In-memory databases

Contents

- In-memory database technology
- Commercial In-memory Databases
- SQL Server Memory Optimized Tables
- Exercise

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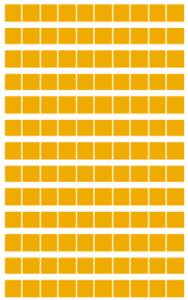
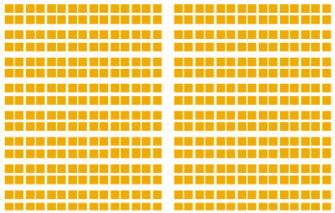
Classical Database Architecture

- Classical Database management systems (DBMS) are designed late 1970's for:
  - Delivering performance on hardware with
    - limited main memory

    and
    - slow disk I/O

    as the main bottleneck
- The focus was on optimizing disk access
  - for example by minimizing the number of disk pages to be read into main memory when processing a query (see chapter about indexing)
- Sequential processing paradigm
  - Data tables are fetched from the database
  - Row by row processing
  - Write-back to the database

Hardware revolution

20 Years Ago		Now	Near Future
			
Memory 1GB	X 6,000	**Memory** 6 TB	**Memory** 48 TB
CPU 4 x 50 Mhz	X 1,800	**CPU** 120 x 3 GHz	**Cores** 480 (8 x 4 x 15)
Transistors (CPU) ~ 1 million		**Transistors (CPU)** 2.6 Billion	

Note: Figures are for single servers

In-memory database technology

The basic idea is that memory is much faster than disk

- a modern CPU has a **memory bandwidth** of **20 GB/sec** and higher
  - a **single disk** is around:
    - **550 Mbyte/sec for SSDs**
    - **180 Mbyte/sec for hard disk drives**
  - => difference by **factor 36 and 110**.
- If a program is using the same memory frequently, it is cached inside the CPU's L1 or L2 cache, speeding up the memory bandwidth by another factor of 10.
- At the same time
  - the disk speed of 180MB/sec is **for sequential read access** only
  - **random access would be times worse** for a disk system

In-memory database technology

- In-memory means that all the data is stored in the RAM memory
- No time waste in reading from disk
- Quick access from CPU to data

In-memory database technology

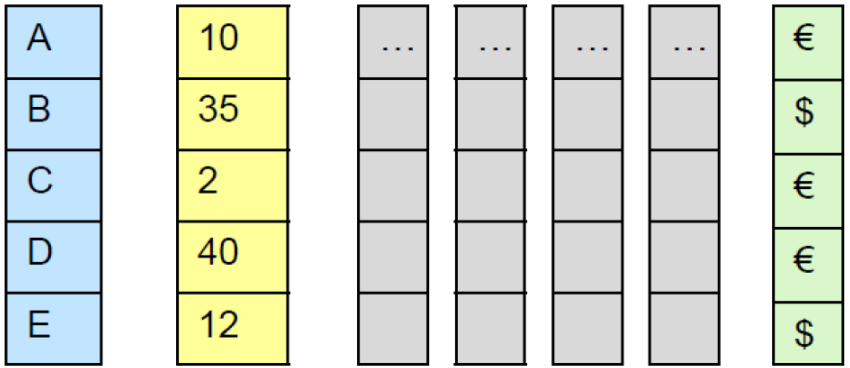
- Pro’s:
  - Fast updating
  - Fast inserting
  - Fast reading
- Cons:
  - When the power is gone => all data are gone
  - Cost:
    - 1 TB , 2 TB server is affordable
    - 64 Tb server is expensive
    - 1000 TB server does not exist

Storing tabular data: two ways

Table of Information

A	10	… many columns	€
B	35		$
C	2		€
D	40		€
E	12		$

… by column

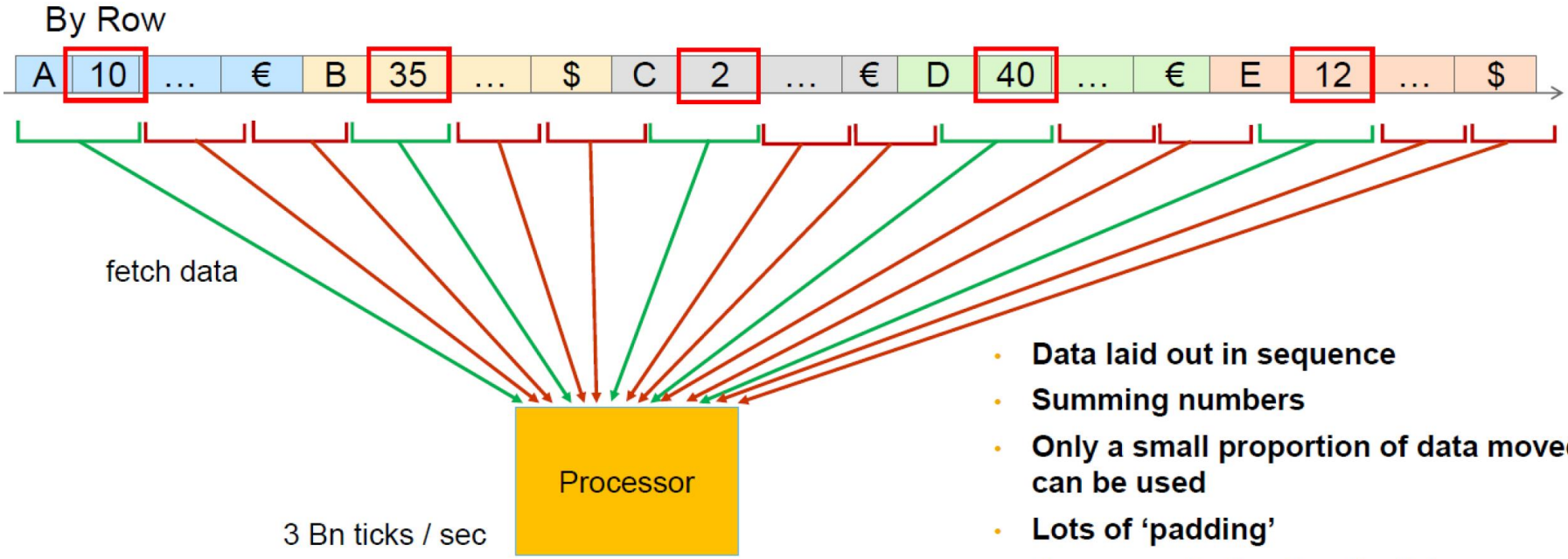


… or by row

A	10	…	€	B	35	…	$	C	2	…	€	D	40	…	€	E	12	…	$

Store by row

For rows, data is moved to the processor in ‘chunks’ but only a tiny proportion of those ‘chunks’ is useful



- **Data laid out in sequence**
- **Summing numbers**
- **Only a small proportion of data moved can be used**
- **Lots of ‘padding’**
- **Processor ‘spins its wheels’**

Columnar storage

Row-based Storage

Order	Country	Product	Sales
456	France	Corn	$1000
457	Italy	Wheat	$2000
458	Italy	Corn	$100
459	Italy	Peas	$110
460	Italy	Ferrari Lug Nut	$200
461	Spain	Rice	$700
462	Germany	Beer	$300

456
457
458
459
460
461
462

France
Italy
Italy
Italy
Italy
Spain
Germany

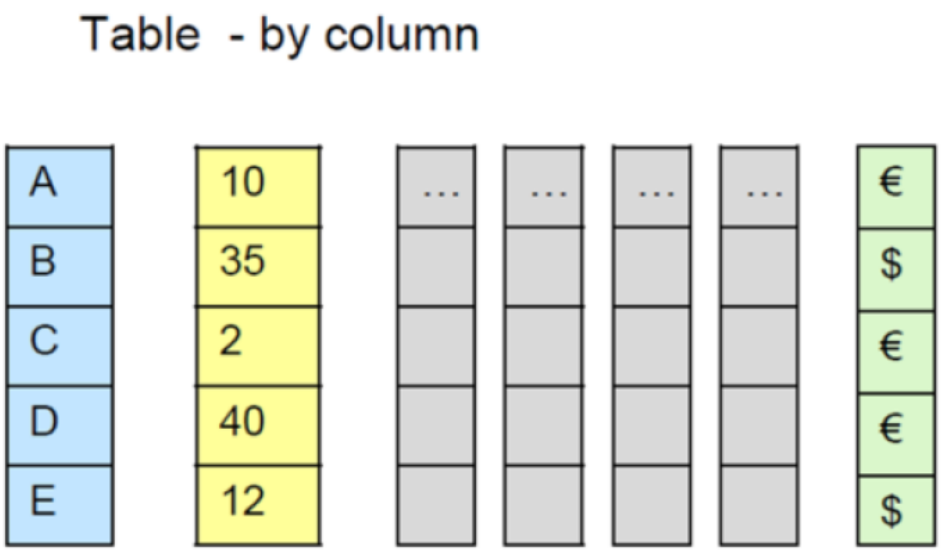
Corn
Wheat
Corn
Peas
Ferrari Lug Nut
Rice
Beer

$1000
$2000
$100
$110
$200
$700
$300

Column-based Storage

- To read a row store, we would have to go through each record one by one
- Columnar Storage will instead store each column separately with its own, separate index
- Allows to easily exclude entire columns not included in the query:
- Ex. queries for Country and sales will ignore Order and Product, thereby increasing the speed and efficiency of the query.

Columnar storage: benefits



- Highly dense data structures
- Compresses nicely
- Multiple values for aggregate calculations available at once
- Easy to add new columns => no need to rewrite table
- Only fetch columns that are asked in query
- Makes optimal use of modern CPU architectures

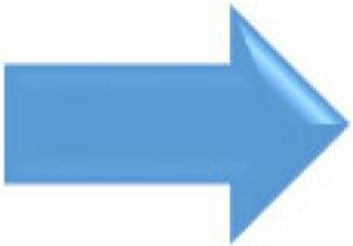
Columnar storage: compression

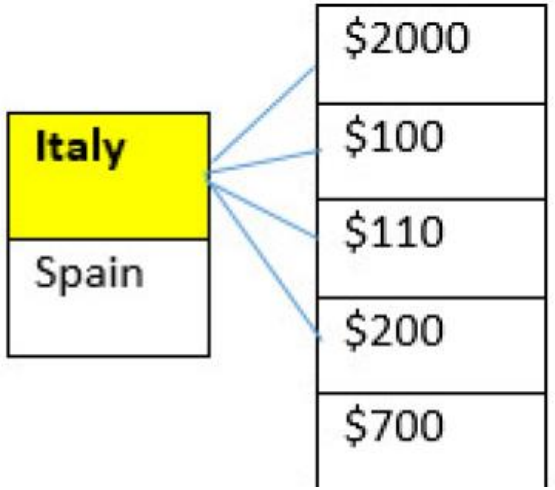
- Basic idea: a single CPU (and RAM) is much faster than the disk
  - Compression of data in order to reduce the amount of data is beneficial as long as the overhead of that is not too huge
- Every DB technology uses compression
  - But compression and decompression ask a toll (time)
  - Most obvious overhead:
    - Update data in a database block
      - Uncompress DB block
      - Merge change data in block
      - Compress DB block again

Columnar storage: compression

- Each column is stored separately => greater rates of compression

Italy	$2000
Italy	$100
Italy	$110
Italy	$200
Spain	$700





- In the example records indicating ‘Italy’ are compressed 4 to 1

Columnar storage with in-memory

- Conclusion: columnar storage
  - reduces required size of data
  - has faster access
  - is only useful for in-memory storage

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Commercial in-memory databases

- SAP Hana: completely redesigned database concept
- Oracle: IM (in-memory) column store:
  - “maintains copies of tables, partitions, and individual columns in a special compressed columnar format that is optimized for rapid scans.”
- Microsoft: “memory-optimized tables”

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SQL Server Memory Optimized Tables

- Up to 30x performance gain according to Microsoft
- It is not (only) fast because it is in-memory; it is fast because it is optimized around the data being in-memory (see previous slides)
- Data lives in-memory does not mean you lose it when there is a failure.
  - By default, all transactions are fully durable.
  - As part of transaction commit, all changes are written to the transaction log on disk.
  - If there is a failure at any time after the transaction commits, your data is there when the database comes back online.

Memory optimized tables: usage scenarios (1/2)

- High-throughput and low-latency transaction processing
  - Core scenario.
  - E.g.: stock trading, sports betting, mobile gaming.
- Data ingestion
  - Ingesting large volumes of data from different sources at same time.
  - E.g.: IoT sensor readings and events.

Memory optimized tables: usage scenarios (2/2)

- Caching and session state
  - E.g. ASP.NET session state
- Tempdb object replacement (MS-SQL Server)
  - Replace temporary tables (#table, ##table) and table variables (@table)
- ETL (Extract Transform Load)
  - ETL workflows often include load of data into a staging table, transformations of the data, and load into the final tables.
  - Use non-durable memory-optimized tables (option: `DURABILITY=SCHEMA_ONLY)` for the data staging. They completely remove all IO, and make data access more efficient.

Memory optimized tables: syntax

See script “MemoryOptimizedTables.sql”

Restrictions:

- Clustered indexes, which are the default for primary keys, are not supported with memory-optimized tables. Specify a NONCLUSTERED index instead.
- Computed columns are not supported with memory-optimized tables.
- The feature ROWGUIDCOL is not supported with memory-optimized tables.
- **Tables that are migrated to memory can’t have foreign key relationships with other tables, so they first have to be removed.** Foreign key relationships also can’t be restored after migration of a single table, so in practice often the complete database has to be migrated to memory if you want to restore foreign keys if all tables are connected through foreign keys.

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Migrating tables to In-Memory: exercise

Database xtreme

- Migrate table Supplier to memory in a durable way.
  - Describe the different steps
  - Check the result

References

“High Performance SQL Server”, 2016, Benjamin Nevarez, Apress

“Expert Performance Indexing in SQL Server 2019”, Jason Strate, 2019, Apress

https://docs.microsoft.com/en-us/sql/relational-databases/in-memory-oltp/overview-and-usage-scenario