Lecture 10

Big Data Storage Technologies

Dr. Lydia Wahid

Agenda

- Introduction
- On-Disk Storage:
  - Distributed File System
  - RDBMS Databases
  - NoSQL Databases
  - NewSQL Databases
- In-Memory Storage:
  - In-Memory Data Grids
  - In-Memory Database (Relational, NoSQL, NewSQL)

Introduction

Introduction

- Storage technology has continued to evolve over time.
- The need to **store Big Data** has radically altered the relational, database-centric view that has been embraced by Enterprise ICT.
- The bottom line is that relational technology is simply **not scalable** in a manner to support **Big Data volumes**.
- Also, businesses can find genuine value in processing **semi-structured** and **unstructured** data, which are generally **incompatible** with relational approaches.

Introduction

- Big Data has pushed the storage boundary to unified views of the available memory and **disk storage** of a cluster.
- If more storage is needed, horizontal scalability allows the expansion of the cluster through the addition of **more nodes**.
- Innovative approaches deliver **realtime** analytics via **in-memory storage**.
- Even **batch-based processing** is accelerated by the performance of Solid State Drives (SSDs), which have become less expensive.

On-Disk Storage

On-Disk Storage

- On-disk storage generally utilizes **low cost** hard-disk drives for long-term storage.

- On-disk storage can be implemented via a **distributed file system** or a **database**.

On-Disk Storage: Distributed File Systems

On-Disk Storage: Distributed File Systems

- Distributed file systems, like any file system, support **schema-less** data storage.
- In general, a distributed file system storage device provides **redundancy** and high **availability** by copying data to multiple locations via **replication**.
- A storage device that is implemented with a distributed file system provides *simple*, *fast access* data storage that is capable of storing large datasets that are non-relational in nature, such as **semi-structured** and **unstructured** data.

On-Disk Storage: Distributed File Systems

- Although based on straightforward file **locking** mechanisms for concurrency control, it provides **fast read/write** capability, which addresses the **velocity** characteristic of Big Data.
- Distributed file system is **not ideal** for datasets comprising a **large number of small files** as this creates excessive **disk-seek activity**, **slowing down** the overall data access.
- Due to these limitations, distributed file systems work best with **fewer but larger files** accessed in a **sequential manner**.

On-Disk Storage: Distributed File Systems

- Multiple smaller files are generally **combined** into a single file to enable optimum *storage* and *processing*.
- This allows the distributed file systems to have increased performance when data must be accessed in **streaming mode** with **no random** reads and writes.
- A distributed file system storage device is suitable when large datasets of **raw data** are to be **stored** or when **archiving** of datasets is required.
- It should be noted that distributed file systems **do not provide the ability to search** the contents of files

On-Disk Storage: RDBMS Databases

On-Disk Storage: RDBMS Databases

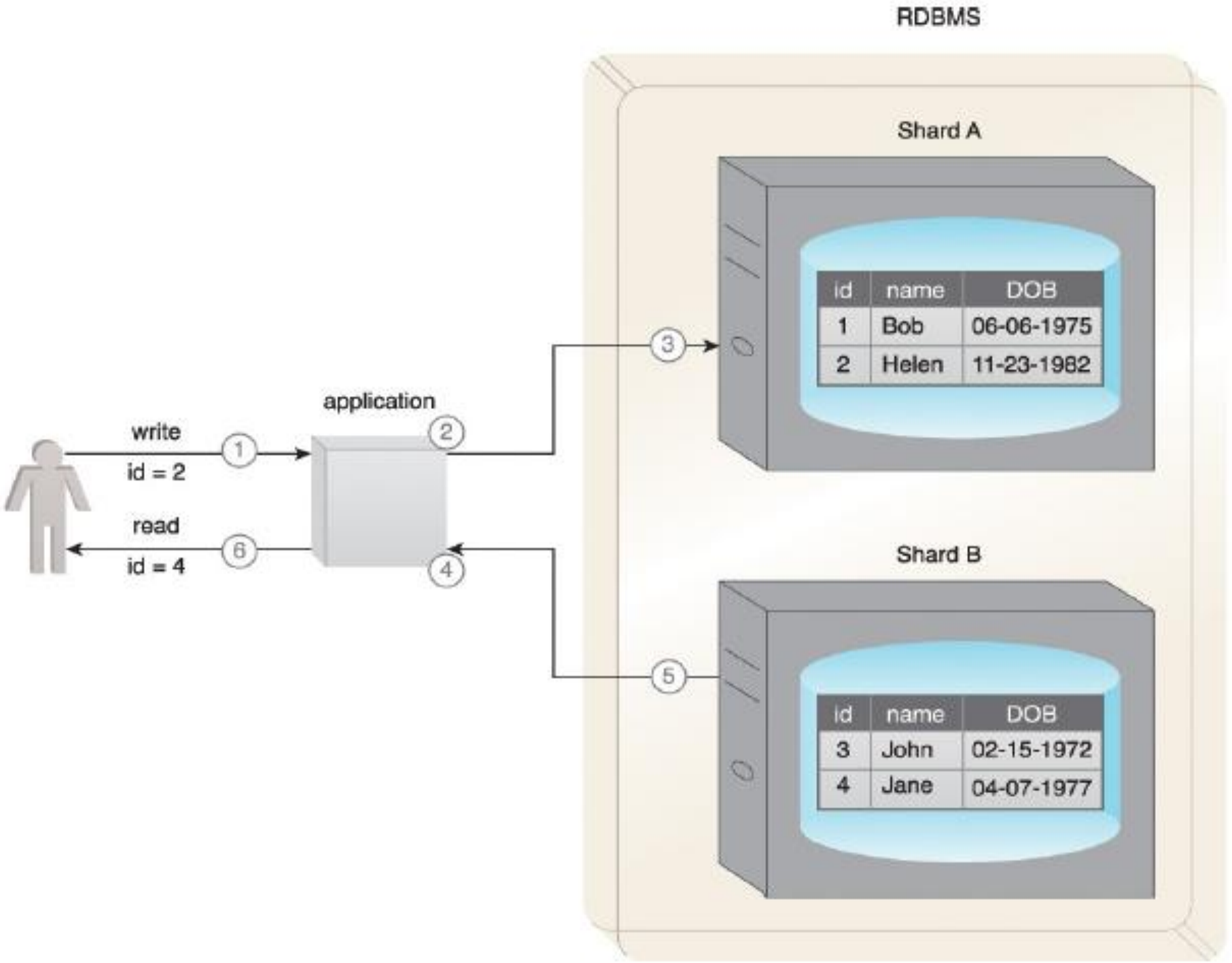
- Relational database management systems (RDBMSs) are good for handling transactional workloads involving **small amounts of data with random read/write properties**.
- RDBMSs are **ACID-compliant**, and they are generally restricted to a **single node**. For this reason, RDBMSs **do not provide** *redundancy* and *fault tolerance*.
- To handle large volumes of data arriving at a fast pace, relational databases generally **need to scale**. RDBMSs employ **vertical scaling**, not horizontal scaling, which is a *more costly* and *disruptive* scaling strategy.

On-Disk Storage: RDBMS Databases

- Note that some relational databases, for example IBM DB2 pureScale, Sybase ASE Cluster Edition, Oracle Real Application Clusters (RAC) and Microsoft Parallel Data Warehouse (PDW), **are capable of being run on clusters**.
- However, these database clusters still **use shared storage** that can act as a single point of failure.
- Relational databases need to be **manually sharded**, mostly using application logic.
- This means that the application logic needs to know which shard to query in order to get the required data. This further **complicates** data processing when data from **multiple shards** is required.

On-Disk Storage: RDBMS Databases

- Consider the following scenario:
  1. A user **writes** a record (id = 2).
  2. The **application logic** determines **which shard** it should be written to.
  3. It is **sent to the shard** determined by the application logic.
  4. The user reads a record (id = 4), and the application logic determines which shard contains the data.
  5. The data is read and returned to the application.
  6. The application then returns the record to the user.


RDBMS
Shard A
id
name
DOB
1
Bob
06-06-1975
2
Helen
11-23-1982
application
write
id = 2
read
id = 4
1
2
3
4
5
6
Shard B
id
name
DOB
3
John
02-15-1972
4
Jane
04-07-1977

On-Disk Storage: RDBMS Databases

- Relational databases generally require data to **adhere to a schema**. As a result, storage of **semi-structured** and **unstructured** data whose schemas are non-relational is **not directly supported**.
- Furthermore, with a relational database schema conformance is validated **at the time of data insert or update** by checking the data against the constraints of the schema. This introduces overhead that creates **latency**.
- This latency makes relational databases a less than ideal choice for storing **high velocity** data that needs a highly available database storage device with *fast* data *write* capability.

On-Disk Storage: NoSQL Databases

NoSQL Databases: Characteristics

- **Not-only SQL** (NoSQL) refers to technologies used to develop next generation **non-relational** databases that are **highly scalable** and **fault-tolerant**.
- Below is a list of the principal characteristics of NoSQL storage devices that differentiate them from traditional RDBMSs:
  - **Schema-less data model** – Data can exist in its raw form.
  - **Highly available** – This is built on cluster-based technologies that provide fault.
  - **Eventual consistency** – Data reads across multiple nodes but may not be consistent immediately after a write. However, all nodes will eventually be in a consistent state.

NoSQL Databases: Characteristics

- Below is a list of the principal characteristics of NoSQL storage devices that differentiate them from traditional RDBMSs (cont.):
  - **Scale out rather than scale up** – More nodes can be added to obtain additional storage with a NoSQL database.
  - **BASE, not ACID** – BASE compliance requires a database to maintain high *availability* in the event of network/node failure, while not requiring the database to be in a *consistent* state whenever an update occurs. NoSQL storage devices are generally *AP* or *CP*.
  - **API driven data access** – Data access is generally supported via API based queries, including *RESTful APIs*, whereas some implementations may also provide *SQL-like query* capability.

NoSQL Databases: Characteristics

- Below is a list of the principal characteristics of NoSQL storage devices that differentiate them from traditional RDBMSs (cont.):
  - **Auto sharding and replication –** To support horizontal scaling and provide high availability, a NoSQL storage device automatically employs sharding and replication techniques.
  - **Distributed query support –** NoSQL storage devices maintain consistent query behavior across multiple shards.
  - **Polyglot persistence –** The use of NoSQL storage does not mandate retiring traditional RDBMSs. In fact, both can be used at the same time, thereby supporting polyglot persistence, which is an approach of *persisting data using different types of storage technologies within the same solution architecture*. This is good for developing systems requiring structured as well as semi/unstructured data.

NoSQL Databases: Characteristics

- Below is a list of the principal characteristics of NoSQL storage devices that differentiate them from traditional RDBMSs (cont.):
  - **Aggregate-focused** – Unlike relational databases that are most effective with fully normalized data, NoSQL storage devices store de-normalized aggregated data (an entity containing merged, often nested, data for an object) thereby eliminating the need for joins and extensive mapping between application objects and the data stored in the database. One exception, however, is that graph database storage devices (introduced shortly) are not aggregate-focused.

NoSQL Databases: Rational

- The emergence of NoSQL storage devices can primarily be attributed to the *volume*, *velocity* and *variety* characteristics of Big Data datasets:
  - **Volume:**
    - The storage requirement of ever increasing data volumes commands the use of databases that are **highly scalable** while keeping costs down for the business to remain competitive.
    - NoSQL storage devices fulfill this requirement by providing **scale out** capability while using **inexpensive** commodity servers.

NoSQL Databases: Rational

- The emergence of NoSQL storage devices can primarily be attributed to the *volume*, *velocity* and *variety* characteristics of Big Data datasets:
  - **Velocity:**
    - The fast influx of data requires databases with fast access data write capability.
    - NoSQL storage devices enable fast writes by using **schema-on-read** rather than **schema-on-write** principle.
    - Being **highly available**, NoSQL storage devices can ensure that **write latency does not occur** because of node or network failure.

NoSQL Databases: Rational

- The emergence of NoSQL storage devices can primarily be attributed to the *volume*, *velocity* and *variety* characteristics of Big Data datasets (cont.):
  - **Variety:**
    - A storage device needs to handle **different data formats** including *documents*, *emails*, *images* and *videos* and *incomplete* data.
    - NoSQL storage devices can store these different forms of **semi-structured** and **unstructured** data formats.
    - At the same time, NoSQL storage devices are able to store schema-less data and incomplete data **with the added ability of making schema changes** as the data model of the datasets evolve.
    - In other words, NoSQL databases support schema evolution.

NoSQL Databases: Types

- NoSQL storage devices can mainly be divided into four types based on the way they store data:
  - Key-value
  - Document
  - Column-family
  - Graph

NoSQL Databases: Types

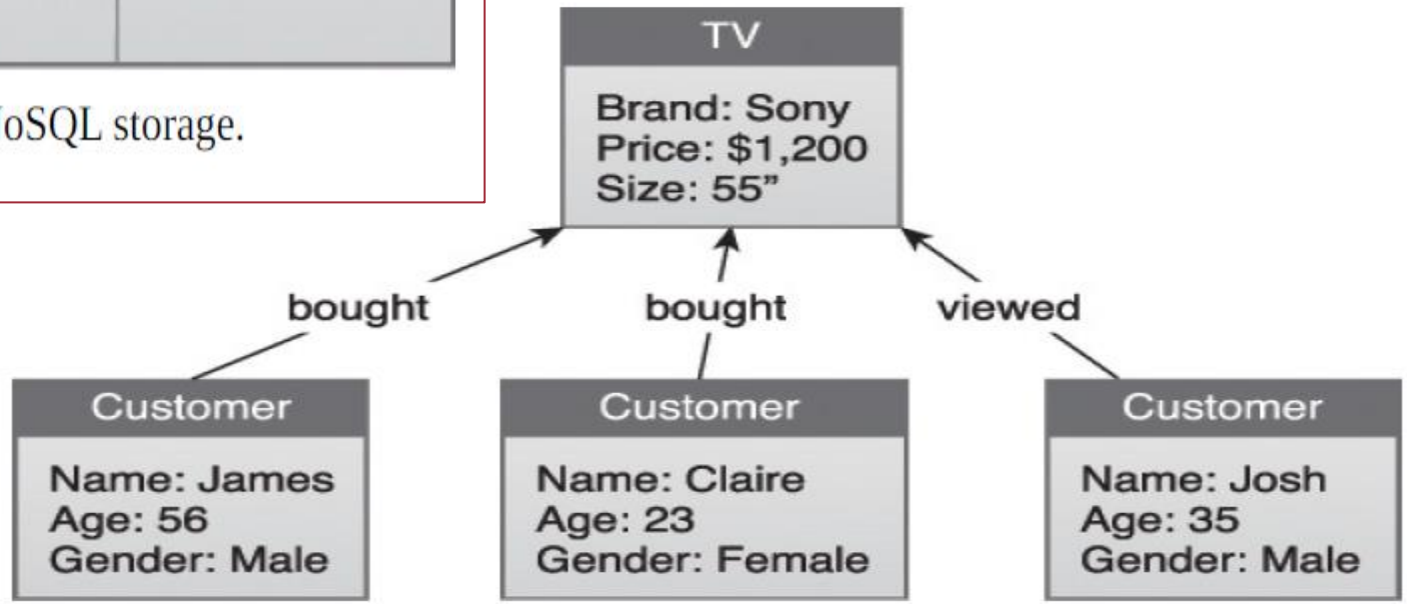
An example of document NoSQL storage.

key	value
631	John Smith, 10.0.30.25, Good customer service
365	1001010111011011110111010101101010010011100110 10
198	<CustomerId>32195</CustomerId><Total>43.25</Total>

An example of key-value NoSQL storage.

studentId	personal details	address	modules history
821	FirstName: Cristie LastName: Augustin DoB: 03-15-1992 Gender: Female Ethnicity: French	Street: 123 New Ave City: Portland State: Oregon ZipCode: 12345 Country: USA	Taken: 5 Passed: 4 Failed: 1
742	FirstName: Carlos LastName: Rodriguez MiddleName: Jose Gender: Male	Street: 456 Old Ave City: Los Angeles Country: USA	Taken: 7 Passed: 5 Failed: 2

An example of column-family NoSQL storage.



An example of graph NoSQL storage.

NoSQL Databases: Key-Value

- Key-value storage devices store data as key-value pairs and act like **hash tables**.
- The table is a list of values where each value is identified by a key. The value is **opaque** to the database and is typically stored as a **BLOB** (Binary large Objects).
- The value stored can be **any aggregate**, ranging from sensor data to videos.
- Value look-up can only be performed via the keys as the database is oblivious to the details of the stored aggregate. Partial updates are not possible. An update is either a **delete** or an **insert** operation.
- Examples of key-value storage devices include Riak, Redis, and Amazon Dynamo DB.

NoSQL Databases: Key-Value

- Key-value writes are quite **fast**. Based on a simple storage model, key-value storage devices are **highly scalable**.
- keys are the only means of retrieving the data.
- A single collection can hold multiple data formats.

key	value	
631	John Smith, 10.0.30.25, Good customer service	← text
365	10101101010110101011101011010101101010111010110	← image
198	<CustomerId>32195</CustomerId><Total>43.25</Total>	← XML

NoSQL Databases: Key-Value

- A key-value storage device is **appropriate** when:
  - unstructured data storage is required
  - high performance read/writes are required
  - the value is fully identifiable via the key alone
  - value is a standalone entity that is not dependent on other values
  - values have a comparatively simple structure or are binary
  - query patterns are simple, involving insert, select and delete operations only
  - stored values are manipulated at the application layer

NoSQL Databases: Key-Value

- A key-value storage device is **inappropriate** when:
  - applications require searching or filtering data using attributes of the stored value
  - relationships exist between different key-value entries
  - a group of keys' values need to be updated in a single transaction
  - multiple keys require manipulation in a single operation
  - schema consistency across different values is required
  - update to individual attributes of the value is required

NoSQL Databases: Document

- Document storage devices also store data as **key-value pairs**.
- However, unlike key-value storage devices, the stored value is a document that can be **queried** by the database.
- These documents can have a **complex nested structure.**
- Like key-value storage devices, most document storage devices provide collections or buckets (like tables) into which key-value pairs can be **organized**.
- The documents can be encoded using either a text-based encoding scheme, such as **XML** or **JSON**, or using a **binary** encoding scheme.
- Examples of document storage devices include MongoDB, CouchDB, and Terrastore.

NoSQL Databases: Document

- The main differences between document storage devices and key-value storage devices are as follows:
  - document storage devices are value-aware
  - the stored value is self-describing; the schema can be inferred from the structure of the value or a reference to the schema for the document is included in the value
  - a select operation can reference a field inside the aggregate value
  - a select operation can retrieve a part of the aggregate value
  - partial updates are supported; therefore a subset of the aggregate can be updated

NoSQL Databases: Document

- Each document can have a **different schema**; therefore, it is possible to store different types of documents in the same collection or bucket.
- **Additional fields** can be added to a document after the initial insert, thereby providing flexible schema support.

An example of document NoSQL storage.

NoSQL Databases: Document

- A document storage device is **appropriate** when:
  - storing semi-structured document-oriented data comprising flat or nested schema
  - schema evolution is a requirement as the structure of the document is either unknown or is likely to change
  - applications require a partial update of the aggregate stored as a document
  - searches need to be performed on different fields of the documents
  - query patterns involve insert, select, update and delete operations

NoSQL Databases: Document

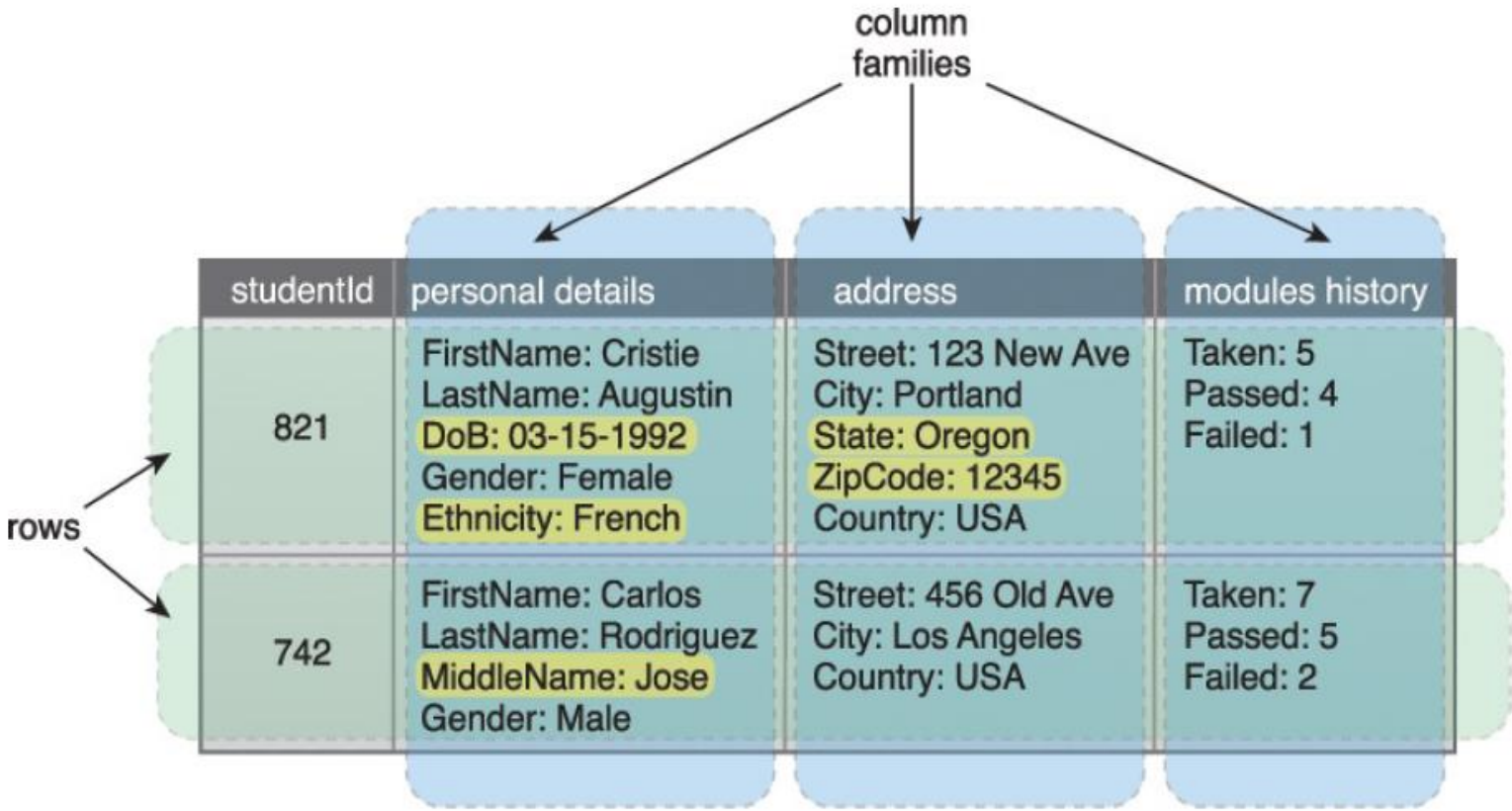
- A document storage device is **inappropriate** when:
  - multiple documents need to be updated as part of a single transaction
  - performing operations that need joins between multiple documents
  - schema enforcement for achieving consistent query design is required as the document structure may change between successive query runs, which will require restructuring the query
  - the stored value is not self-describing and does not have a reference to a schema

NoSQL Databases: Column-Family

- Column-family storage devices store data **much like a traditional RDBMS** but **group related columns** together in a row, resulting in column-families.
- Each column can be a collection of related columns itself, referred to as a **super-column**.
- Each super-column can contain an **arbitrary number of related columns** that are generally retrieved or updated as a single unit.
- Each row consists of **multiple column-families** and can have a different set of columns, thereby manifesting flexible schema support.
- Each row is identified by a **row key**.
- Examples of column-family storage devices include Cassandra, HBase and Amazon SimpleDB.

NoSQL Databases: Column-Family

- Column-family storage devices provide **fast data access** with **random read/write capability.**
- They store different column-families in **separate physical files**, which improves query responsiveness as only the required column-families are searched.



NoSQL Databases: Column-Family

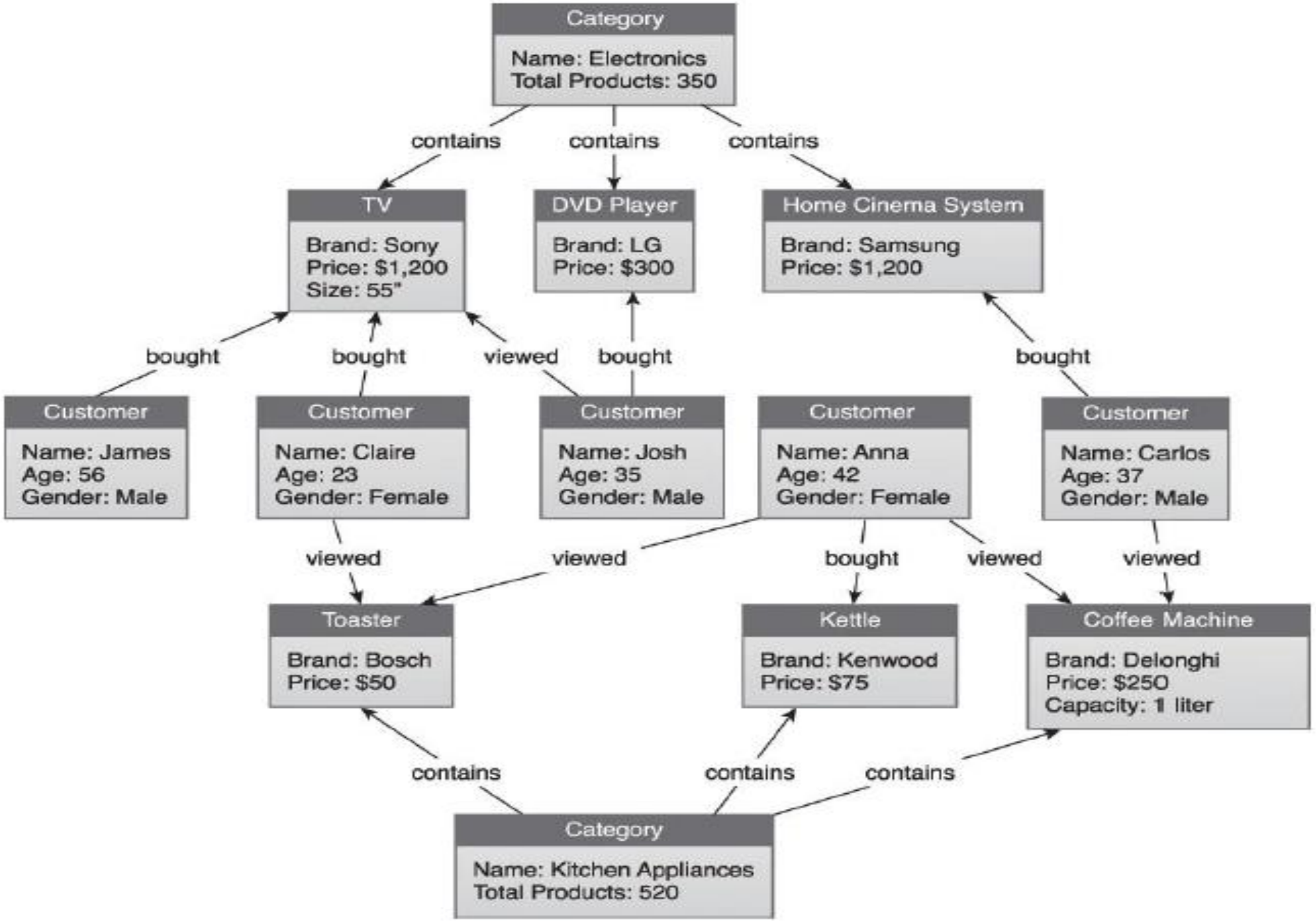
- A column-family storage device is **appropriate** when:
  - data represents a tabular structure, each row consists of a large number of columns and nested groups of interrelated data exist
  - support for schema evolution is required as column families can be added or removed without any system downtime
  - certain fields are mostly accessed together, and searches need to be performed using field values
  - query patterns involve insert, select, update and delete operations

NoSQL Databases: Column-Family

- A column-family storage device is **inappropriate** when:
  - relational data access is required; for example, joins
  - ACID transactional support is required
  - SQL-compliant queries need to be executed
  - query patterns are likely to change frequently because that could initiate a corresponding restructuring of how column-families are arranged

NoSQL Databases: Graph

- Graph storage devices are used to persist **inter-connected entities**.
- Unlike other NoSQL storage devices, where the emphasis is on the structure of the entities, graph storage devices place emphasis on storing the **linkages between entities.**
- **Entities** are stored as **nodes** and are also called vertices, while the **linkages** between entities are stored as **edges**.
- In RDBMS parlance, each node can be thought of a **single row** while the edge denotes a **join**.
- Examples include Neo4J, Infinite Graph and OrientDB.


Category
Name: Electronics
Total Products: 350
contains
contains
contains
TV
Brand: Sony
Price: $1,200
Size: 55"
DVD Player
Brand: LG
Price: $300
Home Cinema System
Brand: Samsung
Price: $1,200
bought
bought
viewed
bought
bought
Customer
Name: James
Age: 56
Gender: Male
Customer
Name: Claire
Age: 23
Gender: Female
Customer
Name: Josh
Age: 35
Gender: Male
Customer
Name: Anna
Age: 42
Gender: Female
Customer
Name: Carlos
Age: 37
Gender: Male
viewed
viewed
bought
viewed
viewed
Toaster
Brand: Bosch
Price: $50
Kettle
Brand: Kenwood
Price: $75
Coffee Machine
Brand: Delonghi
Price: $250
Capacity: 1 liter
contains
contains
contains
Category
Name: Kitchen Appliances
Total Products: 520

NoSQL Databases: Graph

- Nodes can have more **than one type of link** between them through **multiple edges**.
- Each node can have **attribute data** as **key-value pairs**, such as a customer node with ID, name and age attributes.
- Each **edge** can have its **own attribute data** as key-value pairs, which can be used to further filter query results.
- Having multiple edges are similar to defining multiple **foreign keys** in an RDBMS.

NoSQL Databases: Graph

- Generally, graph storage devices provide consistency via **ACID** compliance.
- The degree of usefulness of a graph storage device depends on the **number** and **types** of edges defined between the nodes.
- The greater the number and more diverse the edges are, the more diverse the types of queries it can handle.
- Graph storage devices generally allow **adding new types of nodes** without making changes to the database.
- This also enables defining **additional links** between nodes as new types of relationships or nodes appear in the database.

NoSQL Databases: Graph

- A graph storage device is **appropriate** when:
  - interconnected entities need to be stored
  - querying entities based on the type of relationship with each other rather than the attributes of the entities
  - finding groups of interconnected entities
  - finding distances between entities in terms of the node traversal distance
  - mining data with a view toward finding patterns

NoSQL Databases: Graph

- A graph storage device is **inappropriate** when:
  - updates are required to a large number of node attributes or edge attributes, as this involves searching for nodes or edges, which is a costly operation
  - entities have a large number of attributes or nested data—it is best to store lightweight entities in a graph storage device while storing the rest of the attribute data in a separate non-graph NoSQL storage device
  - queries based on the selection of node/edge attributes dominate node traversal queries

NoSQL Databases: MongoDB

- As mentioned **MongoDB** is a document-based NOSQL system.
- Individual **documents** are stored in a **collection**.
- The operation **createCollection** is used to create each collection.
- For example, the following command can be used to create a collection called **project** to hold PROJECT objects from the COMPANY database:
  - **db.createCollection("project", { capped : true, size : 1310720, max : 500 })**
    - The first parameter "project" is the **name** of the collection, which is followed by an optional document that specifies **collection options**. In our example, the collection is **capped**; this means it has upper limits on its storage space (**size**) and number of documents (**max**).

NoSQL Databases: MongoDB

- For our example, we will create another document collection called **worker** to hold information about the EMPLOYEEs who work on each project; for example:
  - **db.createCollection(“worker”, { capped : true, size : 5242880, max : 2000 }))**
- Each document in a collection has a unique **ObjectId** field, called **_id**, which is automatically indexed in the collection unless the user explicitly requests no index for the _id field.

NoSQL Databases: MongoDB

MongoDB CRUD Operations:

- MongoDb has several **CRUD operations**, where CRUD stands for (create, read, update, delete). Documents can be ***created*** **and inserted** into their collections using the **insert** operation, whose format is:

  db.<collection_name>.insert(<document(s)>)

- The parameters of the insert operation can include either a single document or an array of documents, as shown in the following figure:

NoSQL Databases: MongoDB

inserting the documents into their collections “project” and “worker”:

```
db.project.insert( { _id: “P1”, Pname: “ProductX”, Plocation: “Bellaire” } )
db.worker.insert( [ { _id: “W1”, Ename: “John Smith”, ProjectId: “P1”, Hours: 32.5 }
                    { _id: “W2”, Ename: “Joyce English”, ProjectId: “P1”,
                      Hours: 20.0 } ] )
```

NoSQL Databases: MongoDB

MongoDB CRUD Operations:

- The **delete** operation is called ***remove***, and the format is:

  db.<collection_name>.remove(<condition>)

  The documents to be removed from the collection are specified by a Boolean condition on some of the fields in the collection documents.

- There is also an **update** operation, which has a condition to select certain documents, and a *$set* clause to specify the update.
- For **read** queries, the main command is called ***find***, and the format is:

  db.<collection_name>.find(<condition>)

On-Disk Storage: NewSQL Databases

NewSQL Databases

- NoSQL storage devices are **highly scalable**, **available**, **fault-tolerant** and **fast** for read/write operations.
- However, they do not provide the same transaction and consistency support as exhibited by **ACID** compliant RDBMSs. Following the BASE model, NoSQL storage devices provide **eventual consistency** rather than **immediate consistency**.
- They therefore will be in a soft state while reaching the state of eventual consistency.
- As a result, they are **not appropriate** for use when **implementing large scale transactional systems**.

NewSQL Databases

- NewSQL storage devices combine the **ACID properties** of **RDBMS** with the **scalability and fault tolerance** offered by **NoSQL** storage devices.

- NewSQL databases generally **support SQL** compliant syntax for data definition and data manipulation operations, and they often use a logical **relational data model** for data storage.

NewSQL Databases

- NewSQL databases can be used for developing **OLTP** (online transaction processing) systems with very high volumes of transactions, for example a banking system.

- They can also be used for **realtime analytics** as some implementations leverage **in-memory storage**.

- Examples of NewSQL databases include VoltDB, NuoDB and InnoDB.

In-Memory Storage

In-Memory Storage

- This section presents in-memory storage as a means of providing options for **highly performant**, and **advanced data storage**.
- An in-memory storage device generally utilizes **RAM**, the main memory of a computer, as its storage medium to provide **fast data access**.
- The growing capacity and decreasing cost of RAM, coupled with the increasing read/write speed of solid state hard drives, has made it possible to develop in-memory data storage solutions.

In-Memory Storage

- Storage of data in memory **eliminates the latency of disk I/O** and the data transfer time between the main memory and the hard drive.
- This **overall reduction** in data read/write **latency** makes data processing **much faster**.
- In-memory storage device capacity can be increased massively by **horizontally scaling the cluster** that is hosting the in-memory storage device.
- Cluster-based memory enables storage of large amounts of data, including Big Data datasets, which can be accessed **considerably faster** when compared with an on-disk storage device.

In-Memory Storage

- In-memory storage significantly **reduces the overall execution time** of Big Data analytics, thus **enabling real-time Big Data analytics**.

- An example of a sequential read of **1 MB** of data from an in-memory storage device takes around **0.25 ms**. The same amount of data from an on-disk storage device takes around **20 ms**.

- This demonstrates that reading data from in-memory storage is approximately **80 times** faster than on-disk storage.

In-Memory Storage

- Primarily, in-memory storage enables making sense of the fast influx of data in a Big Data environment (velocity characteristic) by providing a storage medium that facilitates **real-time insight generation**.

- This supports making quick business decisions for mitigating a threat or taking advantage of an opportunity.

- A Big Data in-memory storage device is implemented over a cluster, providing **high availability** and **redundancy**. Therefore, horizontal scalability can be achieved by simply adding more nodes or memory.

In-Memory Storage

- When compared with an on-disk storage device, an in-memory storage device is **expensive** because of the higher cost of memory as compared to a disk-based storage device.

- Apart from being expensive, in-memory storage devices do not provide the same level of support for **durable data storage**. The price factor further affects the achievable **capacity** of an in-memory device when compared with an on-disk storage device.

In-Memory Storage

- An in-memory storage device is **appropriate** when:
  - data arrives at a **fast pace** and **requires real-time analytics** or **event stream processing**
  - **continuous** or **always-on analytics** is required, such as operational BI and operational analytics
  - **interactive query processing** and real-time data visualization needs to be performed
  - developing **low latency** Big Data solutions

In-Memory Storage

- An in-memory storage device is **inappropriate** when::
  - data processing consists of **batch processing**
  - **very large amounts of data** need to be persisted in-memory for a long time in order to perform in-depth data analysis
  - performing strategic BI or strategic analytics that involves access to **very large amounts of data** and involves batch data processing
  - datasets are **extremely large and do not fit** into the available memory
  - an enterprise has a **limited budget**, as setting up an in-memory storage device may require upgrading nodes, which could either be done by node replacement or by adding more RAM

In-Memory Storage

- In-memory storage devices can be implemented as:
  - In-Memory Data Grid (IMDG)
  - In-Memory Database (IMDB)

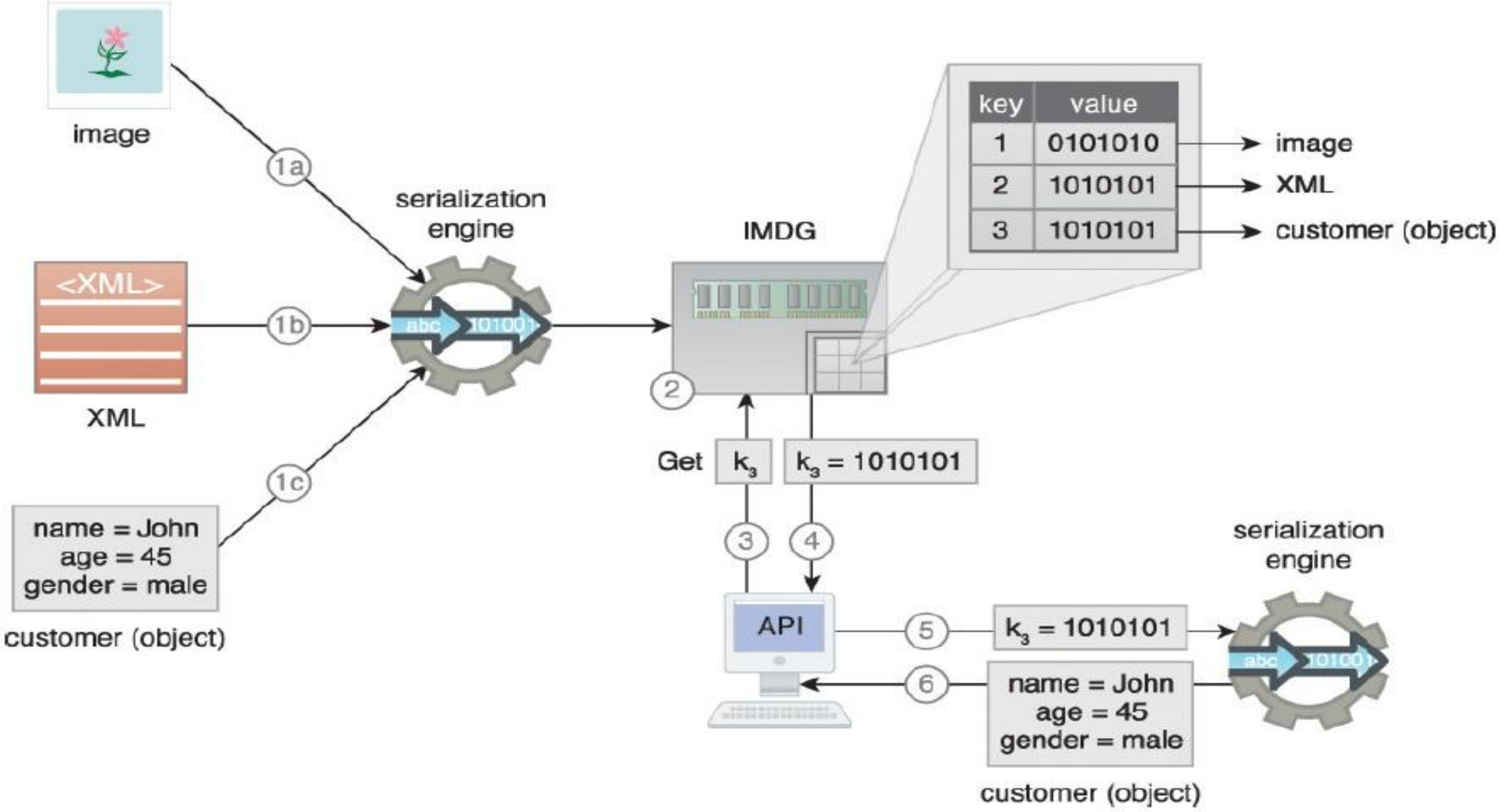
- Although both of these technologies use memory as their underlying data storage medium, what makes them distinct is **the way data is stored in the memory**.

In-Memory Storage: In-Memory Data Grids

In-Memory Storage: In-Memory Data Grid (IMDG)

- IMDGs store data in memory as **key-value pairs** across multiple nodes where the keys and values can be any business object or application data in serialized form.

- This supports schema-less data storage through storage of semi/unstructured data. Data access is typically provided via APIs.



An IMDG storage device.

In-Memory Storage: In-Memory Data Grid (IMDG)

- The previous figure describes the following scenario:
  1. An image (a), XML data (b) and a customer object (c) are first serialized using a serialization engine.
  2. They are then stored as key-value pairs in an IMDG.
  3. A client requests the customer object via its key.
  4. The value is then returned by the IMDG in serialized form.
  5. The client then utilizes a serialization engine to deserialize the value to obtain the customer object…
  6. … in order to manipulate the customer object.

In-Memory Storage: In-Memory Data Grid (IMDG)

- Nodes in IMDGs keep themselves synchronized and collectively provide **high availability**, **fault tolerance** and **consistency**.
- In comparison to **NoSQL**'s eventual consistency approach, IMDGs support **immediate consistency**.
- As compared to relational **IMDBs** (discussed later), IMDGs provide **faster** data access as IMDGs store non-relational data as objects.

In-Memory Storage: In-Memory Data Grid (IMDG)

- **Realtime** processing engines can make use of IMDG where **high velocity data** is stored in the IMDG as it arrives and is processed there before being saved to an on-disk storage device, or data from the on-disk storage device is copied to the IMDG.

- This makes data processing orders of magnitude **faster**.

- IMDGs may also support **in-memory MapReduce** that helps to reduce the latency of disk based MapReduce processing.

In-Memory Storage: In-Memory Data Grid (IMDG)

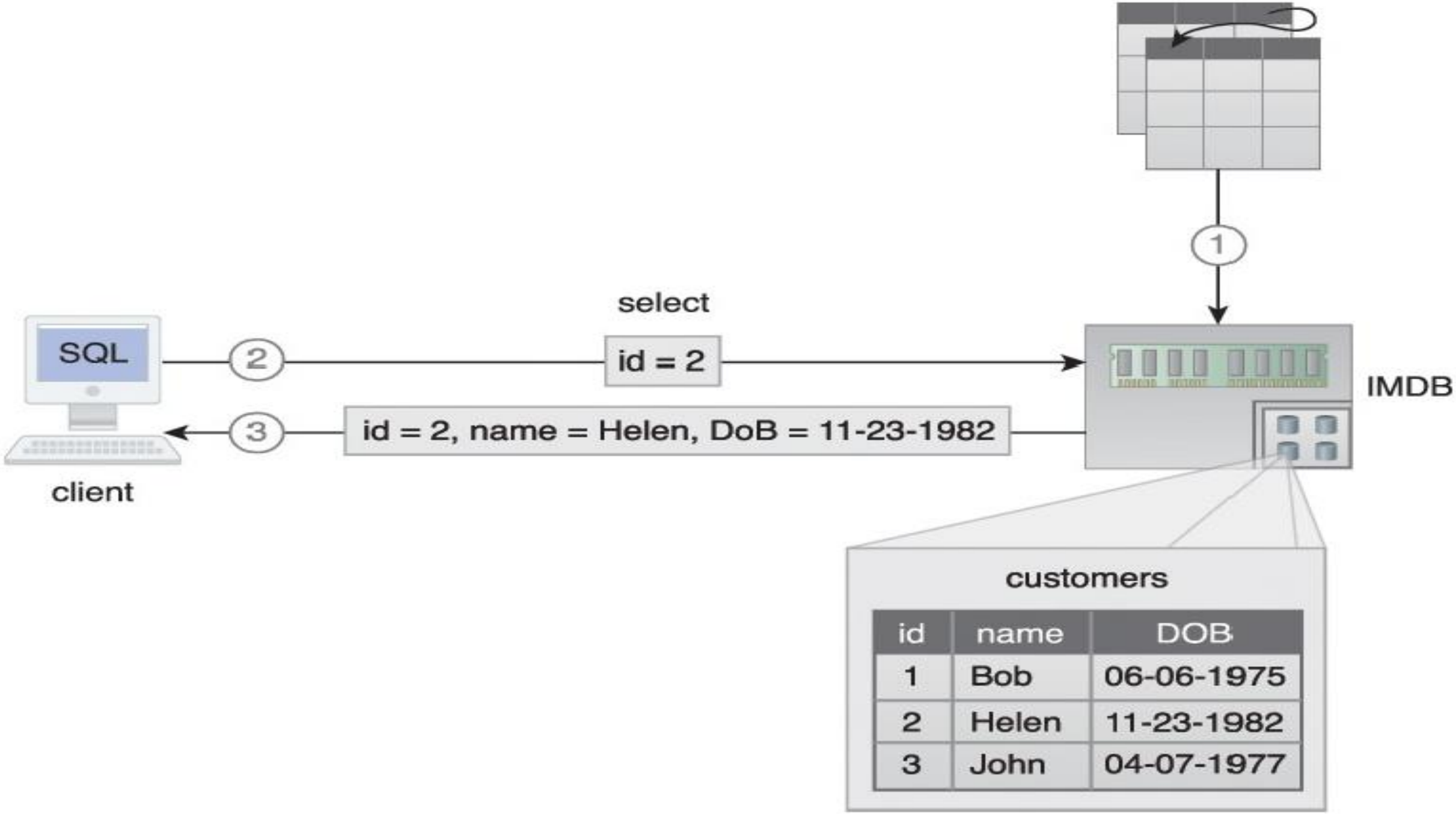
- IMDGs can be added to existing Big Data solutions by introducing them between the existing **on-disk storage device** and the **data processing application**.
- Note that some IMDG implementations may also provide limited or full **SQL support**.
- In a Big Data solution environment, IMDGs are often deployed together with **on-disk storage** devices that act as the **backend storage**.
- Examples include In-Memory Data Fabric, Hazelcast and Oracle Coherence.

In-Memory Storage: In-Memory Database

In-Memory Storage: In-Memory Database (IMDB)

- IMDBs are in-memory storage devices that **employ database technology** and leverage the performance of **RAM** to **overcome runtime latency** issues of the on-disk storage devices.

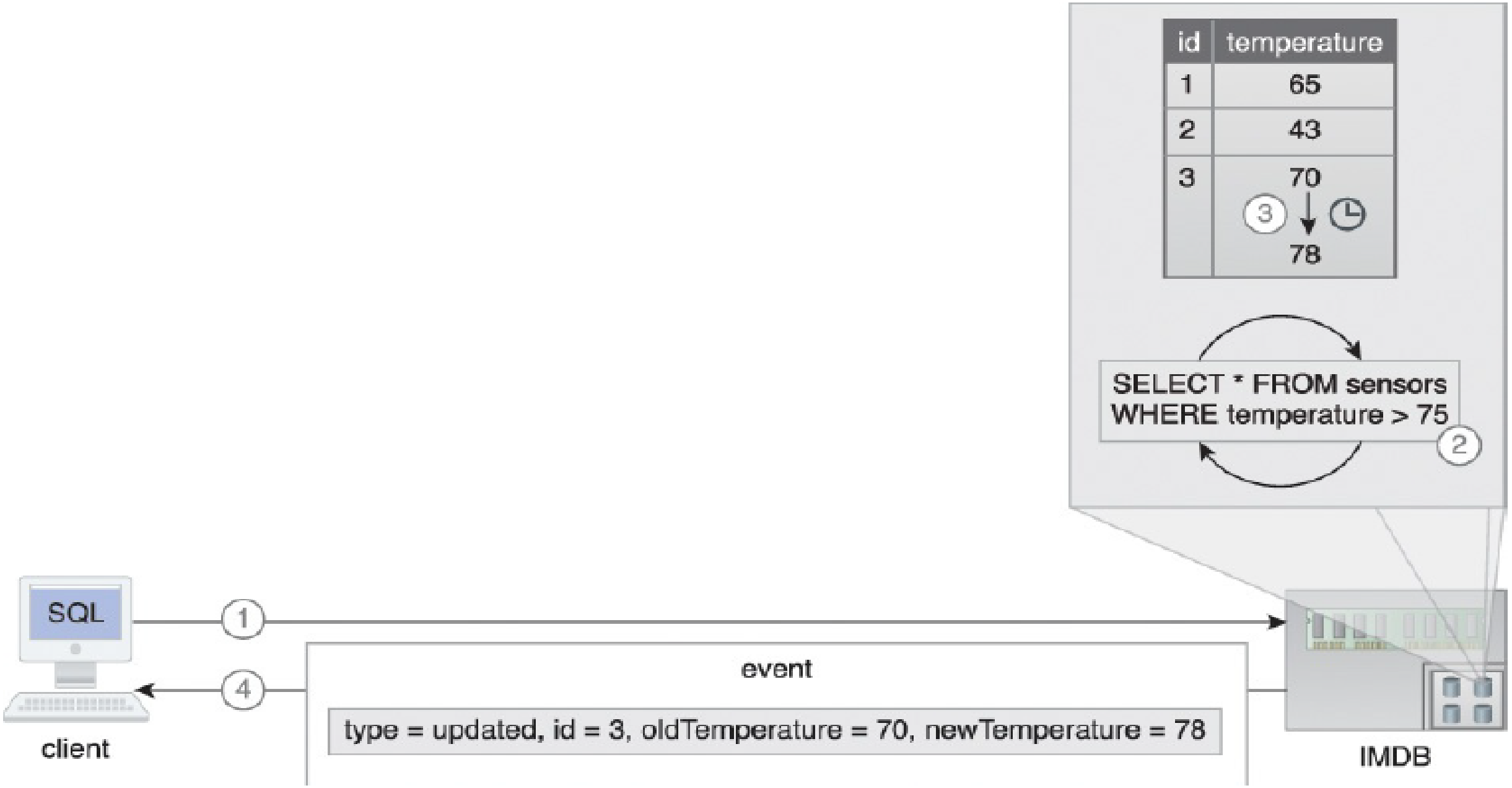
- An IMDB can be **relational** in nature (**relational IMDB**) for the storage of **structured** data, or may leverage **NoSQL** technology (**non-relational IMDB**) for the storage of **semistructured** and **unstructured** data.



An example depicting the retrieval of data from an IMDB.

In-Memory Storage: In-Memory Database (IMDB)

- The previous example describes the following scenario:
  1. A relational dataset is **stored into an IMDB**.
  2. A **client requests** a customer record (id = 2) via SQL.
  3. The relevant customer **record is then returned** by the **IMDB**, which is directly manipulated by the client without the need for any deserialization.



An example of IMDB storage configured with a continuous query.

In-Memory Storage: In-Memory Database (IMDB)

- The previous example describes the following scenario:
  1. A client issues a **continuous query** (select * from sensors where temperature > 75).
  2. It is registered in the **IMDB**.
  3. When the temperature for any sensor exceeds 75F …
  4. … an **updated event** is sent to the subscribing **client** that contains various details about the event.

In-Memory Storage: In-Memory Database (IMDB)

- IMDBs are heavily used in **real-time analytics** and can further be used for developing **low latency applications** requiring full ACID transaction support (relational IMDB).
- Introduction of IMDBs into an existing Big Data solution generally requires **replacement of existing on-disk storage devices**, including any RDBMSs if used.
- Examples include Aerospike, MemSQL, Altibase HDB, eXtreme DB and Pivotal GemFire XD

In-Memory Storage: In-Memory Database (IMDB)

- In the case of replacing an RDBMS with a relational IMDB, **little or no application code** change is required due to SQL support provided by the relational IMDB.
- However, when replacing an RDBMS with a NoSQL IMDB, **code change may be required** due to the need to implement the IMDB's NoSQL APIs.
- In the case of replacing an on-disk NoSQL database with a relational IMDB, **code change** will often be required to establish SQL-based access.
- However, when replacing an on-disk NoSQL database with a NoSQL IMDB, **code change** may still be required due to the implementation of new APIs.

Thank You