

Chapter 4

Column-oriented Database

Column-oriented Database

- A **Column-Oriented Database** is a type of NoSQL database that **stores data in columns instead of rows**.
- This structure allows for highly efficient read and write operations
-

Column-oriented Database

- Column-Oriented Database ideal for :
 - analytics
 - big data processing,
 - and real-time querying.

Column-oriented Database

- Columnar databases **store each column separately**

ID	Name	Age	City
1	Mohamed	60	Batna
2	Ali	40	Msila
3	Ilyes	15	Biskra

- Stored as:
- ID : [1,2,3] 
- Name: [Mohamed, Ali, Ilyes]
- Age : [60, 40, 15]
- City : [Batna, Msila, Biskra]

Column-oriented Database

- Are designed to optimize queries that analyze data across many rows
- Ex : Calculate **total** sales for **San Diego** store? Then for **Cameras** category?

2012-01-01	09:00	San Jose	Men's Clothing	214.05	Amex
2012-01-01	09:00	Fort Worth	Women's Clothing	153.57	Visa
2012-01-01	09:00	San Diego	Music	66.08	Cash
2012-01-01	09:00	Pittsburgh	Pet Supplies	493.51	Discover
2012-01-01	09:00	Omaha	Children's Clothing	235.63	MasterCard
2012-01-01	09:00	Stockton	Men's Clothing	247.18	MasterCard
2012-01-01	09:00	Austin	Cameras	379.6	Visa
2012-01-01	09:00	New York	Electronics	296.8	Cash
2012-01-02	15:20	Lincoln	Cameras	242.2	Discover
2012-01-02	15:20	San Diego	Baby	254.15	MasterCard
2012-01-02	15:20	Wichita	Cameras	446.66	Amex
2012-01-02	15:20	Irvine	Computers	9.23	Discover
2012-01-02	15:20	Anaheim	Cameras	3.64	Visa
2012-01-02	15:21	San Diego	Music	156.68	Cash

Column-oriented Database

- Calculate **total** sales for **San Diego** store? Then for **Cameras** category?
- In Row oriented DB we have to go through all the lines → **Hard Disk problem**
- In a columnar DB all the values in a column store live together on disk.

2012-01-01	09:00	San Jose	Men's Clothing	214.05	Amex
2012-01-01	09:00	Fort Worth	Women's Clothing	153.57	Visa
2012-01-01	09:00	San Diego	Music	66.08	Cash
2012-01-01	09:00	Pittsburgh	Pet Supplies	493.51	Discover
2012-01-01	09:00	Omaha	Children's Clothing	235.63	MasterCard
2012-01-01	09:00	Stockton	Men's Clothing	247.18	MasterCard
2012-01-01	09:00	Austin	Cameras	379.6	Visa
2012-01-01	09:00	New York	Electronics	296.8	Cash
2012-01-02	15:20	Lincoln	Cameras	242.2	Discover
2012-01-02	15:20	San Diego	Baby	254.15	MasterCard
2012-01-02	15:20	Wichita	Cameras	446.66	Amex
2012-01-02	15:20	Irvine	Computers	9.23	Discover
2012-01-02	15:20	Anaheim	Cameras	3.64	Visa
2012-01-02	15:21	San Diego	Music	156.68	Cash

Column-oriented Database

- Column-oriented databases store data in columns of data together on disk.
 - Traditional row-oriented OLTP databases store data in rows of data together on disk.
- ➔ This makes a big difference for analytical data processing.

Column-oriented Database

- Disks, memory, and CPU work faster when data is close together.*

ID, Date, Time, State, Category, amount, card

AAA1, 2012-01-01, 09:00, **San Jose**, Music, 214.05, Visa

AAA2, 2012-01-01, 09:00, Fort Worth, Women's Clothing, 153.57, Visa

AAA3, 2012-01-01, 09:00, San Diego, Music, 66.08, Cash

AAA4 2012-01-01 09:00, **San Jose**, Pet Supplies, 493.51, Visa



AAA1: 0001, AAA2:0002, AAA3 :0003, AAA4:0004

2012-01-01: 0001, 2012-01-01: 0002, 2012-01-01: 0003, 2012-01-01: 0004

09:00 : 0001, 09:00 : 0002, 09:00 : 0003, 09:00 : 0004

San Jose: 0001, , Fort Worth :0002, San Diego :0003, **San Jose** :0004

Music : 0001, Women's Clothing :0002, **Music** :0003, Pet Supplies :0004

214.05 : 0001, 153.57 :0002, 66.08 :0003, 493.51 :0004

Visa : 0001, Visa :0002, Cash :0003, Visa :0004

Column-oriented Database

- The most expensive operations involving hard disks are **search functions**
- Data is stored as follows bytes on the hard disk (or RAM)
- A byte can contain one Row (or several)

AAA1: 0001, AAA2:0002, AAA3 :0003, AAA4:0004
2012-01-01: 0001, 2012-01-01: 0002, 2012-01-01: 0003, 2012-01-01: 0004
09:00 : 0001, 09:00 : 0002, 09:00 : 0003, 09:00 : 0004
San Jose: 0001, , Fort Worth :0002, San Diego :0003, **San Jose** :0004
Music : 0001, Women's Clothing :0002, **Music** :0003, Pet Supplies :0004
214.05 : 0001, 153.57 :0002, 66.08 :0003, 493.51 :0004
Visa : 0001, Visa :0002, Cash :0003, Visa :0004

Column-oriented Database

1. Efficient storage

- search functions need → **Indexing operation**

AAA1: 0001, AAA2:0002, AAA3 :0003, AAA4:0004
2012-01-01: 0001, 2012-01-01: 0002, 2012-01-01: 0003, 2012-01-01: 0004
09:00 : 0001, 09:00 : 0002, 09:00 : 0003, 09:00 : 0004
San Jose: 0001, , Fort Worth :0002, San Diego :0003, **San Jose** :0004
Music : 0001, Women's Clothing :0002, **Music** :0003, Pet Supplies :0004
214.05 : 0001, 153.57 :0002, 66.08 :0003, 493.51 :0004
Visa : 0001, Visa :0002, Cash :0003, Visa :0004



AAA1: 0001; AAA2:0002; AAA3 :0003; AAA4:0004;
2012-01-01: 0001, 0002, 0003, 0004;
09:00 : 0001, 0002, 0003, 0004;
San Jose: **0001, 0004** ; Fort Worth :0002; San Diego :0003;
Music : 0001, 0003 ; Women's Clothing :0002; Pet Supplies :0004;
214.05 : 0001; 153.57 :0002; 66.08 :0003; 493.51 :0004;
Visa : 0001, 0002, 0004; Cash :0003;

Column-oriented Database

2. Data compression

2012-01-01	09:00	San Jose	Men's Clothing	214.05	Amex
2012-01-01	09:00	Fort Worth	Women's Clothing	153.57	Visa
2012-01-01	09:00	San Diego	Music	66.08	Cash
2012-01-01	09:00	Pittsburgh	Pet Supplies	493.51	Discover
2012-01-01	09:00	Omaha	Children's Clothing	235.63	MasterCard
2012-01-01	09:00	Stockton	Men's Clothing	247.18	MasterCard
2012-01-01	09:00	Austin	Cameras	379.6	Visa
2012-01-01	09:00	New York	Electronics	296.8	Cash
2012-01-02	15:20	Lincoln	Cameras	242.2	Discover
2012-01-02	15:20	San Diego	Baby	254.15	MasterCard
2012-01-02	15:20	Wichita	Cameras	446.66	Amex
2012-01-02	15:20	Irvine	Computers	9.23	Discover
2012-01-02	15:20	Anaheim	Cameras	3.64	Visa
2012-01-02	15:21	San Diego	Music	156.68	Cash



Amex : 001, 011; Visa: 002,007,013; Cash: 003,008,014; Discover:004, 009,012;

Column-oriented Database

2. Data compression

AAA1: 0001; AAA2:0002; AAA3 :0003; AAA4:0004;

2012-01-01: 0001, 0002, 0003, 0004;
09:00 : 0001, 0002, 0003, 0004;

San Jose: 0001, 0004 ; Fort Worth :0002; San Diego :0003;

Music : 0001, 0003 ; Women's Clothing :0002; Pet Supplies :0004;
214.05 : 0001; 153.57 :0002; 66.08 :0003; 493.51 :0004;
Visa : 0001, 0002, 0004; Cash :0003;

Column-oriented Database

- **Column-oriented advantage**
- Improved performance for analytical queries
- Data analysis
- Aggregations
- Scalability: Distributed architecture supports petabyte-scale data.

Column-oriented Database

- **Column-oriented advantage**
- **Ex:**
 - Calculate **total** sales for **San Jose** store?
 - Calculate **total Music** sales for **San Jose** store?

AAA1: 0001; AAA2:0002; AAA3 :0003; AAA4:0004;
2012-01-01: 0001, 0002, 0003, 0004;
09:00 : 0001, 0002, 0003, 0004;
San Jose: **0001, 0004** ; Fort Worth :0002; San Diego :0003;
Music : 0001, 0003 ; Women's Clothing :0002; Pet Supplies :0004;
214.05 : 0001; 153.57 :0002; 66.08 :0003; 493.51 :0004;
Visa : 0001, 0002, 0004; Cash :0003;

Column-oriented Database

- **Column-oriented disadvantages**
- ➔ For frequent real-time Transaction and read-write operations (OLTP)

Column-oriented Database

- Example of a column-oriented DB system:
 1. **BigTable** of Google
 2. **Hbase** of Apache (used by Facebook)
 3. **Cassandra** of Apache (used by Facebook)
 4. Amazon **Redshift**
 5. IBM **Informix**
 6. **Oracle Database 12c**
 7. Microsoft SQL Server (**columnstore**)

Column-oriented Database

Hbase

- **HBase** is a **column-oriented** NoSQL database
- Optimized for **big data** and **real-time queries**.
-
- It integrates with **Hadoop** for **distributed storage** and uses **ZooKeeper** for coordination.
-

Column-oriented Database Hbase

- Unlike relational databases, it **scales horizontally** and supports **flexible schema**.
-
- It is used in **data analytics, IoT, logs processing, and ML workloads**.

Column-oriented Database

Hbase

- **HBase Components :**

HBase follows a **master-slave** architecture with key components:

1. **HMaster** : Manages region servers and handles metadata.
2. **Region Servers** : Store and manage subsets of tables (regions).
3. **HDFS** Stores HBase data files.
4. **ZooKeep** : Ensures coordination between nodes.

Column-oriented Database Hbase

Data Model: Tables, Rows, Columns:

Tables store data as **key-value pairs**.

Rows are identified by a unique **row key**.

Columns are grouped into **column families** (stored together).

Cells store data with a **timestamp**.

Column-oriented Database Hbase

Data Model: Tables, Rows, Columns:
Example

Row Key	Column Family: Personal	Column Family: Contact
1	Name: Alice, Age: 25	Email: alice@mail.com, Phone: 123456
2	Name: Bob, Age: 30	Email: bob@mail.com, Phone: 987654

Column Families optimize storage: related data is stored together for fast retrieval.

Column-oriented Database

Apache Cassandra

- Apache Cassandra is a **highly scalable, distributed NoSQL database**
- designed for **high availability and fault tolerance**.
- It was originally developed by Facebook
- and is now an **open-source database** under the Apache Foundation.

Column-oriented Database

Apache Cassandra

- **Decentralized & Distributed**
- **Scalability** – Handles petabytes of data with ease.
- **Fault Tolerance** – Replicates data across multiple nodes.
- **NoSQL (Flexible Schema)** – Uses a column-family storage model.
- **High-Performance** – Optimized for high-speed read and write operations.

Column-oriented Database

Apache Cassandra

Core Components of Cassandra

Cassandra uses a **peer-to-peer (P2P)** architecture,

➔ meaning there is **no master node**.

Component	Description
Node	A single instance of Cassandra storing data.
Cluster	A group of nodes working together.
Keyspace	The highest-level container, similar to a database.
Column Family	A table storing data in columns instead of rows.
Partition Key	Determines how data is distributed across nodes.
Replication Factor	Defines how many copies of data exist in the cluster.

Column-oriented Database

Apache Cassandra

- **Real-World Applications of Cassandra**
- **Netflix** – Stores and analyzes billions of events in real-time.
- **Instagram** – Manages massive user-generated content.
- **Uber** – Uses Cassandra for trip tracking and geospatial data
- **eBay** – Handles auction data and real-time bidding.