each updated row as well as all new
values and an information to uniquely identify the updated row (e.g. primary key).
 - **DELETE**: The log contains one record for each row to be deleted as well as inform
ation to uniquely identify the row to be deleted (e.g. primary key).
- For instance used by MongoDB



Master Replication – Replication Logs

Update on MongoDB collection

```
$ use test
switched to db test
$ db.user.insert({user_id:1})
$ db.user.update({user_id:1}, {$set : {married_to:4711}})
```

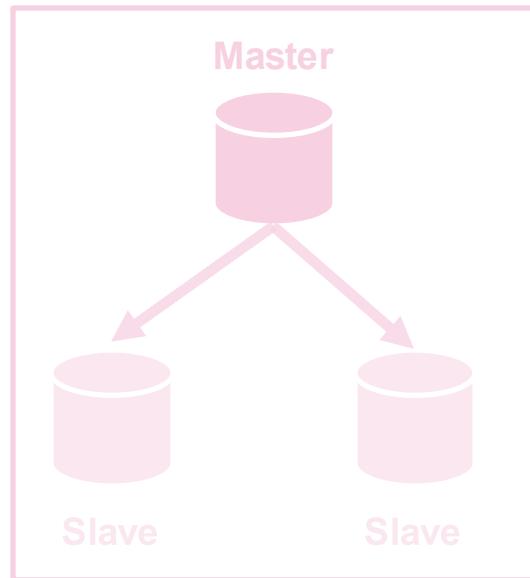
Resulting Replication Log

```
$ use local
switched to db local
$ db.oplog.rs.find()
{
  "ts" : { "t" : 1534616696000, "i" : 1 },
  "h" : NumberLong("1342870845645633201"),
  "op" : "i",
  "ns" : "test.user",
  "o" : {
    "_id" : ObjectId("4cb35859543cc1f4f9f7f85d"),
    "user_id" : 1
  }
}
{
  "ts" : { "t" : 1534616699000, "i" : 1 },
  "h" : NumberLong("1233487572903545434"),
  "op" : "u",
  "ns" : "test.user",
  "o2" : {
    "_id" : ObjectId("4cb35859543cc1f4f9f7f85d")
  },
  "o" : {
    "$set" : { "married_to" : 4711 }
  }
}
```



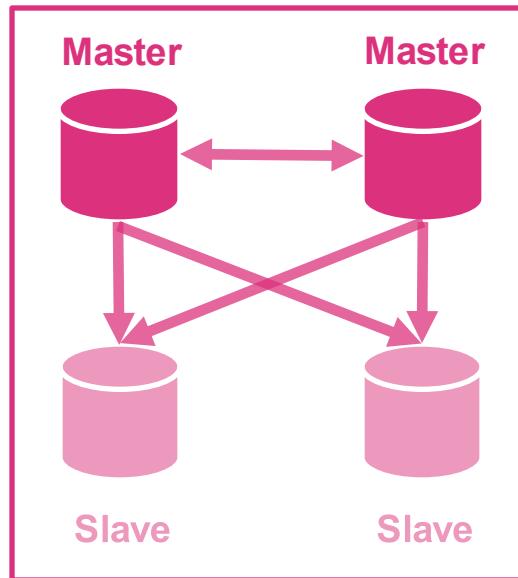
Multi-Master Replication

Master-based



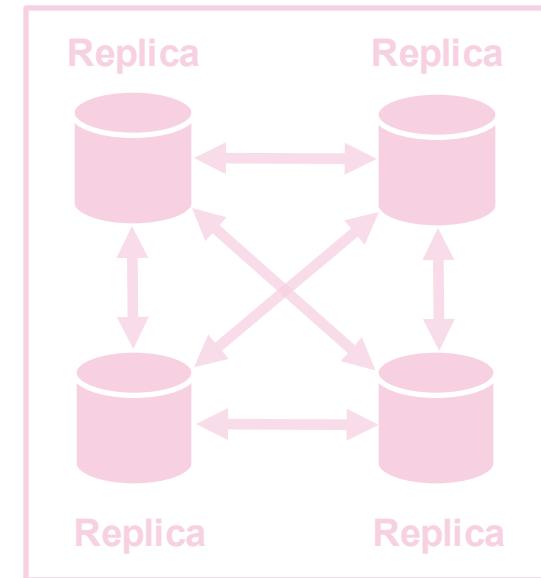
e.g. Oracle, PostgreSQL,
MySQL...

Multi-Master-based



e.g. CouchDB, PostgreSQL,
MySQL...

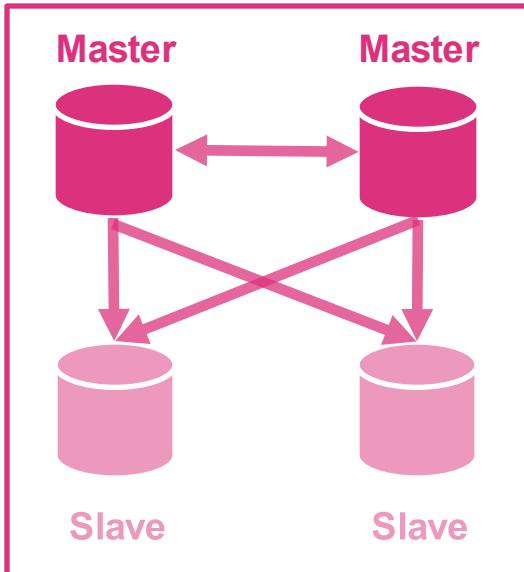
Masterless



e.g. Cassandra, Riak, Vol
demortDB, DynamoDB...

Multi-Master Replication

Also known as: Multi-Leader, Active/Active or Master/Master Replication



Setup:

- **multiple master** nodes (which accept write requests)
- query and replication processing similar to master-based replication

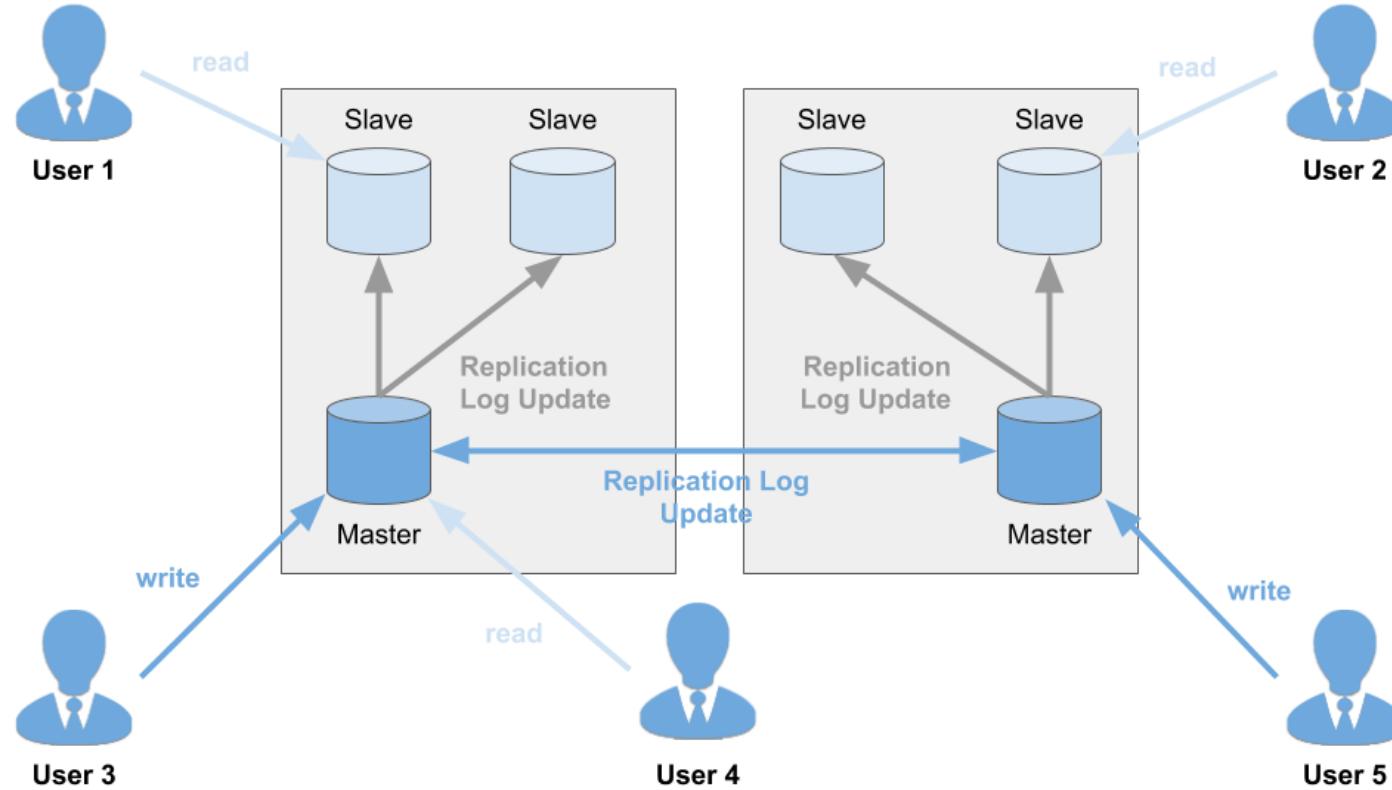
Advantages:

- **fault tolerance** (ability to mitigate faults of master nodes)
- **write performance** and horiz. scalability (parallel writes)
- able to run on **multiple datacenters** (e.g. one master in each of them)

Disadvantages:

- **write conflicts** possible (requires conflict resolution)
- **complexity**

Multi-Master Replication – Example



Multi-Master Replication - Conflicts

- **same record/dataset** is being **edited in parallel** using **multiple master nodes**
 - e.g. editing the same line of a document within Google Docs simultaneously (user 1 on a master node based in Frankfurt and user 2 on a master node in Berlin)
 - Later asynchronous replication between the two master nodes will conflict (this won't happen if you are using a master replication).
 - **Possible solution:** application needs to ensure both users are pushing their write request to the same master.

But what if the application is not able to prevent those conflict? **Approaches:**

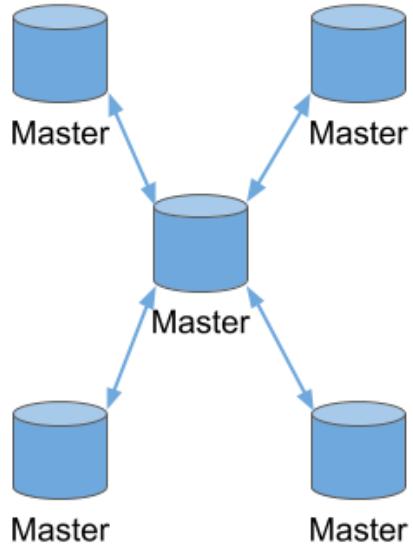
LWW: only accept the most recent operation by e.g. unique operation ID, timestamp or both (*Last-Write-Wins*). It is important to notice that this approach is highly vulnerable to data loss.

Merge: merge values of multiple updates together (e.g. alphabetically or in order of appearance).

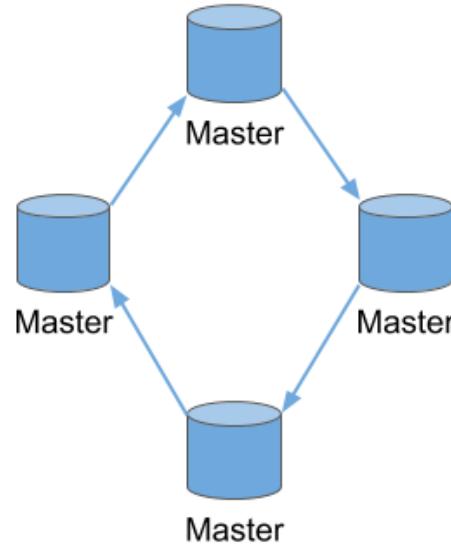
Application Managed: persist the conflict in a way, that it preserves all information without loss and let the application, using the data-system, or rather the user of the application take care about it later on (e.g. implemented by SVN or Git)

Multi-Master Replication - Topologies

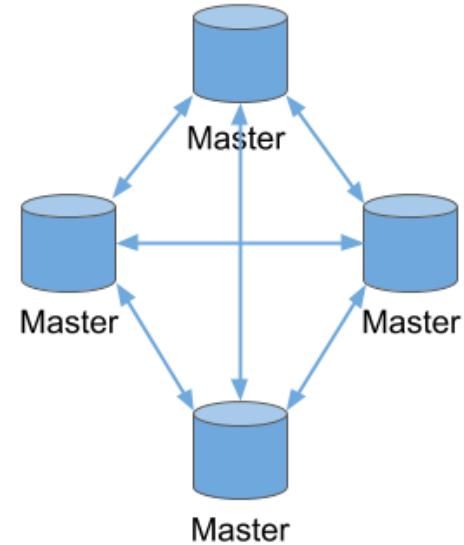
Star Topology



Circle Topology

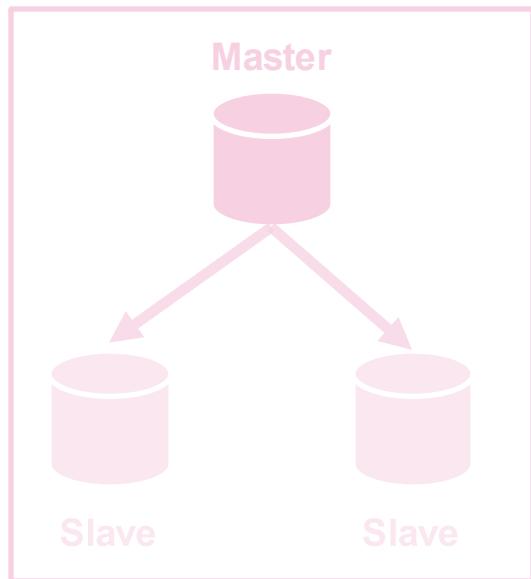


All-To-All Topology



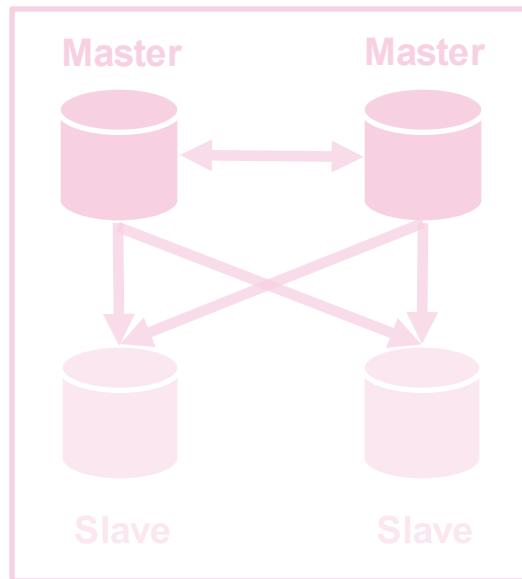
Masterless Replication

Master-based



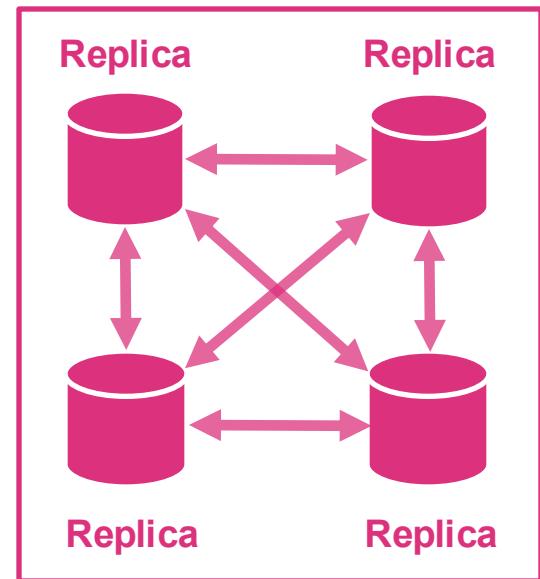
e.g. Oracle, PostgreSQL,
MySQL...

Multi-Master-based



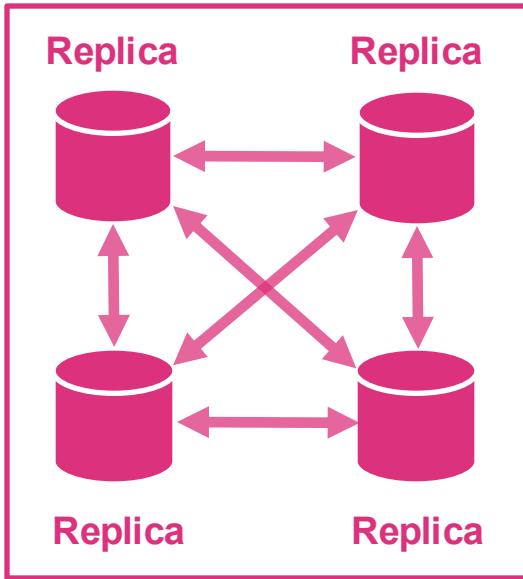
e.g. CouchDB, PostgreSQL,
MySQL...

Masterless



e.g. Cassandra, Riak, Vol
demortDB, DynamoDB...

Masterless Replication



Setup:

- **no leader** (all nodes/replicas accept write requests)
- makes use of **gossip protocol** (all replica nodes run local processes which periodically match their states)
- queries are sent to multiple nodes of data-system
→ if a certain number of nodes succeeded, the query is considered successful

Advantages:

- **fault tolerance** (tolerates multiple failed or slow nodes)
- **write performance** and horiz. scalability (parallel writes)
- able to run on **multiple datacenters** (with respect to *quorum*)

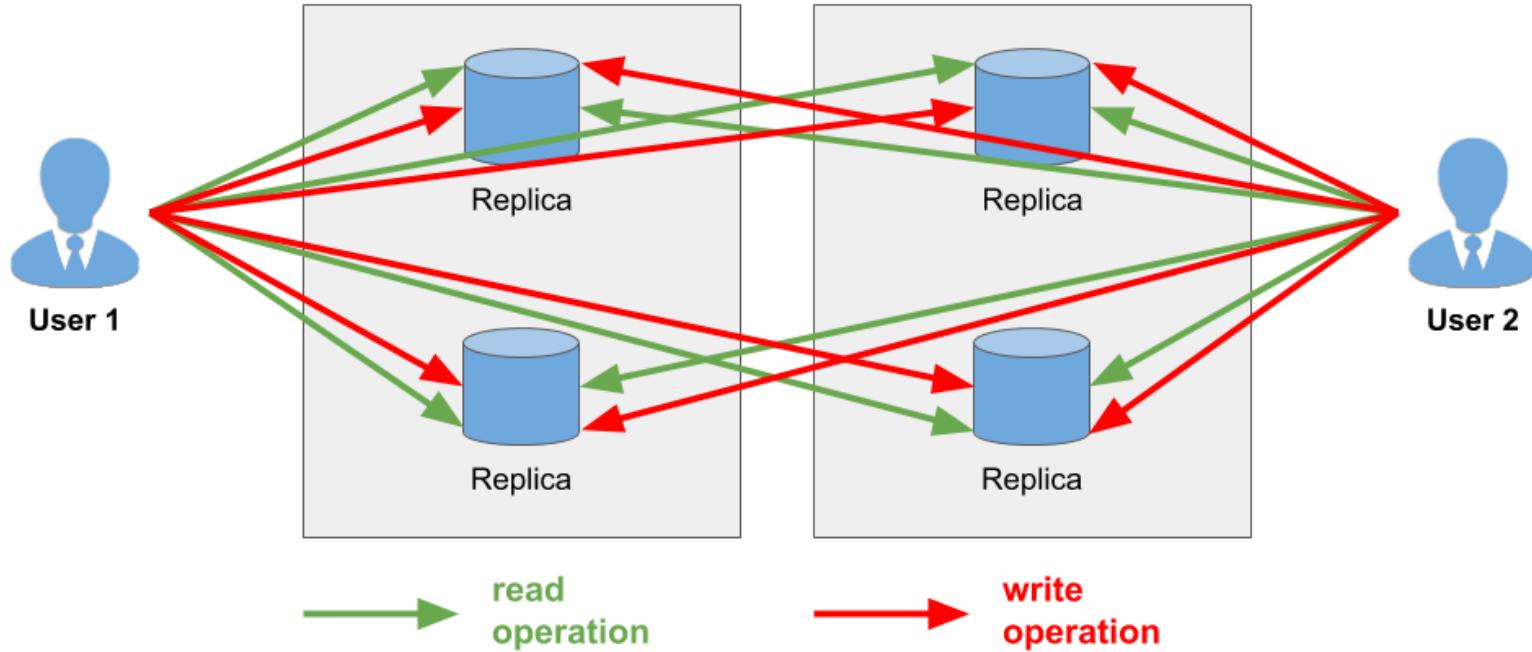
Disadvantages:

- **consistency, complexity** and additional **tasks** clients need to handle (e.g. quorum, conflict resolution, consistency)
- most data-system are key/value stores

Also known as:

Leaderless Replication

Masterless Replication – Example



Masterless Replication- Quorums

Quorum:

- a *quorum* is the **minimum number of votes** that a read/write request to a distributed data-system has to obtain in order to be sure the **requests is successful** (and the result consistent)

Reasonable quorum:

- every **read** and **write request** must be processed and confirmed by at least **r nodes** (read) or acknowledged by at least **w nodes** (write):

$$r + w > n$$

→ sure to get an up-to-date result, as at least one of the replica will have the most recent value

- able to run on **multiple datacenters** (with respect to *quorum*)

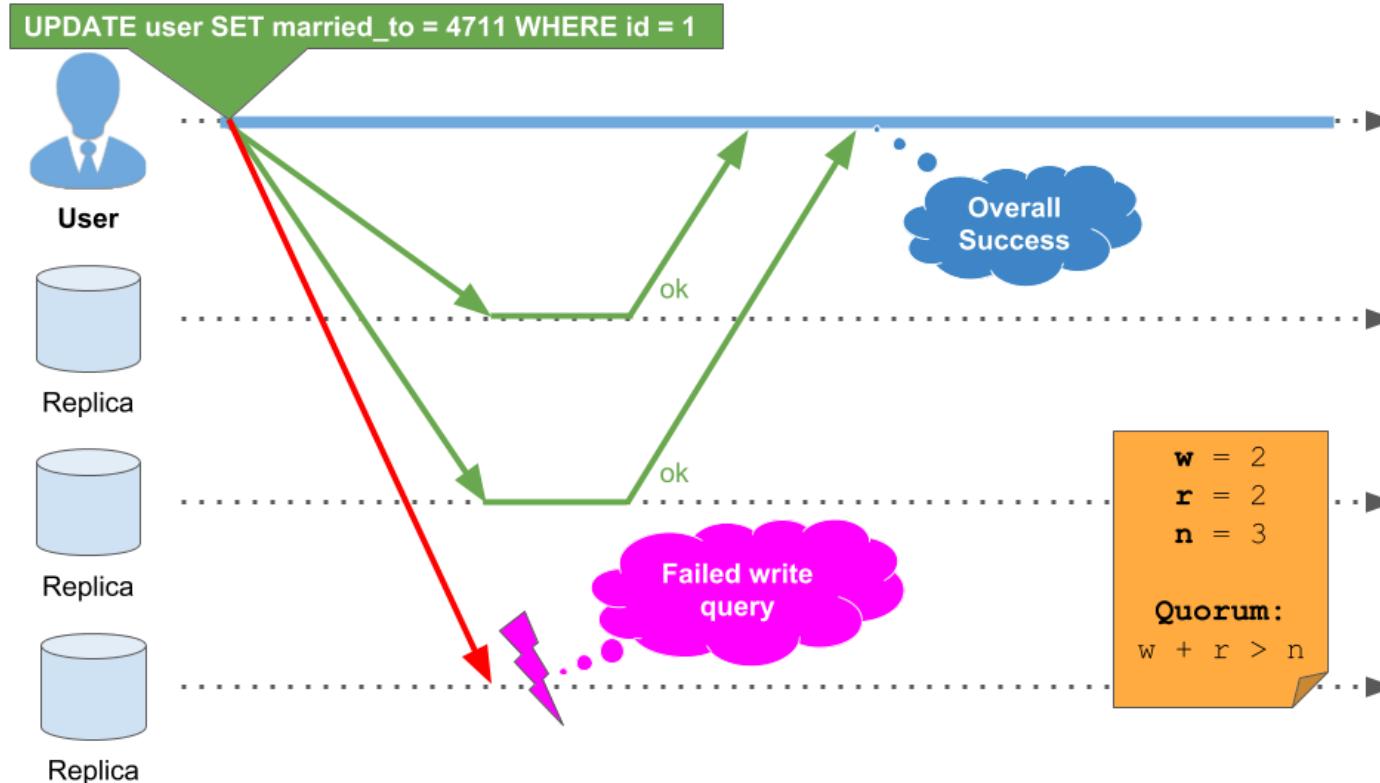


Masterless Replication- Quorums

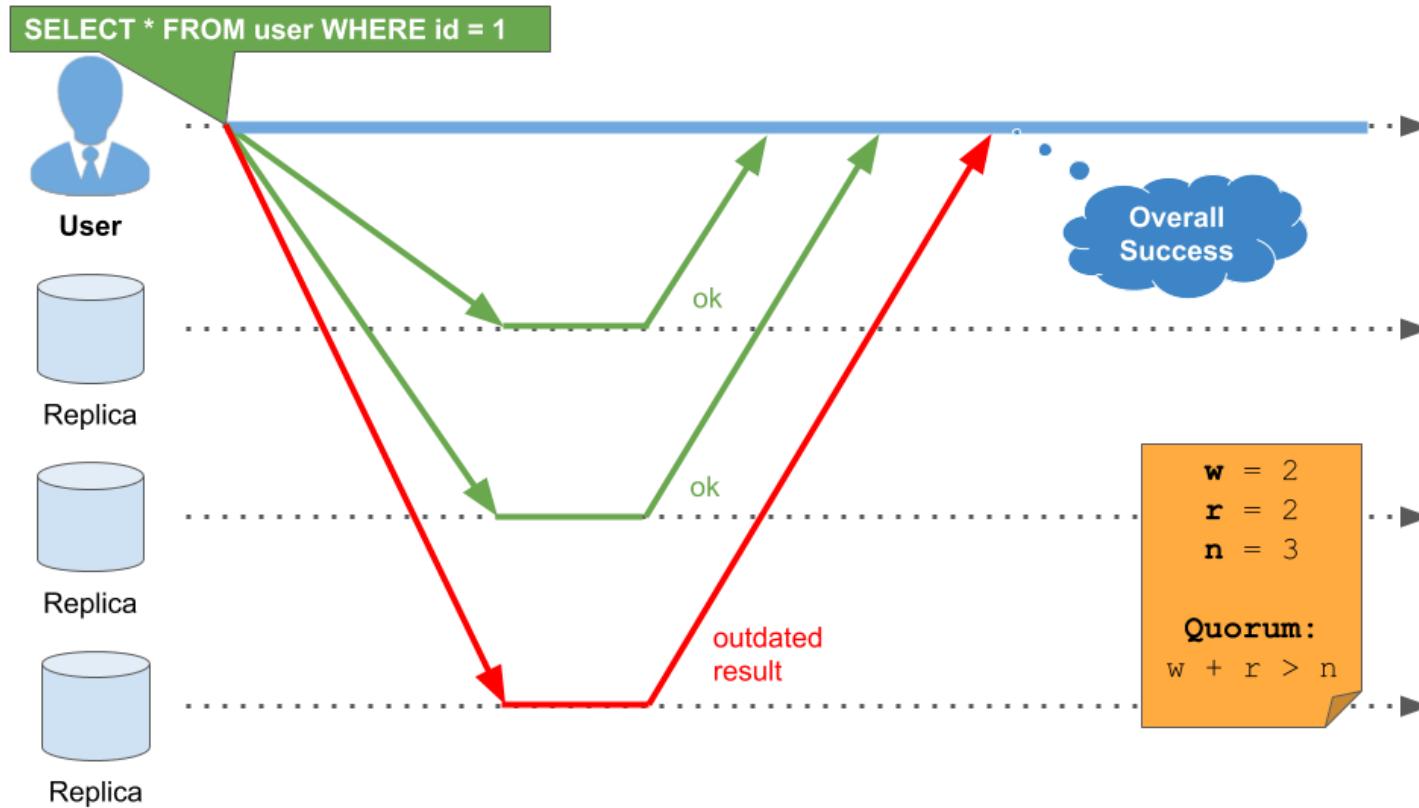
- **r** and **w** are configurable depending on *read/write performance* and *fault-tolerance* you want to achieve
 - smaller **r** = faster reads, slower writes
 - smaller **w** = faster writes, slower reads
- Number of node failures a data-system can handle, is calculated by:
 - **n - r = number** of nodes tolerated to be unavailable for read requests
 - **n - w = number** of nodes tolerated to be unavailable for write requests
- For instance, a data-system of **5 nodes** ($n = 5$, $r = 3$ and $w = 3$) is able to tolerate 2 unavailable nodes.



Masterless Replication- Quorum Write



Masterless Replication- Quorum Read



Masterless Replication – Eventual Consistency

Read Repair: If a user application or controller node executes a read requests and recognizes a replica node with a *stale* value, the user application or controller sends it the most recent value afterwards. For instance used by *Cassandra*, *Riak* and *VoldemortDB*.

Anti-Entropy Repair: Some data-systems are running background processes or provide tools (e.g. *nodetool repair* in case of *Cassandra*) which run in background constantly looking for differences between different replica nodes and copying data from one node to another to keep everything up-to- date. For instance used by *Cassandra* and *Riak* but not supported by *VoldemortDB*.

Hinted Handoff: If a node is unable to process a particular write request, the user application or coordinator node (which executed the write request) preserves the data to be written as a set of hints. As soon as the faulty node comes back online, the user application or coordinator triggers a repair process by handing off hints to the faulty node to catch up with the missed writes.
For instance used by *Cassandra* and *Riak* but not supported by *VoldemortDB*.



Masterless Replication- Limitations of Quorums

Concurrent Writes: If two write requests are executed concurrently, it is **not clear which one happened first**, as both are executed from different controller nodes or applications. Both requests need to be merged, for instance based on a timestamp (*last-write-wins*), which is highly vulnerable to *clock skew*, causing **older values to overwrite more recent ones**.

For instance *Cassandra* is based on *last-write-wins* whereas *Riak* requires the admin to choose whether to make use of *last-write-wins* or *handle write conflicts within the application* using the data-system.

Concurrent Reads And Writes: If **read and write requests** (regarding the same value) happen at the **same time** it is unclear whether the read request returns the **stale or the new value**. As the write request may succeed only on some nodes during execution of the read query, the new value might be under-represented, causing the old value to win the quorum.

Node Failure: If a node previously processed a new value, crashed and comes back online and is **restored** from a node with the **old value**, the **quorum might be violated** as the number of nodes storing the new value might be $< w$.



Masterless Replication- Limitations of Quorums

Sloppy Quorum and Hinted Handoff: There are cases like network or datacenter outages causing some user or consumer applications being cut off from some nodes of a data-system (while the unreachable nodes are still online). In this case it is possible that some user or consumer applications won't be able to achieve a quorum. If the data-systems contains more than n nodes, it needs to make a crucial decision here, whether to ignore all requests that cannot achieve a quorum or still accept write requests and just write them to some nodes outside of n to ensure write availability and durability. A sloppy quorum still requires r and w nodes, but those do not need to be one of the original n nodes. As soon as the network or datacenter outage is fixed, all writes processed by nodes outside of n are sent to the appropriate nodes inside of n (*Hinted Handoff*).

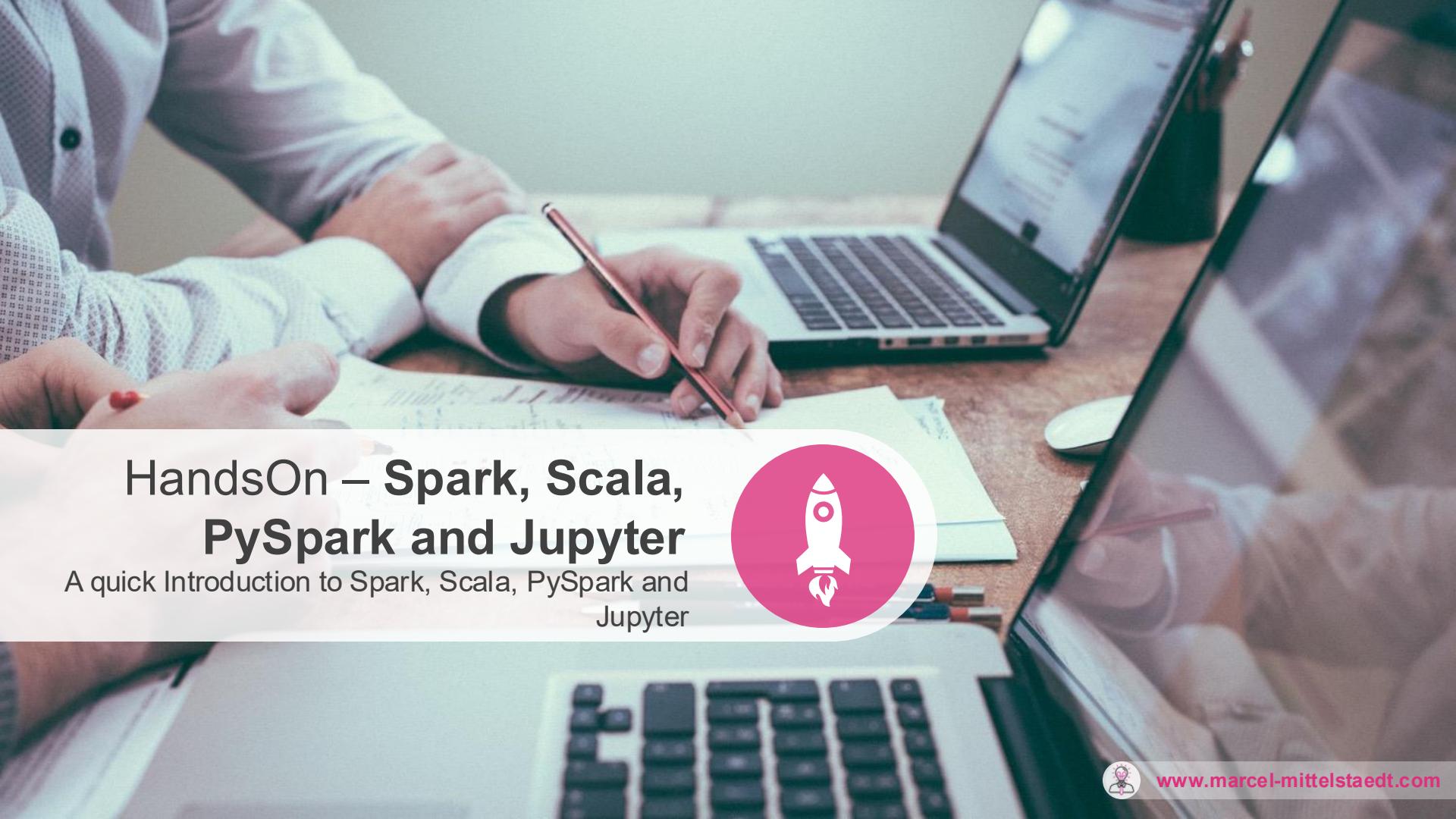
Using this approach it is no longer guaranteed a data-system will provide the most recent value as read and write requests may not overlap on r and w nodes. This could also be mitigated by using versioning of values, like *vector clocks* (e.g. used by *DynamoDB*).

For instance *sloppy quorums* are enabled by default within *Riak* and disabled by default within *Cassandra*.

Break

TIME FOR
A
BREAK



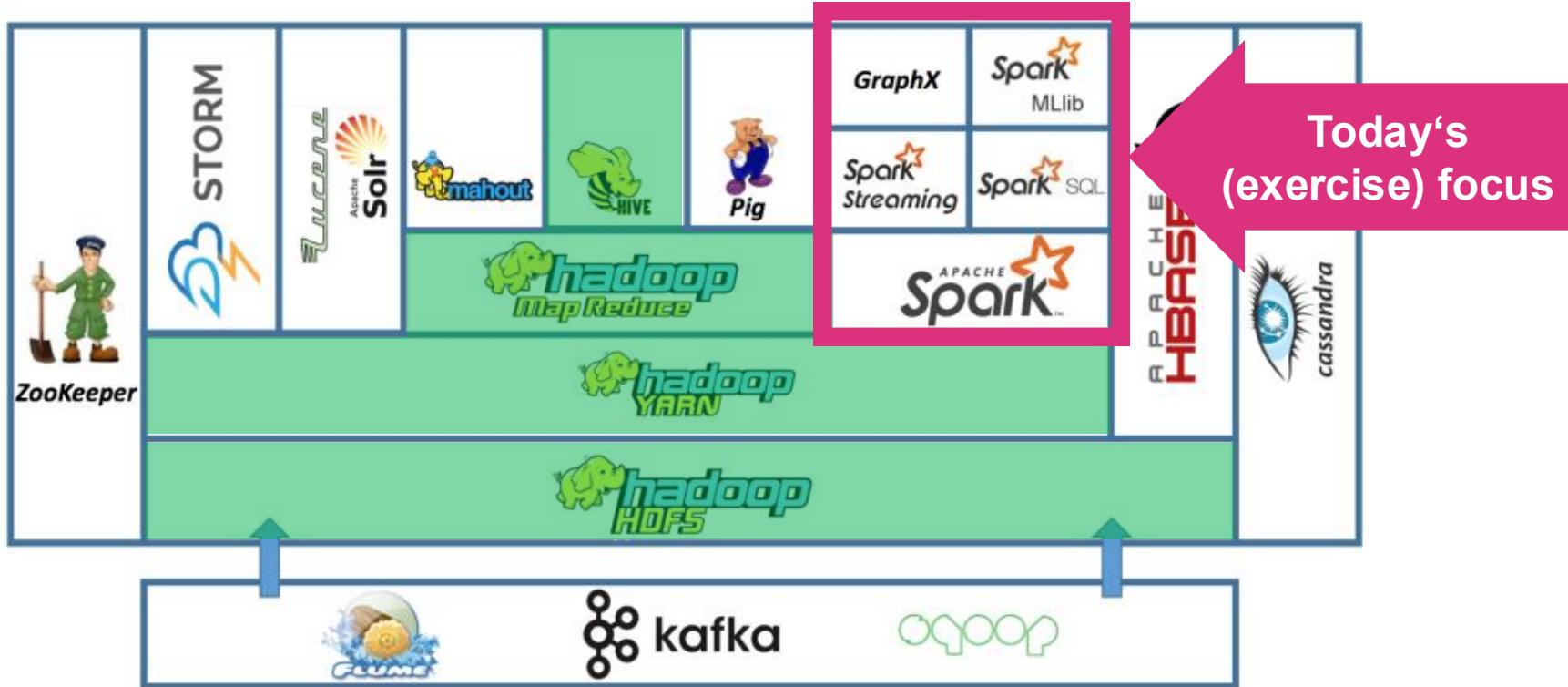


HandsOn – Spark, Scala, PySpark and Jupyter

A quick Introduction to Spark, Scala, PySpark and
Jupyter



The Hadoop Ecosystem



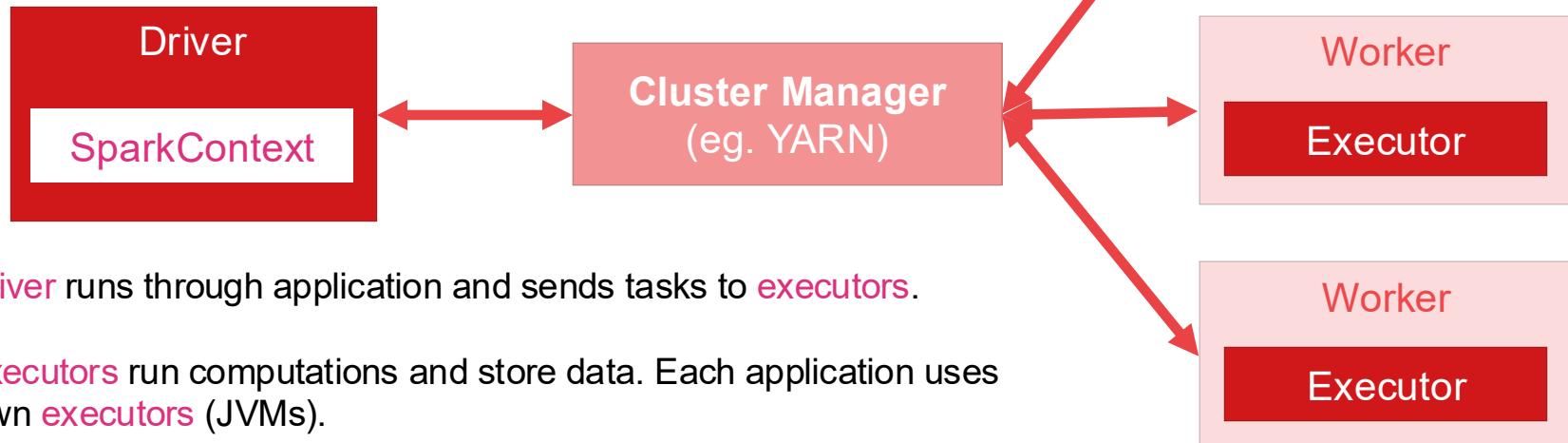
Spark

API Languages:	Java	Scala	Python	R
APIs and Libraries:	Spark SQL	Spark Streaming	Mlib	GraphX
Spark Core				
Ressource/ Cluster Manager:	Standalone	YARN	Mesos	Kubernetes
Data Source APIs:	HDFS, ElasticSearch, Amazon S3, Azure Data Lake, Redis, Riak, Couch-base, MongoDB, Hive, Avro, CSV, Parquet, JDBC DB...			



Spark – Execution Process

1. Spark applications starts and instantiates **SparkContext** (JVM process).
2. Spark acquires **executors** on worker nodes from cluster manager.
3. Cluster manager launches **executors**.



4. **Driver** runs through application and sends tasks to **executors**.
5. **Executors** run computations and store data. Each application uses its own **executors** (JVMs).
6. If any worker crashes, its tasks will be sent to another **executor**.

Spark – RDDs, DataFrame and DataSet

Supported by:

RDD
(2011)

Scala, Java, Python

- Idea:**
- RDD = immutable distributed collection of data
 - partitioned across nodes of cluster
 - can be operated in parallel with a low-level API

Typed: typed, no schema

Use for: unstructured data

DataFrame
(2013)

Scala, Java, Python

- based on RDD
- immutable distributed collection of data
- but organized into columns
- higher level abstraction

untyped, schema

semi-structured and structured data

DataSet
(2015)

Scala, Java

- based on DataFrame API, but type-safe
- immutable distributed collection of data
- high-level API
- converted into optimized RDD

typed, schema

structured data



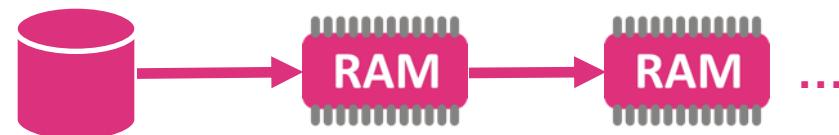
Hadoop MapReduce vs Spark

Hadoop MapReduce



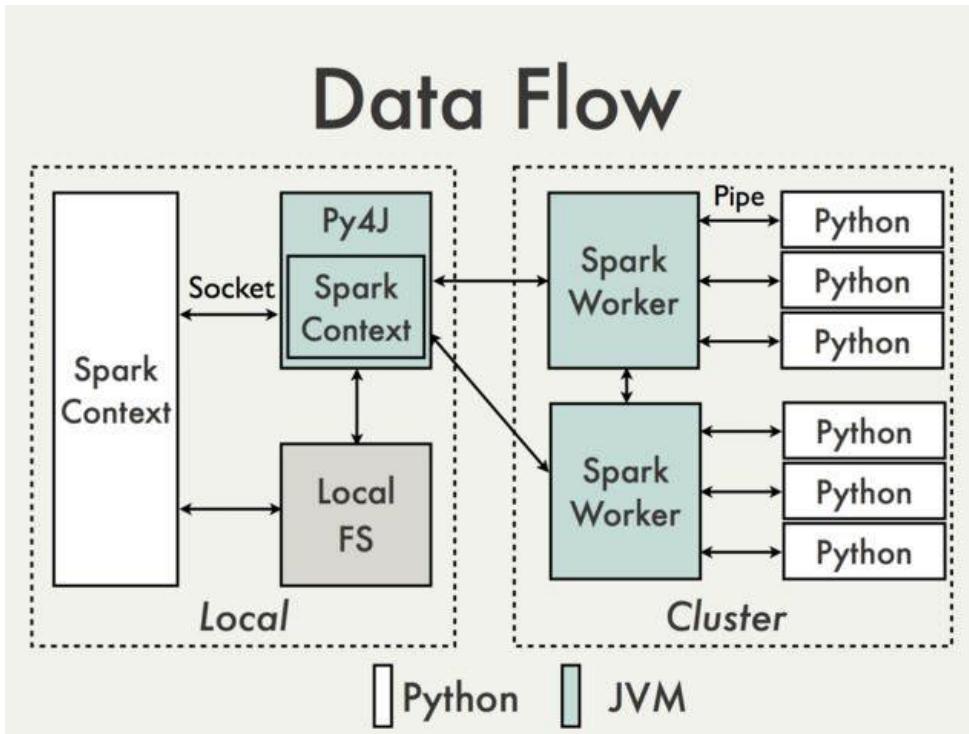
- performs **read** from HDFS (**HDD**) before **every computation**
 - performs **write** on HDFS (**HDD**) after **every computation**
 - using distributed **disk space**

Spark



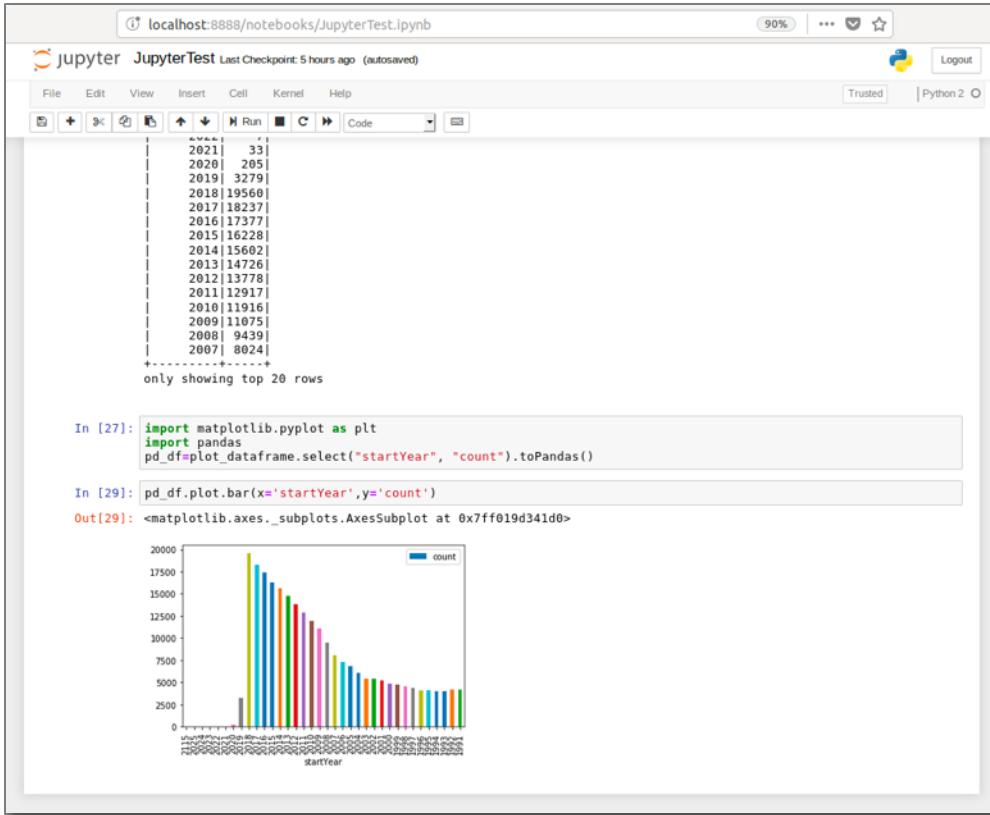
- performs **read** from **RAM** before every computation (except first)
 - performs **write** on **RAM** after every computation
 - using distributed **memory** (as long as free memory is available
→ **spill**)

PySpark



- built on-top of Sparks Java API
- data is processed in Python and cached/shuffled within the JVM
- Spark executors on the cluster start Python interpreter to execute user code
- A Python RDD corresponds to an RDD in the local JVM
- e.g. **sc.textFile()** in Python will call JavaSparkContext **textFile()**

Jupyter (Notebooks)



The screenshot shows a Jupyter Notebook interface running on localhost:8888/notebooks/JupyterTest.ipynb. The notebook contains two code cells and one figure cell.

In [27]:

```
import matplotlib.pyplot as plt
import pandas
pd_df=plt_dataframe.select("startYear", "count").toPandas()
```

In [29]:

```
pd_df.plot.bar(x='startYear',y='count')
```

Out[29]:

```
<matplotlib.axes._subplots.AxesSubplot at 0x7ff019d341d0>
```

A bar chart titled 'startYear' is displayed, showing the count of entries for each year from 2007 to 2021. The y-axis ranges from 0 to 20,000. The chart shows a peak around 2013 and a general decline thereafter.

startYear	count
2021	33
2020	205
2019	3279
2018	19560
2017	18237
2016	17377
2015	16228
2014	15602
2013	14726
2012	13778
2011	12917
2010	11916
2009	11075
2008	9439
2007	8024

- Interactive Web IDE
- Kernel-based Notebooks
- Open-source
- Create and share:
 - code,
 - visualizations and
 - narrative text like documentation
- Supports:
 - Python
 - R
 - Scala
 - ...
- Works well with Spark



Exercises Preparation I

Start Hadoop Cluster and Test Spark Shell
(Word Count Example)



Start Gcloud VM and Connect

1. Start Gcloud Instance:

```
gcloud compute instances start big-data
```

2. Connect to Gcloud instance via SSH (on Windows using Putty):

```
ssh hans.wurst@XXX.XXX.XXX.XXX
```



Pull and Start Docker Container

1. Pull Docker Image:

```
docker pull marcelmittelstaedt/spark_base:latest
```

2. Start Docker Image:

```
docker network create --driver bridge bigdatanet
docker run -dit --name hadoop \
    -p 8088:8088 -p 9870:9870 -p 9864:9864 -p 10000:10000 \
    -p 8032:8032 -p 8030:8030 -p 8031:8031 -p 9000:9000 \
    -p 8888:8888 --net bigdatanet \
    marcelmittelstaedt/spark_base:latest
```

3. Wait till first Container Initialization finished:

```
docker logs hadoop
[...]
Stopping nodemanagers
Stopping resourcemanager
Container Startup finished.
```



Start Hadoop Cluster

1. Get into Docker container:

```
docker exec -it hadoop bash
```

2. Switch to hadoop user:

```
sudo su hadoop
```

```
cd
```

3. Start Hadoop Cluster:

```
start-all.sh
```



Add Test text file to HDFS (Faust 1)

1. Download test Text File (Faust_1.txt):

```
wget https://raw.githubusercontent.com/marcelmittelstaedt/BigData/master/exercises/winter_semester_2025-2026/01_hadoop/sample_data/Faust_1.txt
```

2. Upload file to HDFS:

```
hadoop fs -put Faust_1.txt /user/hadoop/Faust_1.txt
```



Start Spark (on Yarn)

1. Start Spark Shell:

```
spark-shell --master yarn
```

```
Spark context Web UI available at http://localhost:4040
Spark context available as 'sc' (master = yarn, app id = application_1572177196643_0001).
Spark session available as 'spark'.
Welcome to
```

```
Using Scala version 2.11.8 (OpenJDK 64-Bit Server VM, Java 1.8.0_222)
Type in expressions to have them evaluated.
Type :help for more information.
```

scala>



Start Spark – WordCount Example (Scala)

1. Execute Word Count Example in Scala:

```
scala> val text_file = sc.textFile("/user/hadoop/Faust_1.txt")
scala> val words = text_file.flatMap(line => line.split(" "))
scala> val counts = words.map(word => (word, 1))
scala> val reduced_counts = counts.reduceByKey((count1, count2) => count1 + count2)
scala> val sorted_counts = reduced_counts.sortBy(- _.value)
```

```
scala> sorted_counts.take(10)

res0: Array[(String, Int)] = Array(("\"",1603), ("und",509), ("die",463), ("der",440), ("ich",435), ("Und",400), ("nicht",346), ("zu",319), ("ist",291), ("ein",284))
```

2. Save results to HDFS:

```
scala> sorted_counts.saveAsTextFile("/user/hadoop/Faust_1_WordCounts_Scala.txt")
```



Start Spark – WordCount Example (Scala)

3. Get results from HDFS to local filesystem:

```
hadoop fs -get /user/hadoop/Faust_1_WordCounts_Scala.txt/part-00000 Faust_1_WordCounts_Scala.txt
```

4. Check Result:

```
head -10 Faust_1_WordCounts_Scala.txt

(,1603)
(und,509)
(die,463)
(der,440)
(ich,435)
(Und,400)
(nicht,346)
(zu,319)
(ist,291)
(ein,284)
```



Start Spark (on Yarn) – WordCount Example

5. See Spark Shell Container Running on Yarn <http://xxx.xxx.xxx.xxx:8088/cluster>:

hadoop

Logged in as: dr.who

RUNNING Applications

Cluster Metrics																			
Apps Submitted	Apps Pending	Apps Running	Apps Completed	Containers Running	Memory Used	Memory Total	Memory Reserved	Vcores Used	Vcores Total	Vcores Reserved									
5	0	1	4	3	5 GB	8 GB	0 B	3	8	0									
Cluster Nodes Metrics																			
Active Nodes	Decommissioning Nodes			Decommissioned Nodes			Lost Nodes		Unhealthy Nodes		Rebooted Nodes		Shutdown Nodes						
1	0	0	0	0	0	0	0	0	0	0	0	0	0						
Scheduler Metrics																			
Scheduler Type	Scheduling Resource Type			Minimum Allocation			Maximum Allocation			Maximum Cluster Application Priority									
Capacity Scheduler	[memory-mb (unit=M), vcores]			<memory:1024, vCores:1>			<memory:8192, vCores:4>			0									
Show: 20 entries																			
ID	User	Name	Application Type	Queue	Application Priority	StartTime	FinishTime	State	FinalStatus	Running Containers	Allocated CPU Vcores	Allocated Memory MB	Reserved CPU Vcores	Reserved Memory MB	% of Queue	% of Cluster	Progress	Tracking UI	Blacklisted Nodes
application_1572177196643_0005	hadoop	Spark shell	SPARK	default	0	Sun Oct 27 14:18:28 +0100 2019	N/A	RUNNING	UNDEFINED	3	3	5120	0	0	62.5	62.5		ApplicationMaster	0

Showing 1 to 1 of 1 entries

First Previous 1 Next Last



Exercises Preparation II

Test PySpark Shell (Word Count Example)



Start PySpark (on Yarn) – Test Install

1. As PySpark is already installed, start PySpark Shell and execute previous example as Python code:

```
pyspark --master yarn
```

```
Using Python version 3.6.8 (default, Oct  7 2019 12:59:55)
SparkSession available as 'spark'.
>>>
```



PySpark – WordCount Example (Python)

1. Execute Word Count Example in Python:

```
>>> text_file = spark.read.text("/user/hadoop/Faust_1.txt").rdd.map(lambda r: r[0])
>>> words = text_file.flatMap(lambda line: line.split(" "))
>>> counts = words.map(lambda word: (word, 1)).reduceByKey(lambda a,b:a +b)
>>> output = counts.collect()
>>> sorted_output = sorted(output,key=lambda x:(-x[1],x[0]))
```

```
>>> sorted_output[:10]

[(',', 1603), ('und', 509), ('die', 463), ('der', 440), ('ich', 435), ('Und', 400), ('nicht', 346), ('zu', 319), ('ist', 291), ('ein', 284)]
```

2. Save results to HDFS:

```
>>> counts.saveAsTextFile("/user/hadoop/Faust_1_WordCounts_Python.txt")
```



PySpark – WordCount Example (Python)

3. Get results from HDFS to local filesystem:

```
hadoop fs -get /user/hadoop/Faust_1_WordCounts_Python.txt/part-00000 Faust_1_WordCounts_Python.txt
```

4. Check Result:

```
head -10 Faust_1_WordCounts_Python.txt
('Johann', 1)
('Wolfgang', 1)
('von', 133)
('Goethe:', 1)
('Faust,', 8)
('Der', 130)
('Tragödie', 1)
('erster', 2)
('Teil', 6)
(' ', 1603)
```



PySpark (on Yarn) – WordCount Example

5. See PySpark Shell Container Running on Yarn <http://xxx.xxx.xxx.xxx:8088/cluster> :

 **hadoop** Logged in as: dr.who

RUNNING Applications

Cluster Metrics																			
Apps Submitted	Apps Pending	Apps Running	Apps Completed	Containers Running	Memory Used	Memory Total	Memory Reserved	Vcores Used	Vcores Total	Vcores Reserved									
8	0	1	7	3	5 GB	8 GB	0 B	3	8	0									
Cluster Nodes Metrics																			
Active Nodes	Decommissioning Nodes			Decommissioned Nodes			Lost Nodes		Unhealthy Nodes		Rebooted Nodes		Shutdown Nodes						
1	0	0	0	0	0	0	0	0	0	0	0	0							
Scheduler Metrics																			
Scheduler Type	Scheduling Resource Type			Minimum Allocation			Maximum Allocation			Maximum Cluster Application Priority									
Capacity Scheduler	[memory-mb (unit=M), vcores]			<memory:1024, vCores:1>			<memory:8192, vCores:4>			0									
Show 20 entries																			
ID	User	Name	Application Type	Queue	Application Priority	StartTime	FinishTime	State	FinalStatus	Running Containers	Allocated CPU Vcores	Allocated Memory MB	Reserved CPU Vcores	Reserved Memory MB	% of Queue	% of Cluster	Progress	Tracking UI	Blacklisted Nodes
application_1572177196643_0009	hadoop	PySparkShell	SPARK	default	0	Sun Oct 27 14:36:36 +0100 2019	N/A	RUNNING	UNDEFINED	3	3	5120	0	0	62.5	62.5		ApplicationMaster	0

Showing 1 to 1 of 1 entries First Previous 1 Next Last



TIME FOR
A
BREAK



Exercises Preparation III

Start and work with Jupyter Notebooks
(on PySpark)



Start Jupyter

1. Start Jupyter Notebook

```
jupyter notebook

[I 14:02:39.790 NotebookApp] Writing notebook server cookie secret to /home/hadoop/.local/share/jupyter/runtime/notebook_cookie_secret
[I 14:02:40.957 NotebookApp] Serving notebooks from local directory: /home/hadoop
[I 14:02:40.957 NotebookApp] The Jupyter Notebook is running at:
[I 14:02:40.957 NotebookApp] http://e0f4472dcb12:8888/?token=76b68a3c700b415790b019e07a3dd46a0d068c153a732d27
[I 14:02:40.957 NotebookApp] or http://127.0.0.1:8888/?token=76b68a3c700b415790b019e07a3dd46a0d068c153a732d27
[I 14:02:40.957 NotebookApp] Use Control-C to stop this server and shut down all kernels (twice to skip confirmation).
[W 14:02:40.979 NotebookApp] No web browser found: could not locate runnable browser.
[C 14:02:40.980 NotebookApp]
```

To access the notebook, open this file in a browser:
`file:///home/hadoop/.local/share/jupyter/runtime/nbserver-8624-open.html`

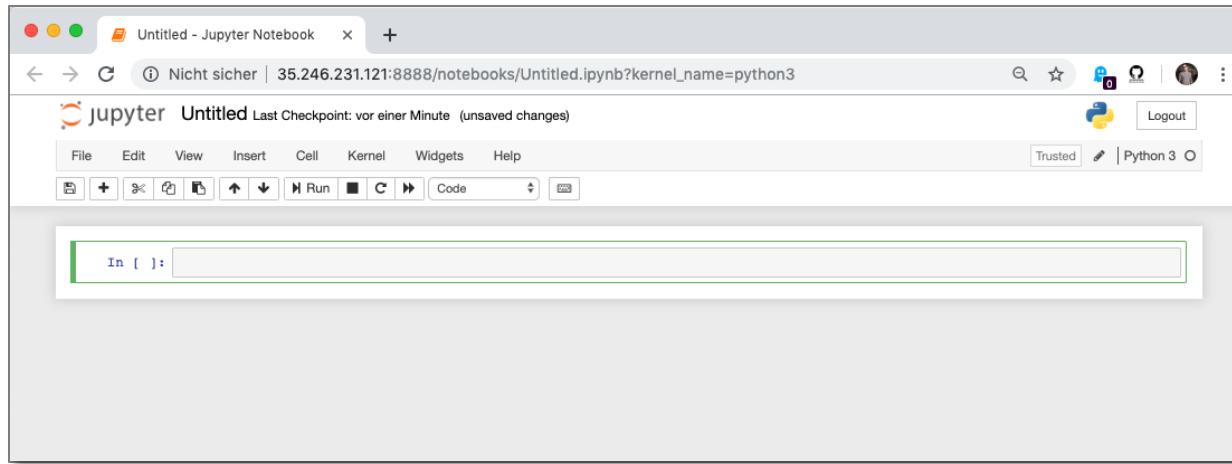
Or copy and paste one of these URLs:

`http://e0f4472dcb12:8888/?token=76b68a3c700b415790b019e07a3dd46a0d068c153a732d27`
or `http://127.0.0.1:8888/?token=76b68a3c700b415790b019e07a3dd46a0d068c153a732d27`



Start Jupyter

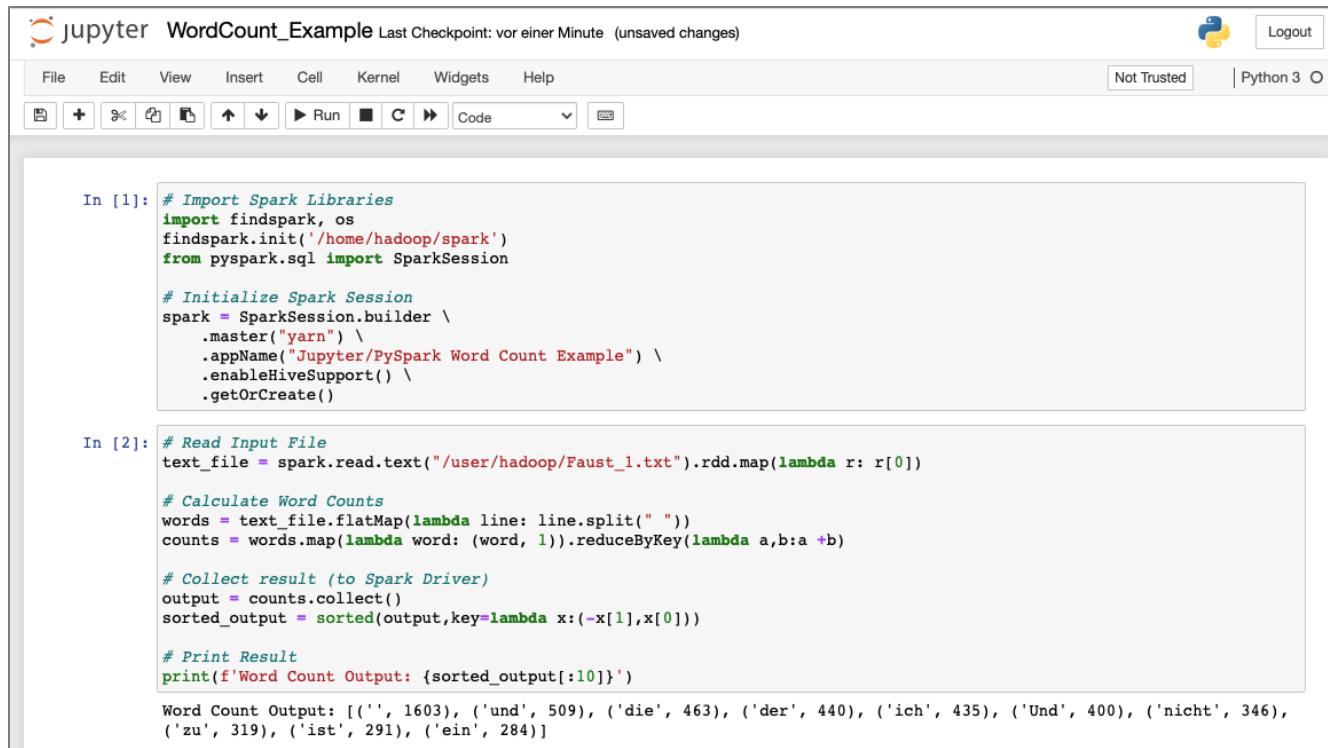
2. Open Notebook in Browser: [http://XXX.XXX.XXX.XXX:8888/?token=\[XYZXYZXYZ\]](http://XXX.XXX.XXX.XXX:8888/?token=[XYZXYZXYZ])



Use Jupyter (Word Count Example)

1. Execute previous Word Count example

https://github.com/marcelmittelstaedt/BigData/tree/master/exercises/winter_semeister_2025-2026/04_spark_pyspark_jupyter/WordCount_Example.html



The screenshot shows a Jupyter Notebook interface with two code cells. The first cell (In [1]) imports Spark libraries and initializes a Spark session. The second cell (In [2]) reads an input file, calculates word counts, collects the results, and prints the top 10 words. The output of the second cell shows the word count for the first ten words of the Faust 1 text.

```
In [1]: # Import Spark Libraries
import findspark, os
findspark.init('/home/hadoop/spark')
from pyspark.sql import SparkSession

# Initialize Spark Session
spark = SparkSession.builder \
    .master("yarn") \
    .appName("Jupyter/PySpark Word Count Example") \
    .enableHiveSupport() \
    .getOrCreate()

In [2]: # Read Input File
text_file = spark.read.text("/user/hadoop/Faust_1.txt").rdd.map(lambda r: r[0])

# Calculate Word Counts
words = text_file.flatMap(lambda line: line.split(" "))
counts = words.map(lambda word: (word, 1)).reduceByKey(lambda a,b:a +b)

# Collect result (to Spark Driver)
output = counts.collect()
sorted_output = sorted(output,key=lambda x:(-x[1],x[0]))

# Print Result
print(f'Word Count Output: {sorted_output[:10]}')

Word Count Output: [('(', 1603), ('und', 509), ('die', 463), ('der', 440), ('ich', 435), ('Und', 400), ('nicht', 346), ('zu', 319), ('ist', 291), ('ein', 284)]
```



Use Jupyter (Word Count Example)

2. See Jupyter PySpark Container Running on Yarn <http://xxx.xxx.xxx.xxx:8088/cluster>



Cluster Metrics

Apps Submitted	0	Apps Pending	1	Apps Running	0	Apps Completed	0	Containers Running	4	Memory Used	7 GB	Memory Total	16 GB	Memory Reserved	0 B	Vcores Used	4	Vcores Total	8	Vcores Reserved	0
----------------	---	--------------	---	--------------	---	----------------	---	--------------------	---	-------------	------	--------------	-------	-----------------	-----	-------------	---	--------------	---	-----------------	---

Cluster Nodes Metrics

Active Nodes	1	Decommissioning Nodes	0	Decommissioned Nodes	0	Lost Nodes	0	Unhealthy Nodes	0	Rebooted Nodes	0	Shutdown Nodes	0
--------------	---	-----------------------	---	----------------------	---	------------	---	-----------------	---	----------------	---	----------------	---

Scheduler Metrics

Scheduler Type	Capacity Scheduler	Scheduling Resource Type	[memory-mb (unit=Mi), vcores]	Minimum Allocation	<memory:1024, vcores:1>	Maximum Allocation	<memory:8192, vcores:4>	Maximum Cluster Application Priority	0
----------------	--------------------	--------------------------	-------------------------------	--------------------	-------------------------	--------------------	-------------------------	--------------------------------------	---

Show 20 entries

ID	User	Name	Application Type	Queue	Application Priority	StartTime	FinishTime	State	FinalStatus	Running Containers	Allocated CPU Vcores	Allocated Memory MB	Reserved CPU Vcores	Reserved Memory MB	% of Queue	% of Cluster	Progress	Tracking UI	Blacklisted Nodes
application_1614532561077_0001	hadoop	Jupyter/PySpark Word Count Example	SPARK	default	0	Sun Feb 28 18:16:38 +0100 2021	N/A	RUNNING	UNDEFINED	4	4	7168	0	0	43.8	43.8		ApplicationMaster	0

Showing 1 to 1 of 1 entries

All Applications

Logged in as: dr.who

First	Previous	1	Next	Last
-------	----------	---	------	------



Get some data...

1. Get some IMDb data:

```
wget https://datasets.imdbws.com/title.basics.tsv.gz && gunzip title.basics.tsv.gz  
wget https://datasets.imdbws.com/title.ratings.tsv.gz && gunzip title.ratings.tsv.gz
```

2. Put them into HDFS:

```
hadoop fs -mkdir /user/hadoop/imdb
```

```
hadoop fs -mkdir /user/hadoop/imdb/title_basics  
hadoop fs -mkdir /user/hadoop/imdb/title_ratings
```

```
hadoop fs -put title.basics.tsv /user/hadoop/imdb/title_basics/title.basics.tsv  
hadoop fs -put title.ratings.tsv /user/hadoop/imdb/title_ratings/title.ratings.tsv
```



PySpark Operations

1. Initialize Spark Session:

```
In [1]: # Import Spark Libraries
import findspark, os
findspark.init('/home/hadoop/spark')
from pyspark.sql import SparkSession

# Initialize Spark Session
spark = SparkSession.builder \
    .master("yarn") \
    .appName("Jupyter/PySpark Exercises") \
    .enableHiveSupport() \
    .getOrCreate()
```

The screenshot shows the Hadoop YARN web interface with the title "RUNNING Applications". On the left, there's a sidebar with cluster metrics and a scheduler metrics section. The main area displays a table of running applications. One application is listed:

ID	User	Name	Application Type	Queue	Application Priority	StartTime	FinishTime	State	FinalStatus	Running Containers	Allocated CPU Vcores	Allocated Memory MB	Reserved CPU Vcores	Reserved Memory MB	% of Queue	% of Cluster	Progress	Tracking UI	Blacklisted Nodes
application_1614532561077_0003	hadoop	Jupyter/PySpark Exercises	SPARK	default	0	Sun Feb 28 19:41:41 +0100 2021	N/A	RUNNING	UNDEFINED	3	3	5120	0	0	31.3	31.3	0	ApplicationMaster	0

https://github.com/marcelmittelstaedt/BigData/tree/master/exercises/winter_semester_2025-2026/04_spark_pyspark_jupyter/Exercises.html



PySpark Operations

2. Basic PySpark operations: Read Files from HDFS into DataFrames:

```
In [2]: # Read IMDb title basics CSV file from HDFS
df_title_basics = spark.read \
    .format('csv') \
    .options(header='true', delimiter='\t', nullValue='null', inferSchema='true') \
    .load('/user/hadoop/imdb/title_basics/title.basics.tsv')

In [3]: # Print Schema of DataFrame
df_title_basics.printSchema()

root
 |-- tconst: string (nullable = true)
 |-- titleType: string (nullable = true)
 |-- primaryTitle: string (nullable = true)
 |-- originalTitle: string (nullable = true)
 |-- isAdult: string (nullable = true)
 |-- startYear: string (nullable = true)
 |-- endYear: string (nullable = true)
 |-- runtimeMinutes: string (nullable = true)
 |-- genres: string (nullable = true)

In [4]: # Print First 3 Rows of DataFrame Data
df_title_basics.show(3)

+-----+-----+-----+-----+-----+-----+
| tconst|titleType| primaryTitle| originalTitle|isAdult|startYear|endYear|runtimeMinutes|
+-----+-----+-----+-----+-----+-----+
| tt0000001| short| Carmencita| Carmencita| 0| 1894| \N| 1| Documentar
y,Short|
| tt0000002| short| Le clown et ses c...|Le clown et ses c...| 0| 1892| \N| 5| Animatio
n,Short|
| tt0000003| short| Pauvre Pierrot| Pauvre Pierrot| 0| 1892| \N| 4| Animation,Com
edy,...|
+-----+-----+-----+-----+-----+-----+
only showing top 3 rows
```

https://github.com/marcelmittelstaedt/BigData/tree/master/exercises/winter_semester_2025-2026/04_spark_pyspark_jupyter/Exercises.htmlq



PySpark Operations

3. Basic PySpark: Operations on DataFrames (aggregations...):

```
In [5]: # Get Number of Rows of a DataFrame  
df_title_basics.count()
```

```
Out[5]: 7656314
```

```
In [6]: # Groups and Counts: Get column titleTypes values with counts and ordered descending  
from pyspark.sql.functions import desc  
df_title_basics \  
    .groupby("titleType") \  
    .count() \  
    .orderBy(desc("count")) \  
    .show()
```

titleType	count
tvEpisode	5556805
short	796470
movie	569437
video	296405
tvSeries	202321
tvMovie	130185
tvMiniSeries	36080
tvSpecial	31590
videoGame	27416
tvShort	9602
audiobook	1
episode	1
radioSeries	1

```
In [7]: # Calculate average Movie length in minutes
```

```
from pyspark.sql.functions import avg, col  
df_title_basics \  
    .where(col('titleType') == 'movie') \  
    .agg(avg('runtimeMinutes')) \  
    .show()
```

avg(runtimeMinutes)
89.62651045204976



PySpark Operations

4. Basic PySpark: Save PySpark DataFrame back to HDFS (as partitioned parquet files):

```
In [8]: # Save Dataframe back to HDFS (partitioned) as Parquet files
df_title_basics.repartition('startYear').write \
    .format("parquet") \
    .mode("overwrite") \
    .partitionBy('startYear') \
    .save('/user/hadoop/imdb/title_basics_partitioned_files')
```

/user/hadoop/imdb/title_basics_partitioned_files									Go!			
Show 25 entries									Search:			
<input type="checkbox"/>	Permission	Owner	Group	Size	Last Modified	Replication	Block Size	Name				
<input type="checkbox"/>	drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:53	0	0 B	startYear=2005				
<input type="checkbox"/>	drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:53	0	0 B	startYear=2006				
<input type="checkbox"/>	drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:53	0	0 B	startYear=2007				
<input type="checkbox"/>	drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:53	0	0 B	startYear=2008				
<input type="checkbox"/>	drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:53	0	0 B	startYear=2009				
<input type="checkbox"/>	drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:53	0	0 B	startYear=2010				
<input type="checkbox"/>	drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:53	0	0 B	startYear=2011				

PySpark Operations

5. Basic PySpark: Save PySpark DataFrame back to HDFS (as table and partitioned parquet files):

```
In [9]: # Save Dataframe back to HDFS (partitioned) as EXTERNAL TABLE and Parquet files
df_title_basics.repartition('startYear').write \
    .format("parquet") \
    .mode("overwrite") \
    .option('path', '/user/hadoop/imdb/title_basics_partitioned_table') \
    .partitionBy('startYear') \
    .saveAsTable('default.title_basics_partitioned')
```

/user/hadoop/imdb/title_basics_partitioned_table							
Show 25 entries							
Permission	Owner	Group	Size	Last Modified	Replication	Block Size	Name
drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:54	0	0 B	startYear=2006
drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:54	0	0 B	startYear=2007
drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:54	0	0 B	startYear=2008
drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:54	0	0 B	startYear=2009
drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:54	0	0 B	startYear=2010
drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:54	0	0 B	startYear=2011
drwxr-xr-x	hadoop	supergroup	0 B	Feb 28 19:54	0	0 B	startYear=2012

```
In [10]: spark.sql('SHOW TABLES').show(10, False)
```

database	tableName	isTemporary
default	title_basics_partitioned	false

PySpark Operations

6. Basic PySpark: Interact with Spark Tables (using plain Spark SQL):

```
In [12]: # Read External Spark table using plain Spark SQL
df = spark.sql('SELECT tconst, primaryTitle, startYear FROM default.title_basics_partitioned WHERE startYear = 2020')
# Print Result
df.show(3)
```

tconst	primaryTitle	startYear
tt0060366	A Embalagem de Vidro	2020
tt0062336	El Tango del Viud...	2020
tt0065392	Bucharest Memories	2020

only showing top 3 rows



7. Basic PySpark: Interact with Spark Tables (using Spark programmatically):

```
In [11]: # Read External Spark table in programmatical way
df = spark.table('default.title_basics_partitioned') \
    .where(col('startYear') == '2020') \
    .select('tconst', 'primaryTitle', 'startYear')
# Print Result
df.show(3)
```

tconst	primaryTitle	startYear
tt0060366	A Embalagem de Vidro	2020
tt0062336	El Tango del Viud...	2020
tt0065392	Bucharest Memories	2020

only showing top 3 rows

PySpark Operations

8. PySpark SQL: Join Spark DataFrames:

```
In [13]: # Read title.ratings.tsv into Spark dataframe
df_title_ratings = spark.read \
    .format('csv') \
    .options(header='true', delimiter='\t', nullValue='null', inferSchema='true') \
    .load('/user/hadoop/imdb/title_ratings/title.ratings.tsv')

In [14]: # Print Schema of title_ratings dataframe
df_title_ratings.printSchema()

root
 |-- tconst: string (nullable = true)
 |-- averageRating: double (nullable = true)
 |-- numVotes: integer (nullable = true)

In [15]: # Show first 3 rows of title_ratings dataframe
df_title_ratings.show(3)

+-----+-----+-----+
| tconst|averageRating|numVotes|
+-----+-----+-----+
|tt0000001|      5.7|     1685|
|tt0000002|      6.0|      208|
|tt0000003|      6.5|     1425|
+-----+-----+-----+
only showing top 3 rows
```

PySpark Operations

9. Basic PySpark: Filtering, Ordering and Selecting: Get Top 5 TV Series

```
In [19]: top_tvseries = joined_df \
    .where(col('titleType') == 'tvSeries') \
    .where(col('numVotes') > 200000) \
    .orderBy(desc('averageRating')) \
    .select('originalTitle', 'startYear', 'endYear', 'averageRating', 'numVotes')

# Print Top 5 TV Series
top_tvseries.show(5)

+-----+-----+-----+-----+
| originalTitle|startYear|endYear|averageRating|numVotes|
+-----+-----+-----+-----+
|      Breaking Bad|     2008|    2013|         9.5| 1470997|
|        The Wire|     2002|    2008|         9.3| 286432|
| Game of Thrones|     2011|    2019|         9.3| 1775327|
|   Rick and Morty|     2013|       \N|         9.2| 377428|
| Avatar: The Last ...|     2005|    2008|         9.2| 249236|
+-----+-----+-----+-----+
only showing top 5 rows
```



PySpark Operations

10. Basic PySpark: Add/Calculate Columns:

```
In [20]: from pyspark.sql.functions import when, lit

# Add a calculated column: classify movies as being either 'good' or 'worse' based on average rating
df_with_classification = joined_df \
    .withColumn('classification',
                when(col('averageRating') > 8, lit('good')) \
                .otherwise(lit('worse'))) \
    .select('primaryTitle', 'startYear', 'averageRating', 'classification')

# Print Result
df_with_classification.show(3, False)

+-----+-----+-----+-----+
|primaryTitle      |startYear|averageRating|classification|
+-----+-----+-----+-----+
|The Puppet's Nightmare|1908     |6.4          |worse        |
|The Lighthouse Keeper|1911     |7.1          |worse        |
|Home Folks          |1912     |3.7          |worse        |
+-----+-----+-----+-----+
only showing top 3 rows
```



PySpark Operations

11. Basic PySpark/Python: Plot Data:

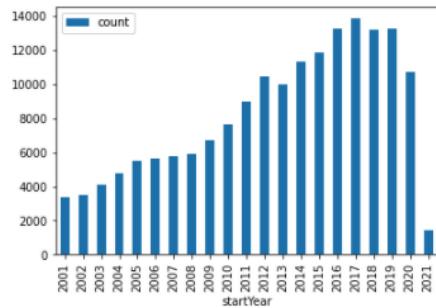
```
In [21]: # Plot data: good movies per year
import matplotlib.pyplot as plt
import pandas

# Create DataFrame to be plotted
good_movies = df_with_classification \
    .select('startYear', 'classification') \
    .where(col('classification') == 'good') \
    .where(col('startYear') > 2000) \
    .groupBy('startYear') \
    .count() \
    .sort(col('startYear').asc())

# Convert Spark DataFrame to Pandas DataFrame
pandas_df = good_movies.toPandas()

# Plot DataFrame
pandas_df.plot.bar(x='startYear', y='count')

Out[21]: <AxesSubplot:xlabel='startYear'>
```



TIME FOR
A
BREAK



Exercises

Use PySpark Shell or Jupyter Notebooks on
PySpark to solve exercises



PySpark Exercises - IMDB

1. Execute Tasks of previous HandsOn Slides
2. Create External Spark Table `title_ratings` on HDFS containing data of IMDb file `title.ratings.tsv`
3. Create External Spark Table `name_basics` on HDFS containing data of IMDb file `name.basics.tsv`
4. Use PySpark to answer following questions:
 - a) How many **movies** and how many **TV series** are within the IMDB dataset?
 - b) Who is the **youngest** actor/writer/... within the dataset?



PySpark Exercises - IMDB

4. Use PySpark to answer following questions:

- c) Create a list (`tconst`, `original_title`, `start_year`,
`average_rating`, `num_votes`) of movies which are:
 - equal or newer than year 2010
 - have an average rating equal or better than 8,1
 - have been voted more than 100.000 times

- d) Save result of c) as external Spark Table to HDFS.?

5. Create a Spark Table `name_basics_partitioned`, which:

- contains all columns of table `name_basics`
- is partitioned by column `partition_is_alive`, containing:
 - „alive“ in case actor is still alive
 - „dead“ in case actor is already dead



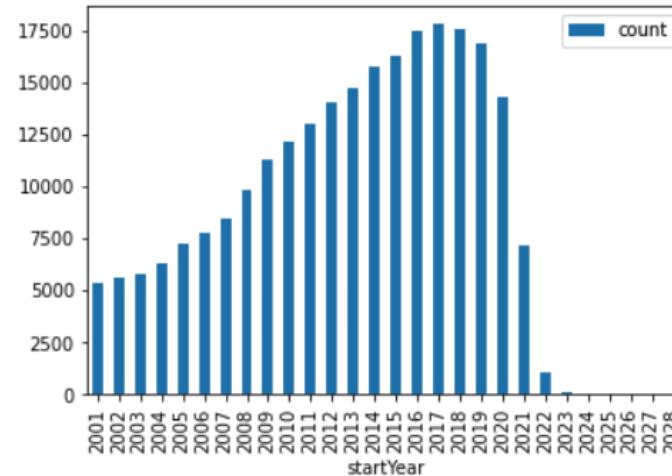
PySpark Exercises - IMDB

6. Create a partitioned Spark table `imdb_movies_and_ratings_partitioned`, which:

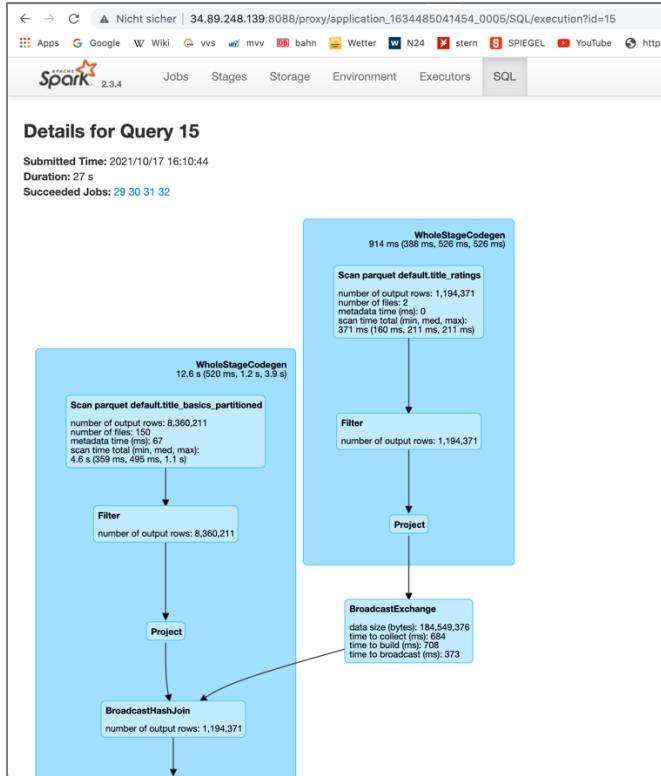
- contains all columns of the two tables `title_basics_partitioned` and `title_ratings` and
- is partitioned by start year of movie (create and add column `partition_year`).

7. Create following plot, which visualizes:

- the amount of movies (type!)
- per year
- since 2000



Let's not forget Spark UI!



Nicht sicher | 34.89.248.139:8088/proxy/application_1634485041454_0005/jobs/

Apache Spark 2.3.4 Jobs Stages Storage Environment Executors SQL

Spark Jobs (?)

User: hadoop
Total Uptime: 16 min
Scheduling Mode: FIFO
Completed Jobs: 37

Event Timeline

Completed Jobs (37)

Job Id	Description	Submitted	Duration	Stages: Succeeded/Total	Tasks (for all stages): Succeeded/Total
36	toPandas at <ipython-input-12-e0d98ead4724>:19	2021/10/17 16:11:14	1 s	2/2 (1 skipped)	228/228 (3 skipped)
35	toPandas at <ipython-input-12-e0d98ead4724>:19	2021/10/17 16:11:13	2 s	2/2	203/203
34	showString at NativeMethodAccesso...impl.java:0	2021/10/17 16:11:12	65 ms	1/1	1/1
33	Listing leaf files and directories for 144 paths: hdfs://hadoop:9000/user/hadoop/mdb/mdb_movies_and_ratings_partitioned_table/partition_year=%5CN, ...	2021/10/17 16:11:11	0.8 s	1/1	144/144
32	saveAsTable at NativeMethodAccesso...impl.java:0	2021/10/17 16:11:09	0.1 s	1/1	2/2
31	Listing leaf files and directories for 144 paths: hdfs://hadoop:9000/user/hadoop/mdb/mdb_movies_and_ratings_partitioned_table/partition_year=%5CN, ...	2021/10/17 16:11:08	1.0 s	1/1	144/144
30	saveAsTable at NativeMethodAccesso...impl.java:0	2021/10/17 16:10:45	22 s	2/2	207/207
29	run at ThreadPoolExecutor.java:1149	2021/10/17 16:10:44	0.6 s	1/1	2/2
28	showString at NativeMethodAccesso...impl.java:0	2021/10/17 16:10:15	1 s	1/1	2/2
27	showString at NativeMethodAccesso...impl.java:0	2021/10/17 16:10:14	1 s	1/1	1/1
26	saveAsTable at NativeMethodAccesso...impl.java:0	2021/10/17 16:09:23	50 s	2/2	204/204
25	showString at NativeMethodAccesso...impl.java:0	2021/10/17 16:09:11	0.1 s	1/1	1/1



Stop Your VM Instances

**DON'T FORGET TO
STOP YOUR VM
INSTANCE!**



```
gcloud compute instances stop big-data
```



Well Done

WE'RE DONE
FOR
...TODAY

