Large-Scale and Multi-Structured Databases

Column Databases Introduction

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OLTP vs OLAP

- ***OLTP*** - Online Transaction Processing: software architectures oriented towards ***handling ACID transactions***.

- ***OLAP*** - Online Analytics Processing: software architectures oriented towards ***interactive*** and ***fast analysis*** of data. Typical of ***Business Intelligence*** Software.

OLTP vs OLAP

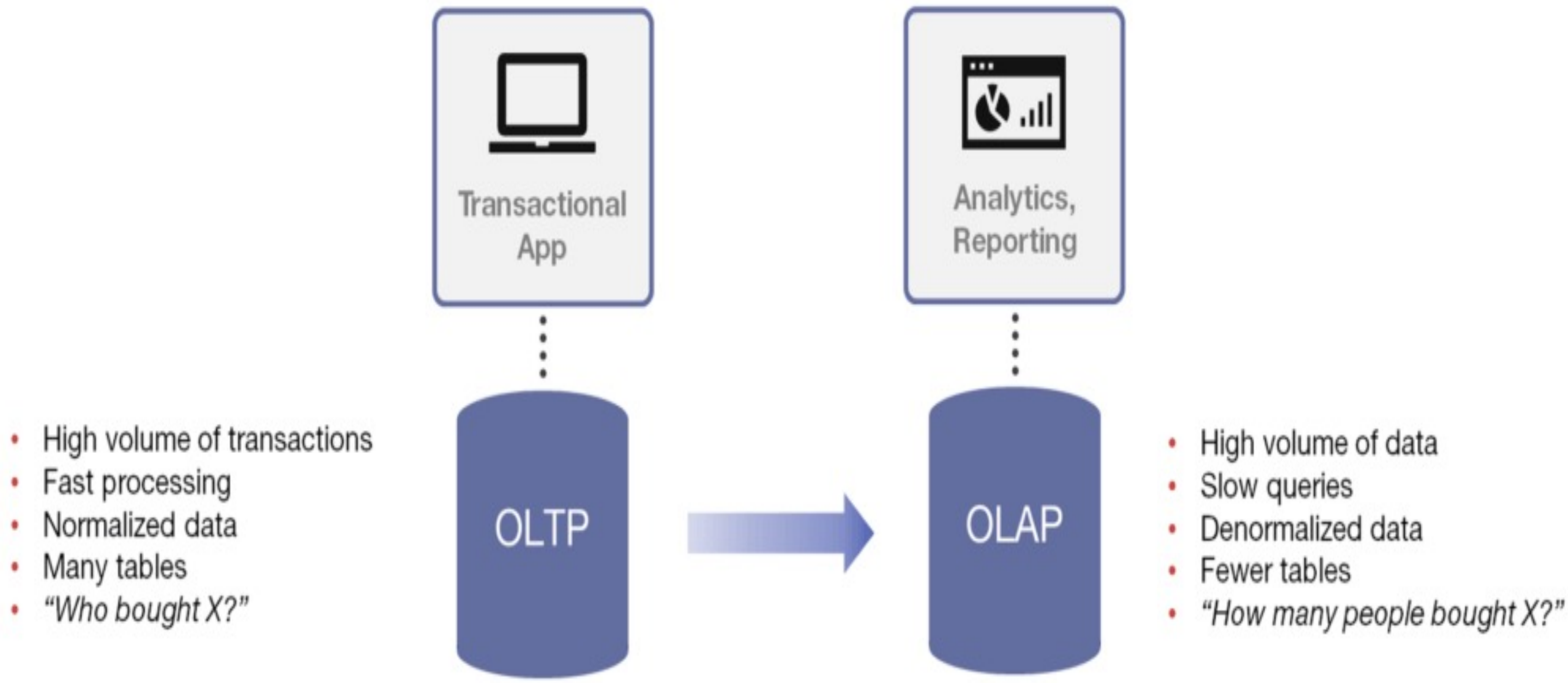


Image extracted from: https://diffzi.com/oltp-vs-olap/

Row Data Organization

Since the beginning of ***digital files***, the data of each record were physically organized in ***rows***.

OLTP processing is mainly oriented towards handling ***one record*** at a time processing.

When the ***first relational databases*** were designed, the world was mainly experiencing the OLTP era.

The ***record-oriented*** workflow handled by the first relational databases and ***the row-oriented*** physical structure of early digital files provided ***good performance***.

CRUD and Queries

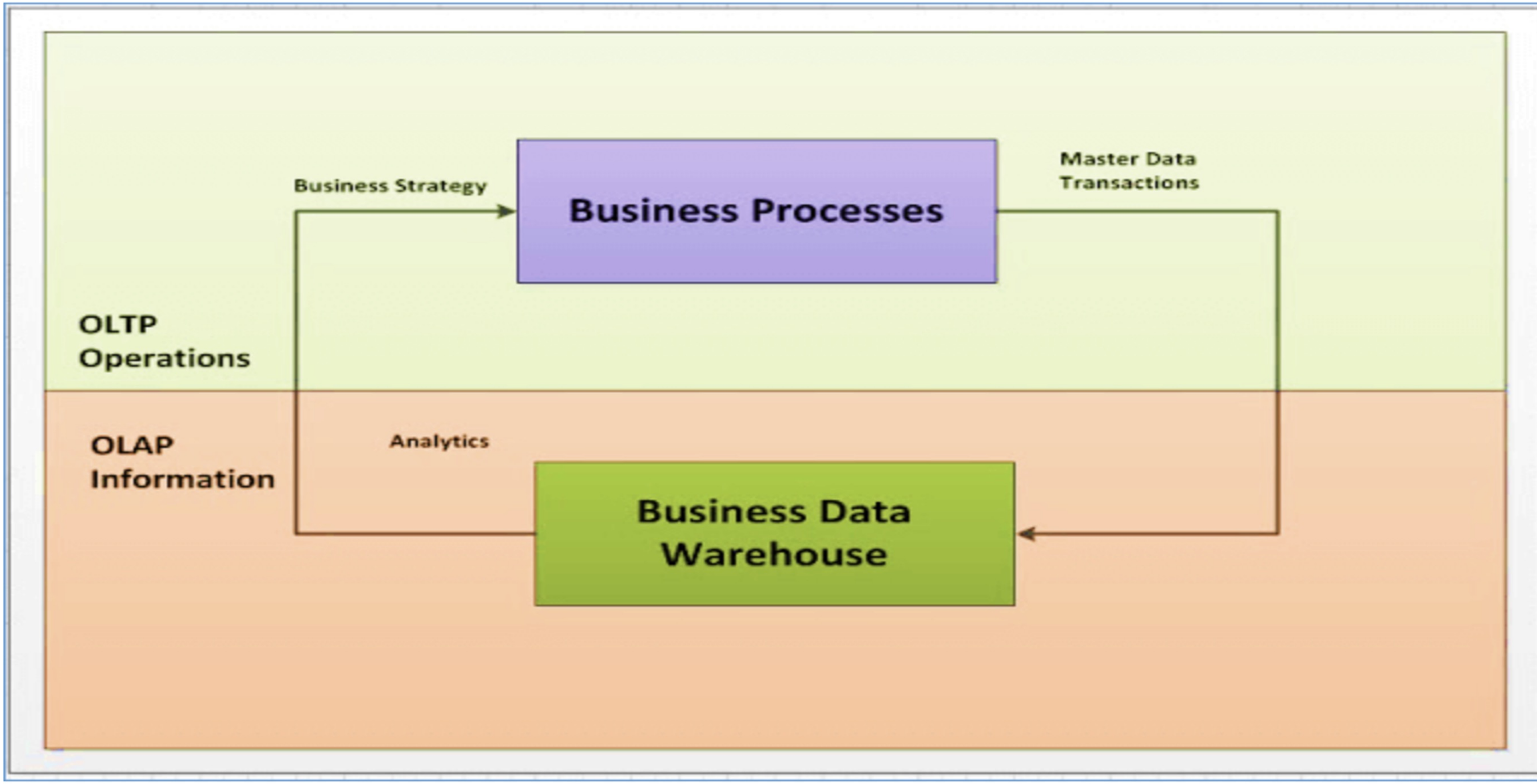
In the ***record-based processing era*** (up to the end of the 80s of the last century), CRUD operations (Create, Read, Update, Delete) were the most time-critical ones.

Reporting programs were typically iterated through entire tables and were run in a ***background*** batch mode. The ***time response*** to the queries was ***not*** a critical ***issue***.

When ***Business Intelligence*** software started to spread, ***OLAP*** processing assumed ***a big relevance***, thus the ***time response*** to queries became a ***critical issue*** to appropriately handle.

Data Warehouse

Data warehouses: relational databases tasked with supporting ***analytic*** and ***decision support*** applications (80's-90's era).



Star Schemas in Data Warehouse

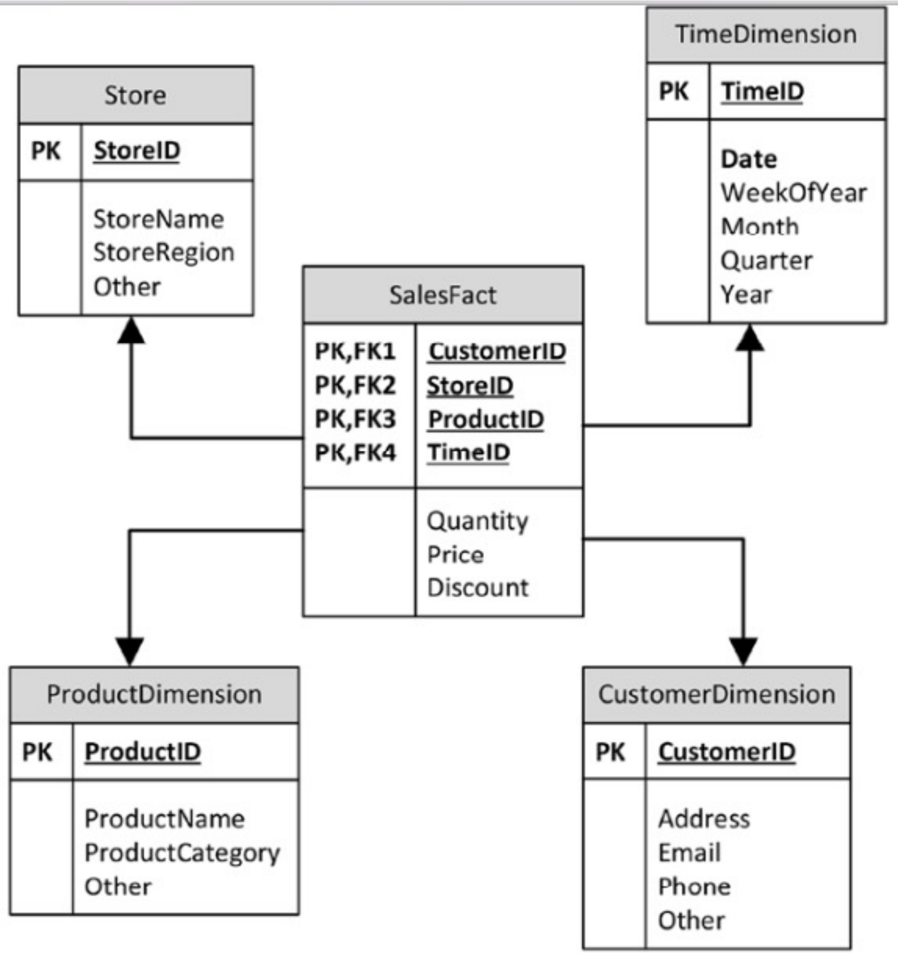


Image extracted from:"Guy Harrison, Next Generation Databases, Apress, 2015"

It is a ***relational solution*** where central ***large fact*** tables are associated with ***numerous smaller*** *dimension* tables.

Aggregate ***queries*** could execute ***quickly***.

Star Schemes do ***not*** represent a fully ***normalized*** relational model of data (redundancies are often accepted, information sometimes depend partly on the primary key).

Star Schemas: Main Drawbacks

- ***Data processing*** in data warehouses remained severely ***CPU*** and ***IO intensive***.
- The ***data volumes*** grew up along with and ***user demands*** for ***interactive*** response times.
- In general, around mid 90s of the last century, the ***discontent*** with traditional data warehousing performance ***increased***.

The Columnar Storage

When processing data for making ***analytics***, in most of cases, we are not interested in retrieving ***all the information*** of each single records.

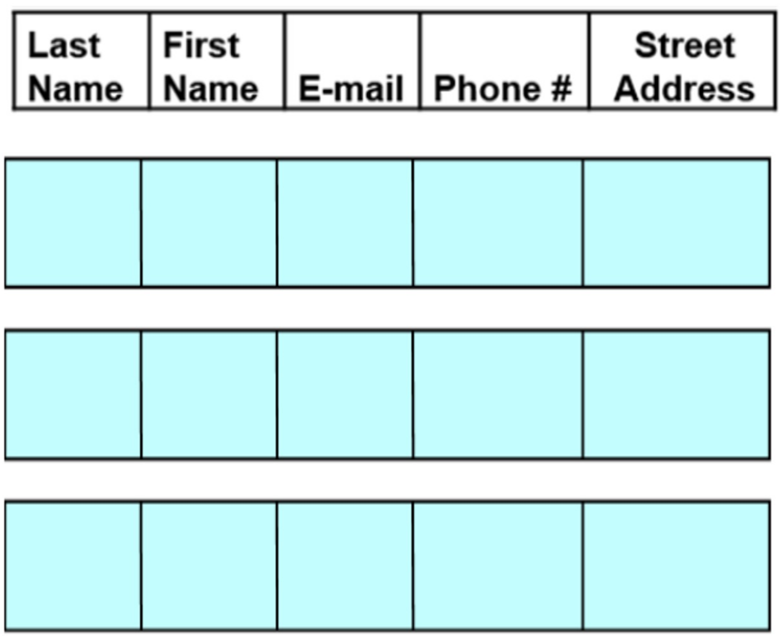
Indeed, we are interested, for example, in retrieving the values of ***one attribute*** of a ***set of records*** (for making trend graphs, or calculating statistics).

When dealing with ***row-based*** storage of records, we have to ***access*** to ***all the records*** of the considered set for retrieving just the values of one attribute.

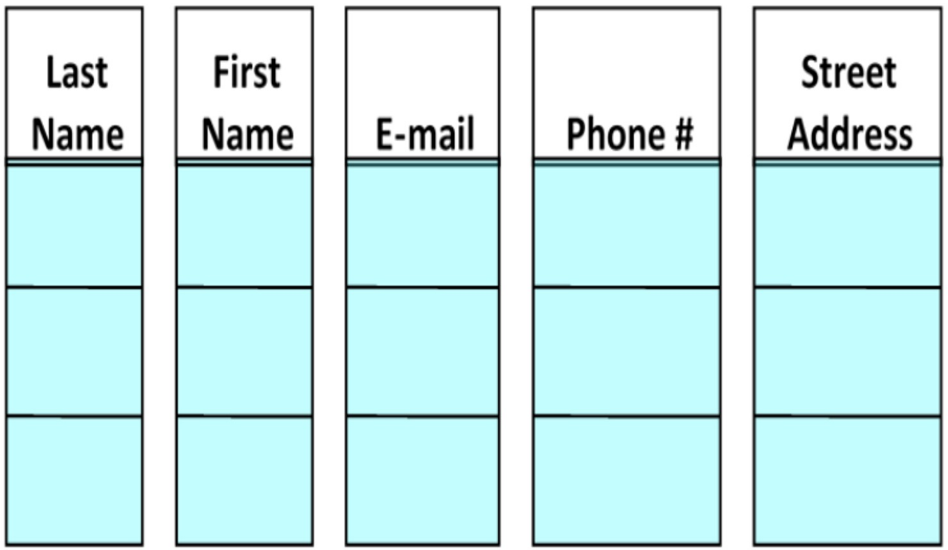
If all the values of an attribute are ***grouped*** together on the ***disk (***or in the block of a disk***)***, the task of retrieving the values of one attribute will be ***faster*** than a row-based storage of records.

Rows vs Columns

Row Storage



Columnar Storage



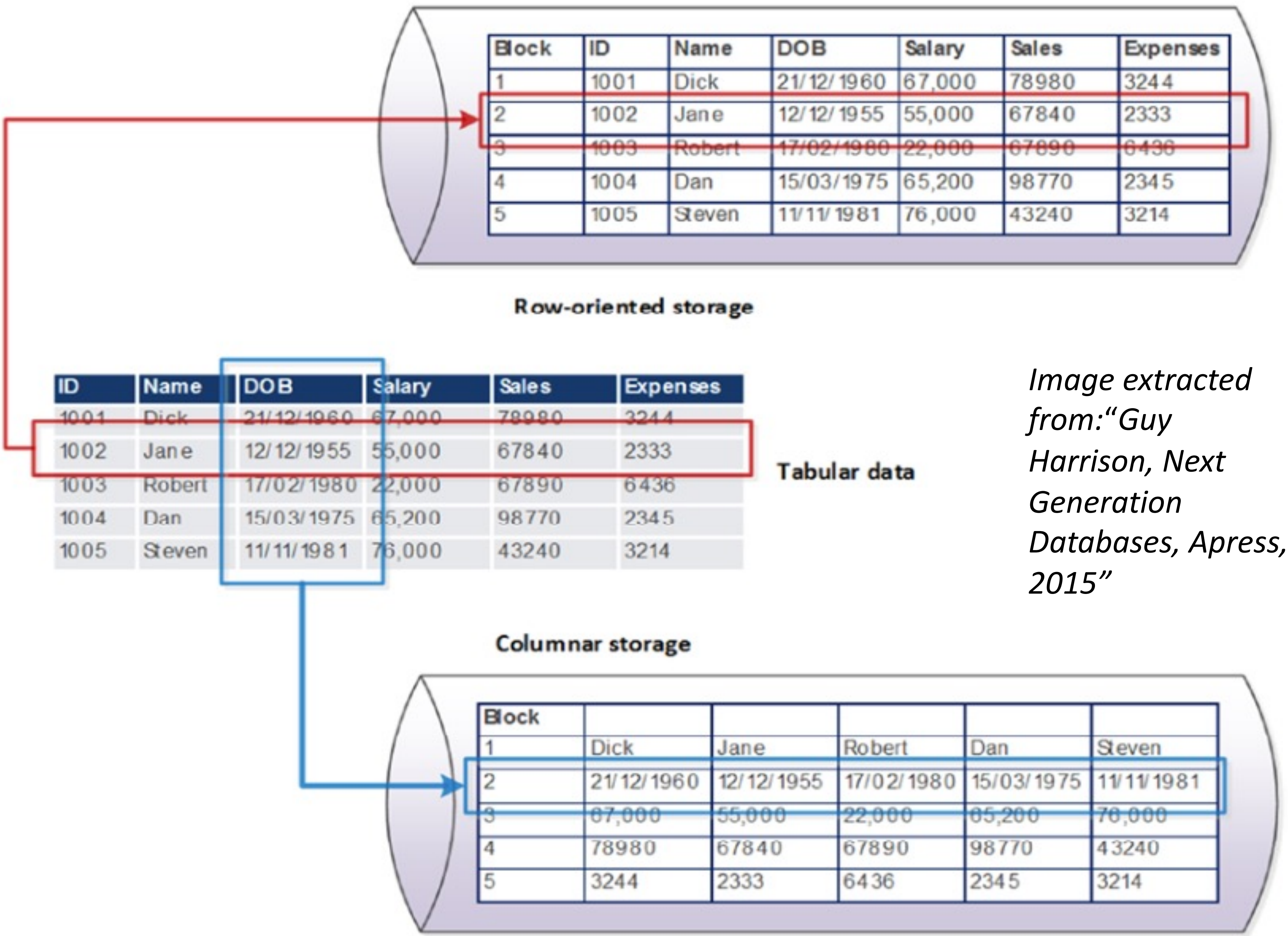


Image extracted from:“Guy Harrison, Next Generation Databases, Apress, 2015”

An Example

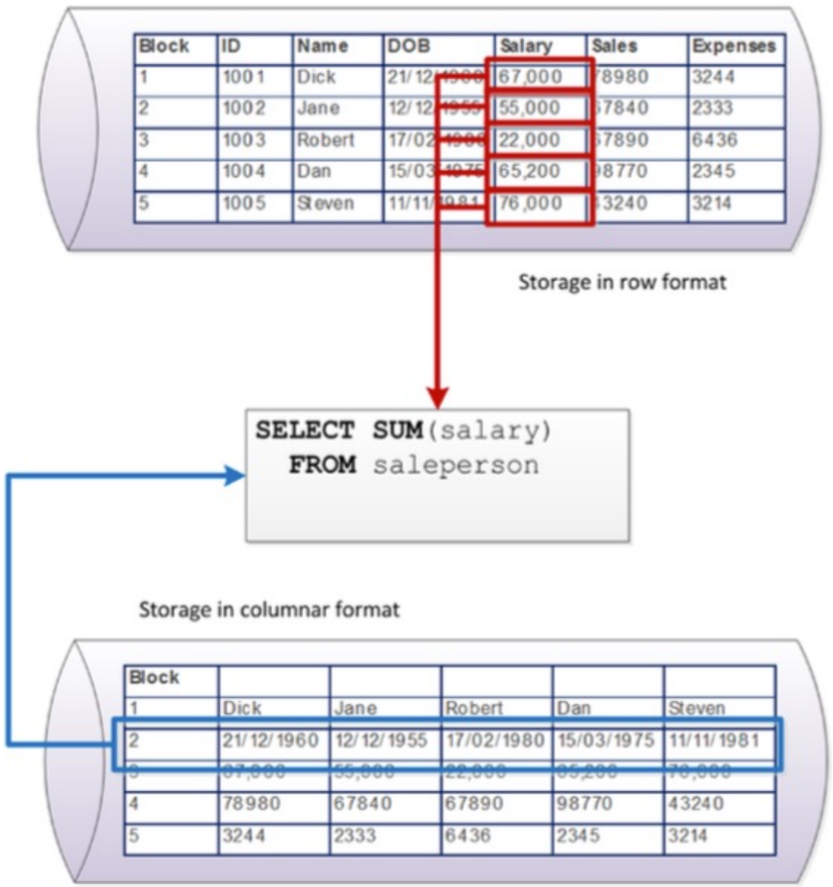


Image extracted from:"Guy Harrison, Next Generation Databases, Apress, 2015"

If data are stored by ***rows***, in order to retrieve the sum of salaries we must scan ***five*** blocks.

In the case of ***column*** store, a ***single block access*** is enough.

In general, queries that work across ***multiple rows*** are significantly accelerated in a columnar database.

Columnar Compression

Data compression algorithms basically ***remove redundancy*** within data values.

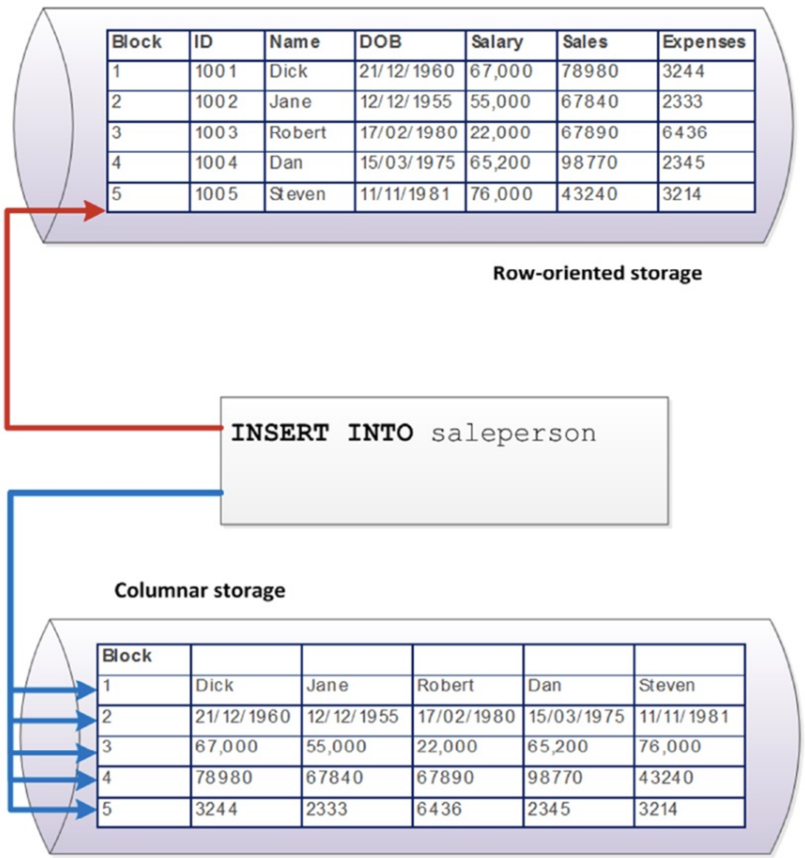
The higher the redundancy, the higher the compression ratios.

To find redundancy, data compressions algorithms usually try to ***work*** on ***localized*** subsets of the data.

If data are stored in a column databases, very ***high compression ratio*** can be achieved with very ***low computational overheads***.

As an example, often in a columnar database data are stored in a ***sorted order***. In this case, very high compression ratios can be achieved simply by representing each column value as a "***delta***" from the preceding column value.

Single Row Operations Penalty



Block	ID	Name	DOB	Salary	Sales	Expenses
1	1001	Dick	21/12/1960	67,000	78980	3244
2	1002	Jane	12/12/1955	55,000	67840	2333
3	1003	Robert	17/02/1980	22,000	67890	6436
4	1004	Dan	15/03/1975	65,200	98770	2345
5	1005	Steven	11/11/1981	76,000	43240	3214

Block					
1	Dick	Jane	Robert	Dan	Steven
2	21/12/1960	12/12/1955	17/02/1980	15/03/1975	11/11/1981
3	67,000	55,000	22,000	65,200	76,000
4	78980	67840	67890	98770	43240
5	3244	2333	6436	2345	3214

Image extracted from:"Guy Harrison, Next Generation Databases, Apress, 2015"

Column databases perform ***poorly*** during ***single-row modifications***.

The ***overhead*** needed for ***reading*** rows, can be ***partly reduced*** by caching and multicolumn projections (storing multiple columns together on disk).

In general, handling a row means accessing to more than once blocks of the disk.

Delta Store

Problem: The basic column storage architecture is ***unable*** to cope with ***constant*** stream of ***row-level modifications***.

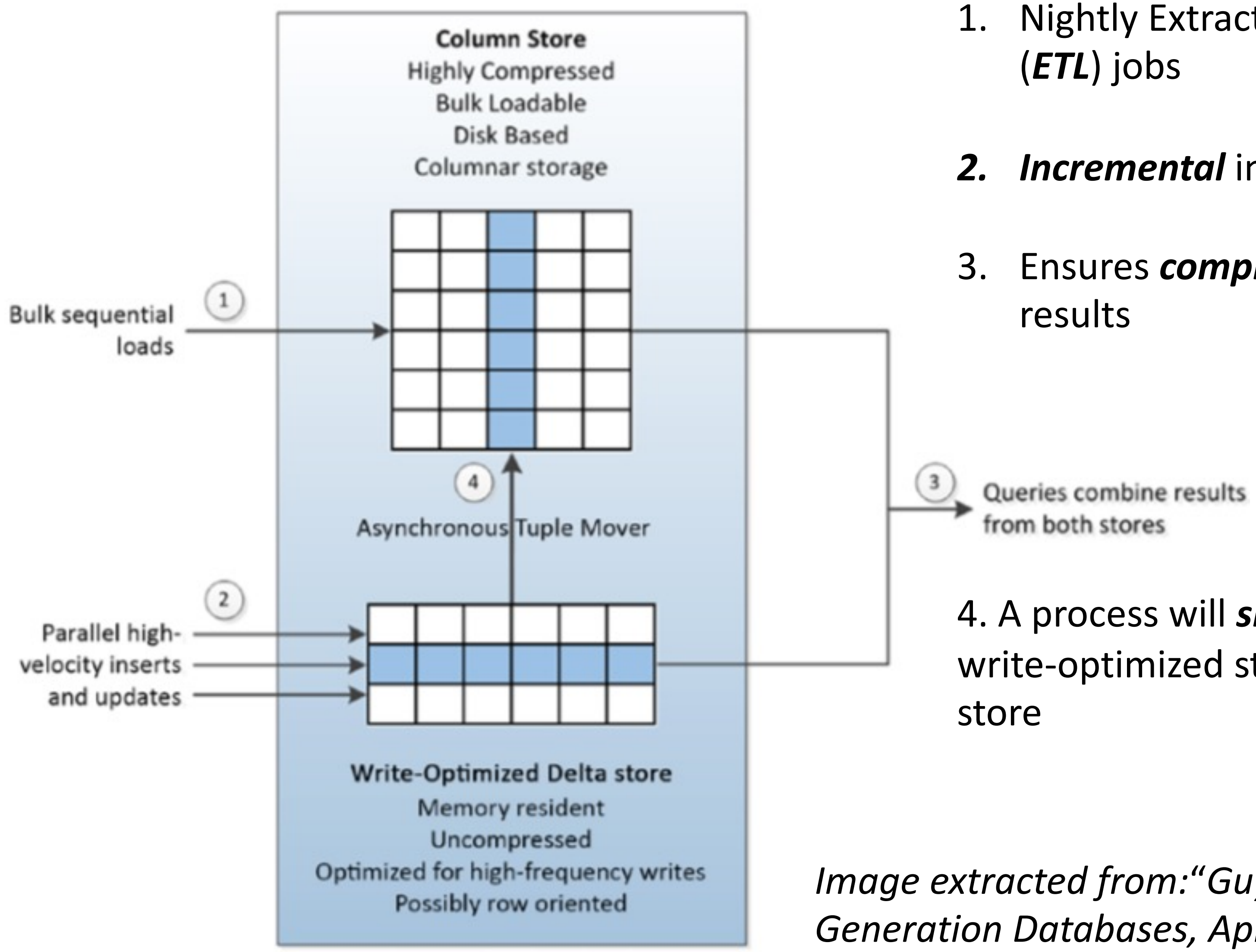
These modifications are needed whenever ***data warehouse*** have to provide real-time "***up-to-the-minute***" information .

Solution: Delta store is an area of the database, resident in ***in-memory uncompressed*** and optimized for high-frequency data modifications.

Data in the delta store is ***periodically merged*** with the main ***columnar***-oriented store (often data are ***highly compressed***).

Queries may need to ***access both*** the delta store and the column store in order to return complete and accurate results.

Delta Store: Architecture



1. Nightly Extract, Transform, Load (***ETL***) jobs

2. ***Incremental*** inserts and updates

3. Ensures ***complete*** and ***consistent*** results

4. A process will ***shift data*** from the write-optimized store to the column store

Image extracted from:"Guy Harrison, Next Generation Databases, Apress, 2015"

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Projections

Problem:
Complex queries often need to read ***combinations*** of column data.

Solution:
Some column databases adopts ***projections***.

Projections: combinations of columns that are ***frequently*** accessed together.

Columns of specific projections are ***stored together*** on the disk.

In the following slide, we show an example of database architecture based on projections.

Region	Customer	Product	Sales
A	G	C	789
B	C	C	743
D	F	D	675
C	C	A	23
A	R	B	654

Logical Table
Table appears to user in relational normal form

Physical Storage

Region	A	B	D	C	A
Customer	G	C	F	C	R
Product	C	C	D	A	B
Sales	789	743	675	23	654

1. **Super-Projection**
Default projection unsorted columnar storage of all columns. Used to resolve queries that have no specific supporting projection

Region	A	A	B	C	D
Product	B	C	C	A	D
Sales	654	789	743	23	675

Sort Columns

2. **Projection 1**
This might support query:

```
SELECT Region, Product, SUM(Sales)
 GROUP BY Region, Product
```

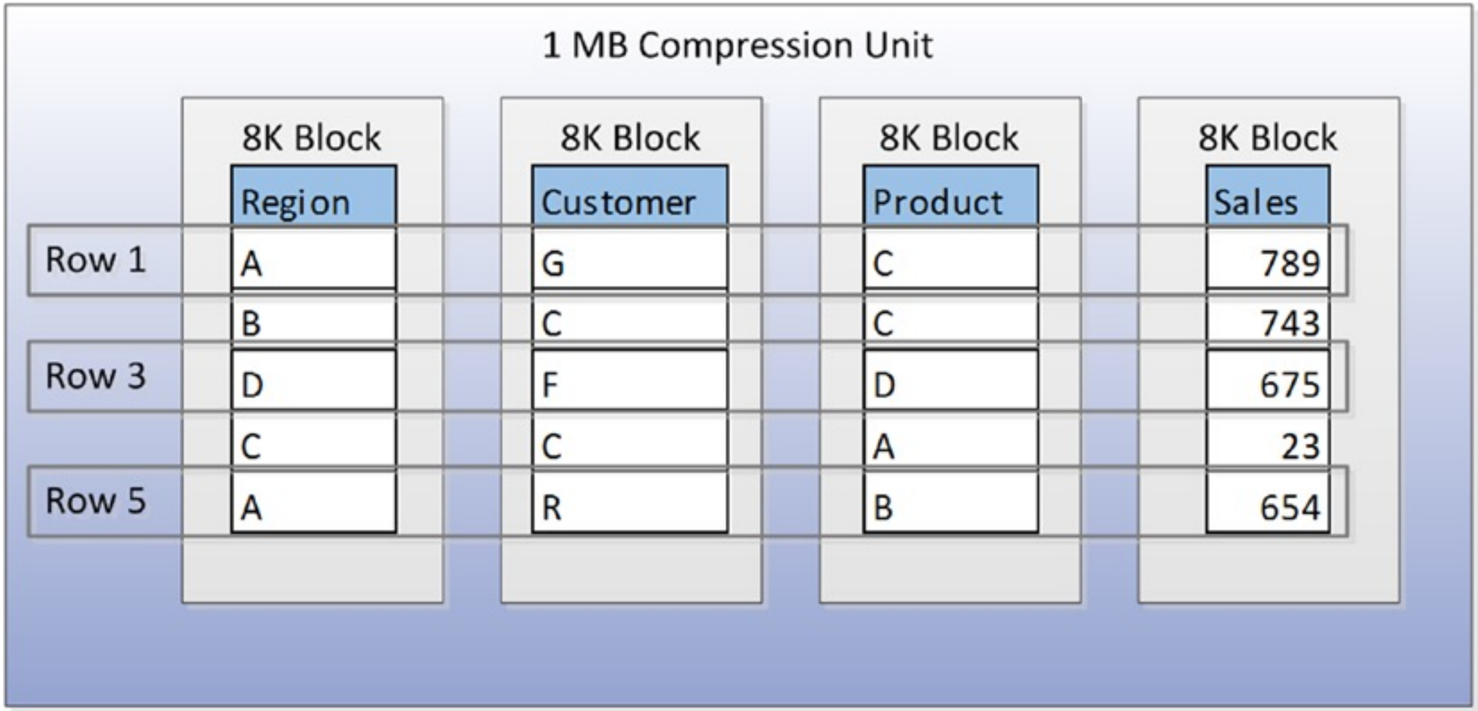
Customer	C	C	F	G	R
Sales	743	23	675	789	654

Sort Column

3. **Projection 2**
This might support query:

```
SELECT Customer, SUM(Sales)
GROUP BY Customer
```

Hybrid Columnar Compression (Oracle Solution)



- Rows of data are contained within compression units of about 1 MB
- Columns stored together within smaller 8K blocks

Suggested Readings

Chapter 6 of the book *"Guy Harrison, Next Generation Databases, Apress, 2015"*.