Examples of exam question types

Databases for Big Data

NoSQL data stores and techniques

?Explain the main reasons for why NoSQL data stores appeared.

List and describe the main characteristics of NoSQL data stores.

1.A broad category of disparate solutions

2.simple and flexible non-relational data models

3.High availability & relax data consistency requirement (CAP theorem)

4.Easy to distribute – horizontal scalability

5.Data are replicated to multiple nodes

6.Cheap & easy (or not) to implement (open source)

Explain the difference between ACID and BASE properties.

ACID: properties needed to guarantee consistency and availability

• Atomicity ☾ A transaction is an atomic unit: It is either executed completely or not at all

• Consistency ☾ A database that is in a consistent state before the execution of a transaction, is also in a consistent state after the execution of the transaction

• Isolation ☾ A transaction should act as if it is executed in isolation from the other transactions

• Durability ☾ Changes in the database made by a committed transaction are permanent

BASE: properties come into play if availability and partition tolerance is favored (schema-free, easy replication support, simple API, eventually consistent/BASE)

• Basically Available ☾ an application works basically all the time (despite partial failures)

• Soft State ☾ is in flux and non-deterministic (changes all the time)

• Eventual Consistency ☾ will be in some consistent state (at some time in future)

?Discuss the trade-off between consistency and availability in a distribute data store setting.

Discuss different consistency models and why they are needed.

• Strong consistency – after the update completes, any subsequent access will return the updated value.

• Weak consistency – the system does not guarantee that subsequent accesses will return the updated value.

– inconsistency window

• Weak consistency

– Eventual consistency – if no new updates are made to the object, eventually all accesses will return the last updated value

• Popular example: DNS

Explain how **consistency** between **replicas** is achieved in a distributed data store.

N – number of nodes that store replicas

R – number of nodes for a successful read

W – number of nodes for a successful write

R + W > N strong consistency: Consistency (& reduced availability)

W=N – R + W ⩽ N eventual consistency: Inconsistency window – the period until all replicas have been updated in a lazy manner

Explain the **CAP theorem**.
CAP Theorem: Consistency, Availability, Partition Tolerance

Explain the differences between **vertical and horizontal scalability**.
Scalability: system can handle growing amounts of data without losing performance.
• Vertical Scalability (scale up)
– add resources (more CPUs, more memory) to a single node
– using more threads to handle a local problem
• Horizontal Scalability (scale out)
– add nodes (more computers, servers) to a distributed system
– gets more and more popular due to low costs for commodity hardware
– often surpasses scalability of vertical approach

Explain how **consistent hashing** works and what are the problems it addresses.
distributed data storage, replication (how to distribute the data) Consistent hashing
• find machine that stores data for a specified key k
• trivial hash function to distribute data on n nodes: h(k; n) = k mod n
• if number of nodes changes, all data will have to be redistributed!

Explain how **vector clocks** work and what are the problems they address.
– VC1: Initially, Vi [j] = 0, for i , j = 1, 2, ... N
– VC2: Just before pi timestamps an event, it sets Vi [i] := Vi [i] + 1
– VC3: pi includes the value t = Vi in every message it sends
– VC4: When pi receives a timestamp t in a message, it sets Vi [j] := max(Vi [j]; t [j]), for j = 1, 2, ... N

List and describe dimensions that can be used to classify NoSQL data stores.(HBase)
• Data model – how the data is stored
• Storage model – in-memory vs persistent
• Consistency model – strict, eventual consistent, etc.
    – Affects reads and writes requests
• Physical model – distributed vs single machine
• Read/Write performance – what is the proportion between reads and writes
• Secondary indexes - sort and access tables based on different fields and sorting orders
• Failure handling – how to address machine failures
• Compression – result in substantial savings in raw
storage
• Load balancing – how to address high read or write rate
• Atomic read-modify-write – difficult to achieve in a distributed system
• Locking, waits and deadlocks – locking models and version control

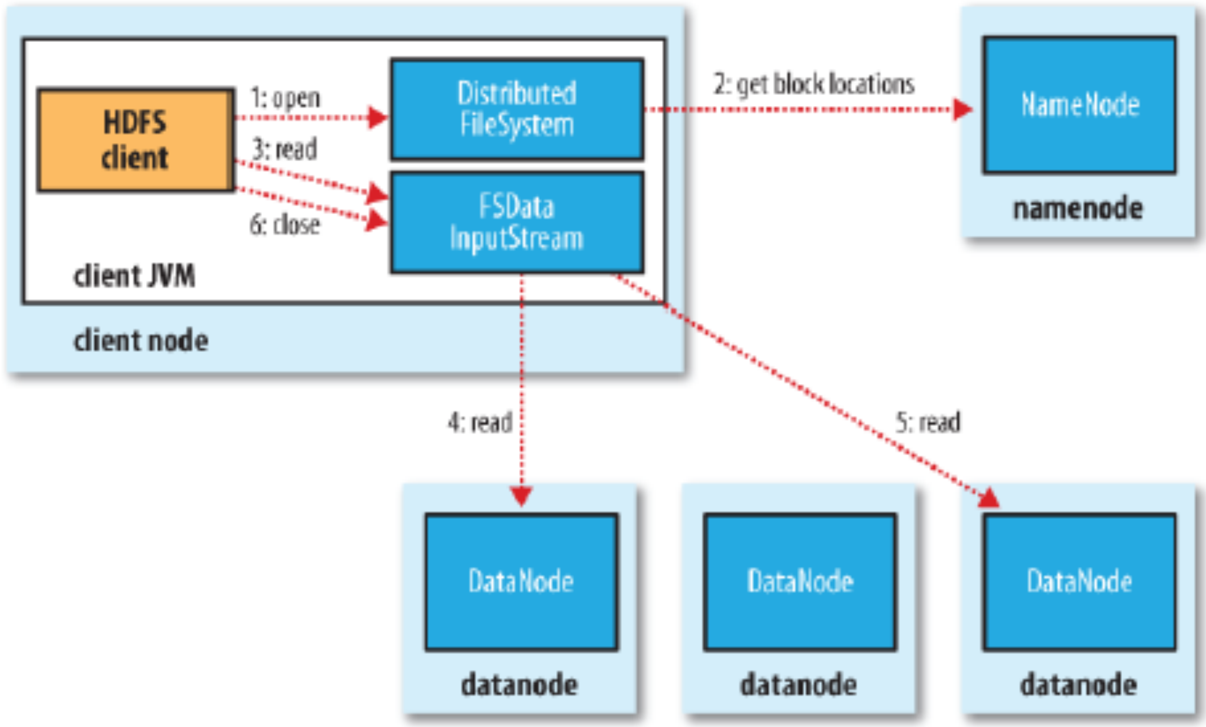
List and describe the main characteristics and applications of NoSQL data stores according to their data models.
(Impacts application, querying, scalability)
• Key-Value Stores
Characteristics:
Schema-free
– Keys are unique
– Values of arbitrary types
Efficient in storing distributed data
Limited query facilities and indexing
– get(key),put(key,value)
– Value ☾ opaque to the data store ☾ no data level querying and indexing
Applications:
– Storingwebsessioninformation
– User profiles and configuration
– Shoppingcartdata
– Using them as a caching layer to store results of expensive operations (create a user-tailored web page)
• Document Stores
• Schema-free
– Keys are unique
– Values are documents – complex (nested) data structures in JSON, XML, binary (BSON), etc.
• Indexing and querying based on primary key and content
• The content needs to be representable as a document
• MongoDB, CouchDB, Couchbase
• Applications:
– Items with similar nature but
different structure
– Bloggingplatforms
– Contentmanagementsystems
– Eventlogging
– Fast application development
• Column-Family Stores
• Schema-free
– Rows have unique keys
– Values are varying column families and act as keys for the columns they hold
– Columns consist of key-value pairs
• Better than key-value stores for querying and indexing
• Types
– Googles BigTable, Hadoop HBase
– No column families –
Amazon SimpleDB, DynamoDB
– Supercolumns-Cassandra
• Graph Databases
• Graph model
– Nodes/verticesandlinks/edges

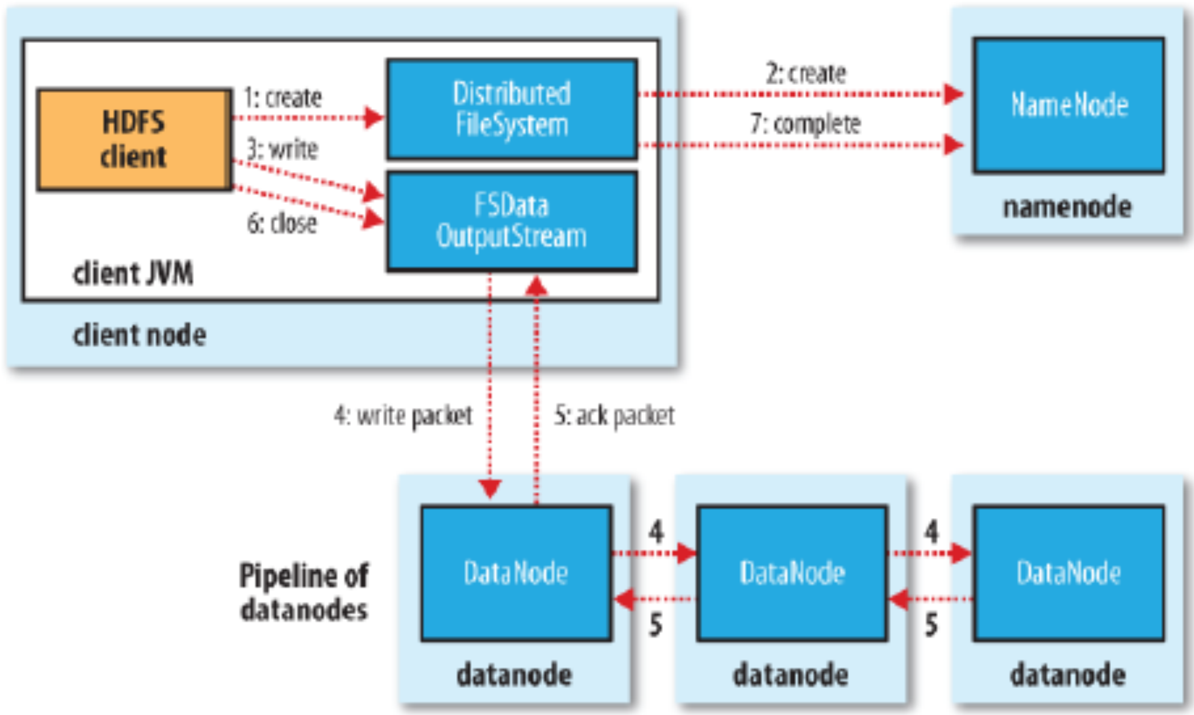
– Properties consisting of key-value pairs
• Suitable for very interconnected data since they are efficient in traversing relationships
• Not as efficient
– as other NoSQL solutions for non-graph applications – horizontal scaling
• Applications:
– location-basedservices
– recommendationengines
– complexnetwork-basedapplications
• social, information, technological, and biological network
– memory leak detection

HDFS
Explain what HDFS is and for what types of applications it is (not) good for.
• Runs on top of the native file systems
  – Files are very large divided into 128 MB chunks
• To minimize the cost of seeks
  – Caching blocks is possible
  – Singlewriter,multiplereaders
  – Exposes the locations of file blocks via API
  – Usually replicated three times on different compute nodes
• Handles failures – disk/node/rack failures
• Based on GFS (Google File System - proprietary)
Good for ...
• Store very large files – GBs and TBs
• Streaming access
  – Write-once,readmanytimes
  – Time to read the entire dataset is more important than the latency in reading the first record.
• Commodity hardware
  – Clusters are built from commonly available hardware
  – Designed to continue working without a noticeable interruption in case of failure
Not Good for ...
• Low-latency data access
  – HDFS is optimized for delivering high throughput of data
• Lots of small files
  – the amount of files is limited by the memory of the
namenode; blocks location is stored in memory
• Multiple writers and arbitrary file modifications
  – HDFS files are append only – write always at the end of the file
Explain the organization of HDFS.
• Namenode (master)
  – Manages the filesystem namespace and metadata
  – Stores in memory the location of all blocks for a given file
• Datanodes (workers)
  – Storeandretrieveblocks
  – Sendheartbeattothenamenode

- Secondary namenode
    - Periodically merges the namespace image with the edit log – Not a backup for a namenode, only a checkpoint

Explain the process of reading and writing to HDFS.





Explain how high availability is achieved in HDFS.

- The namenode is single point of failure:
    - Ifanamenodecrashestheclusterisdown
- Secondary node

  - – periodically merges the namespace image with the edit log to prevent the edit log from becoming too large.
  - – lags the state of the primary prevents data loss but does not provide high availability
  - – time for cold start 30 minutes
- • In practice, the case for planned downtime is more important
- • Pair of namenodes in an active stand-by configuration:
  - – Highly available shared storage for the shared edit log
  - – Datanodes send block reports to all namenodes
  - – Clients must provide transparent to the user mechanism to handle failover
  - – The standby node takes checkpoints of the active namenode namespace instead of the secondary node

Dynamo

Explain the data model and list main applications of Dynamo.

- • Highly-available key-value store
- • CAP: Availability and Partition Tolerance
- • Use case: customer should be able to view and add to the shopping cart during various failure scenarios
  - – always serve writes and reads
- • Many Amazon services only need primary-key access
  - – Best seller lists
  - – Customer preferences – Product catalog

Example: a single page is rendered employing the responses from over 150 services

Explain the Dynamo design considerations and what are the advantages of Dynamo in comparison to RDBMSs.

not RDBMS?

- • Amazon's services often store and retrieve data only by key
  - – thus do not need complex querying and managing functionalities
- • Replication technologies usually favor consistency, not availability
- • Cannot scale out easily

Explain how basic NoSQL techniques are applied in Dynamo.

NoSQL: Techniques – Consistent Hashing [Karger]

Basic idea:

- • arrange the nodes in a ring
- • include hash values of all nodes in hash structure
- • calculate hash value of the key to be added/retrieved
- • choose node which occurs next clockwise in the ring
- • if node is dropped or gets lost, missing data is redistributed to adjacent nodes
- • if a new node is added, its hash value is added to the hash table
- • the hash realm is repartitioned, and hash data will be transferred to new neighbor

⟶ no need to update remaining nodes!

Explain versioning and semantic reconciliation in Dynamo.
• Asynchronous update propagation
• Use case: shopping cart
• Each update is a new, immutable version --> many versions of an object may exist
• Replicas eventually become consistent
• Reconciliation
  – Syntactic
  – Semantic
• Vector clocks
  – Client specifies which version is updating
  – All leave objects are returned if syntactic reconciliation fails

HBase
?Explain the difference between column-oriented and row-oriented storage.
Column-oriented Databases
• Saved data grouped by columns
• Not all values are needed for some
queries/applications
  – Analytical databases
• Leads to
  – Reduced I/O
  – Better compression due to similar values

Explain the data model of HBase.
HBase – a Column-family Database
• Hosts very large sparse tables
• Based on Google BigTable and built on top of HDFS
• Provide low-latency real-time read/write random access on a (sequence of) cell level
• Scales linearly on commodity hardware
• Atomic access to row data
• CAP: provides strong consistency and partition tolerance --> sacrifices availability
• Started at the end of 2006, in May 2010 became Apache Top Level Project

Give example applications of HBase.
Facebook,
(– Facebook Messaging - High write throughput
– Facebook Insights – Real-time analytics
– Facebook Metric System - Fast reads of Rrecent data and table scans)
Adobe, StumbleUpon, Twitter, and groups at Yahoo!
Hive and Shark/SparkSQL

Explain the problem that Hive and Shark/SparkSQL address.
• MapReduce programming model is low level
• Hadoop/Spark lacks expressiveness
  – end users need to write code even for simplest aggregations, hard to maintain and reuse
• Many experienced SQL developers
• Business intelligence tools already provide SQL interfaces

Explain the data model of Hive and Shark/SparkSQL.
Hive
• Shark project started around 2011
    – built on the Hive codebase
    – swaps Hadoop with Spark • SparkSQL
    – Shark code base hard to optimize and maintain
    – Shark and Hive compatible
• Hive's SQL dialects, UDF (user-defined functions) & nested data types

?Discuss the trade-off between schema-on-read and schema-on-write approaches.

?Explain the difference between OLAP(online analyst processing) and OLTP(online transaction processing).

Explain the main differences between Hive and Shark and what are the advantages they lead to.

Explain how fault tolerance is achieved in Shark/SparkSQL.
• Main-memory databases
    – track fine-grained updates to tables
    – replicate writes across the network
    – expensive on large commodity clusters
• Shark
    – tracks coarse-grained operations, eg, map, join, etc.
    – recovers by tracking the lineage of each dataset and recomputing lost data
    – supports machine learning and graph computations

Parallel Computing
PAR-Q1: Define the following technical terms:
(Be thorough and general. An example is not a definition.)

Cluster (in high-performance resp. big-data computing)
Aggregate LOTS of computers ‡ Clusters
l Need scalable parallel algorithms
l Need to exploit multiple levels of parallelism
l Fault tolerance
?Parallel work (of a parallel algorithm)

Parallel speed-up
the factor by how much faster we can solve a problem with p processors than with 1 processor, usually in range (0«p)
Parallel efficiency = Speed-up / #processors, usually in (0«1)

?Communication latency (for sending a message from node Pi to node Pj)

Temporal data locality
re-access same data element multiple times within a short time interval

?Dynamic task scheduling

PAR-Q2: Explain the following parallel algorithmic paradigm: Parallel Divide-and-Conquer.
Recursive calls can be done in parallel.
Parallelize, if possible, also the divide and combine phase.
Switch to sequential divide-and-conquer when enough parallel tasks have been created.

?PAR-Q3: Discuss the performance effects of using large vs. small packet sizes in streaming.

?PAR-Q4: Why should servers (cluster nodes) in datacenters that are running I/O-intensive tasks (such as file/database accesses) get (many) more tasks to run than they have cores?

?PAR-Q5: In skeleton programming, which skeleton will you need to use for computing the maximum element in a large array? Sketch the resulting pseudocode (explain your code).

PAR-Q6: Describe the advantages/strengths and the drawbacks/limitations of high-level parallel programming using algorithmic skeletons.
advantages/strengths:
Abstraction, hiding complexity (parallelism and low-level programming)
Parallelization for free
Easier to analyze and transform
drawbacks/limitations:
Enforces structuring, restricted set of constructs
Requires complete understanding and rewriting of a computation
Available skeleton set does not always fit
May lose some efficiency compared to manual parallelization

PAR-Q7: Derive Amdahl's Law and give its interpretation.
Consider execution (trace) of parallel algorithm A:

sequential part A^s where only 1 processor is active
parallel part A^p that can be sped up perfectly by p processors

$\rightarrow$ total work $w_A(n) = w_{A^s}(n) + w_{A^p}(n)$, time $T = T_{A^s} + \frac{T_{A^p}}{p}$,

Amdahl's Law

If the sequential part of A is a *fixed* fraction of the total work irrespective of the problem size n, that is, if there is a constant β with

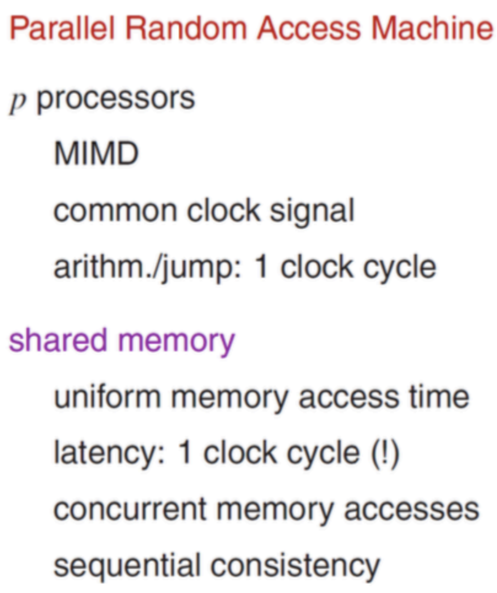
$$\beta = \frac{w_{A^s}(n)}{w_A(n)} \leq 1$$

the relative speedup of A with p processors is limited by

$$\frac{p}{\beta p + (1-\beta)} < 1/\beta$$

?PAR-Q8: What is the difference between relative and absolute parallel speed-up? Which of these is expected to be higher?

PAR-Q9: The PRAM (Parallel Random Access Machine) computation model has the simplest-possible parallel cost model. Which aspects of a real-world parallel computer does it represent, and which aspects does it abstract from?



Parallel Random Access Machine

p processors

- MIMD
- common clock signal
- arithm./jump: 1 clock cycle

shared memory

- uniform memory access time
- latency: 1 clock cycle (!)
- concurrent memory accesses
- sequential consistency

PAR-Q10: Which property of streaming computations makes it possible to overlap computation with data transfer?
Streaming applies pipelining to processing of large (possibly, infinite) data streams from or to memory, network or devices, usually partitioned in fixed-sized data packets.
in order to overlap the processing of each packet of data in time with access of subsequent units of data and/or processing of preceding packets of data.

MapReduce
MR-Q1: A MapReduce computation should process 12.8 TB of data in a distributed file with block (shard) size 64MB. How many mapper tasks will be created, by default? (Hint: 1 TB (Terabyte) = 10^12 byte)
Large files are distributed (”sharded” = split into blocks of e.g. 64MB (shards) and spread out across cluster nodes)

MR-Q2: Discuss the design decision to offer just one MapReduce construct that covers both mapping, shuffle, sort and reducing. Wouldn't it be easier to provide one separate construct for each phase instead? What would be the performance implications of such a design operating on distributed files?

MR-Q3: Reformulate the wordcount example program to use no Combiner.

MR-Q4: Consider the local reduction performed by a Combiner: Why should the user-defined Reduce function be associative and commutative? Give examples for reduce functions that are associative and commutative, and such that are not.

MR-Q5: Extend the wordcount program to discard words shorter than 4 characters.

MR-Q6: Write a wordcount program to only count all words of odd and of even length. (There are several possibilities.)

MR-Q7: Show how to calculate a database join with MapReduce.

MR-Q8: Sometimes, workers might be temporarily slowed down (e.g. repeated disk read errors) without being broken. Such workers could delay the completion of an entire MapReduce computation considerably. How could the master speed up the overall MapReduce processing if it observes that some worker is late?

Spark-Q1: Why can MapReduce emulate any distributed computation?

Spark-Q2: For a Spark program consisting of 2 subsequent Map computations, show how Spark execution differs from Hadoop/Mapreduce execution.

Spark-Q3: Given is a text file containing integer numbers. Write a Spark program that adds them up.

Spark-Q4: Write a wordcount program for Spark. (Solution proposal: see last slide in lecture 8.)

Spark-Q5: Modify the wordcount program by only considering words with at least 4 characters.

Cluster Resource Management
YARN-Q1: Why is it reasonable that Application Masters can request and return resources dynamically from/to the Resource Manager (within the maximum lease initially granted to their job by the RM), instead of requesting their maximum lease on all nodes immediately and keeping it throughout the job's lifetime? Contrast this mechanism to the resource allocation performed by batch queuing systems for clusters.
YARN-Q2: Explain why the Node Manager's tasks are better performed in a daemon process controlled by the RM and not under the control of the framework-specific application.

Machine Learning for Big Data
Implement in MapReduce or Spark a machine learning algorithm,
e.g.
logistic regression,
k-means,
EM algorithm,
support vector machines,
neural nets, etc.

(The pseudo-code of the algorithm will be provided in the exam.)