Lecture 09

Kafka, NoSQL, Cassandra

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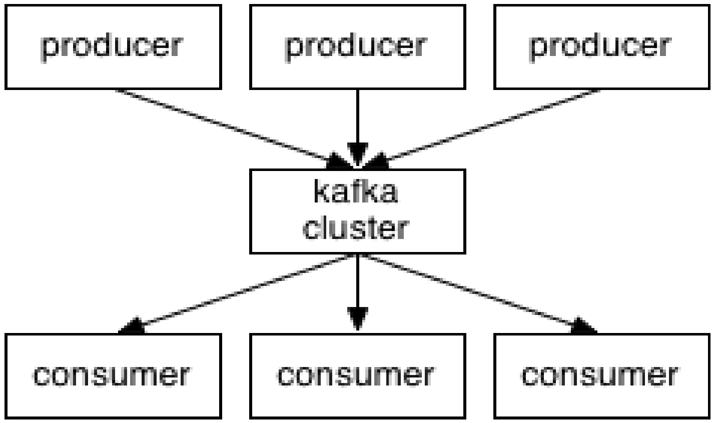
csci e63 Big Data Analytics

Kafka

Call in Kafka

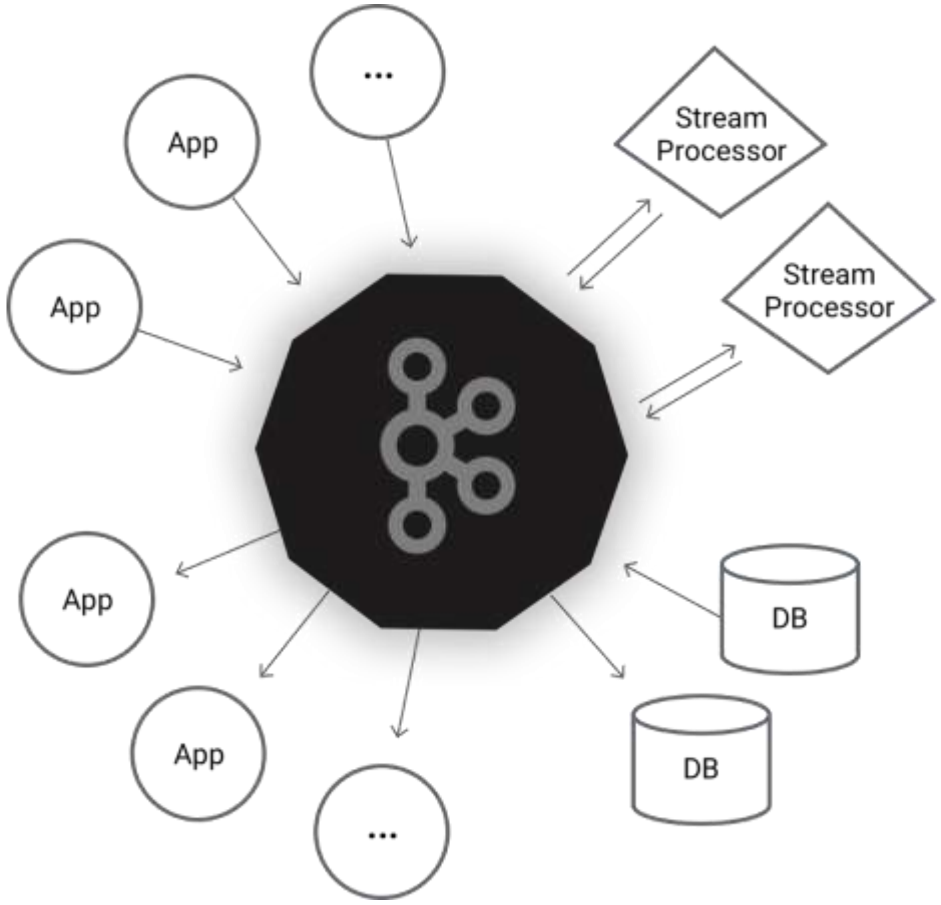
- Spark Streaming might have difficulties keeping up with incoming messages.
- Sometimes we need some kind of buffer, to keep messages in place, while Spark catches its breath. Apache Kafka provides that service.
- Kafka is a distributed, partitioned, replicated commit log service. It provides the functionality of a messaging system, but with a unique design.
- Kafka maintains feeds of messages in categories called *topics.*
- Processes that publish messages to a Kafka topic are called *producers.*
- Processes that subscribe to topics and process the feed of published messages are called *consumers.*
- Kafka is run as a cluster comprised of one or more servers each called a *broker*.
- If you need Kafka to process more messages you add machines in Kafka cluster.

- For several Kafka machines (processes, servers) to run in coordination, we need a "Cluster coordination software" called Zookeeper.
- Kafka could serve as:
  - Messaging system
  - Storage system
  - Stream processing system



Kafka

- Apache Kafka® is *a distributed streaming platform*.
- Streaming platform has three key capabilities:
  - It lets you publish and subscribe to streams of records. In this respect it is similar to a message queue or enterprise messaging system.
  - It lets you store streams of records in a fault-tolerant way.
  - It lets you process streams of records as they occur.
- What is Kafka good for?
  - Building real-time streaming data pipelines that reliably get data between systems or applications
  - Building real-time streaming applications that transform or react to the streams of data



Kafka Concepts & APIs

Kafka is run as a cluster on one or more servers.

- Kafka cluster stores streams of records in categories called topics.
- Each record consists of a key, a value, and a timestamp.
- In Kafka the communication between the clients and the servers is done with a simple, high-performance, TCP protocol.

Kafka has four core APIs:

- The Producer API allows an application to publish a stream of records to one or more Kafka topics.
- The Consumer API allows an application to subscribe to one or more topics and process the stream of records produced to them.
- The Streams API allows an application to act as a stream processor, consuming an input stream from one or more topics and producing an output stream to one or more output topics, effectively transforming the input streams to output streams.
- The Connector API allows building and running reusable producers or consumers that connect Kafka topics to existing applications or data systems. For example, a connector to a relational database might capture every change to a table.

Kafka as a Messaging System

- Messaging traditionally has two models: queuing and publish-subscribe.
- In a queue, a pool of consumers may read from a server and each record goes to one of them;
- In publish-subscribe the record is broadcast to all consumers.
- The strength of queuing is that it allows you to divide up the processing of data over multiple consumer instances, which lets you scale your processing. Unfortunately, queues aren't multi-subscriber—once one process reads the data it's gone.
- Publish-subscribe allows you broadcast data to multiple processes, but scales poorly since every message goes to every subscriber.
- The consumer group concept in Kafka generalizes these two concepts. As with a queue the consumer group allows you to divide up processing over a collection of processes (the members of the consumer group).
- As with publish-subscribe, Kafka allows you to broadcast messages to multiple consumer groups.
- The advantage of Kafka's model is that every topic has both these properties—it can scale processing and is also multi-subscriber—there is no need to choose one or the other.
- Kafka has stronger ordering guarantees than a traditional messaging system, too.
- A traditional queue retains records in-order on the server, and if multiple consumers consume from the queue then the server hands out records in the order they are stored. However, although the server hands out records in order, the records are delivered asynchronously to consumers, so they may arrive out of order on different consumers. This effectively means the ordering of the records is lost in the presence of parallel consumption.
- Kafka is able to provide both ordering guarantees and load balancing over a pool of consumer processes

Kafka as a Storage System

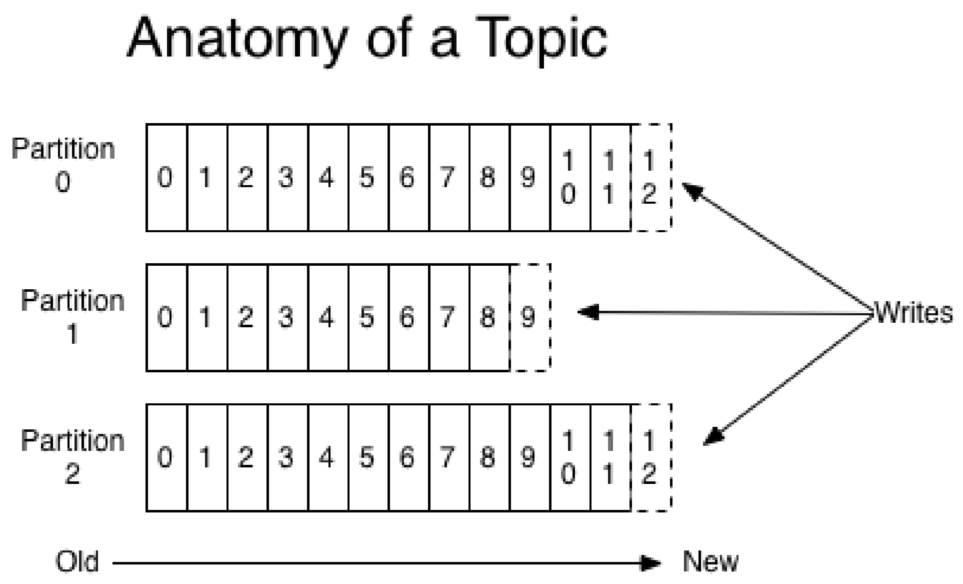
- Any message queue that allows publishing messages decoupled from consuming them is effectively acting as a storage system for the in-flight messages.
- Kafka is that it is a very good storage system.
- Data written to Kafka is written to disk and replicated for fault-tolerance.
- Kafka allows producers to wait on acknowledgement so that a write isn't considered complete until it is fully replicated and guaranteed to persist even if the server written to fails.
- The disk structures Kafka uses scale well—Kafka will perform the same whether you have 50 KB or 50 TB of persistent data on the server.
- As a result of taking storage seriously and allowing the clients to control their read position, you can think of Kafka as a kind of special purpose distributed filesystem dedicated to high-performance, low-latency commit log storage, replication, and propagation.

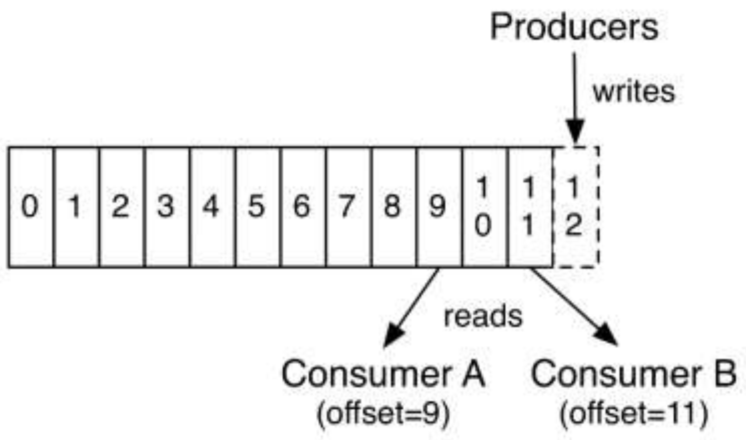
Kafka for Stream Processing

- Besides reading, writing, and storing streams of data, Kafka can perform real-time processing of streams.
- In Kafka a stream processor is anything that takes continual streams of data from input topics, performs some processing on this input, and produces continual streams of data to output topics.
- It is possible to do simple processing directly using the producer and consumer APIs. However for more complex transformations Kafka provides a fully integrated Streams API. This allows building applications that do non-trivial processing that compute aggregations off of streams or join streams together.
- This facility helps solve the hard problems this type of application faces: handling out-of-order data, reprocessing input as code changes, performing stateful computations, etc.
- The streams API builds on the core primitives Kafka provides: it uses the producer and consumer APIs for input, uses Kafka for stateful storage, and uses the same group mechanism for fault tolerance among the stream processor instances.

Kafka Topics and Logs

- A topic is a category or feed name to which records are published. Topics in Kafka are always multi-subscriber; that is, a topic can have zero, one, or many consumers that subscribe to the data written to it.
- For each topic, the Kafka cluster maintains a partitioned log that looks like this:





- Each partition is an ordered, immutable sequence of records that is continually appended to—a structured commit log. The records in the partitions are each assigned a sequential id number called the *offset* that uniquely identifies each record within the partition.

Retention Period

- The Kafka cluster retains all published records—whether or not they have been consumed—using a configurable retention period. For example, if the retention policy is set to two days, then for the two days after a record is published, it is available for consumption, after which it will be discarded to free up space. Kafka's performance is effectively constant with respect to data size so storing data for a long time is not a problem.
- In fact, the only metadata retained on a per-consumer basis is the offset or position of that consumer in the log. This offset is controlled by the consumer: normally a consumer will advance its offset linearly as it reads records, but, in fact, since the position is controlled by the consumer it can consume records in any order it likes. For example a consumer can reset to an older offset to reprocess data from the past or skip ahead to the most recent record and start consuming from "now".

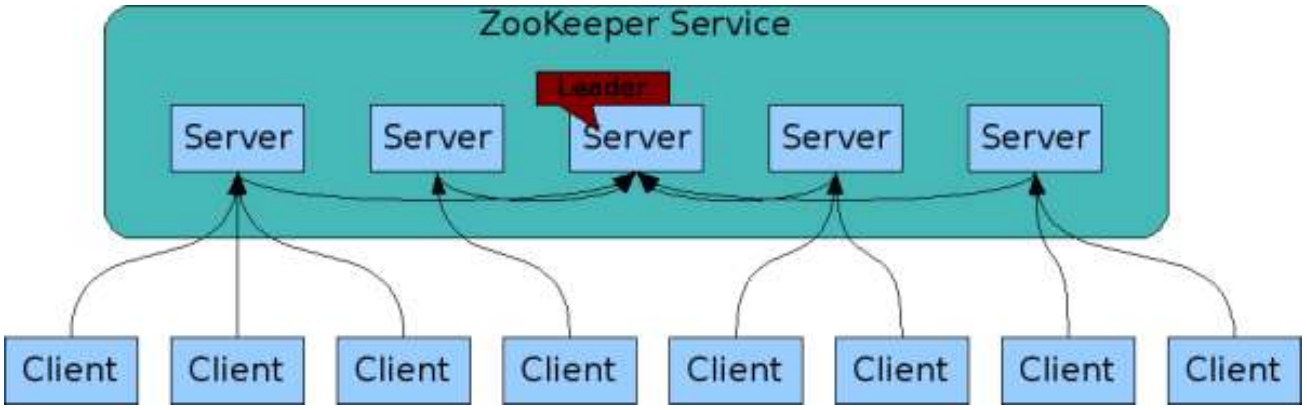
- This combination of features means that Kafka consumers are very cheap—they can come and go without much impact on the cluster or on other consumers. For example, you can use our command line tools to "tail" the contents of any topic without changing what is consumed by any existing consumers.
- The partitions in the log serve several purposes. First, they allow the log to scale beyond a size that will fit on a single server. Each individual partition must fit on the servers that host it, but a topic may have many partitions so it can handle an arbitrary amount of data.

Zookeper

- ZooKeeper is a high-performance coordination service for distributed applications. It exposes common services - such as naming, configuration management, synchronization, and group services - in a simple interface so you don't have to write them from scratch.
- We can use Zookeeper off-the-shelf to implement consensus, group management, leader election, and presence protocols.
- Many frameworks, like Kafka, are built to use Zookeeper.
- ZooKeeper allows distributed processes to coordinate with each other through a shared hierarchal namespace which is organized similarly to a standard file system. The name space consists of data registers - called znodes, in ZooKeeper parlance - and these are similar to files and directories. Unlike a typical file system, which is designed for storage, ZooKeeper data is kept in-memory, which means ZooKeeper can achieve high throughput and low latency numbers.
- The ZooKeeper implementation puts a premium on high performance, highly available, strictly ordered access. The performance aspects of ZooKeeper means it can be used in large, distributed systems. The reliability aspects keep it from being a single point of failure. The strict ordering means that sophisticated synchronization primitives can be implemented at the client.
- **ZooKeeper is replicated.** Like the distributed processes it coordinates, ZooKeeper itself is intended to be replicated over a sets of hosts called an ensemble.

Zookeeper

- The servers that make up the ZooKeeper service must all know about each other. They maintain an in-memory image of state, along with a transaction logs and snapshots in a persistent store. As long as a majority of the servers are available, the ZooKeeper service will be available.
- Clients connect to a single ZooKeeper server. The client maintains a TCP connection through which it sends requests, gets responses, gets watch events, and sends heart beats. If the TCP connection to the server breaks, the client will connect to a different server.
- **ZooKeeper is fast.** It is especially fast in "read-dominant" workloads. ZooKeeper applications run on thousands of machines, and it performs best where reads are more common than writes, at ratios of around 10:1.



What do you do with Zookeeper

- Usually nothing. You just start it.
- When dealing with Kafka examples or HDFS examples on a single machine, you do not have to do anything. You just make sure that Zookeeper is up and running.
- If running on a large cluster, you might have to install Zookeeper yourself.
- If you are using software that relies on Zookeeper that typically is all you do. Most frameworks that need Zookeeper install Zookeeper themselves.
- You will need to deal with Zookeeper APIs only if you are writing your own distributed application that needs to incorporate Zookeeper service.
- It appears that there is no real alternative to Zookeeper.

Install Kafka with `yum`

- On CentOS you can do the following, as well:

```
$ sudo yum install kafka
$ which kafka
/usr/bin/kafka
$ ls -la /usr/bin/kafka
Oct 27 10:41 /usr/bin/kafka -> /usr/hdp/current/kafka-broker/bin/kafka
```

- This Kafka was installed today.

- What about Zookeeper.

```
$ which zookeeper-server
/usr/bin/zookeeper-server
$ ls -la /usr/bin/zookeepr-*
Sep 15 12:29 /usr/bin/zookeeper-client -> /usr/hdp/current/zookeeper-
client/bin/zookeeper-client
Sep 15 12:29 /usr/bin/zookeeper-server -> /usr/hdp/current/zookeeper-
server/bin/zookeeper-server
Sep 15 12:29 /usr/bin/zookeeper-server-cleanup ->
/usr/hdp/current/zookeeper-server/bin/zookeeper-server-cleanup
```

- This Zookeeper was installed with Spark, when I was building my Spark VM.

Zookeeper that came with Kafka

- Examine Kafka installation directory create by yum

```
$ ls -la /usr/hdp/current/kafka-broker/bin
-rwxr-xr-x. 1 root root 1052 Aug 25  2016 connect-distributed.sh
-rwxr-xr-x. 1 root root 1051 Aug 25  2016 connect-standalone.sh
-rwxr-xr-x. 1 root root 4513 Aug 25  2016 kafka
-rwxr-xr-x. 1 root root  861 Aug 25  2016 kafka-acls.sh
-rwxr-xr-x. 1 root root  864 Aug 25  2016 kafka-configs.sh
-rwxr-xr-x. 1 root root 1315 Aug 25  2016 kafka-console-consumer.sh
-rwxr-xr-x. 1 root root 1312 Aug 25  2016 kafka-console-producer.sh
-rwxr-xr-x. 1 root root  871 Aug 25  2016 kafka-consumer-groups.sh
-rwxr-xr-x. 1 root root 1238 Aug 25  2016 kafka-consumer-offset-checker.sh
-rwxr-xr-x. 1 root root 1315 Aug 25  2016 kafka-consumer-perf-test.sh
-rwxr-xr-x. 1 root root  862 Aug 25  2016 kafka-mirror-maker.sh
. . . . .
-rwxr-xr-x. 1 root root 1364 Aug 25  2016 kafka-server-start.sh
-rwxr-xr-x. 1 root root  975 Aug 25  2016 kafka-server-stop.sh
-rwxr-xr-x. 1 root root 1235 Aug 25  2016 kafka-simple-consumer-shell.sh
-rwxr-xr-x. 1 root root  945 Aug 25  2016 kafka-streams-application-reset.sh
-rwxr-xr-x. 1 root root  863 Aug 25  2016 kafka-topics.sh
-rwxr-xr-x. 1 root root  958 Aug 25  2016 kafka-verifiable-consumer.sh
-rwxr-xr-x. 1 root root  958 Aug 25  2016 kafka-verifiable-producer.sh
-rwxr-xr-x. 1 root root 4328 Aug 25  2016 kafka-zookeeper-run-class.sh
drwxr-xr-x. 2 root root 4096 Oct 27 10:41 windows
-rwxr-xr-x. 1 root root  867 Aug 25  2016 zookeeper-security-migration.sh
-rwxr-xr-x. 1 root root 1389 Aug 25  2016 zookeeper-server-start.sh
-rwxr-xr-x. 1 root root  978 Aug 25  2016 zookeeper-server-stop.sh
-rwxr-xr-x. 1 root root  968 Aug 25  2016 zookeeper-shell.sh
```

- You see Zookeeper scipts installed by Kafka installation.

Start the Server

- We will use Zookeeper that came with Kafka.

Step 1: Start Zookeeper server

- Kafka uses ZooKeeper so we need to first start a ZooKeeper server.
- We can use the convenience script packaged with Kafka to get a quick-and-dirty single-node ZooKeeper instance.

```
> bin/zookeeper-server-start.sh config/zookeeper.properties
```

-
  ```
  [2016-03-22 15:01:37,495] INFO Reading configuration from:
  config/zookeeper.properties
  (org.apache.zookeeper.server.quorum.QuorumPeerConfig)
  ```

- If you get a message that the port is in use, run `zookeeper-server-stop.sh.` On your Cloudera VM go to directory `/etc/init.d` and run

```
$ sudo service zookeeper-server stop
```

- Now start the Kafka server:

```
> bin/kafka-server-start.sh config/server.properties
[2016-0-22 15:01:47,028] INFO Verifying properties
(kafka.utils.VerifiableProperties)
[2016-03-22 15:01:47,051] INFO Property socket.send.buffer.bytes is
overridden to 1048576 (kafka.utils.VerifiableProperties)
```

Create Topic, Start Producer, Consumer

Step 2: Create a topic

- We will create a topic named "test" with a single partition and only one replica:

```
> bin/kafka-topics.sh --create --zookeeper localhost:2181 --replication-
factor 1 --partitions 1 --topic test
```

- We can now see that topic if we run the list topic command:

```
bin/kafka-topics.sh --list --zookeeper localhost:2181
test
```

- Alternatively, instead of manually creating topics you can also configure your brokers to auto-create topics when a non-existent topic is published to.

Step 3: Send some messages

- Kafka comes with a command line client that will take input from a file or from standard input and send it out as messages to the Kafka cluster. By default each line will be sent as a separate message.
- Run the producer and then type a few messages into the console to send to the server.

```
> bin/kafka-console-producer.sh --broker-list localhost:9092 --topic test
```

This is a message

This is another message

Step 4: Start a consumer

- Kafka also has a command line consumer that will dump out messages to standard output.

```
➢ bin/kafka-console-consumer.sh --zookeeper localhost:2181 --topic test2 -
  -from-beginning
```

This is a message

This is another message

- If you have each of the above commands running in a different terminal then you should now be able to type messages into the producer terminal and see them appear in the consumer terminal.

Python’s Kafka Consumers and Producers

- To use Python to create Kafka consumers and producers you need kafka-python package.
- On CentOS 7.4 VM with Python 2.7.5 I did the following:

```
[centos@localhost kafka-broker]$ sudo pip install kafka-python
Collecting kafka-python
  Downloading kafka_python-1.3.5-py2.py3-none-any.whl (207kB)
    100% |████████████████████████████████| 215kB 1.5MB/s
Installing collected packages: kafka-python
Successfully installed kafka-python-1.3.5
[centos@localhost kafka-broker]$
```

Python Kafka Producer

```
from kafka import KafkaProducer
import time

producer = KafkaProducer(bootstrap_servers='localhost:9092')
topic = 'Test2'

for batch in range(3):
        print 'Starting batch #' + str(batch)
        for i in range(4):
                print 'sending message #' + str(i)
                producer.send(topic, b'test message #' + str(i) )
        print 'Finished batch #' + str(batch)
        print 'Sleeping for 5 seconds ...'
        time.sleep(5)

print 'Done sending messages'
```

Python Kafka Consumer

```
from __future__ import print_function
from kafka import KafkaConsumer, TopicPartition
from kafka.errors import KafkaError
import logging
import sys
from kafka.errors import OffsetOutOfRangeError
logging.basicConfig(level=logging.INFO)
log = logging.getLogger(__name__)
def main(broker_str, topic):
    #topic = "Test1"
    group = "my-group1"
    #bootstrap_servers = ['localhost:9092']
    bootstrap_servers = [broker_str]

    print('Topic is: ', topic)
    print('Group is: ', group)
```

Python Kafka Consumer, continued

```
# To consume latest messages and auto-commit offsets
try:
    consumer = KafkaConsumer(
        group_id=group, bootstrap_servers=bootstrap_servers,
        auto_offset_reset="latest")
    consumer.subscribe([topic])
    while True:
        # Process messages
        try:
            k_msg = consumer.poll(timeout_ms=200)
        except OffsetOutOfRangeError:
            log.info("Offset out of range. Seeking to begining")
            # consumer.seek_to_beginning(tp)
            # You can save `consumer.position(tp)` to redis after this,
            # but it will be saved after next message anyway
        else:
            if k_msg:
                for msgs in list(k_msg.values()):
                    for msg in msgs:
                        print('got msg: ', str(msg))
                        # Process message and increment offset
   print('partition: ', msg.partition, 'message offset: ', msg.offset)
```

Python Kafka Consumer, continued

```
    except KafkaError as e:
        log.info('Got kafka error %s: %s' % (str(e), type(e)))
    except Exception as e:
        log.info('Got exception %s: %s' % (str(e), type(e)))
    else:
        log.info('No exception raised!')
    finally:
        consumer.close()

if __name__ == '__main__':
    if len(sys.argv) != 3:
        print("Usage: kafka_consumer2.py <broker_list> <topic>",
file=sys.stderr)
        exit(-1)
    main(sys.argv[1], sys.argv[2])
```

Spark Streaming & Kafka Integration, Python

- Spark Streaming can receive data from Kafka. In Python, a WordCount client reads:

```
from __future__ import print_function
from pyspark import SparkConf
import sys
from pyspark import SparkContext
from pyspark.streaming import StreamingContext
from pyspark.streaming.kafka import KafkaUtils
if __name__ == "__main__":
    if len(sys.argv) != 3:
        print("Usage: direct_kafka_wordcount.py <broker_list> <topic>", file=sys.stderr)
        exit(-1)
    conf = SparkConf().setAppName("PythonStreamingDirectKafkaWordCount")
    conf = conf.setMaster("local[5]")
    sc = SparkContext(appName="PythonStreamingDirectKafkaWordCount")
    ssc = StreamingContext(sc, 2)

    brokers, topic = sys.argv[1:]
    kvs = KafkaUtils.createDirectStream(ssc, [topic], {"metadata.broker.list": brokers})
    lines = kvs.map(lambda x: x[1])
    counts = lines.flatMap(lambda line: line.split(" ")) \
        .map(lambda word: (word, 1)) \
        .reduceByKey(lambda a, b: a+b)
    counts.pprint()
    ssc.start()
ssc.awaitTermination()
```

Receiver Approach, Dependencies

- The Receiver is implemented using the Kafka high-level consumer API.
- The data received from Kafka through a Receiver is stored in Spark executors, and then jobs launched by Spark Streaming processes the data.
- Under the default configuration, this approach can lose data under failures. To ensure zero-data loss, you have to additionally enable Write Ahead Logs in Spark Streaming. These logs synchronously save all the received Kafka data into write ahead logs on a distributed file system (e.g HDFS), so that all the data can be recovered on failure.

- For Scala/Java applications using SBT/Maven project definitions, link your streaming application with the following artifact.

```
groupId = org.apache.spark
artifactId = spark-streaming-kafka-0-10_2.11
version = 2.2.0
```

- Do not manually add dependencies on `org.apache.kafka` artifacts (e.g. `kafka-clients`). The `spark-streaming-kafka-0-10` artifact has the appropriate transitive dependencies already, and different versions may be incompatible in hard to diagnose ways.
- For Python applications, you will also have to add the above library and its dependencies when deploying the application.

Receiver Approach, Programming

- In the streaming application code, import `KafkaUtils` and create an input `DStream:`

```
import org.apache.spark.streaming.kafka.*;
 JavaPairReceiverInputDStream<String, String> kafkaStream =
     KafkaUtils.createStream(streamingContext,
     [ZK quorum], [consumer group id], [per-topic number of Kafka
partitions to consume]);
```

- You can also specify the key and value classes and their corresponding decoder classes using variations of `createStream`.
- Topic partitions in Kafka do not correlate to partitions of RDDs generated in Spark Streaming. Increasing the number of topic-specific partitions in the `KafkaUtils.createStream()` only increases the number of threads using which topics that are consumed within a single receiver. It does not increase the parallelism of Spark in processing the data.
- Multiple Kafka input `DStreams` can be created with different groups and topics for parallel receiving of data using multiple receivers.
- If you have enabled Write Ahead Logs with a replicated file system like HDFS, the received data is already being replicated in the log. Hence, the storage level in storage level for the input stream to `StorageLevel.MEMORY_AND_DISK_SER` (that is, use `KafkaUtils.createStream(..., StorageLevel.MEMORY_AND_DISK_SER))`.

Deploying

- As with any Spark applications, `spark-submit` is used to launch your application. However, the details are slightly different for Scala/Java applications and Python applications.
- For Scala and Java applications, if you are using SBT or Maven for project management, then package `spark-streaming-kafka-0-10_2.11` and its dependencies into the application JAR.
- For Python applications which lack SBT/Maven project management, `spark-streaming-kafka-0-10_2.11` and its dependencies can be directly added to spark-submit using –packages.

```
 ./bin/spark-submit --packages org.apache.spark:spark-streaming-
kafka-0-10_2.11:2.2.0 ...
```

- Alternatively, you can also download the JAR of the Maven `artifact` `spark-streaming-kafka-assembly` from the Maven repository and add it to `spark-submit with --jars`

Direct Approach

- This new receiver-less "direct" approach periodically queries Kafka for the latest offsets in each topic+partition, and accordingly defines the offset ranges to process in each batch. When the jobs to process the data are launched, Kafka's simple consumer API is used to read the defined ranges of offsets from Kafka (similar to read files from a file system).

This approach has the following advantages over the receiver-based approach:

- **Simplified Parallelism**: No need to create multiple input Kafka streams and union them. With directStream, Spark Streaming will create as many RDD partitions as there are Kafka partitions to consume, which will all read data from Kafka in parallel. So there is a one-to-one mapping between Kafka and RDD partitions, which is easier to understand and tune.
- **Efficiency:** Achieving zero-data loss in the first approach required the data to be stored in a Write Ahead Log, which further replicated the data. This is actually inefficient as the data effectively gets replicated twice - once by Kafka, and a second time by the Write Ahead Log. This second approach eliminates the problem as there is no receiver, and hence no need for Write Ahead Logs. As long as you have sufficient Kafka retention, messages can be recovered from Kafka.
- **Exactly-once semantics:** The first approach uses Kafka's high level API to store consumed offsets in Zookeeper. This is traditionally the way to consume data from Kafka. While this approach (in combination with write ahead logs) can ensure zero data loss (i.e. at-least once semantics), there is a small chance some records may get consumed twice under some failures. This occurs because of inconsistencies between data reliably received by Spark Streaming and offsets tracked by Zookeeper. Hence, in this second approach, we use simple Kafka API that does not use Zookeeper. Offsets are tracked by Spark Streaming within its checkpoints. This eliminates inconsistencies between Spark Streaming and Zookeeper/Kafka, and so each record is received by Spark Streaming effectively exactly once despite failures.
- **One disadvantage** of this approach is that it does not update offsets in Zookeeper, hence Zookeeper-based Kafka monitoring tools will not show progress.

Programming

- This approach is supported only in Scala/Java application. Link your SBT/Maven project with the following artifact

```
groupId = org.apache.spark
artifactId = spark-streaming-kafka_2.10
version = 1.6.1
```

- In the streaming application code, import `KafkaUtils` and create an input `DStream` as:

```
 import org.apache.spark.streaming.kafka.*;

  JavaPairReceiverInputDStream<String, String> directKafkaStream =
      KafkaUtils.createDirectStream(streamingContext,
          [key class], [value class], [key decoder class], [value decoder
class],
          [map of Kafka parameters], [set of topics to consume]);
```

- You can also pass a `messageHandler` to `createDirectStream` to access `MessageAndMetadata` that contains metadata about the current message and transform it to any desired type. See the API docs and the example.
- In the Kafka parameters, you must specify either `metadata.broker.list` or `bootstrap.servers`. By default, it will start consuming from the latest offset of each Kafka partition. If you set configuration `auto.offset.reset` in Kafka parameters to smallest, then it will start consuming from the smallest offset.
- You can also start consuming from any arbitrary offset using other variations of KafkaUtils.createDirectStream. Furthermore, if you want to access the Kafka offsets consumed in each batch, you can do the following

Code Snippet

```
 // Hold a reference to the current offset ranges, so it can be used downstream
 final AtomicReference<OffsetRange[]> offsetRanges = new AtomicReference<>();

 directKafkaStream.transformToPair(
   new Function<JavaPairRDD<String, String>, JavaPairRDD<String, String>>() {
     @Override
     public JavaPairRDD<String, String> call(JavaPairRDD<String, String> rdd) throws
Exception {
       OffsetRange[] offsets = ((HasOffsetRanges) rdd.rdd()).offsetRanges();
       offsetRanges.set(offsets);
       return rdd;
     }
   }
 ).map(
   ...
 ).foreachRDD(
   new Function<JavaPairRDD<String, String>, Void>() {
     @Override
     public Void call(JavaPairRDD<String, String> rdd) throws IOException {
       for (OffsetRange o : offsetRanges.get()) {
         System.out.println(
           o.topic() + " " + o.partition() + " " + o.fromOffset() + " " +
o.untilOffset()
         );
       }
       ...
       return null;
     }
   }
 );
```

Near Real-Time Stack

- For data scientists and developers working with real-time data pipelines, Spark Streaming and Kafka are not all that is needed. Often a large volume of data needs to be stored or retrieved, either before or after processing with Spark Stream. Spark Streaming-Kafka-Cassandra has recently emerged as the stack of choice for such applications,.
- This stack satisfies the key requirements for real-time data analytics:
  - **Spark Streaming** is an extension of the core Spark API; it allows integration of near real-time data from disparate event streams.
  - **Kafka:** a messaging system to capture and publish streams of data. With Spark you can ingest data from Kafka, filter that stream down to a smaller data set, augment the data, and then push that refined data set to a persistent data store.
  - **Cassandra:** appears to be an excellent choice when data needs to be written to a scalable and resilient operational database for persistence, easy application development, and real-time analytics.
- These open source frameworks are powerful and well-suited for the requirements of building real-time data pipelines.

NoSQL , Cassandra & Co.

History of the World, Part 1

- Relational Databases – mainstay of business
  - For the longest time (and still true today), the big relational database vendors such as Oracle, IBM, Sybase, and Microsoft were the mainstay of how data was stored.
  - During the Internet boom, startups looking for low-cost RDBMS alternatives turned to MySQL and PostgreSQL.
- Web-based applications caused spikes
  - Could have hundreds of thousands of visitors in a short-time span. Especially true for public-facing e-Commerce sites
- Developers begin to front RDBMS with memcache or integrate other caching mechanisms within the application (ie. Ehcache)
- As datasets grew, the simple memcache/MySQL model (for lower-cost startups) started to become problematic.

Scaling Up

- Best way to provide ACID and a rich query model is to have the dataset on a single machine.
- Issues with scaling up when the dataset is just too big
- RDBMS were not designed to be distributed
- Began to look at multi-node database solutions
- Known as ‘scaling out’ or ‘horizontal scaling’
- Different approaches include:
  - Master-slave
  - Sharding

Scaling RDBMS – Master/Slave

- Master-Slave
  - All writes are written to the master. All reads performed against the replicated slave databases
  - Critical reads may be incorrect as writes may not have been propagated down
  - Large data sets can pose problems as master needs to duplicate data to slaves

Scaling RDBMS - Sharding

- Partitioning or sharding
- Different sharding approaches:
- Vertical Partitioning: Have tables related to a specific feature sit on their own server. May have to rebalance or reshard if tables outgrow server.
- Range-Based Partitioning: When single table cannot sit on a server, split table onto multiple servers. Split table based on some critical value range.
- Key or Hash-Based partitioning: Use a key value in a hash and use the resulting value as entry into multiple servers.
- Directory-Based Partitioning: Have a lookup service that has knowledge of the partitioning scheme . This allows for the adding of servers or changing the partition scheme without changing the application.
  - Scales well for both reads and writes
  - Not transparent, application needs to be partition-aware
  - Can no longer have relationships/joins across partitions
  - Loss of referential integrity across shards

Other ways to scale RDBMS

- Multi-Master replication.
  - The multi-master replication system is responsible for propagating data modifications made by each member to the rest of the group, and resolving any conflicts that might arise between concurrent changes made by different members.
- INSERT only, not UPDATES/DELETES.
  - For INSERT-only, data is versioned upon update.
  - Data is never DELETED, only inactivated.
- No JOINs, thereby reducing query time
  - This involves de-normalizing data
  - Consistency is the responsibility of the application.
- In-memory databases
- In-memory databases have not caught on mainstream and regular RDBMS are more disk-intensive that memory-intensive

What is NoSQL?

- Stands for **N**ot **O**nly **SQL**
- Class of non-relational data storage systems
- Usually do not require a fixed table schema nor do they use the concept of joins
- All NoSQL offerings relax one or more of the ACID properties.
- For data storage, an RDBMS cannot be the only solution.
- Just as there are different programming languages, need to have other data storage tools in the toolbox
- Relational databases offer a very good general purpose solution to many different data storage needs.
- In other words, it is the safe choice and will work in many situations.

How did we get here?

- Explosion of social media sites (Facebook, Twitter) with large data needs. These datasets have high read/write rates.
- Rise of cloud-based solutions such as Amazon S3 (simple storage solution) made NoSQL universally accessible
- Like a move to dynamically-typed languages (Ruby/Groovy), a shift to dynamically-typed data with frequent schema changes
- All of the NoSQL options with the exception of Amazon S3 (Amazon Dynamo) are open-source solutions.

DynamoDB and BigTable

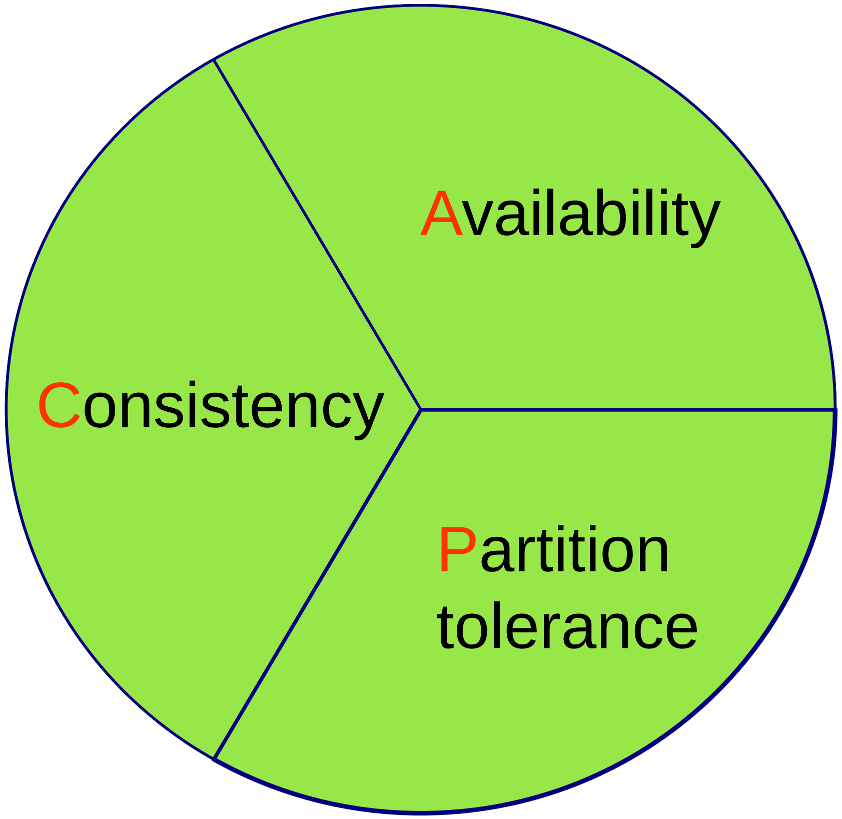
- Three major papers were the seeds of the NoSQL movement
  - BigTable (Google, 2006)
    - BigTable: `https://static.googleusercontent.com/media/research.google.com/en//archive/bigtable-osdi06.pdf`

      DynamoDB (Amazon, 2007)
    - `http://www.allthingsdistributed.com/2007/10/amazons_dynamo.html` and
    - `http://www.allthingsdistributed.com/files/amazon-dynamo-sosp2007.pdf`
    - Gossip protocol (discovery and error detection)
    - Distributed key-value data store
    - Eventual consistency
      - Amazon and consistency
      - `http://www.allthingsdistributed.com/2010/02`
      - `http://www.allthingsdistributed.com/2008/12`
  - CAP Theorem (discuss in a sec ..)

The Perfect Storm

- Large datasets, acceptance of alternatives, and dynamically-typed data has come together in a perfect storm.
- Industry have reached a point where a read-only cache and write-based RDBMS isn’t delivering the throughput necessary to support many internet scale application.
- Not a backlash/rebellion against RDBMS
- The NoSQL databases are a pragmatic response to growing scale of databases and the falling prices of commodity hardware.
- Most likely, 10 years from now, majority of business related data will still be stored in RDBMS.
- SQL is a rich query language that could not be pushed out by the current list of NoSQL offerings

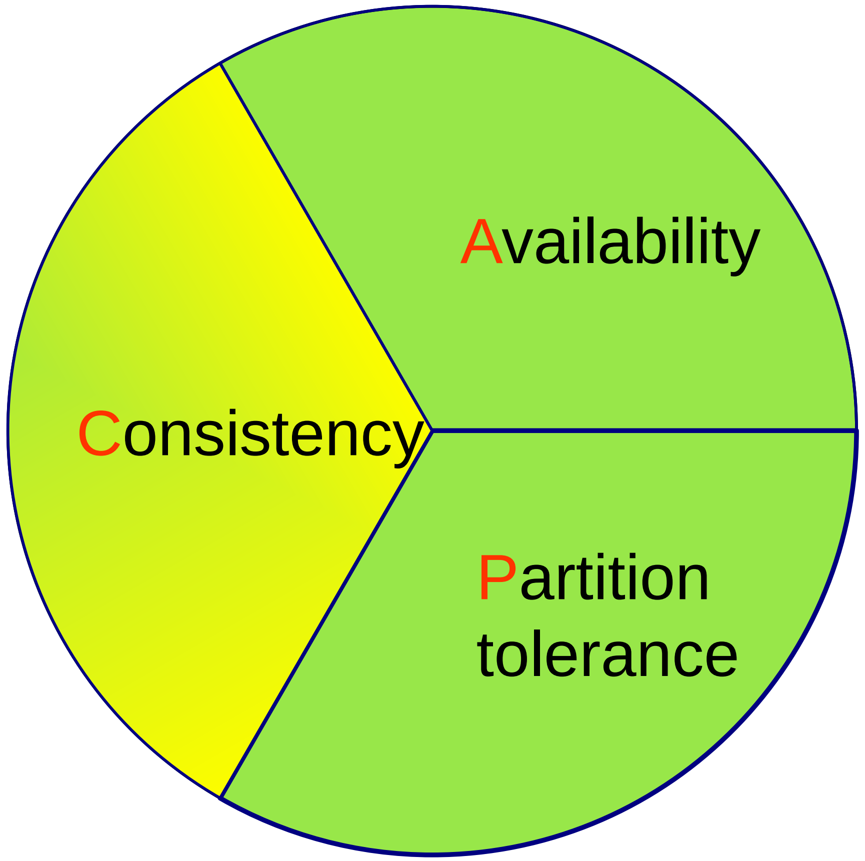
The CAP Theorem



CAP Theorem

- Proposed by Eric Brewer (talk on Principles of Distributed Computing July 2000).
- Three properties of a system: **C**onsistency, **A**vailability and **P**artitionability.
- **You can have at most two of these three properties for any shared-data system**
  - Partitionability: Can divide nodes into small groups that can see other groups, but they can't see everyone.
  - Consistency: write a value and then you read the value you get the same value back. In a partitioned system there are windows where that's not true.
  - Availability: may not always be able to write or read. The system will say you can't write because it wants to keep the system consistent.
- To scale you have to partition, so you are left with choosing either high consistency or high availability for a system. Find the right overlap of availability and consistency. Choose an approach based on the service
- For the checkout process you always want to honor requests to add items to a shopping cart because it's revenue producing. In this case you choose high availability. Errors are hidden from the customer and sorted out later.
- When a customer submits an order you favor consistency because several services--credit card processing, shipping and handling, reporting— are simultaneously accessing the data.

The CAP Theorem



Once a writer has written, all readers will see that write.

- Two kinds of consistency:
  - strong consistency – ACID(Atomicity Consistency Isolation Durability)
  - weak consistency – BASE(Basically Available Soft-state Eventual consistency)

What is NoSQL?

- NoSQL is not a relational database. The reality is that a relational database model may not be the best solution for all situations.
- The easiest way to think of NoSQL, is that of a database which does not adhere to the traditional relational database management system (RDMS) structure.
- Sometimes you will also see it referred to as 'not only SQL'.

What kinds of NoSQL

- NoSQL solutions fall into two major areas:
  - Key/Value or ‘the big hash table’.
    - Amazon S3 (Dynamo)
    - Voldemort
    - Scalaris
    - Memcached (in-memory key/value store)
    - Redis
  - Schema-less which comes in multiple flavors, column-based, document-based or graph-based.
    - Cassandra (column-based)
    - CouchDB (document-based, document: views are stored as rows which are kept sorted by key.)
    - MongoDB(document-based)
    - Neo4J (graph-based, is a network database that uses edges and nodes to represent and store data)
    - HBase (column-based)

Key/Value

Pros:

– very fast
– very scalable
– simple model
– able to distribute horizontally

Cons:

- many data structures (objects) can't be easily modeled as key value pairs

Schema-Less

Pros:

- Schema-less data model is richer than key/value pairs
- eventual consistency
- many are distributed
- still provide excellent performance and scalability

Cons:

- typically no ACID transactions or joins

Common Advantages

- Cheap, easy to implement (open source)
- Data are replicated to multiple nodes (therefore identical and fault-tolerant) and can be partitioned
  - **Down nodes easily replaced**
  - **No single point of failure**
  - **As the data is written, the latest version is on at least one node. The data is then versioned/replicated to other nodes within the system.**
- Eventually, the same version is on all nodes.
- Easy to distribute
- Don't require a schema
- Can scale up and down
- Relax the data consistency requirement (CAP)

What am I giving up?

- joins
- group by
- order by
- ACID transactions
- SQL as a sometimes frustrating but still powerful query language
- easy integration with other applications that support SQL

Row Oriented Databases

- A relational database management system maintains data that represents two-dimensional tables, with columns and rows. For example, a database might have table Employee:

EmpId	Lastname	Firstname	Salary
10	Smith	Joe	40000
12	Jones	Mary	50000
11	Johnson	Cathy	44000
22	Jones	Bob	55000

- This two-dimensional format exists only on paper. Storage hardware requires the data to be serialized into a sequence of “cells” and placed onto the hard drives.
- The most expensive operations involving hard drives are seeks. In order to improve overall performance, related data should be stored in a fashion to minimize the number of seeks. Hard drives are organized into a series of blocks of a fixed size, typically enough to store several rows of the table. This minimizes the number of data retrievals.

Row Organized Data

- The common solution to the storage problem is to serialize each row of data, and assign to it a row id. Rows of the previous table could be packaged like this:

```
001:10,Smith,Joe,40000;002:12,Jones,Mary,50000;003:11,Johnson,Cat
hy,44000;004:22,Jones,Bob,55000;
```

- Indicators `001, 002, 003` and `004` represent row ids. In practice, those identifiers are usually longer, 64-bit or 128-bit strings.
- In OLTP systems, we need the entire raw(s) of data in order to populate entire object(s). It makes every sense to store all components of a row of data together. By storing the record's data in a single block on the disk, along with related records, the system can quickly retrieve records with a minimum of disk operations.
- Row-based systems are not efficient at performing operations that apply to the entire data set, as opposed to a specific record. For instance, in order to find all the records in the example table that have salaries between 40,000 and 50,000, the DBMS would have to seek through the entire data set looking for matching records.

Indexes Help

- To improve the performance of these sorts of operations, most DBMS's support the use of database indexes, which store all the values from a set of columns along with pointers back into the original rowid.
- An index on the salary column would look something like this:

```
001:40000;002:50000;003:44000;004:55000;
```

- As they store only single pieces of data, rather than entire rows, indexes are generally much smaller than the main table stores. By scanning smaller sets of data the number of disk operations is reduced. If the index is heavily used, it can provide dramatic time savings for common operations. However, maintaining indexes adds overhead to the system, especially when new data is written to the database. In this case not only is the record stored in the main table, but any attached indexes have to be updated as well.
- Database indexes on one or more columns are typically sorted by value, which makes operations like range queries fast.

Modern RDBMS

- There is a number of row-oriented databases that are designed to fit entirely in RAM, the so called an in-memory database (Oracle Times Ten).
- RAM is rapidly getting cheaper and big vendors like Oracle, (Microsoft,) IBM are offering specialized hardware with enormous RAM-s (several TB-s)
- These systems do not depend on disk operations, and have equal-time access to the entire dataset. This reduces the need for indexes, as it is required the same amount of operations to full scan the original data as a complete index for typical aggregation purposes. Such systems are simpler and smaller, but can only manage databases that fit into the memory.
- Classical Hard Drives are being replaced by Solid State Drives (SSD-s, Flash Drives) and several vendors (Aerospike, Amazon DynamoDB) are rewriting RDBMS systems to take advantage of new technology. Consistent reads and writes complete in under 1 millisecond on such systems. This is two orders of magnitude faster than on the classical HD systems.
- Traditional databases also try to scale with volume of data by using cluster technology. For whatever reason there are limitations to such scaling.
- **RDBMS are far from dead. They will remain the backbone of all IT systems.**

Column-oriented Systems

- Important column-oriented databases have been present for a while(Vertica, 2005; Statistics Canada RAPID System, 1969).
- A column-oriented database serializes all of the values of a column together, then the values of the next column, and so on. For our example table, the data would be stored in this fashion:

```
10:001,12:002,11:003,22:004;
Smith:001,Jones:002,Johnson:003,Jones:004;
Joe:001,Mary:002,Cathy:003,Bob:004;
40000:001,50000:002,44000:003,55000:004;
```

- Any one of the columns more closely matches the structure of an index in a row-based system. This creates an impression that column-oriented store "is really just" a row-store with an index on every column.
- It is the mapping of the data that differs dramatically. In a row-oriented indexed system, the primary key is the rowid that is mapped to indexed data.

Data organization in Column-oriented systems

- In the column-oriented system primary key is the data, mapping back to rowids. The difference can be seen in the case when we have two rows (users) with the same last name. Column “last_name” would be stored as:

`…;Smith:001,Jones:002,004,Johnson:003;…`

- Record `“Jones”` could be saved only once in the column store along with pointers to all of the rows that match it. For many common searches, like "find all the people with the last name Jones", the answer is retrieved in a single operation. Similarly, counting the number of matching records, can be greatly improved through this organization.
- In a column-oriented system operations that retrieve complete data for objects would be slower, requiring numerous disk operations to collect data from multiple columns to build up the record.
- In the many cases, only a limited subset of data is retrieved. If we are collecting the first and last names from many rows in order to build a list of contacts, columnar organization is vastly beneficial.
- This is even more true for writing data into the database, especially if the data tends to be "sparse" with many optional columns.

Benefits

- Column-oriented organizations are more efficient when an aggregate needs to be computed over many rows but only for a notably small subset of all columns of data
- Column-oriented organizations are more efficient when new values of a column are supplied for all rows at once, because that column data can be written efficiently and replace old column data without touching any other columns for the rows.
- Row-oriented organizations are more efficient when many columns of a single row are required at the same time, and when row-size is relatively small, as the entire row can be retrieved with a single disk seek.
- Row-oriented organizations are more efficient when writing a new row if all of the row data is supplied at the same time, as the entire row can be written with a single disk seek.
- In practice, row-oriented storage layouts are well-suited for OLTP-like workloads which are more heavily loaded with interactive transactions. Column-oriented storage layouts are well-suited for OLAP-like workloads.

Compression

- Column data is of uniform type. Many popular modern compression schemes, such as LZW or run-length encoding, make use of the similarity of adjacent data to compress. While the same techniques may be used on row-oriented data, a typical implementation will be less effective.
- To improve compression, sorting rows can also help. For example, using bitmap indexes, sorting can improve compression by an order of magnitude. To maximize the compression benefits of the lexicographical order with respect to run-length encoding, it is best to use low-cardinality columns as the first sort keys. For example, given a table with columns sex, age, name, it would be best to sort first on the value sex (cardinality of two), then age (cardinality of <150), then name.
- Columnar compression achieves a reduction in disk space at the expense of efficiency of retrieval. Retrieving all data from a single row is more efficient when that data is located in a single location, such as in a row-oriented architecture. Further, the greater adjacent compression achieved, the more difficult random-access may become, as data might need to be uncompressed to be read.

New Breed of Databases

- With large popularity of Big Data Analytics, several databases became quite fashionable. Among the most popular are: Cassandra, HBase, MongoDB, and CouchDB.
- Some of those databases are referred to as key-value pair database, some as columnar-databases and all as NoSQL database.
- NoSQL databases claim to deliver faster performance than legacy RDBMS systems in various use cases, most notably those involving big data. While this is oftentimes the case, it should be understood that not all NoSQL databases are created alike where performance is concerned.
- System architects and IT managers need to compare NoSQL databases in their own environments using data and user interactions that are representative of their expected production workloads before deciding which NoSQL database to use for a new application.
- DataStax performed a benchmark of three top NoSQL databases – Apache Cassandra, Apache HBase, and MongoDB – using a variety of different workloads on AWS clusters.

Benchmark Configuration, DataStax Evaluations

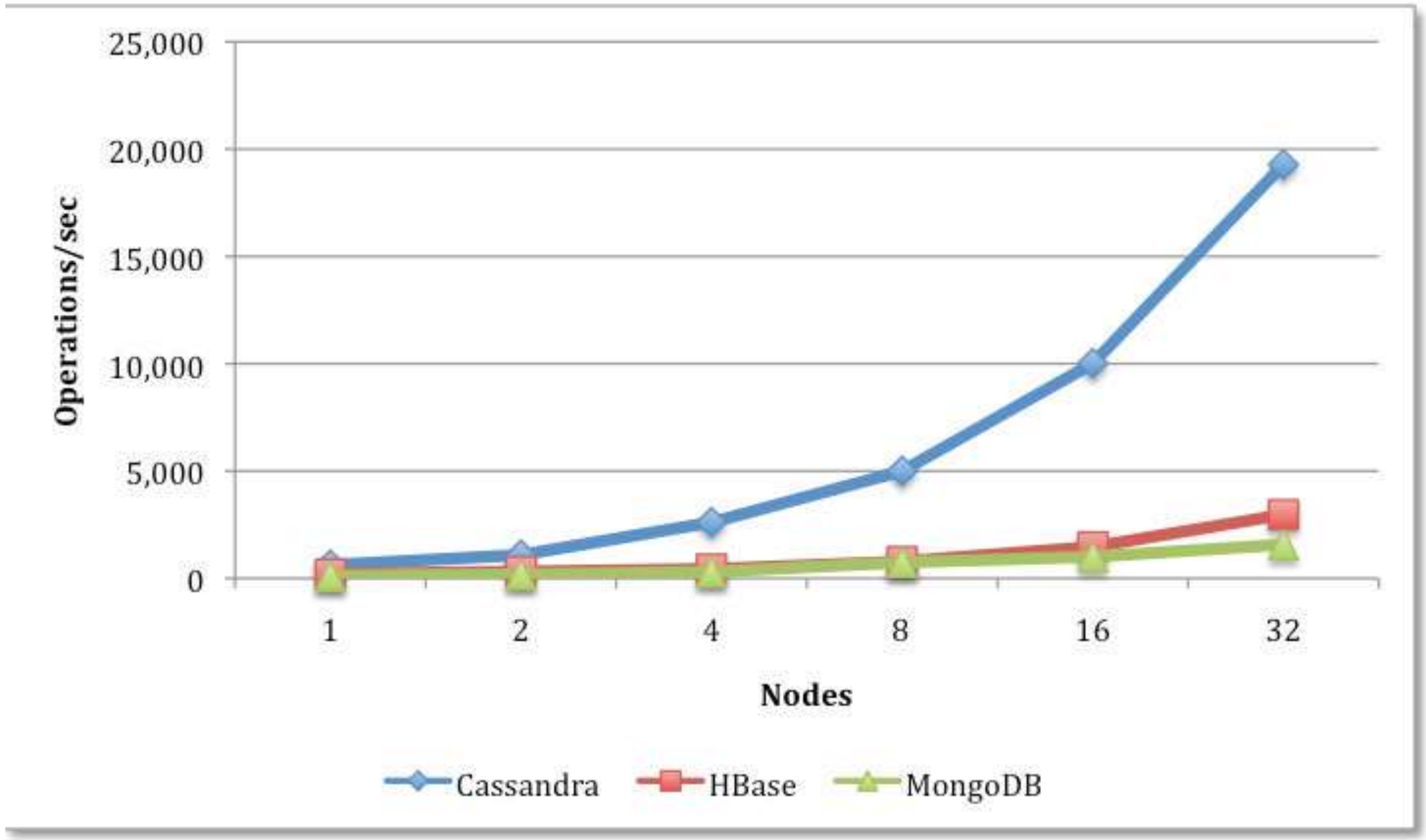
- The tests ran in the cloud on Amazon Web Services (AWS) EC2 instances, using spot instances to ensure cost efficiency while getting the same level of performance.
- The tests ran exclusively on m1.xlarge size instances (15 GB RAM and 4 CPU cores) using local instance storage for performance. The m1.xlarge instance type allows for up to 4 local instance devices; the instances were allocated all 4 block devices, which were then combined on boot into a single 1.7TB RAID-1 volume.
- The instances use customized Ubuntu 12.04 LTS AMI’s with Oracle Java 1.6 installed as a base.
- On start up, each instance calls back to a parent instance for its configuration. A customized script was written to drive the benchmark process, including managing the start up, configuration, and termination of EC2 instances, calculation of workload parameters, and driving the clients to run the tests.

Tested Workloads

The following workloads were included in the benchmark:

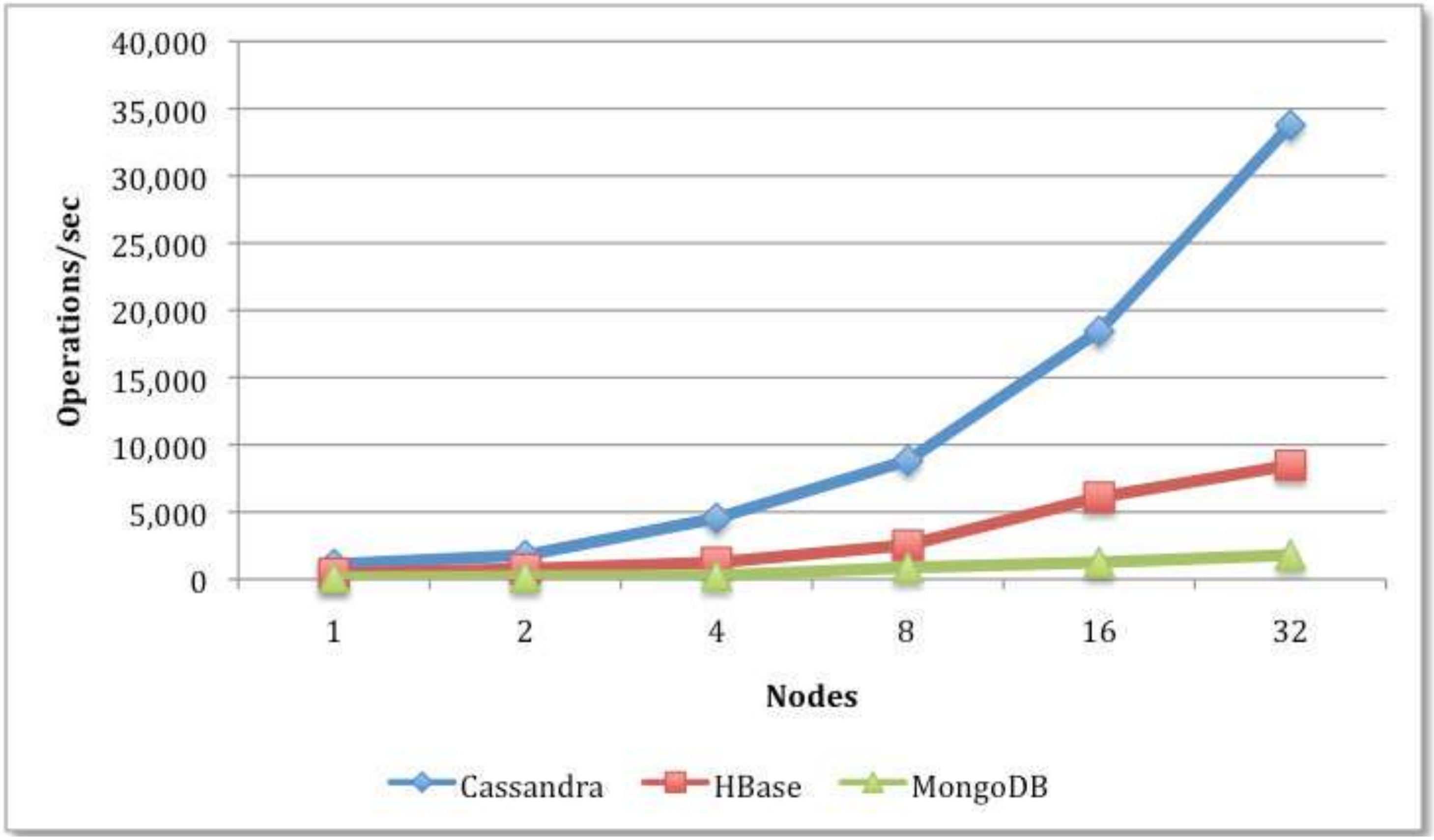
1. Read-mostly workload, based on YCSB’s provided workload B: 95% read to 5% update ratio
2. Read/write combination, based on YCSB’s workload A: 50% read to 50% update ratio
3. Write-mostly workload: 99% update to 1% read
4. Read/scan combination: 47% read, 47% scan, 6% update
5. Read/write combination with scans: 25% read, 25% scan, 25% update, 25% insert
6. Read latest workload, based on YCSB workload D: 95% read to 5% insert
7. Read-modify-write, based on YCSB workload F: 50% read to 50% read-modify-write

Read-Mostly Workload



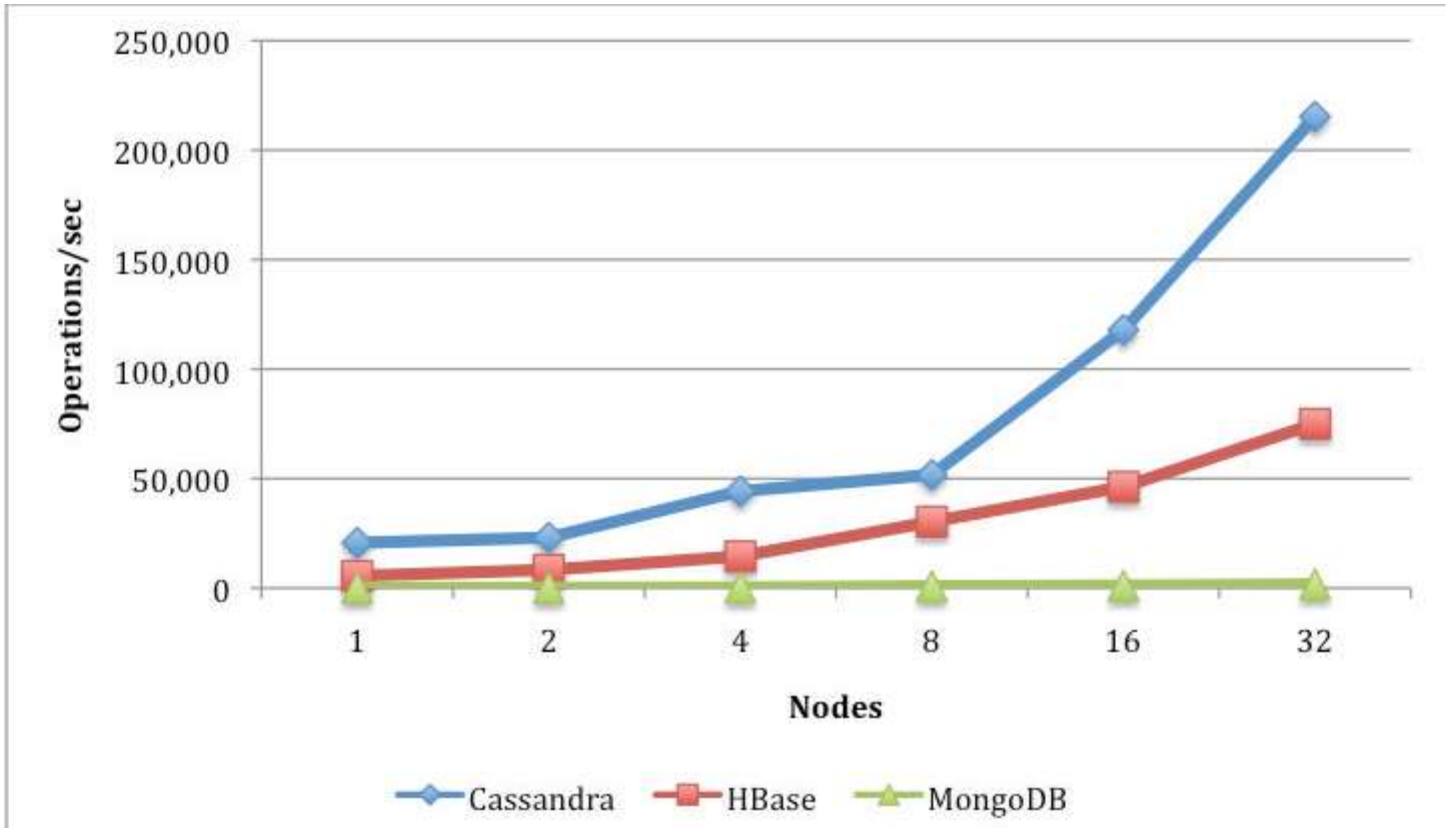
- Different workloads are important for different use cases and one should really examine the intended usage of a NoSQL database before deciding which product to use.

Read/Write Mix Workload



Complete white paper on this series of tests can be found at:
http://www.datastax.com/resources/whitepapers/benchmarking-top-nosql-databases

Write-mostly Workload



- Here we presented only 3 of 8 tested workload scenarios. It appears that in all of them Cassandra demonstrated the highest throughput.

Choose

- Based on results for all tested workloads, it appears that Cassandra is an overwhelming winner.
- Cassandra has some “deficiencies”. For example, it does not implement a very strong consistency model and does not consider ACID properties to be sacrosanct.
- ACID (*Atomicity, Consistency, Isolation, Durability*) is a set of properties that guarantee that database transactions are processed reliably. Old fashioned RDBMS-s like Oracle, DB2, PostgreSQL, MySQL, and others guaranty that those properties will hold in any of your transactions.
- HBase, for example, pays due respect to consistency property and you might decide to select HBase over Cassandra if data consistency is critical for your application, in spite of HBase’s less-than-stellar performance.
- Also, Cloudera which “owns” HBase claims that they made significant improvements recently. Also, if your data is all in HDFS or you want it in HDFS, HBase is a natural choice.
- In the following we will look at some properties of Cassandra, HBase and MongoDB.

Cassandra

Cassandra

- In the following we will examine the installation process for Cassandra Database and review some of its properties.
- Cassandra was developed at Facebook.
- Major promoter and contributor to Cassandra is DataStax corporation. The same people who are commercializing Spark.
- Cassandra is an Apache project. The latest stable version is 3.10.0. CQL 3.4
- Cassandra is available for
  - Mac OS x10.x, Unix
  - Red Hat Enterprise Linux, CentoOS 6.5+
  - Latest Ubuntu LTS and Debian Linux
  - Cassandra could be installed on Windows 7 and Windows Server 2008??
- Client Drivers exist for:
  - Java, Python, Ruby, C#/.NET, Go, Node.js, Clojure, PHP and C++

What is your OS

- You can find out what is the Linux Operating System you are working with by listing the following files:

```
[cloudera@quickstart ~]$ cat /etc/issue
CentOS release 7.4 (Final)
Kernel \r on an \m

[cloudera@quickstart ~]$ cat /etc/centos-release
CentOS release 7.4 (Final)
[cloudera@quickstart ~]$
```

- It appears that Cloudera VM runs `CentOS 7.4`

Create Linux User `cassandra`

- Casandra server should be run by Linux user `cassandra`. Let us create it

```
$ su -        # to become root
$ groupadd cassandra          # greate Linux group cassandra
$ useradd cassandra -g cassandra     # create Linux user cassandra
$ passwd cassandra          # set password for user  cassandra
Enter password: cassandra
```

- Make user `cassandra` a `sudo` user

```
$ chmod + w /etc/sudoers          # make /etc/sudoers writable
$ visudo -f /etc/sudoers          # open the file with special Vi editor
```

- Add a line for user `cassandra similar to the line for user cloudera`. Also, tell the system to remember `JAVA_HOME` and PATH variables when executing as a `sudo` user:

```
cloudera ALL=(ALL) NOPASSWD: ALL
cassandra ALL=(ALL) NOPASSWD: ALL
Defaults  env_keep += "LC_TIME LC_ALL LANGUAGE LINGUAS _XKB_CHARSET XAUTHORITY"
Defaults  env_keep += "JAVA_HOME PATH"
```

- Make file /etc/sudoers read only.

```
$ chmod -w /etc/sudoers
```

Installing Cassandra using `yum`

- For newest versions of Cassandra, DataStax recommends Java 8. Cloudera VM has Java `1.7.0_67`. That is why we have to install an older version of Cassandra, `2.1.13`
- Cassandra 2.1 requires Python 2.6. Cloudera VM has 2.6.6 . We are OK.
- To check which version of Java is installed, run the command:

```
$ java -version
```

- Create file `/etc/yum.repos.d/datastax.repo` referring to the DataStax Community repository. Add the following lines to the file:

```
[datastax]
name = DataStax Repo for Apache Cassandra
baseurl = https://rpm.datastax.com/community
enabled = 1
gpgcheck = 0
```

- Install the packages:

```
$ sudo yum install dsc21-2.1.13-1 cassandra2.1.6-1
$ sudo yum install cassandra21-tools-2.1.13-1  ##Installs optional utilities.
```

- You are done. As user `cassandra` find whether Cassandra executable exists:

```
$ which cassandra
/usr/sbin/cassandra
```

- Start Cassandra server as Linux user `cassandra` by typing: `$ cassandra &`

Alternate Installations and Prerequisites

- We could also use the binary tarball
- Download the tarball using the URL for Cassandra 2.1.13 which you will find on this page:
  `http://cassandra.apache.org/download/`
- Become user `cassandra`

```
$ su – cassandra
Password: cassandra
```

Move the file from `/home/cloudera/Downloads` to `/home/cassandra`. Expand it:

```
$ tar -xzvf apache-cassandra-2.1.13-bin.tar.gz
```

- Remove residual tar.gz file and rename directory `apache-cassandra-2.1.13 to cassandra-2.1.13`

```
$  mv apache-cassandra-2.1.13 cassandra-2.1.13
```

- Place `/home/cassandra/cassandra-2.1.13/bin in cassandra's .bash_profile` file. Source the file:

```
$ source .bash_profile
```

Starting Cassandra Server

- To start `Cassandra` server, as Linux user `cassandra`, in directory

`~cassandra/cassandra-2.1.13/bin`, type:

```
 $ cassandra -f
```

- The switch `-f` tells Cassandra to stay in the foreground instead of running as a background process. This so that all of the server logs will print to the standard out and you can see them in your terminal window, which is useful for testing.
- To stop `Cassandra` type `Ctrl C` in the console.
- Under normal circumstances, running server will write a fairly long output to the console. The output starts and ends with lines like the ones on the next two page. There is interesting and important information in those line. For example, you can find out where Cassandra writes its logs and data.

Console output, beginning, Normally Running Server

```
[cassandra@quickstart bin]$ ./cassandra -f
CompilerOracle: inline org/apache/cassandra/db/AbstractNativeCell.compareTo
(Lorg/apache/cassandra/db/composites/Composite;)I
CompilerOracle: inline
org/apache/cassandra/db/composites/AbstractSimpleCellNameType.compareUnsigned
(Lorg/apache/cassandra/db/composites/Composite;Lorg/apache/cassandra/db/composites/Composite;
)I
CompilerOracle: inline org/apache/cassandra/io/util/Memory.checkBounds (JJ)V
CompilerOracle: inline org/apache/cassandra/io/util/SafeMemory.checkBounds (JJ)V
CompilerOracle: inline org/apache/cassandra/utils/ByteBufferUtil.compare
(Ljava/nio/ByteBuffer;[B)I
CompilerOracle: inline org/apache/cassandra/utils/ByteBufferUtil.compare
([BLjava/nio/ByteBuffer;)I
CompilerOracle: inline org/apache/cassandra/utils/ByteBufferUtil.compareUnsigned
(Ljava/nio/ByteBuffer;Ljava/nio/ByteBuffer;)I
CompilerOracle: inline
org/apache/cassandra/utils/FastByteOperations$UnsafeOperations.compareTo
(Ljava/lang/Object;JILjava/lang/Object;JI)I
CompilerOracle: inline
org/apache/cassandra/utils/FastByteOperations$UnsafeOperations.compareTo
(Ljava/lang/Object;JILjava/nio/ByteBuffer;)I
CompilerOracle: inline
org/apache/cassandra/utils/FastByteOperations$UnsafeOperations.compareTo
(Ljava/nio/ByteBuffer;Ljava/nio/ByteBuffer;)I
INFO  18:36:12 Hostname: quickstart.cloudera
INFO  18:36:12 Loading settings from file:/home/cassandra/cassandra-
2.1.13/conf/cassandra.yaml
INFO  18:36:12 Node configuration:[authenticator= . . . . . .
```

Console output, end

```
INFO  18:05:51 Completed flushing
/home/cassandra/cassandra/bin/../data/data/system/local-
7ad54392bcdd35a684174e047860b377/system-local-tmp-ka-9-Data.db (0.000KiB)
for commitlog position ReplayPosition(segmentId=1457719550068,
position=105384)
INFO  18:05:51 Node localhost/127.0.0.1 state jump to NORMAL
INFO  18:05:51 Compacted 4 sstables to
[/home/cassandra/cassandra/bin/../data/data/system/local-
7ad54392bcdd35a684174e047860b377/system-local-ka-10,].  6,361 bytes to
5,779 (~90% of original) in 68ms = 0.081048MB/s.  4 total partitions merged
to 1.  Partition merge counts were {4:1, }
INFO  18:05:51 Netty using native Epoll event loop
INFO  18:05:51 Using Netty Version: [netty-buffer=netty-buffer-
4.0.23.Final.208198c, netty-codec=netty-codec-4.0.23.Final.208198c, netty-
codec-http=netty-codec-http-4.0.23.Final.208198c, netty-codec-socks=netty-
codec-socks-4.0.23.Final.208198c, netty-common=netty-common-
4.0.23.Final.208198c, netty-handler=netty-handler-4.0.23.Final.208198c,
netty-transport=netty-transport-4.0.23.Final.208198c, netty-transport-
rxtx=netty-transport-rxtx-4.0.23.Final.208198c, netty-transport-sctp=netty-
transport-sctp-4.0.23.Final.208198c, netty-transport-udt=netty-transport-
udt-4.0.23.Final.208198c]
INFO  18:05:51 Starting listening for CQL clients on
localhost/127.0.0.1:9042...
INFO  18:05:51 Binding thrift service to localhost/127.0.0.1:9160
INFO  18:05:51 Listening for thrift clients...
```

Directories used by cassandra

- When normally installed with yum or apt, Cassandra uses the following directories:
  - For configuration settings `$CASSANDRA_INSTALL/conf/cassandra.yaml`
  - data_file_directories (`/var/lib/cassandra/data`),
  - commitlog_directory (`/var/lib/cassandra/commitlog`), and
  - saved_caches_directory (`/var/lib/cassandra/saved_caches`).
- Make sure these directories exist and can be written to.
- By default, Cassandra will write its logs in `/var/log/cassandra/`.
- All these directories are owned by user `cassandra` and that is the reason why you should start the server as that Linux user .
- In Cassandra 2.1+, the logger in use is `logback`, so change this logging directory in your `conf/logback.xml` file such as:

```
<file>/var/log/cassandra/system.log</file>
```

- JVM-level settings such as heap size can be set in

  `conf/cassandra-env.sh.`
- In the situation when Casandra is installed from the tarball the way we did it, all the above directories will be under:
  `$CASSANDRA_INSTALL=/home/cassandra/cassandra-2.1.13`

Command Line Interface,

- `$CASSANDRA_INSTALL/bin/cqlsh` is the command line interface for examining data in Cassandra server.
- You can define the schema and interact with data using `cqlsh`.
- Run the following command to connect to your local Cassandra instance:

```
$ ./cqlsh
Connected to Test Cluster at localhost:9160. [cqlsh 5.0.1 | Cassandra
2.1.13 | CQL spec 3.2.1 | Native protocol v3]
Use HELP for help. Commands are terminated with a semicolon (;)
cqlsh>
```

- First, create a keyspace -- a namespace of tables.

```
CREATE KEYSPACE mykeyspace WITH REPLICATION = { 'class' :
'SimpleStrategy', 'replication_factor' : 1 };
USE mykeyspace;       # Move to new keyspace , create a table, insert data
CREATE TABLE users (
 user_id int PRIMARY KEY,
 fname text,
 lname text );
INSERT INTO users (user_id, fname, lname) VALUES (1745, 'john', 'smith');
INSERT INTO users (user_id, fname, lname) VALUES (1744, 'john', 'doe');
INSERT INTO users (user_id, fname, lname) VALUES (1746, 'john', 'smith');
```

CQL, Retrieve Data, Create Index

- We can retrieve data using customary tools and commands

```
cqlsh> SELECT * FROM users;
user_id | fname | lname
--------+-------+-------
   1745 | john  | smith
   1744 | john  | doe
   1746 | john  | smith
```

- You can retrieve data faster (about users whose last name is smith) by creating an index, then querying the table as follows:

```
CREATE INDEX ON users (lname);
SELECT * FROM users WHERE lname = 'smith';
 user_id | fname | lname
---------+-------+-------
    1745 | john  | smith
    1746 | john  | smith
```

- The language we are using here is called CQL of Cassandra Query Language which is very similar to SQL.
- If you watch the console, you will see that the console reports on your activity

Cassandra Data Model

- Cassandra's data model is a partitioned row store with tunable consistency.
- Rows are organized into tables; the first component of a table's primary key is the partition key; within a partition, rows are clustered by the remaining columns of the key. Other columns can be indexed separately from the primary key.
- Tables can be created, dropped, and altered at runtime without blocking updates and queries.
- Cassandra does not support joins or subqueries, except for batch analysis through Hadoop.
- Rather, Cassandra emphasizes denormalization through features like collections

Example, Music Service: Playlist/Songs

- A social music service requires a songs table having a title, album, and artist column, plus a column called data for the actual audio file itself.
- The table uses a UUID as a primary key.

```
CREATE TABLE songs (
id uuid PRIMARY KEY,
title text, album text, artist text, data blob );
# playlist_id  );# In relational design, playlist_id would be the foreign key to playlists
```

- in Cassandra, we denormalize the data. playlist data, is presented by table:

```
CREATE TABLE playlists ( id uuid,
song_order int, song_id uuid, # In relational design these fields
title text, album text, artist text,
PRIMARY KEY (id, song_order ) ); # would not be here
```

- The combination of the id and song_order in the playlists table uniquely identifies a row in the playlists table. We could have more than one row with the same (playlist) id as long as the rows contain different song_order values.

```
CREATE TABLE playlist_songs (  # Relational design needs another
playlistid uuid,               # table to resent song order
song_id    uuid,
song_order int);
```

Example, Music Service

- If one would like to select playlist content for a particular artist, as things are organized now, Cassandra would have to make a full table scan. To avoid doing that you create an index:

```
CREATE INDEX ON playlists(artist );
```

- Now, you can query the playlists for songs by Fu Manchu, for example:

```
SELECT * FROM playlists WHERE artist = 'Fu Manchu';
```

- and Cassandra will efficiently return all relevant rows.
- Notice that the primary key on playlists table had two elements:

```
PRIMARY KEY (id, song_order ) );
```

- The first portion is called the partition key. The remaining keys are called clustering keys.
- Cassandra stores data on a node by partition key. If you have too much data in a partition and want to spread the data over multiple nodes, use a composite partition key.
- One consideration is whether to use surrogate or natural keys for a table.
- A surrogate key is a generated key (such as a UUID) that uniquely identifies a row, but has no relation to the actual data in the row.

Compound Keys and Clustering

- A compound primary key includes the partition key, which determines on which node data is stored first, and one or more additional columns that determine clustering.
- Cassandra uses the first column name in the primary key definition as the partition key. For example, in the playlists table, `id` is the partition key.
- The remaining column, or columns that are not partition keys in the primary key definition are the clustering columns. In the case of the playlists table, the `song_order` is the clustering column.
- The data for each partition is clustered by the remaining column or columns of the primary key definition.
- On a physical node, when rows for a partition key are stored in order based on the clustering columns, retrieval of rows is very efficient. For example, because the `id` in the playlists table is the partition key, all the songs for a playlist are clustered in the order of the remaining `song_order` column.
- Insertion, update, and deletion operations on rows sharing the same partition key for a table are performed atomically and in isolation.

Collection Columns

- CQL introduces three collection types:
- set, list, and map
- In a relational database, to allow users to have multiple email addresses, you usually create an `email_addresses` table having a many-to-one (joined) relationship to the `users` table.
- CQL handles the classic multiple email addresses use case, and other use cases, by defining columns as collections.
- For example, to add a collection named `tag` with elements of type `text` to table `songs`, we would issue statement like this:

```
ALTER TABLE songs ADD tags set<text>;
```

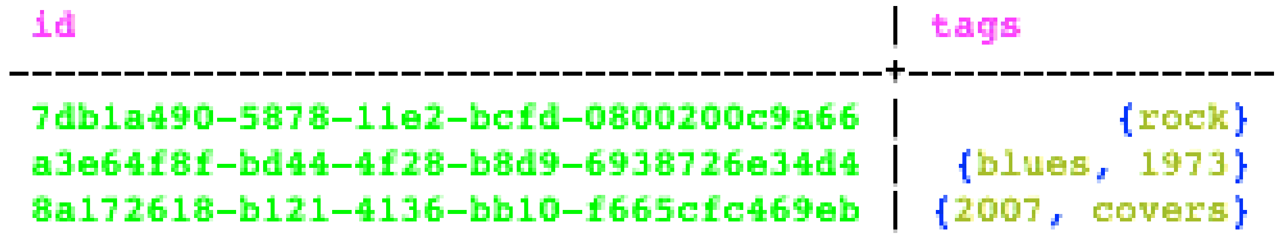
- One updates collection columns using + operator

```
UPDATE songs SET tags = tags + {'2007'}
WHERE id = 8a172618-b121-4136-bb10-f665cfc469eb;
UPDATE songs SET tags = tags + {'covers'}
WHERE id = 8a172618-b121-4136-bb10-f665cfc469eb;
```

Querying Collections

- To query a collection, include the name of the collection column in the select expression.
- For example, selecting the tags set returns the set of tags, sorted alphabetically in this case because the tags set is of the text data type:

```
SELECT id, tags FROM songs;
```



```
 id                                   | tags
--------------------------------------+-----------------
 7db1a490-5878-11e2-bcfd-0800200c9a66 |          {rock}
 a3e64f8f-bd44-4f28-b8d9-6938726e34d4 |   {blues, 1973}
 8a172618-b121-4136-bb10-f665cfc469eb | {2007, covers}
```

Indexing

- An index in Cassandra refers to an index on column values. Cassandra implements an index as a hidden table, separate from the table that contains the values being indexed. Using CQL, you can create an index on a column after defining a table.

```
CREATE INDEX artist_names ON playlists( artist );
```

- An index name is optional. If you provide an index name, such as `artist_idx`, the name must be unique within the keyspace.
- After creating an index for the artist column and inserting values into the playlists table, greater efficiency is achieved when you query Cassandra directly for artist by name, such as Fu Manchu:

```
SELECT * FROM playlists WHERE artist = 'Fu Manchu';
```

- As mentioned earlier, when looking for a row in a large partition, narrow the search. This query, although a contrived example using so little data, narrows the search to a single id.

```
SELECT * FROM playlists WHERE id = 62c36092-82a1-3a00-93d1-
46196ee77204 AND artist = 'Fu Manchu';
```

Using Multiple Indexes

- One can create multiple indexes on different columns of a table. For example:

```
CREATE INDEX album_name ON playlists ( album );
CREATE INDEX title_name ON playlists ( title );
SELECT * FROM playlists
WHERE album = 'Roll Away' AND title = 'Outside Woman Blues' ALLOW
FILTERING ;
```

- When multiple occurrences of data match a condition in a WHERE clause, Cassandra selects the least-frequent occurrence of a condition for processing first for efficiency.
- For example, suppose data for Blind Joe Reynolds and Cream's versions of "Outside Woman Blues" were inserted into the playlists table. Cassandra queries on the album name first if there are fewer albums named Roll Away than there are songs called "Outside Woman Blues" in the database

DataStax Java Driver 2.0 for Apache Cassandra

- Cassandra has many drivers for several popular languages. This is perhaps a testimony to its popularity.
- We will present a Java driver maintained by Datastax Corp. Our hope is that a driver maintained by a commercial entity will have a long shelf life.
- Material on the following slides could be found at:

http://www.datastax.com/documentation/developer/java-driver/2.0/common/drivers/introduction/introArchOverview_c.html

- The Java Driver 2.0 for Apache Cassandra works exclusively with the Cassandra Query Language version 3 (CQL3) and Cassandra's new binary protocol which was introduced in Cassandra version 1.2.
- The driver architecture is a layered. At the bottom lies the driver core. This core handles everything related to the connections to a Cassandra cluster (for example, connection pool, discovering new nodes, etc.) and exposes a simple, relatively low-level API on top of which a higher level layer can be built.
- A Mapping and a JDBC module will be added on top.

DataStax Java Driver 2.0 for Apache Cassandra

- The driver relies on Netty to provide non-blocking I/O with Cassandra for providing a fully asynchronous architecture.
- Netty is *an asynchronous event-driven NIO client-server network application framework* for rapid development of maintainable high performance protocol servers & clients. (see: http://netty.io)
- Multiple queries can be submitted to the driver which then will dispatch the responses to the appropriate client threads.
- The driver has the following features:
  - connection pooling
  - node discovery
  - automatic failover
  - load balancing
- The default behavior of the driver can be changed or fine tuned by using tuning policies and connection options.
- Queries can be executed synchronously or asynchronously, prepared statements are supported, and a query builder auxiliary class can be used to build queries dynamically.

Dependencies

- The Java driver only supports the Cassandra Binary Protocol and CQL3

Cassandra binary protocol

- The driver uses the binary protocol that was introduced in Cassandra 1.2. It only works with a version of Cassandra greater than or equal to 1.2. Furthermore, the binary protocol server is not started with the default configuration file in Cassandra 1.2. Edit the `cassandra.yaml` file for each node and set: `start_native_transport: true.` Then restart the node.

Maven dependencies

- The latest release of the driver is available on Maven Central. You can install it in your application using the following Maven dependency:

```
<dependency>
        <groupId>com.datastax.cassandra</groupId>
        <artifactId>cassandra-driver-core</artifactId>
        <version>2.0.10</version>
</dependency>
```

Download Driver

- From the site

http://downloads.datastax.com/java-driver/cassandra-java-driver-2.1.6.tar.gz

- download binary driver and use provide jar files.
- Binary driver downloads as `cassandra-java-driver-2.1.6.tar.gz`
- Untar the file using command

```
$ tar zxvf cassandra-java-driver-2.1.6.tar
```

- In the resulting directory, you will see two jar files:

  `cassandra-driver-core-2.1.6.jar` and

  `cassandra-driver-dse-2.1.6 lin`

Also, in the subdirectory `lib` you will see a bunch of additional jars:

  `bsh-2.0b4.jar, guava-16.0.1.jar, jcommander-1.27.jar,`
  `log4j-1.2.17.jar, lz4-1.2.0.jar,`
  `metrics-core-3.0.2.jar, netty-3.9.0.Final.jar,`
  `slf4j-api-1.7.5.jar, slf4j-log4j12-1.7.6.jar,`and
  `snappy-java-1.0.5.jar`

- All of those jars need to be referenced in the `CLASSPATH` variable of your Java applications or in the `Build Path` of your Java projects.

Install Eclipse

- It is convenient to create Java applications using Eclipse.
- Eclipse can be installed on your Debian Linux VM. This not difficult at all. Eclipse for 64 bit Linux is packaged as tar.gz file. Download and un-`tar` the file. In the resulting directory "`eclipse`" find executable "`eclipse`". Run the executable from the command line as

```
$./eclipse
```

- the familiar GUI will open. If you want to be fancy, copy your directory `eclipse` to `/usr/local` directory, and then create a symbolic link in `/usr/bin` directory pointing to the `eclipse` executable:

```
$ sudo ln –s /usr/local/eclipse/eclipse /usr/bin/eclipse
```

- Make sure that any Linux user can run the executable by issuing command:

```
$ sudo +x /usr/bin/eclipse
```

- Now you can open start `eclipse` from any directory.
- Client applications will connect to Cassandra cluster and run some database commands: create database tables, modify tables, insert, update or delete objects (rows) in those tables.

Creating Client

- In Eclipse, before creating the client class, create a project. You can call the project `CassandraClient`, for example.
- Our client will be the class, `edu.hu.cassandra.SimpleClient`
- We will need an instance field, `cluster`, to hold a Cluster reference.

```
private Cluster cluster;
```

- We will add an instance method, `connect(),` to our new class.

```
public void connect(String node) {}
```

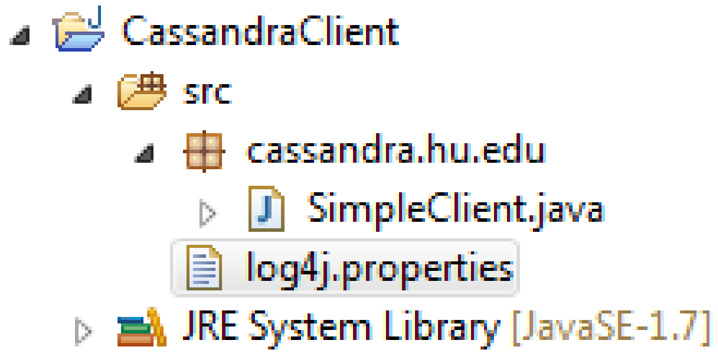
- The `connect()` method:
  - adds a contact point (node IP address) using the `Cluster.Build` auxiliary class, builds a cluster instance,
  - retrieves metadata from the cluster and prints out:
    - the name of the cluster, the datacenter, host name or IP address, and rack for each of the nodes in the cluster
- We could run the client class as a Java application from the Eclipse itself.
- Complete code of this class is presented on one of the following slides.

Create Eclipse Project, add `log4j.properties` File

- Before running the client class, create a file named: `log4j.properties`, with a content similar to the following:

```
log4j.rootLogger=debug, stdout, R
log4j.appender.stdout=org.apache.log4j.ConsoleAppender
log4j.appender.stdout.layout=org.apache.log4j.PatternLayout
# Pattern to output the caller's file name and line number.
log4j.appender.stdout.layout.ConversionPattern=%5p [%t](%F:%L) - %m%n
log4j.appender.R=org.apache.log4j.RollingFileAppender
log4j.appender.R.File=example.log
log4j.appender.R.MaxFileSize=100KB
# Keep one backup file
log4j.appender.R.MaxBackupIndex=1
log4j.appender.R.layout=org.apache.log4j.PatternLayout
log4j.appender.R.layout.ConversionPattern=%p %t %c - %m%n
```

- Place file `log4j.properties` in the `src` directory of your Eclipse project, like in the image to the right. This is important. Otherwise, the driver will complain that your Log4J is not properly initialized.



edu.hu.cassandra.SimpleClient

```
package edu.hu.cassandra;
import com.datastax.driver.core.Cluster; import com.datastax.driver.core.Host;
import com.datastax.driver.core.Metadata;
public class SimpleClient {
   private Cluster cluster;
   public void connect(String node) {
      cluster = Cluster.builder().addContactPoint(node).build();
      Metadata metadata = cluster.getMetadata();
      System.out.printf("Connected to cluster: %s\n",
            metadata.getClusterName());
      for ( Host host : metadata.getAllHosts() ) {
         System.out.printf("Datatacenter: %s; Host: %s; Rack: %s\n",
               host.getDatacenter(), host.getAddress(), host.getRack());
      }
   }
   public void close() {
      cluster.close(); }
   public static void main(String[] args) {
      SimpleClient client = new SimpleClient();
      client.connect("127.0.0.1");
      client.close();
   }
}
```

Running your Client

- When you right clink on your Java client class, select Run as Java Application.
- The result should look something like this:

-
  ```
  DEBUG [main] (Cluster.java:930) - Starting new cluster with
  contact points [/127.0.0.1]
  DEBUG [main] (ControlConnection.java:226) - [Control connection]
  Refreshing node list and token map
  DEBUG [main] (ControlConnection.java:229) - [Control connection]
  Refreshing schema
  DEBUG [main] (ControlConnection.java:154) - [Control connection]
  Successfully connected to /127.0.0.1
  Connected to cluster: Test Cluster
  Datacenter: datacenter1; Host: /127.0.0.1; Rack: rack1
  DEBUG [main] (Cluster.java:1037) - Shutting down
  ```
- This basically tells you that your Java client did connect to Cassandra server (cluster). Not bad at all.

Client that executes SQL Commands

- We will create a client class, `CQLClient` and enable it to execute CQL (SQL like) commands. We start building `CQLClient` by copying the content of SimpleClient class. Subsequently, we add new code.
- In order to execute CQL commands we need to create an object of type:

```
com.datastax.driver.core.Session;
```

- We do that by adding an instance field, `session`, of type `Session`:

```
private Session session;
```

- We get the session from the `cluster` object using method `connect()`:

```
session = cluster.connect();
```

- Queries are executed by calling the `execute()` method on the `session` object. The `session` maintains multiple connections to the cluster nodes, provides policies to choose which node to use for each query (round-robin on all nodes of the cluster by default), and handles retries for failed queries when it makes sense.
- A given `session` can only be set to one keyspace at a time, so one instance per `keyspace` is necessary. Your application typically only needs a single cluster object, unless you're dealing with multiple physical clusters

Create Schema

- We need to add an instance method that will create Schema.

```
public createSchema() { }
```

- Inside this method we will execute an CQL command to create a keyspace `simplex`, i.e.

```
 session.execute("CREATE KEYSPACE simplex WITH replication " +
  "= {'class':'SimpleStrategy', 'replication_factor':3};");
```

- We will also execute statements to create two new tables, `songs` and `playlists`.

```
session.execute( "CREATE TABLE simplex.songs (" + "id uuid
PRIMARY KEY," + "title text," + "album text," + "artist text," +
"tags set<text>," + "data blob" + ");");
session.execute( "CREATE TABLE simplex.playlists (" + "id uuid,"
+ "title text," + "album text, " + "artist text," + "song_id
uuid," + "PRIMARY KEY (id, title, album, artist)" + ");");
```

Load Data

- Data will be loaded using instance method `loadData()`

```
public void loadData() { }
```

- The code that performs Insert statements for two table looks like the following:

```
session.execute(
"INSERT INTO simplex.songs (id, title, album, artist, tags) " +
"VALUES (" + "756716f7-2e54-4715-9f00-91dcbea6cf50," +
"'La Petite Tonkinoise'," + "'Bye Bye Blackbird'," +
"'Joséphine Baker'," + "{'jazz', '2013'})" + ";");

session.execute(
"INSERT INTO simplex.playlists (id, song_id, title, album, " +
" artist) " +
"VALUES (" + "2cc9ccb7-6221-4ccb-8387-f22b6a1b354d," +
"756716f7-2e54-4715-9f00-91dcbea6cf50," +
"'La Petite Tonkinoise'," +
"'Bye Bye Blackbird'," + "'Joséphine Baker'" + ");");
```

Select content of `playlists` table

- Lastly, we will query the content of the `playlists` table. For that purpose we add instance method `querySchema().`
- Inside querySchema() method we execute query (select statement) which returns an object of type: `com.datastax.driver.core.ResultSet`. `ResultSet` object contains objects of type `com.datastax.driver.core.Row` which represents rows returned by the select statement.

```
ResultSet results = session.execute("SELECT * FROM
simplex.playlists " + "WHERE id = 2cc9ccb7-6221-4ccb-8387-
f22b6a1b354d;");
```

- To see individual rows we iterate through the `ResultSet`

```
for (Row row : results) {
   System.out.println(String.format("%-30s\t%-20s\t%-20s",
        row.getString("title"), row.getString("album"),
        row.getString("artist")));
}
```

`main()` Method

- Method main() organizes above instance methods in the proper order:

```
public static void main(String[] args) {
    CQLClient client = new CQLClient();
    client.connect("127.0.0.1");
    client.createSchema();
     client.loadData();
    client.querySchema();
    client.close();
}
```

- We should note that it is wise and necessary to close or end cluster connection. We do that using method `close()`, defined as:

```
public void close() {
    cluster.close(); // .shutdown();
}
```

- Complete code of class CQLClient is presented on the following slides.

CQLClient.java

```
package cassandra.hu.edu;

import com.datastax.driver.core.Cluster;
import com.datastax.driver.core.Host;
import com.datastax.driver.core.Metadata;
import com.datastax.driver.core.Session;
import com.datastax.driver.core.ResultSet;
import com.datastax.driver.core.Row;

public class CQLClient {
   private Cluster cluster;
   private Session session;
   public void connect(String node) {
      cluster = Cluster.builder()
            .addContactPoint(node).build();
      session = cluster.connect();
   }
```

CQLClient.createSchema()

```
public void createSchema() {
    session.execute("CREATE KEYSPACE simplex WITH replication " +
       "= {'class':'SimpleStrategy', 'replication_factor':1};");
    session.execute(
       "CREATE TABLE simplex.songs (" +
             "id uuid PRIMARY KEY," +
             "title text," + "album text," +
             "artist text," + "tags set<text>," +
             "data blob" +
             ");");
   session.execute(
       "CREATE TABLE simplex.playlists (" +
             "id uuid," +
             "title text," + "album text, " +
             "artist text," + "song_id uuid," +
             "PRIMARY KEY (id, title, album, artist)" +
             ");");
   }
```

CQLClient.loadData()

```
public void loadData() {
  session.execute("INSERT INTO simplex.songs (id, title,album,"
+ "artist, tags)" +
      "VALUES (" +
          "756716f7-2e54-4715-9f00-91dcbea6cf50," +
          "'La Petite Tonkinoise'," +
          "'Bye Bye Blackbird'," +
          "'Joséphine Baker'," +
          "{'jazz', '2013'})" +
          ";");
session.execute( "INSERT INTO simplex.playlists (id, song_id," +
" title, album, artist) " +
      "VALUES (" +
          "2cc9ccb7-6221-4ccb-8387-f22b6a1b354d," +
          "756716f7-2e54-4715-9f00-91dcbea6cf50," +
          "'La Petite Tonkinoise'," +
          "'Bye Bye Blackbird'," +
          "'Joséphine Baker'" +
          ");");
}
```

CQLClient.querySchema()

```
public void querySchema(){
  ResultSet results = session.execute(
"SELECT * FROM simplex.playlists " +
        "WHERE id = 2cc9ccb7-6221-4ccb-8387-
f22b6a1b354d;");System.out.println(String.format(
"%-30s\t%-20s\t%-20s\n%s", "title", "album", "artist",
"-------------------------------+-----------------------" +
"---+--------------------"));
   for (Row row : results) {
    System.out.println(String.format("%-30s\t%-20s\t%-20s",
    row.getString("title"),
    row.getString("album"),  row.getString("artist")));
   }
   System.out.println();
}
public void close() {
      cluster.close(); // .shutdown();
}
```

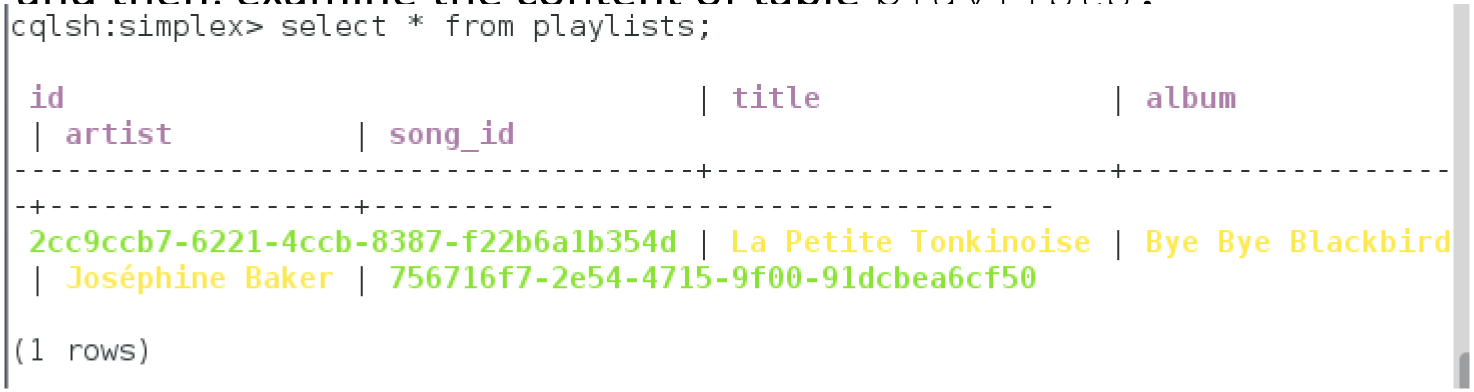
CQLClieNT.main(String[] arg)

```
public static void main(String[] args) {
      CQLClient client = new CQLClient();
      client.connect("127.0.0.1");
      client.createSchema();   client.loadData();
      client.querySchema();   client.close();
   }
 }
```

- The output on the Eclipse console is presented on the next slide. We have removed a few DEBUG lines to fit the output into one slide.
- One can open `cqlsh` prompt, issue command:

```
cqlsh> user simplex;
```

- and then, examine the content of table `playlists`:



```
cqlsh:simplex> select * from playlists;

 id                                   | title                  | album
 | artist            | song_id
--------------------------------------+------------------------+------------------
-+------------------+--------------------------------------
 2cc9ccb7-6221-4ccb-8387-f22b6a1b354d | La Petite Tonkinoise | Bye Bye Blackbird
 | Joséphine Baker | 756716f7-2e54-4715-9f00-91dcbea6cf50

(1 rows)
```

Console Output of CQLClient

```
DEBUG [main] (Cluster.java:930) - Starting new cluster with contact points [/127.0.0.1]
DEBUG [Cassandra Java Driver worker-0] (SessionManager.java:238) - Adding /127.0.0.1 to list of
queried hosts
Connected to cluster: Test Cluster
Datatacenter: datacenter1; Host: /127.0.0.1; Rack: rack1
DEBUG [New I/O worker #1] (Cluster.java:1466) - Received event EVENT CREATED simplex,
scheduling delivery
DEBUG [New I/O worker #1] (Cluster.java:1466) - Received event EVENT CREATED simplex.songs,
scheduling delivery
DEBUG [New I/O worker #2] (Cluster.java:1433) - Refreshing schema for simplex
DEBUG [New I/O worker #1] (Cluster.java:1466) - Received event EVENT CREATED
simplex.playlists, scheduling delivery
DEBUG [Cassandra Java Driver worker-1] (ControlConnection.java:242) - [Control connection]
Refreshing schema for simplex
DEBUG [New I/O worker #2] (Cluster.java:1433) - Refreshing schema for simplex
DEBUG [Cassandra Java Driver worker-0] (ControlConnection.java:507) - Checking for schema
agreement: versions are [d5a20e46-0062-35fd-b148-180af989ae5f]
title                          album                 artist
------------------------------+----------------------+--------------------
La Petite Tonkinoise       Bye Bye Blackbird  Joséphine Baker
DEBUG [main] (Cluster.java:1037) - Shutting down
DEBUG [main] (HostConnectionPool.java:393) - Shutting down pool
```

Drivers for Cassandra

Cassandra has a large number of drivers. The following is a partial list (04/2014)

- *Ruby:*
  - *Cassandra: http://github.com/fauna/cassandra/tree/master*
  - *Cassandra_object*: http://github.com/NZKoz/cassandra_object/tree/master (for Rails)
  - Small Record: http://github.com/astrails/smallrecord/tree/master (for ruby/ActiveModel, Rails)
- Perl:
  - Net-Cassandra: http://search.cpan.org/dist/Net-Cassandra/lib/Net/Cassandra.pm
  - Net-Cassandra-Easy: http://search.cpan.org/dist/Net-Cassandra-Easy/ (A simpler, much less Thrift-oriented interface than Net::Cassandra; includes a CLI called cassidy.pl)
- Python:
  - Telephus: http://github.com/driftx/Telephus/tree/master (Twisted)
  - Pycassa: http://github.com/vomjom/pycassa (version 0.3.0)
  - Tragedy: http://github.com/enki/tragedy/
  - Lazy Boy: http://github.com/digg/lazyboy/tree/master

Drivers for Cassandra

- Scala:
  - Scromium: http://github.com/cliffmoon/scromium
  - Cascal: http://github.com/shorrockin/cascal
  - Cassandra4o: http://code.google.com/p/cassandra4o/ (works with Java, includes hooks for Hibernate-like Object-mapping)
  - Akka: http://akkasource.org/ (Akka includes a Cassandra client but is more than that)
  - Cassie: http://github.com/codahale/cassie
- Java :
  - Hector: http://github.com/rantav/hector
  - Pelops: http://code.google.com/p/pelops/
  - HelenaORM: http://github.com/marcust/HelenaORM (ORM layer built on Hector)
  - OCM: http://github.com/charliem/OCM (higher level client built on Hector)
  - Datanucleus-Cassandra plug-in: http://github.com/PedroGomes/datanucleus-cassandra (Persistence of objects through the JDO/JPA APIs under the Datanucleus platform).
  - Jassandra: http://code.google.com/p/jassandra/
  - Kundera: http://code.google.com/p/kundera/

Drivers for Cassandra

- PHP :
  - PHP Cassandra Client Library: http://github.com/kallaspriit/Cassandra-PHP-Client-Library
  - Pandra: http://github.com/mjpearson/Pandra/tree/master
  - PHP Cassa: http://github.com/hoan/phpcassa [port of pycassa to PHP]
- Clojure :
  - CLJ-Cassandra: http://github.com/robertluo/clj-cassandra
  - Grails : Grails-Cassandra: http://github.com/wolpert/grails-cassandra (Download 0.5.4 from the github site for 0.6 compatibility)
- C++ :
  - LibCassandra: http://github.com/posulliv/libcassandra
- C# / .NET
  - Aquiles: http://aquiles.codeplex.com/
  - Hector Sharp: http://www.hectorsharp.com
  - Fluent Cassandra: http://github.com/managedfusion/fluentcassandra

References

- Moderately complete documentation on CQL language could be found at

http://www.datastax.com/documentation/cql/3.0/cql/aboutCQL.html#../cql/aboutCQL.html

Drivers for Cassandra could be found at:

- JDBC:

http://code.google.com/a/apache-extras.org/p/cassandra-jdbc/

- DATASTAX Java Driver Similar to JDBC

http://www.datastax.com/documentation/developer/java-driver/1.0/common/drivers/introduction/introArchOverview_c.html

- Thrift is the low level driver used by many other drivers

http://wiki.apache.org/cassandra/ThriftExamples

- Hector

http://hector-client.github.io/hector/build/html/index.html

What is MongoDB?

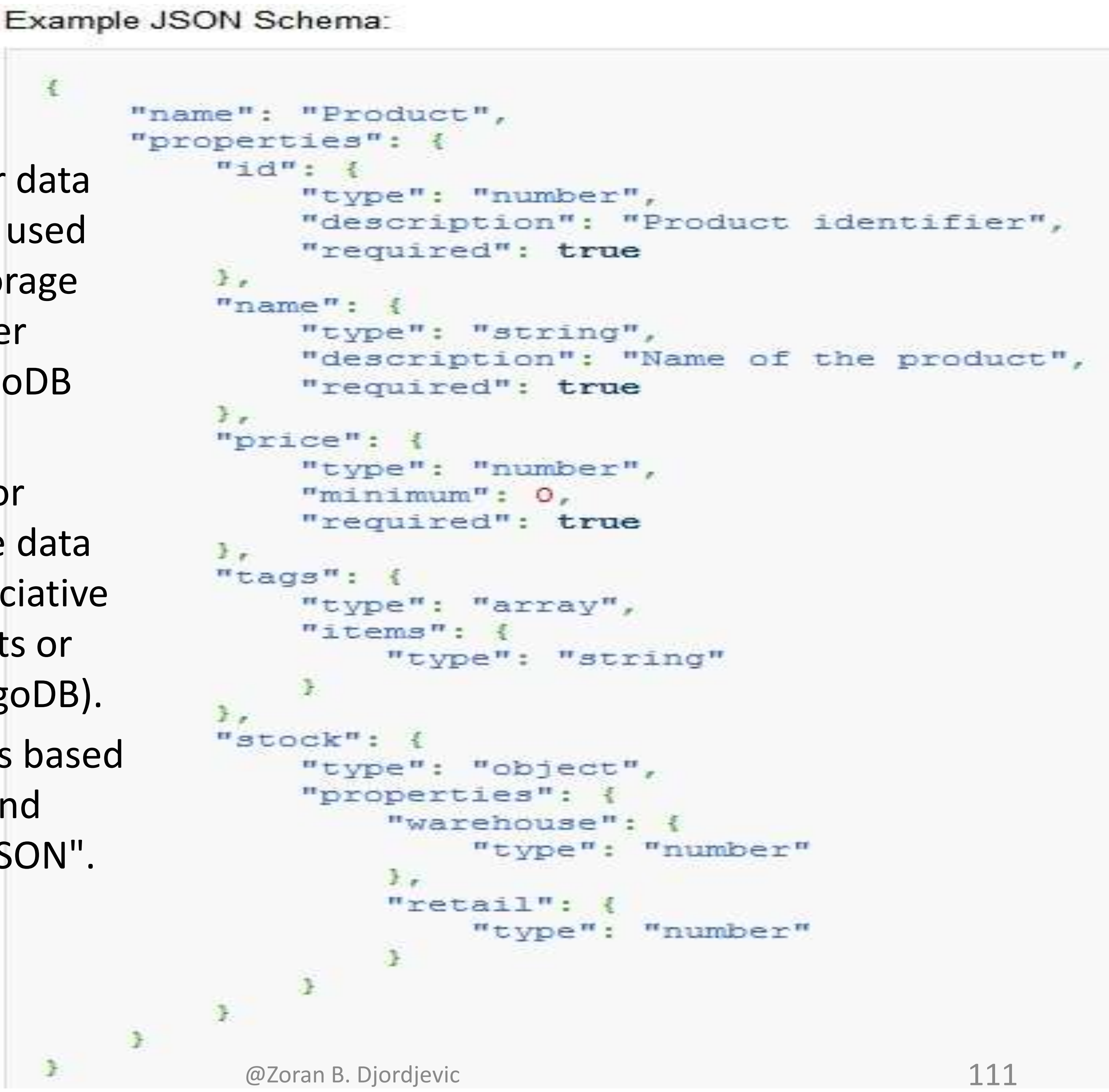
MongoDB (from "humongous") is an

- Open-source document database
- Written in C++
- Agile and scalable.

History of MongoDB

- First developed by 10gen (now MongoDB Inc.) in October 2007 as a component of a planned platform as a service product, the company shifted to an open source development model in 2009, with 10gen offering commercial support and other services.
- Since then, MongoDB has been adopted as backend software by a number of major websites and services, including Craigslist, eBay, Foursquare, SourceForge, and The New York Times, among others. MongoDB is the most popular NoSQL database system.

- BSON is a computer data interchange format used mainly as a data storage and network transfer format in the MongoDB database.
- It is a binary form for representing simple data structures and associative arrays (called objects or documents in MongoDB).
- The name "BSON" is based on the term JSON and stands for "Binary JSON".



Example JSON Schema:

```
{
    "name": "Product",
    "properties": {
        "id": {
            "type": "number",
            "description": "Product identifier",
            "required": true
        },
        "name": {
            "type": "string",
            "description": "Name of the product",
            "required": true
        },
        "price": {
            "type": "number",
            "minimum": 0,
            "required": true
        },
        "tags": {
            "type": "array",
            "items": {
                "type": "string"
            }
        },
        "stock": {
            "type": "object",
            "properties": {
                "warehouse": {
                    "type": "number"
                },
                "retail": {
                    "type": "number"
                }
            }
        }
    }
}
```

Terminology and Concepts

SQL Terms/Concepts	MongoDB Terms/Concepts
database	*database*
table	*collection*
row	*document* or *BSON* document
column	*field*
index	*index*
table joins	embedded documents and linking
primary key Specify any unique column or column combination as primary key.	*primary key* In MongoDB, the primary key is automatically set to the *_id* field.

SQL to MongoDB Mapping

SQL Schema Statements	MongoDB Schema Statements
CREATE TABLE users (id MEDIUMINT NOT NULL AUTO_INCREMENT, user_id Varchar(30), age Number, status char(1), PRIMARY KEY (id))	db.users.insert({ user_id: "abc123", age: 55, status: "A" }) Implicitly created on first insert() operation. The primary key _id is automatically added if _id field is not specified.
SELECT * FROM users	db.users.find()

MongoDB Server-Side JavaScript

- JavaScript may be executed in the MongoDB server processes for various functions, such as query enhancement and map/reduce processing.
- Example:

```
for (var i = 1; i <= 25; i++) db.testData.insert( { x : i } )
```

`db.testData.find()` displays first 20 docs in the collection

```
{ "_id" : ObjectId("51a7dc7b2cacf40b79990be6"), "x" : 1 } { "_id" :
ObjectId("51a7dc7b2cacf40b79990be7"), "x" : 2 } { "_id" :
ObjectId("51a7dc7b2cacf40b79990be8"), "x" : 3 }
```

Data Models

- Data in MongoDB has a *flexible schema*.
- *Collections* do not enforce *document* structure.
- This flexibility gives you data-modeling choices to match your application and its performance requirements.
- In other words: Data Modeling for MongoDB Applications documents in the same collection do not need to have the same set of fields or structure, and common fields in a collection’s documents may hold **different types** of data.

Indexes

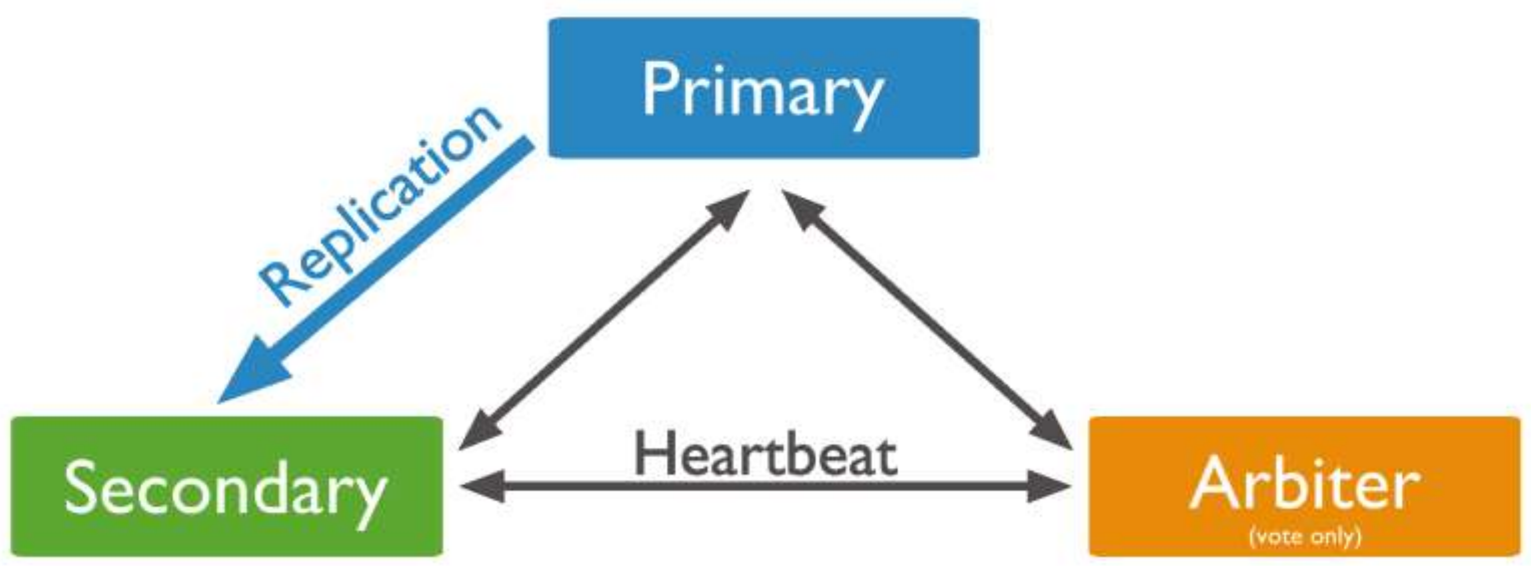
- Indexes provide high performance read operations for frequently used queries.
- Full Index Support - Index on any attribute, just like you're used to.
- Example, **Create an Index on a Single Field:**

```
db.people.ensureIndex( { "phone-number": 1 } )
```

- A value of 1 specifies an index that orders items in ascending order.
- A value of -1 specifies an index that orders items in descending order

Replication

- Replication provides redundancy and increases data availability. Example:



- The primary is the only member in the replica set that receives write operations. A secondary maintains a copy of the primary's data set. Replica sets may have arbiters to add a vote in elections of for primary.

Sharding

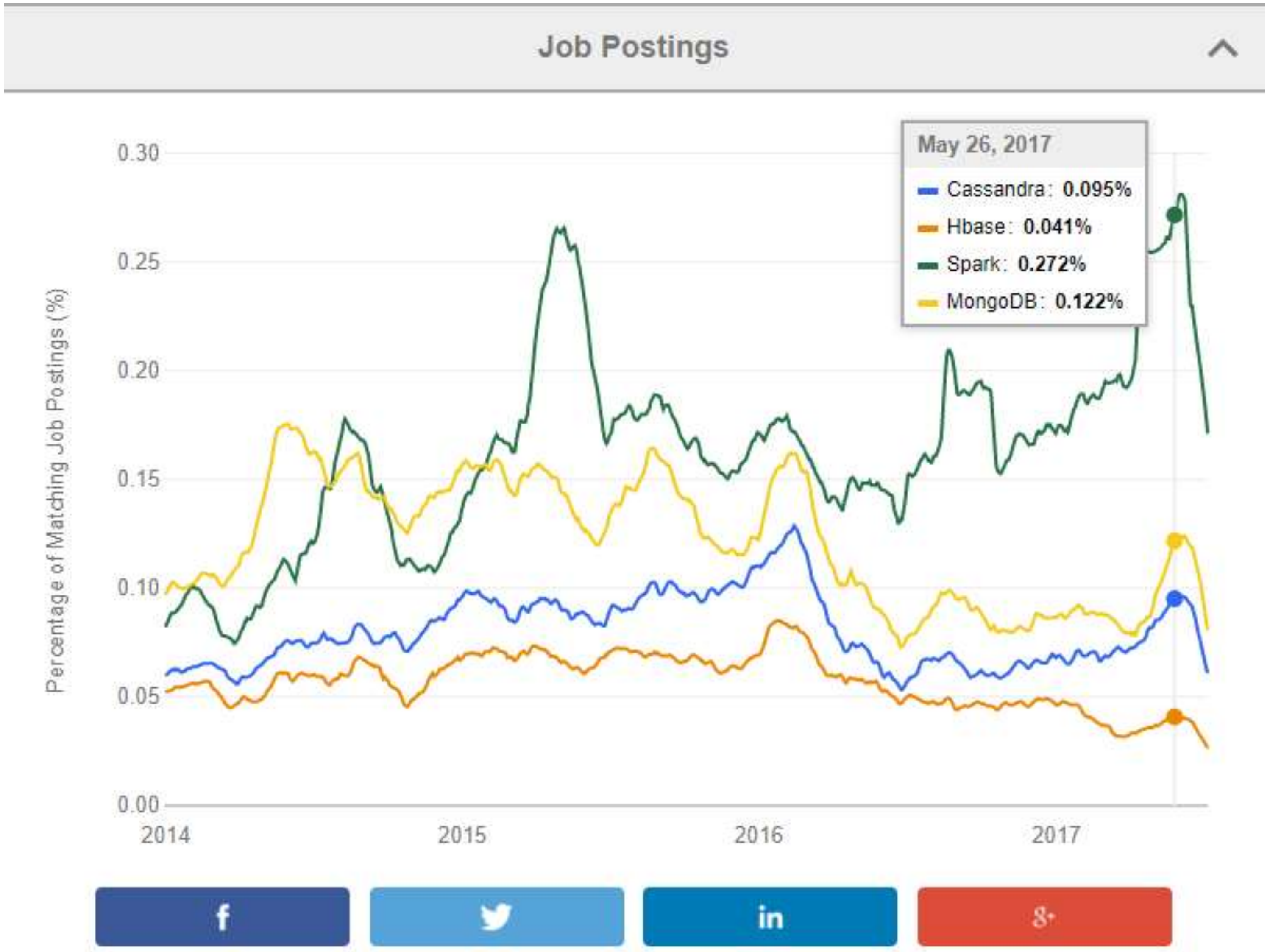
- Sharding is the process of storing data records across multiple machines and is MongoDB’s approach to meeting the demands of data growth.
- As the size of the data increases, a single machine may not be sufficient to store the data nor provide an acceptable read and write throughput.
- Sharding solves the problem with horizontal scaling.
- With sharding, you add more machines to support data growth and the demands of read and write operations.

Java Driver API

```
MongoClient mongoClient = new MongoClient();
mongoClient.close();
DB db = mongoClient.getDB(dbName);
DBCollection dBCollection = db.getCollection(c);
BasicDBObject doc = new BasicDBObject();
doc.put(string1, string2);
newCollection.insert(doc);
collection.ensureIndex(new BasicDBObject("STR", 1),
indexName);
BasicDBObject query = new BasicDBObject();
query.put("_id", new ObjectId(id));
DBObject dbObj = dbCollection.findOne(query);
```

Indeed.com job trend for Cassandra, MongoDB, Hbase, Spark

- If I read this right, HBase skill's are least sought for



HBase

- HBase is a clone of Google's Bigtable, originally created for use with Hadoop (it's actually a subproject of the Apache Hadoop project). In the way that Google's Bigtable uses the Google File System (GFS), HBase provides database capabilities for Hadoop, allowing you to use it as a source or sink for MapReduce jobs. Unlike some other columnar databases that provide eventual consistency, HBase is strongly consistent.
- Perhaps it is interesting to note that Microsoft is a contributor to HBase, following their acquisition of Powerset.
- **Website**: *http://hbase.apache.org*
- **Orientation**: Columnar
- **Created**: HBase was created at Powerset in 2007 and later donated to Apache.
- **Implementation language**: Java
- **Distributed**: Yes. You can run HBase in standalone, pseudodistributed, or fully distributed mode. Pseudodistributed mode means that you have several instances of HBase, but they're all running on the same host.

HBase

- **Storage**: HBase provides Bigtable-like capabilities on top of the Hadoop File System.
- **Schema**: HBase supports unstructured and partially structured data. To do so, data is organized into column families (a term that appears in discussions of Apache Cassandra). You address an individual record, called a "cell" in HBase, with a combination of row key, column family, cell qualifier, and timestamp. As opposed to RDBMS, in which you must define your table well in advance, with Hbase you can simply name a column family and then allow the cell qualifiers to be determined at runtime. This lets you be very flexible and supports an agile approach to development.
- **Client**: You can interact with HBase via Thrift, a RESTful service gateway, Protobuf (see "Additional Features" below), or an extensable JRuby Shell

Hbase (C+P)

- HBase is strongly consistent. Each row is hosted by a single region server at a time, and a combination of row locks and multi-version concurrency control is used to provide consistency within a row.
- During failover, we take care to not allow writes from a new region server until the previous one has been blocked out.
- Replication is taken care of at the HDFS layer.
- HBase will also be completely durable - no edit will be acknowledged to the client until it has been flushed to three HDFS replicas.

HBase is ..

- HBase is an **open-source**, **distributed**, **column-oriented** database built on top of HDFS based on concept developed by Google BigTable!
- A distributed data store that can scale horizontally to 1,000s of commodity servers and petabytes of indexed storage.
- Designed to operate on top of the Hadoop distributed file system (HDFS) for scalability, fault tolerance, and high availability.

HBase Deficiencies

- Tables have one primary index, the *row key*.
- No join operators.
- Scans and queries can select a subset of available columns, perhaps by using a wildcard.
- There are three types of lookups:
  - Fast lookup using row key and optional timestamp.
  - Full table scan
  - Range scan from region start to end.

HBase Is Not ...(2)

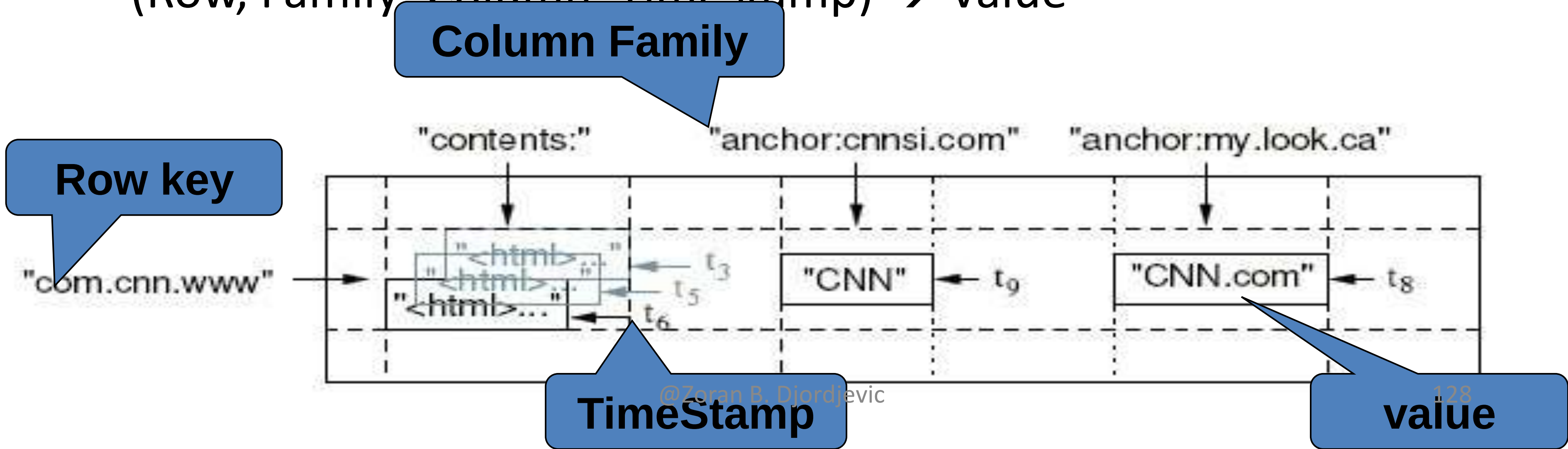
- Limited atomicity and transaction support.
  - HBase supports multiple batched mutations of single rows only.
  - Data is unstructured and untyped.
- Not accessed or manipulated via SQL.
  - Programmatic access via Java, REST, or Thrift APIs.
  - Scripting via JRuby.

Why HBase ?

- HBase is a Bigtable clone.
- It is open source
- It has a good community and promise for the future
- It is developed on top of and has good integration for the Hadoop platform, if you are using Hadoop already.
- *No real indexes*
- *Automatic partitioning*
- *Scale linearly and automatically with new nodes*
- *Commodity hardware*
- *Fault tolerance*
- *Batch processing*

Data Model

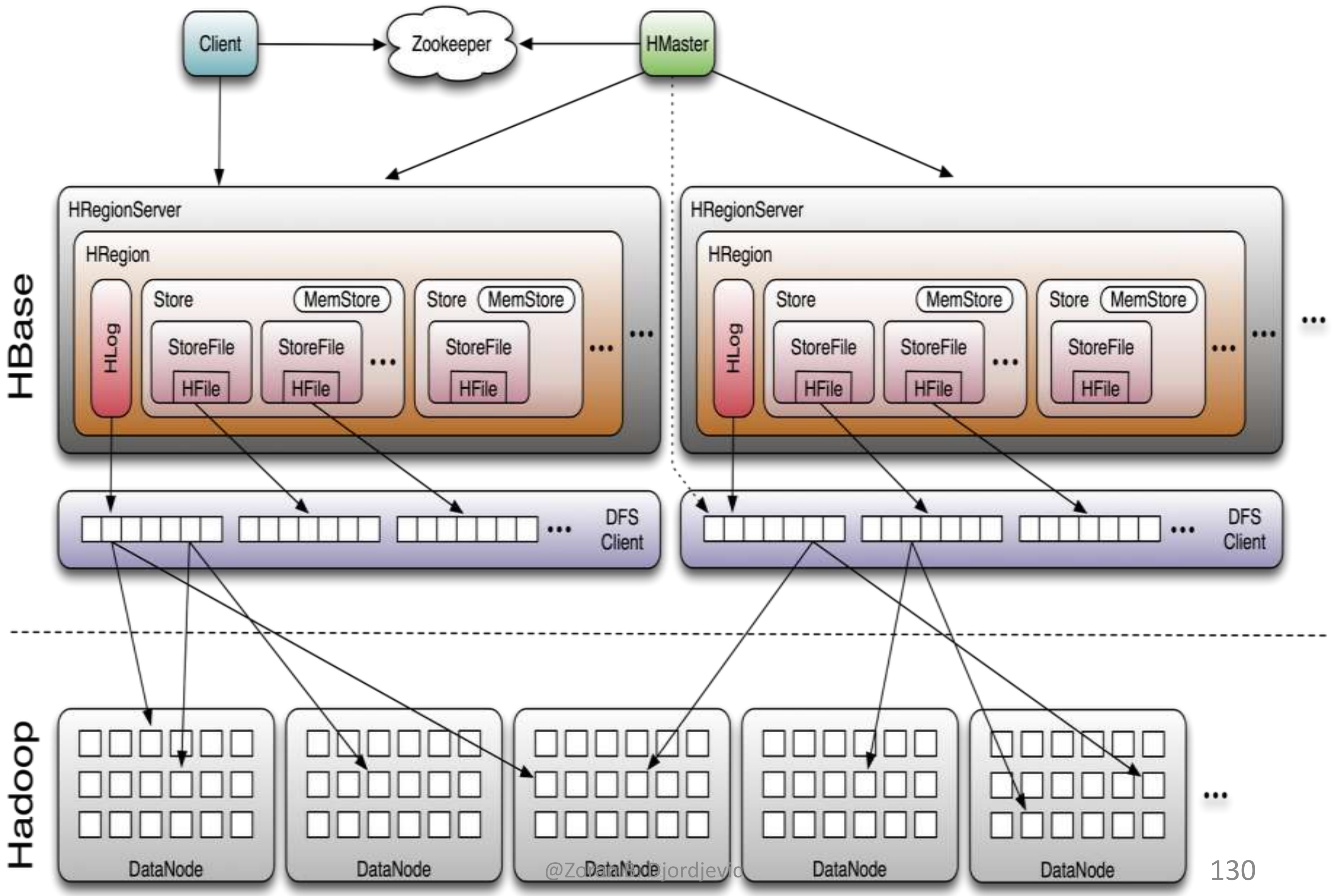
- Tables are sorted by Row
- Table schema only define it's *column families* .
  - Each family consists of any number of columns
  - Each column consists of any number of versions
  - Columns only exist when inserted, NULLs are free.
  - Columns within a family are sorted and stored together
- Everything except table names are byte[]
- (Row, Family: Column, Timestamp) → Value



Hbase Components

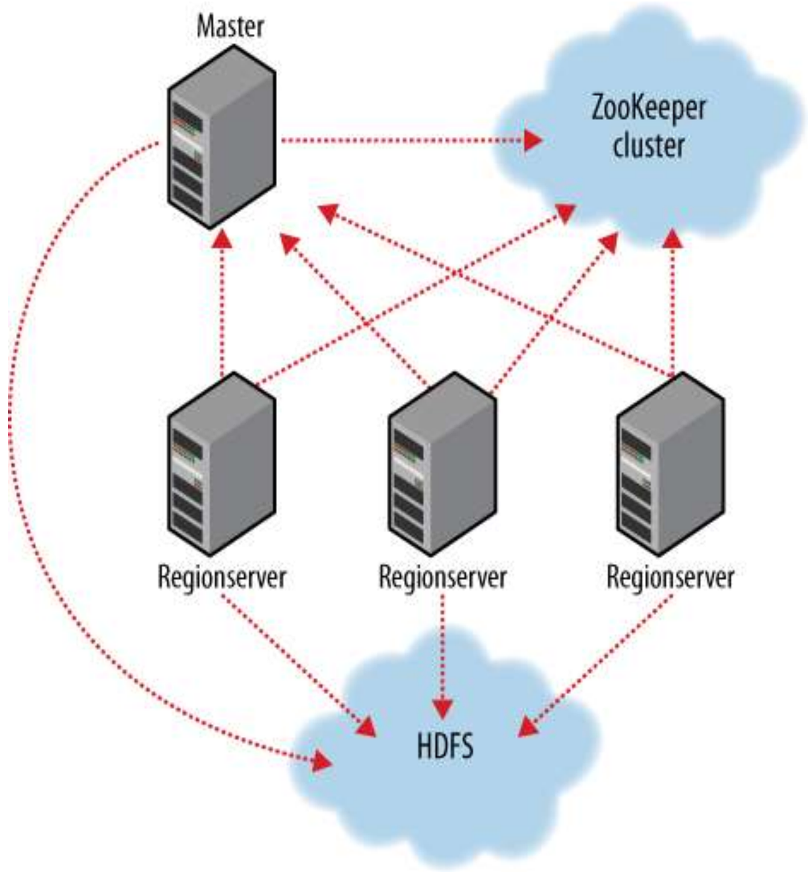
- *Master*
  - Responsible for monitoring region servers
  - Load balancing for regions
  - Redirect client to correct region servers
  - The current SPOF
- *Region Server* slaves
  - Serving requests(Write/Read/Scan) of Client
  - Send HeartBeat to Master
  - Throughput and Region numbers are scalable by region servers

Architecture



HBase uses ZooKeeper

- HBase depends on ZooKeeper and by default it manages a ZooKeeper instance as the authority on cluster state.



Installation (1)

- If you want a distributed system, must have Hadoop in place.
- HBase could work as a standalone system and that is what you want to use for development and initial testing.
- Download the tarball from the Apache HBase website's download section (`http://hbase.apache.org/)`:

```
$ mkdir hbase-install
$ cd hbase-install
$ wget http://apache.claz.org/hbase/hbase-0.92.1/hbase-
0.92.1.tar.gz
$ tar xvfz hbase-0.92.1.tar.gz
$export HBASE_HOME=`pwd`/hbase-0.92.1
```

- Once that's done, you can spin up HBase using the provided scripts:

```
$ $HBASE_HOME/bin/start-hbase.sh
starting master, logging to .../hbase-0.92.1/bin/../logs/...-
master out
```

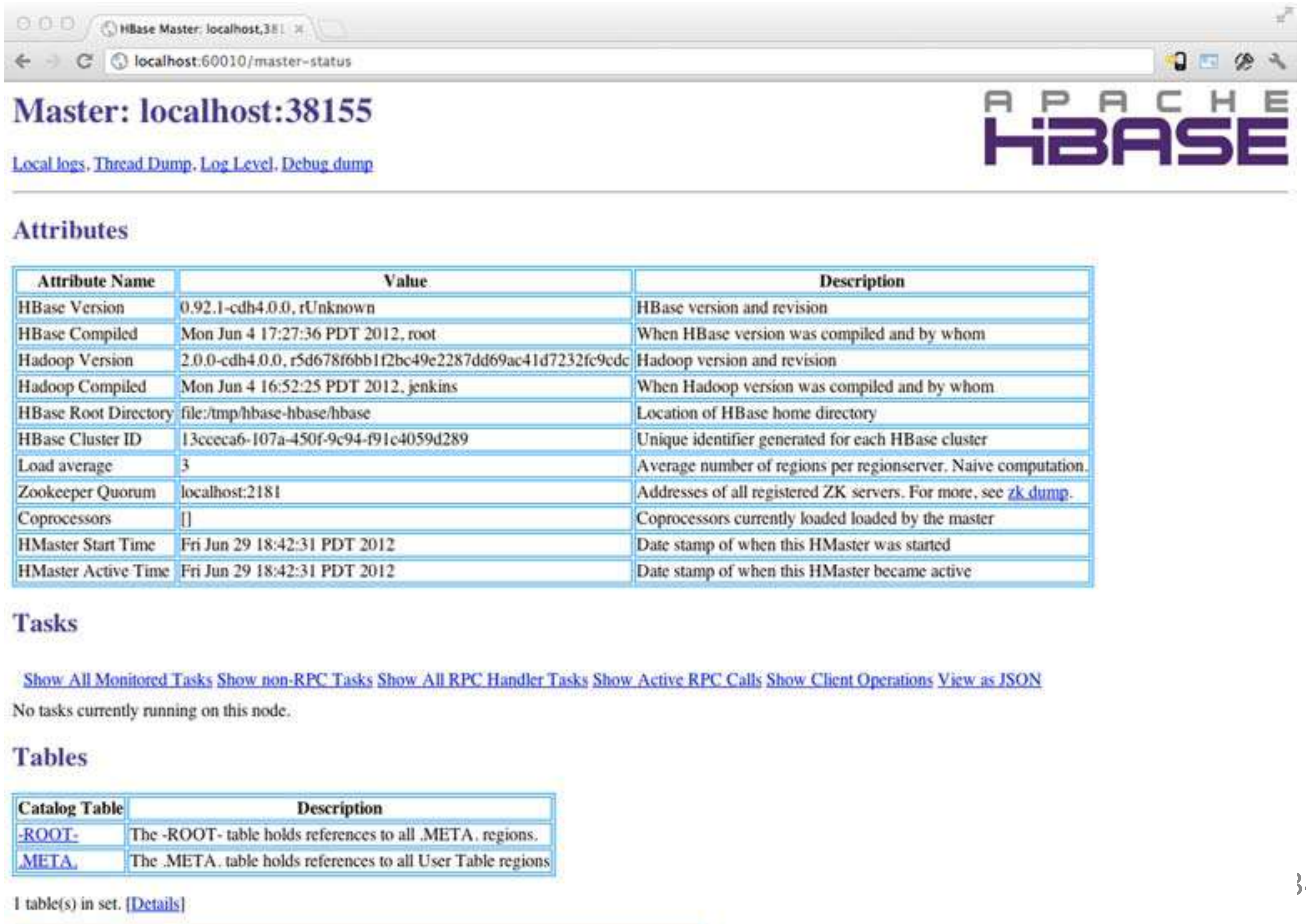
Setup

- If you want, you can also put `$HBASE_HOME/bin` in your PATH so you can simply run `hbase` rather than `$HBASE_HOME/bin/hbase` next time.
- That's all there is to it. You just installed HBase in *standalone* mode.
- The configurations for HBase primarily go into two files: `hbase-env.sh` and `hbase-site.xml.`
- These exist in the `/etc/hbase/conf/` directory.
- By default in standalone mode, HBase writes data into `/tmp`, which isn't the most durable place to write to.
- You can edit the `hbase-site.xml` file and put the following configuration into it to change that location to a directory of your choice:

```
<property>
   <name>hbase.rootdir</name>
   <value>file:///home/user/myhbasedirectory/</value>
</property>
```

Examine HBase, Master Status Page

- Your HBase install has a management console of sorts running on `http://localhost:60010.`



HBase Master: localhost,38

localhost:60010/master-status

Master: localhost:38155

Local logs, Thread Dump, Log Level, Debug dump

Attributes

Attribute Name	Value	Description
HBase Version	0.92.1-cdh4.0.0, rUnknown	HBase version and revision
HBase Compiled	Mon Jun 4 17:27:36 PDT 2012, root	When HBase version was compiled and by whom
Hadoop Version	2.0.0-cdh4.0.0, r5d678f6bb1f2bc49e2287dd69ac41d7232fc9cdc	Hadoop version and revision
Hadoop Compiled	Mon Jun 4 16:52:25 PDT 2012, jenkins	When Hadoop version was compiled and by whom
HBase Root Directory	file:/tmp/hbase-hbase/hbase	Location of HBase home directory
HBase Cluster ID	13cceca6-107a-450f-9c94-f91c4059d289	Unique identifier generated for each HBase cluster
Load average	3	Average number of regions per regionserver. Naive computation.
Zookeeper Quorum	localhost:2181	Addresses of all registered ZK servers. For more, see zk dump.
Coprocessors	[]	Coprocessors currently loaded loaded by the master
HMaster Start Time	Fri Jun 29 18:42:31 PDT 2012	Date stamp of when this HMaster was started
HMaster Active Time	Fri Jun 29 18:42:31 PDT 2012	Date stamp of when this HMaster became active

Tasks

Show All Monitored Tasks Show non-RPC Tasks Show All RPC Handler Tasks Show Active RPC Calls Show Client Operations View as JSON

No tasks currently running on this node.

Tables

Catalog Table	Description
-ROOT-	The -ROOT- table holds references to all .META. regions.
.META.	The .META. table holds references to all User Table regions

1 table(s) in set. [Details]

Testing (4)

```
$ hbase shell
> create 'test', 'data'
0 row(s) in 4.3066 seconds
> list
test
1 row(s) in 0.1485 seconds
> put 'test', 'row1', 'data:1', 'value1'
0 row(s) in 0.0454 seconds
> put 'test', 'row2', 'data:2', 'value2'
0 row(s) in 0.0035 seconds
> put 'test', 'row3', 'data:3', 'value3'
0 row(s) in 0.0090 seconds
```

```
> scan 'test'
ROW COLUMN+CELL
row1 column=data:1, timestamp=1240148026198,
        value=value1
row2 column=data:2, timestamp=1240148040035,
        value=value2
row3 column=data:3, timestamp=1240148047497,
        value=value3
3 row(s) in 0.0825 seconds
> disable 'test'
09/04/19 06:40:13 INFO client.HBaseAdmin: Disabled
        test
0 row(s) in 6.0426 seconds
> drop 'test'
09/04/19 06:40:17 INFO client.HBaseAdmin: Deleted
        test
0 row(s) in 0.0210 seconds
> list
0 row(s) in 2.0645 seconds
```

Connecting to HBase

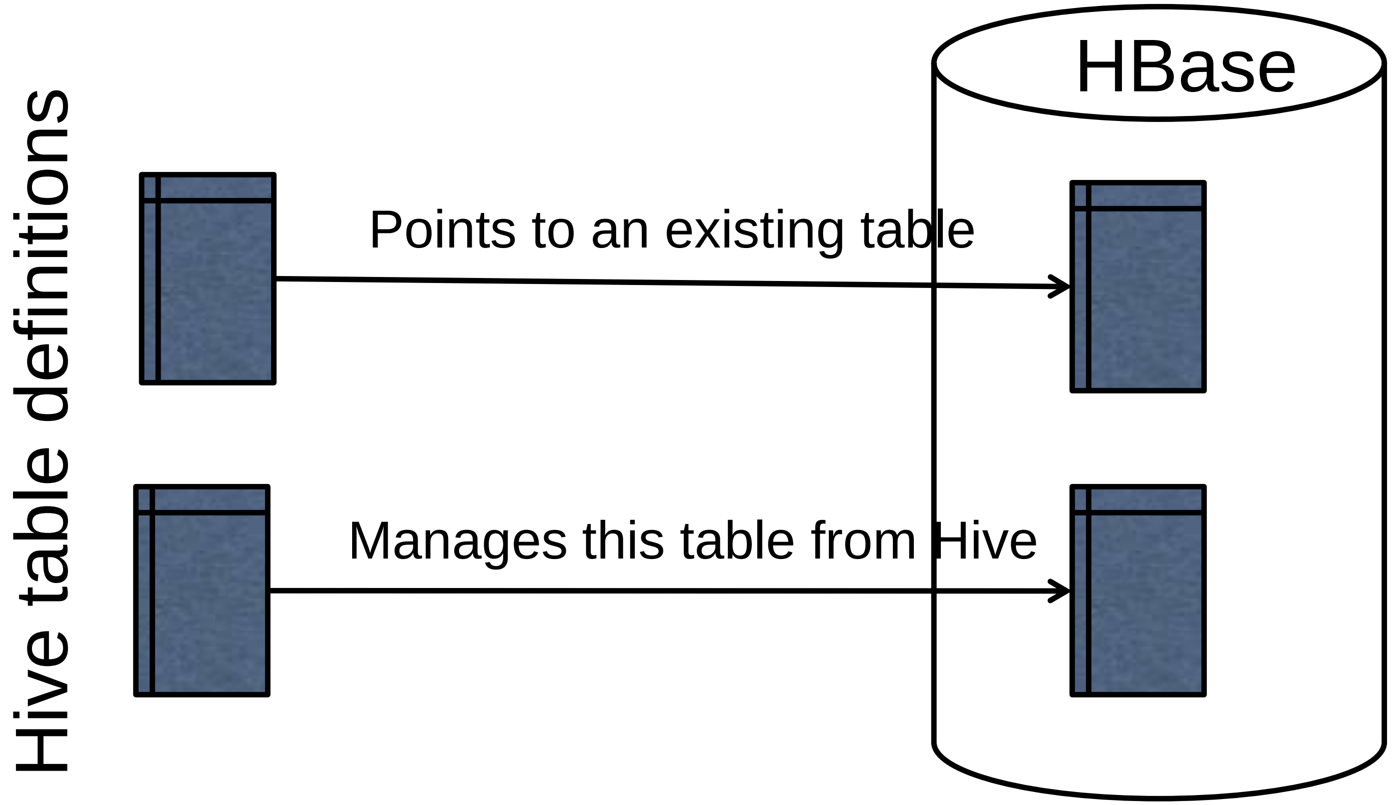
- Java client
  - *get(byte [] row, byte [] column, long timestamp, int versions);*
- Non-Java clients
  - Thrift server hosting HBase client instance
- Sample ruby, c++, & java (via thrift) clients
  - REST server hosts HBase client
- TableInput/OutputFormat for MapReduce
  - HBase as MR source or sink
- HBase Shell
  - JRuby IRB with “DSL” to add get, scan, and admin
  - *./bin/hbase shell YOUR_SCRIPT*

Hive and HBase Could be Integrated

- Reasons to use Hive on HBase:
  - A lot of data sitting in HBase due to its usage in a real-time environment, but never used for analysis
  - Give access to data in HBase usually only queried through MapReduce to people that don’t code (business analysts)
  - When needing a more flexible storage solution, so that rows can be updated live by either a Hive job or an application and can be seen immediately to the other

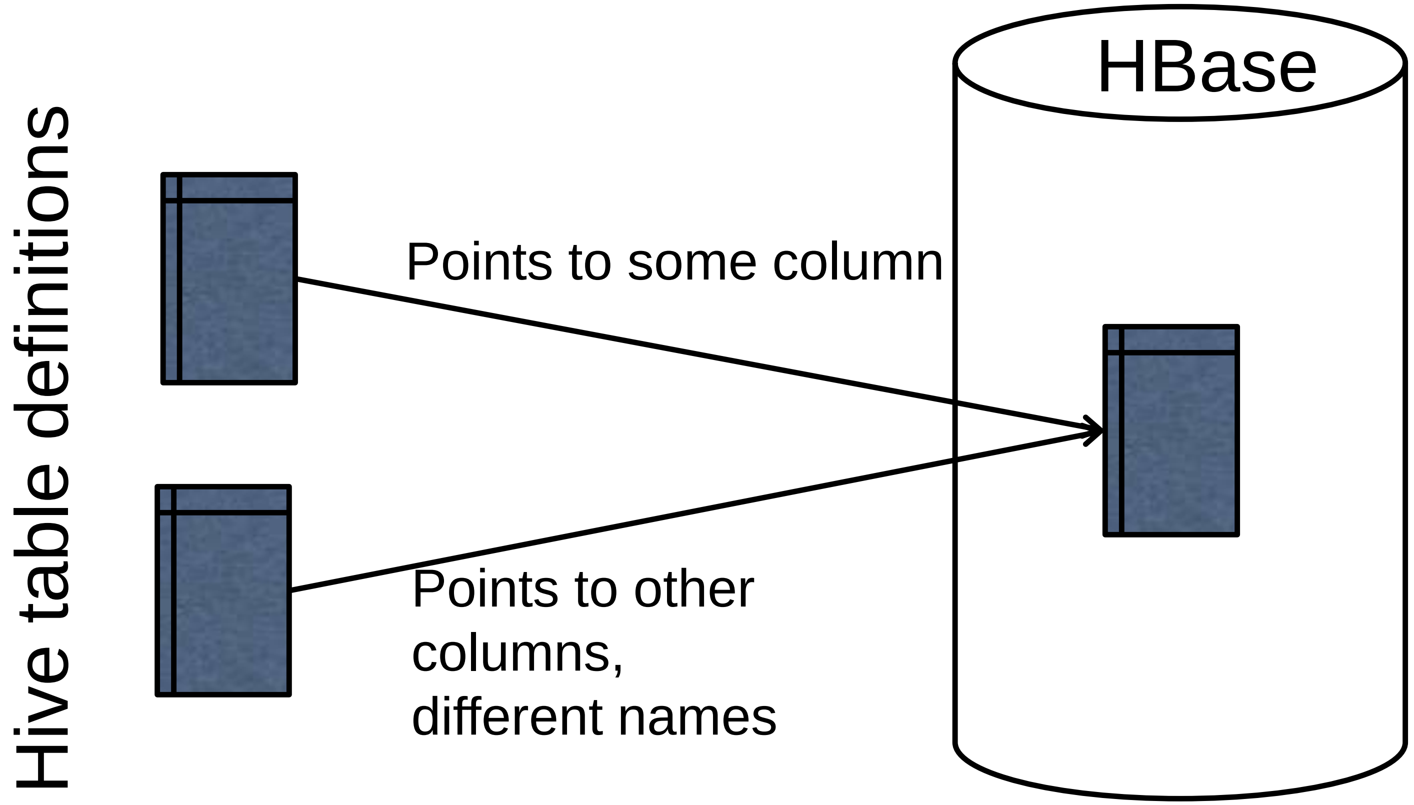
Integration

- Hive can use tables that already exist in HBase or manage its own ones, but they still all reside in the same HBase instance



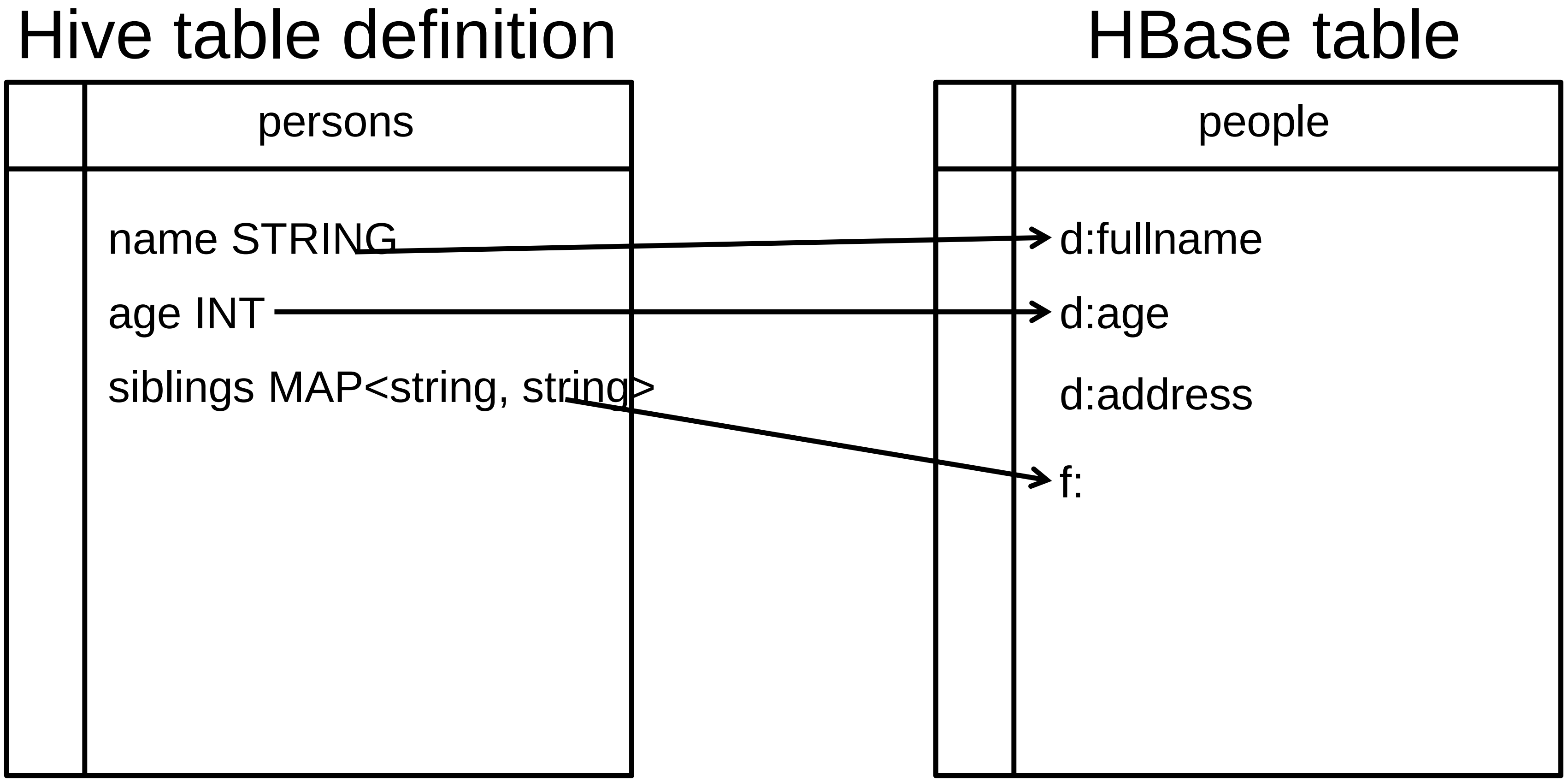
Integration

- When using an already existing table, defined as EXTERNAL, you can create multiple Hive tables that point to it



Integration

- Columns are mapped however you want, changing names and giving types



Using a simple table in HBase:

```
CREATE EXTERNAL TABLE blocked_users(
 userid INT,
 blockee INT,
 blocker INT,
 created BIGINT)
STORED BY 'org.apache.hadoop.hive.hbase.HBaseStorageHandler’
WITH SERDEPROPERTIES ("hbase.columns.mapping" =
 ":key,f:blockee,f:blocker,f:created")
TBLPROPERTIES("hbase.table.name" = "m2h_repl-
userdb.stumble.blocked_users");
```

- HBase is a special case here, it has a unique row key map with :key
- Not all the columns in the table need to be mapped

Using a complicated table in HBase:

```
CREATE EXTERNAL TABLE ratings_hbase(
 userid INT,
 created BIGINT,
 urlid INT,
 rating INT,
 topic INT,
 modified BIGINT)
STORED BY
'org.apache.hadoop.hive.hbase.HBaseStorageHandler’
WITH SERDEPROPERTIES ("hbase.columns.mapping" =
":key#b@0,:key#b@1,:key#b@2,default:rating#b,default:topic#
b,default:modified#b")
TBLPROPERTIES("hbase.table.name" = "ratings_by_userid");
```

#b means binary, @ means position in composite key

HBase Provides Low-latency Random Access

HBase provides Low-latency Random Access

Writes:

- 1-3ms, 1k-10k writes/sec per node

Reads:

- 0-3ms cached, 10-30ms disk
- 10-40k reads / second / node from cache

Cell size:

- 0-3MB preferred
- Read, write and insert data anywhere in the table
- No sequential write limitations