Introduction to Hadoop and Ecosystems

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Slides credits: Cloudera Academic Partners Program

Goals

- The goal of this section is to give you a basic understanding of Hadoop's core components (HDFS and MapReduce) and ecosystem
- In this section, you will learn
  - Which factors led to the era of Big Data
  - What Hadoop is and what significant features it provides
  - How does it offer reliable storage for massive amounts of data with HDFS
  - How does it support large scale data processing through MapReduce
  - What are the new capabilities introduced by YARN?
  - How can Hadoop Ecosystem tools boost an analyst's productivity

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Topics

- The Motivation For Hadoop
- Hadoop Overview
- HDFS
- MapReduce
- The Hadoop Ecosystem

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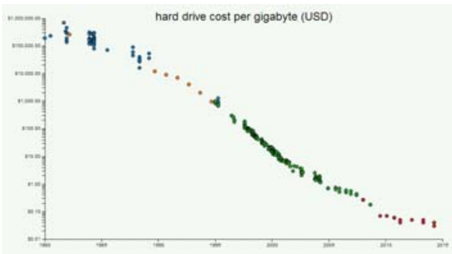
Cost of Data Storage



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Traditional storing big data is prohibitively expensive

- How has industry typically dealt with these problem?
  - Perform an ETL (Extract, Transform, Load) on the data to summarize the data, before archiving the result in a data warehouse
    - Discarding the details
  - Run queries against the summary data
- Unfortunately, this process often resulted in lost detail
  - But there could be real nuggets in the lost detail
  - More data == Deeper understanding
    - "There's no data like more data" (Moore 2001)
    - "It's not who has the best algorithms that wins. It's who has the most data"

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Now we can store data cheaply

- But we're having too much data to process with traditional tools
- Two key problems to address
  - How can we reliably store large amounts of data at a reasonable cost?
    - Hardware failures
  - How can we analyze all the data we have stored?
    - Time needed to read the data into memory for analysis
- Hadoop provides reliable distributed storage, and a general framework for parallel processing at low cost.

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- The Motivation For Hadoop
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- MapReduce
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What Is Apache Hadoop?

- A system for providing scalable, economical data storage and processing.
- 'Core' Hadoop consists of two main components
  - Storage: The Hadoop Distributed File System (HDFS)
    - A framework for distributing data across a cluster in ways that are scalable, reliable, available, fast, and economical
  - Processing: MapReduce
    - A framework for processing data in ways that are scalable, reliable, available, and fast
  - Plus the infrastructure needed to make them work, including
    - Filesystem and administration utilities
    - Job scheduling and monitoring

Where Did Hadoop Come From?

- Started with research that originated at Google back in 2003
  - Google's objective was to index the entire World Wide Web
  - Google had reached the limits of scalability of RDBMS technology
  - This research led to a new approach to store and analyze large quantities of data
    - Google File Systems (Ghemawat, et al 2003)
    - MapReduce: Simplified Data Processing on Large Clusters (Dean and Ghemawat 2004)
- A developer by the name of Doug Cutting was wrestling with many of the same problems in the implementation of his own open-source search engine, Lucene
  - He started an open-source project based on Google's research and created Hadoop in 2005.
  - Hadoop was named after his son's toy elephant.

More @ White 2015: A brief history of Apache Hadoop, pp12-14

Hadoop Cluster and Scalability

- Hadoop is a distributed system
  - A collection of servers running Hadoop software is called a **cluster**
- Individual servers within a cluster are called **nodes**
  - Typically standard rack-mount servers running Linux
  - Each node both stores and processes data
    - Called "data locality"
- Add more nodes to the cluster to increase scalability
  - Facebook and Yahoo are each running clusters in excess of 4400 nodes
  - Scalability is linear
  - Horizontal scaling simplifies capacity planning as well
    - **Horizontal scaling**: scale by adding more machines to the pool of resources
    - **Vertical scaling**: scale by adding more power CPU/RAM to an existing machine

Powerful Hadoop clusters can be built from cheap commodity hardware, resulting in lowered cost!

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Fault Tolerance

- Paradox: adding nodes increases chances that any one of them will fail
  - Solution: build redundancy into the system and handle it automatically.
- Files loaded into HDFS are replicated across nodes in the cluster
  - If a node fails, its data is re-replicated using one of the other copies
- Data processing jobs are broken into individual tasks
  - Each task takes a small amount of data as input
  - Thousands of tasks (or more) often run in parallel
  - If a node fails during processing, its tasks are rescheduled elsewhere
- Routine failures are handled automatically without any loss of data
  - Developers/Users do not need to worry about hardware failures

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Review Question

- Advantages of a Hadoop system

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Topics

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HDFS: Hadoop Distributed File System

- Provides inexpensive and reliable storage for massive amounts of data
  - Optimized for a relatively small number of large files
    - Each file likely to exceed 100 MB, multi-gigabyte files are common
  - Store file in hierarchical directory structure
    - e.g. , `/sales/reports/asia.txt`
  - Cannot modify files once written
    - Need to make changes? remove and recreate
  - Use Hadoop specific utilities to access HDFS

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HDFS and Unix File System*

- In some ways, HDFS is similar to a UNIX filesystem
  - Hierarchical, with UNIX/style paths (e.g. `/sales/reports/asia.txt`)
  - UNIX/style file ownership and permissions
- There are also some major deviations from UNIX
  - No concept of a current directory
  - Cannot modify files once written
    - You can delete them and recreate them, but you can't modify them
  - Must use Hadoop specific utilities or custom code to access HDFS

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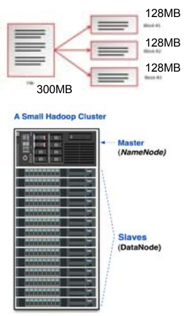
HDFS Architecture (1 Of 3)

- **Blocks**: HDFS files are broken into blocks, a smallest unit for read and write. HDFS uses128 MB blocks by default (Windows default block size is 4 KB).
  - Each block is replicated multiple times and stored in different nodes of the cluster
- An HDFS cluster has a master/slave architecture
- HDFS NameNode (one or two)
  - Manages namespace (file to block mappings) and metadata (block to machine mappings).
  - Monitors dataNodes
- HDFS DataNodes (many)
  - Reads and writes the actual data



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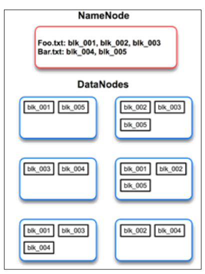
HDFS Architecture (2 Of 3)

- Example:
  - The NameNode holds metadata for the two files
    - Foo.txt (300MB) and Bar.txt (200MB)
    - Assume HDFS is configured for 128MB blocks
  - The DataNodes hold the actual blocks
    - Each block is 128MB in size
    - Each block is replicated three times on the cluster
    - Block reports are periodically sent to the NameNode



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HDFS Architecture (3 Of 3)

- Optimal for handling millions of large files, rather than billions of small files, because:
  - In pursuit of responsiveness, the NameNode stores all of its file/block information in memory
    - A rule of thumb is each block/directory/file takes about 150 bytes
    - A name node can handle millions of objects, but not billions
    - Too many files will cause the NameNode to run out of memory
    - Too many blocks (if the blocks are small) will also cause the NameNode to run out of memory
  - A Java Virtual Machine (JVM) is required to process a block; if you have too many blocks, you will need many JVMs at the same time, and you will begin to see the limits of HDFS scalability.

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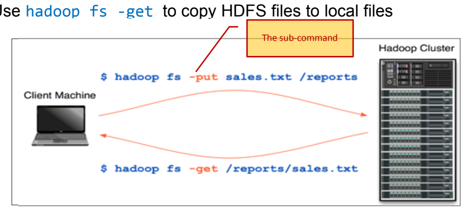
Copying Local Data To And From HDFS

- Remember that HDFS is separated from your local filesystem
  - Use `hadoop fs -put` to copy local files to HDFS
  - Use `hadoop fs -get` to copy HDFS files to local files



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Review Question

- HDFS Design

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Introducing MapReduce

- Now that we have described how Hadoop stores data, lets turn our attention to how it processes data
- We typically process data in Hadoop using MapReduce
- MapReduce is not a language, it's a programming model
- MapReduce consists of two functions: map and reduce
- Before MapReduce, coordinating the processes in a large-scale distributed computation is a challenge.
  - MapReduce spare the programmer from having to think about failure, since the implementation detects failed tasks and reschedules replacements on machines that are healthy.
  - MapReduce follows **shared-nothing** architecture, meaning that tasks **have no dependence** on one other. MapReduce programmers need not worry about order in which tasks run. By contrast, other distributed computing models often require programmers to explicitly manage their own checkpointing and recovery.

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Map function

- The map function always runs first
  - Each mapper takes <key, value> pairs as input, one pair at a time
  - Many mappers run in parallel to each other, each assigned to a chunk of the input data.
  - For each input pair, a mapper emits a list of output pairs.
    - `(key, value) → list(key, value)`
    - `E.g. "fox jumps over" --> ("fox",1),("jumps",1),("over",1)`
    - `"fox jumps over" --> ("FOX JUMPS OVER")`
  - Typically used to "break down"
    - Filter, transform, or parse data,
    - e.g. Parse the stock symbol, price and time from a data feed
    - Break a sentence into words
  - The output from the map function (eventually) becomes the input to the reduce function

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Reduce function

- The reduce function takes a list of values for every key, and transforms the data on the (aggregation) logic provided in the reduce function
  - It takes a <key, value-list> pair as input, and emits a list of <key, value> pairs as output
    `(Key, List of values for the key) --> List(Key, Value)`
  - `E.g. ("jumps",(1,1,2,1,1)) --> ("jumps",6)`
  - Each job may have multiple reducers, each responsible for a specific key range.
  - Typically used to aggregate data from the map function
    - e.g. Compute the average hourly price of the stock
  - A reduce step is optional
    - You can run something called a "map-only" job
- Between map and reduce, there is typically a hidden phase known as the "Shuffle and Sort" which organizes map outputs for delivery to the reducer.

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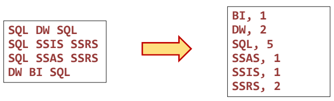
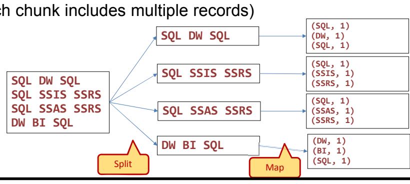
A MapReduce Example

- The following slides will explain an entire MapReduce job
  - Input: a text document (a list of sentences)
  - Output: word counts



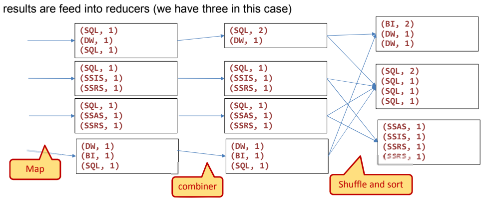
A MapReduce Example – Split and Map

- Hadoop splits a job into many individual map tasks
  - The number of map tasks is determined by the amount of input data
  - Each map task receives a portion of the overall job input to process in parallel
  - In this case, there are 4 mappers, each processing one chunk (in practice, each chunk includes multiple records)



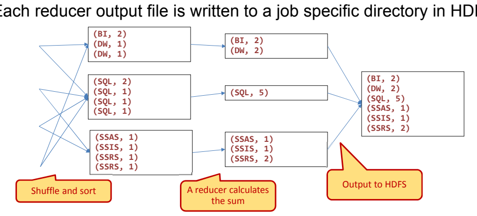
A MapReduce Example – Shuffle & Sort

- Map outputs are shuffled and sorted by key
  - Sometimes a combiner is run to before shuffle and sort to reduce the amount of data transferred across the network
    - There may not be a combiner for certain aggregate operations
    - E.g. there are combiners for sum and max. but there is no combiner for average.
  - Shuffle and sort is implicit and carried out by the MapReduce framework.
  - It results are feed into reducers (we have three in this case)

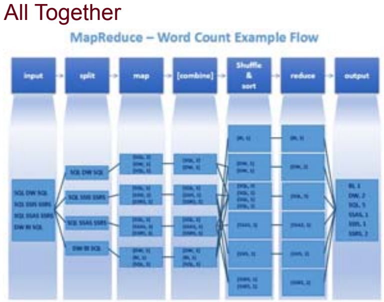


A MapReduce Example – Reduce

- Reducer input comes from the shuffle and sort process
  - All value for the same key is collected and feed into a reducer
  - The reducers aggregates the values and emit a key value pair
  - Each reducer output file is written to a job specific directory in HDFS



Putting It All Together



Note: we used 6 reducers here, but 3 in the step-wise example

Group Exercise: MapReduce

- In groups of 3-4 (preferably from different organizations)
  - Work out the following example using pence & paper.
- **Input**: a file consists of order ID, employee name, and sales amount, separated by spaces

```
0 Alice 5
1 Bob 4
2 Alice 3
3 Alice 9
4 Diana 1
5 Bob 9
```

Hands On

Paper & pencil approach to MapReduce

- **Desired output**: sum of sales by employees.
  - Following the word count example to draw the steps of a MapReduce work flow (assuming two mappers/reducers)

Benefits of MapReduce

- Simplicity (via fault tolerance)
  - Particularly when compared with other distributed programming models
- Flexibility
  - Offers more analytic capabilities and works with more data types than platforms like SQL (key, value pairs can accommodate different kinds of structured and unstructured data)
- Scalability
  - Because it works with
    - Small quantities of data at a time
    - Running in parallel across a cluster
    - Sharing nothing among the participating nodes

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Review Question

- The role of MapReduce ☆
- The Benefits of MapReduce ☆

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Hadoop 2.0

- So far we have focused original ideas of Hadoop
  - It has batch processing in mind
  - It supports only MapReduce applications, which has too high a latency for interactive and streaming applications.
- Since then, many improvements have been made to the Hadoop, including
  - YARN (**Y**et **A**nother **R**esource **N**egotiator)
  - The ability to run non MapReduce applications (e.g. support Spark)
  - Beyond batch processing: the ability to support interactive and streaming applications.

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YARN

- YARN (**Y**et **A**nother **R**esource **N**egotiator) is a new component added in Hadoop 2.0
  - In Hadoop 1.0, MapReduce does both distributed computing and resource management (via jobtracker)
    - Limits availability, scalability, resource utilization, and running non-MapReduce applications. If the job tracker fails, all jobs must restart.
  - YARN takes over the resource management (CPU, memory etc) and job scheduling, allows multiple kinds of processing to run on a single Hadoop cluster (e.g. batch processing, interactive application, streaming)

Read more: http://saphanatutorial.com/how-yarn-overcomes-mapreduce-limitations-in-hadoop-2-0/

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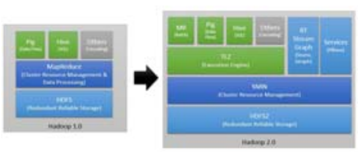
Hadoop 2.0 Architecture

- Separate MapReduce into a YARN layer and MR (for batch processing)
- Support non-MapReduce applications, e.g. streaming and interactive applications (e.g. Impala, Spark, Storm, HBase, Giraph etc)
- Improved nameNode availability



Read more: http://saphanatutorial.com/hadoop-1-0-vs-hadoop-2-0/

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Review Qustion

- Hadoop 2.0 improvements

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- The Hadoop Ecosystem

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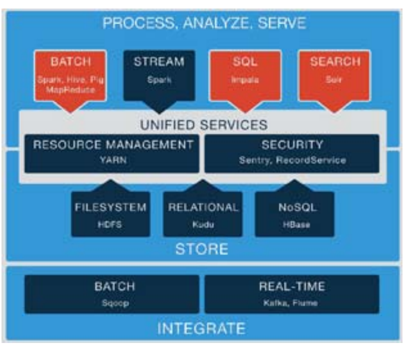

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Data Storage

- **Hadoop Distributed File System (HDFS)**
  - HDFS is the storage layer for Hadoop
  - Provides inexpensive reliable storage for massive amounts of data on commodity hardware
  - Data is distributed when stored
- **Apache HBase**
  - A NoSQL distributed database built on HDFS
  - Scales to support very large amounts of data
  - High throughput
  - A table can have many thousands of columns & billions of rows
  - No high-level query language, API access only.

Apache Kudu

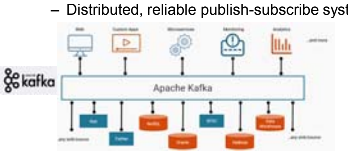
- Distributed columnar (key-value) storage for structured data
- Allows random access and updating data (unlike HDFS)
- Supports **SQL**-based analytics
- Works directly on native file system; is not built on HDFS
- Integrates with Spark, MapReduce, and Apache Impala
- Created at Cloudera, donated to Apache Software Foundation

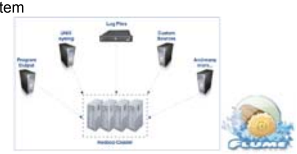
Data Integration Tools (1)

- **HDFS**
  - Direct file transfer
- **Apache Sqoop**
  - High speed import for HDFS from RDBMS (and vice versa)
  - Supports many RDBMS:
    - E.g. Oracle, Teradata, MySQL, MongoDB, Netezza

Data Integration Tools (2)

- **Apache Kafka**
  - A high throughput, scalable **messaging** system https://kafka.apache.org/powered-by
  - Distributed, reliable publish-subscribe system





- **Apache Flume**
  - Distributed service for ingesting streaming data
  - Ideally suited for **event data** from multiple systems

Batch Processing Tools (1 of 4)

- **Hadoop MapReduce** is the original Hadoop framework
  - Primarily Java based
  - Was the core Hadoop processing engine
  - Has mature fault tolerance built into the framework
  - But quickly losing ground to Spark and other engines

```
map(String name, String contents):
    for each word w in contents:
        if (IsCapitalized(w)):
            uppercase->Increment();
        EmitIntermediate(w, "1");
```

Batch Processing Tools (2 of 4)

- **Apache Pig** builds on Hadoop to offer high-level data processing
  - An alternative to write low-level MapReduce code
  - Useful for ETL (extract, transformation, and loading)
  - Used by developers and analysts
- Pig Interpreter
  - Turns Pig Latin scripts into MapReduce (or Spark) Jobs
  - Submits those jobs to a Hadoop cluster

```
people = LOAD '/user/training/customers' AS (cust_id, name);
orders = LOAD '/user/training/orders' AS (ord_id, cust_id, cost);
groups = GROUP orders BY cust_id;
totals = FOREACH groups GENERATE group, SUM(orders.cost) AS t;
result = JOIN totals BY group, people BY cust_id;
DUMP result;
```

Batch Processing Tools (3 of 4)

- **Apache Hive** is the data warehouse application for Hadoop.
  - Uses a SQL-like language called HiveQL
  - Useful for managing and querying large tables in Hadoop
  - Translate SQL to MapReduce jobs

```
  SELECT  zipcode, SUM(cost) AS total
    FROM  customers
    JOIN  orders
      ON  customers.cust_id = orders.cust_id
   WHERE  zipcode LIKE '63'
GROUP BY  zipcode
ORDER BY  total DESC;
```

Batch Processing Tools (4 of 4)

- **Spark:** Spark is a fast large-scale in-memory processing engine
  - – Interface with YARN clusters and HDFS, and many other storage options
  - – Highly popular, is overtaking Hadoop
  - – Has core spark and four components
    - SQL, Streaming, Mllib, GraphX
- **Spark SQL** – for SQL operations; not a SQL engine but flexible for SQL based data munging.

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Interactive Query Tools (1 of 2)

- **Apache Impala** is a high-performance, interactive SQL engine
  - – Very low latency – measured in milliseconds
  - – Run on Hadoop clusters
  - – Supports a dialect of SQL (Impala SQL)

```
 SELECT  zipcode, SUM(cost) AS total
    FROM  customers
    JOIN  orders
      ON  customers.cust_id = orders.cust_id
   WHERE  zipcode LIKE '63'
GROUP BY  zipcode
ORDER BY  total DESC;
```

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Interactive Query Tools (2 of 2)

- **Apache Drill** is a high performance SQL engine that can query a variety of structured, semi-structured data formats
  - – Uses Standard ANSI SQL
  - – Query semi-structured data formats and sources, e.g. HDFS, HBase, JSON, MongoDB, Amazon S3.
  - – High performance, scalable.

```
SELECT * FROM dfs.root.`/web/logs`;

SELECT country, count(*)
  FROM mongodb.web.users
  GROUP BY country;

SELECT timestamp
  FROM s3.root.`clicks.json`
  WHERE user_id = 'jdoe';
```

Machine Learning

- **Apache Mahout** is a machine learning (ML) software for Hadoop
  - It provides a host of pre-made ML algorithms
  - Recently undergone big changes to provide a R-like programming environment
- **Apache Spark MLlib**: a Machine Learning component of spark
- **H2O**: in-memory, distributed, fast, and scalable machine learning platform; can be used from R, Python, Scala.
- **H2O/Sparkling Water**: Combine H2O with Spark

Streaming

- **Apache Storm** is a distributed and fault-tolerance real-time computation platform
  - Horizontal scalability
  - Guaranteed data processing
  - Fault-tolerance
  - High-performance
- **Spark Streaming**: the streaming component of Apache Spark

Other Hadoop Ecosystem Tools

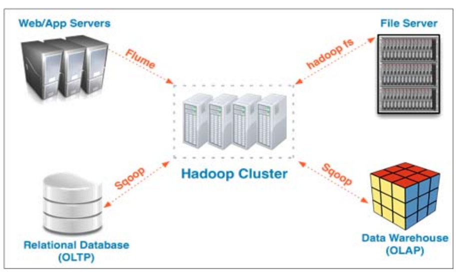
- **Apache Sentry**: Provides fine-grained access control for varous Hadoop ecosystem components.
- **Apache Zookeeper**: a distributed hierarchical key-value store for providing a distributed configuration service, synchronization service, and naming registry for large distributed systems.
- **Apache Ooozie**: A workflow engine that ensures jobs are submitted in the correct sequence.

Zookeeper

The Hadoop Ecosystem

- Data ingestion/integration:
- Storage:
- Batch processing:
- Interactive Processing: Impala, Drill
- Machine Learning:
- Streaming processing:

Data Center Integration



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Hadoop & Data Lake

- A **Data Lake** approach
  - The traditional **Data Mart /Data Warehouse** is a "*store of bottled water*"
  - The data lake is a "large body of water in a more nature state" (James Dixon, CTO of Pentaho)
  - Contents of the data lake stream in from a source to fill the lake, and various uses can examine, dive in, or take samples.
- **Hadoop** is an ideal platform for building a data lake
  - It provides for storing a mixture of structured and unstructured data, side by side.
  - It could be used to store far more detail about the transaction than you would in an ordinary RDBMS (due to costs limitations)

Source: data science central
Read more: Hester, L. 2016. "Maximizing Data Value with a Data Lake," *Data Science Central Blog*.

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Review Question

- Hadoop ecosystem tools ☆

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Bibliography

- The following offer more information on topics discussed in this section
  - Hadoop: The Definitive Guide, 4th Edition (**U of M Students have free access**)
    - https://goo.gl/4kQVSy
  - Guide to HDFS Commands
    - http://hadoop.apache.org/docs/stable/hadoop-project-dist/hadoop-common/FileSystemShell.html
  - Cloudera Version and Packaging Information (installed on our VM)
    - https://www.cloudera.com/documentation/enterprise/release-notes/topics/cdh_vd_cdh_package_tarball_510.html#tarball_510x

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