In-Memory Columnar Databases (SanssouciDB)

Big Data Management

Knowledge objectives

1. Justify the viability of in-memory databases
2. Explain the principles of NUMA architecture
3. Enumerate 3 techniques to optimize cache usage
4. Give 4 arguments for columnar storage
5. Explain 3 classical optimization techniques in RDBMS related to column storage
6. Sketch the functional architecture of SanssouciuDB
7. Explain 4 optimizations implemented in SanssouciuDB to improve data access
8. Explain how to choose the best layout
9. Identify the difference between column-stores and NOSQL related to transactions
10. Explain 3 difficulties of pipelining in column-stores
11. Explain 3 problems to implement parallelism in in-memory column-stores
12. Explain 5 query optimization techniques specific of columnar storage

Understanding objectives

1. Given a data setting, justify the choice of either row or column storage
2. Given the data in a column, use run-length encoding with dictionary to compress it

In-Memory management

Some figures

- Hw Offers
  - Memory:

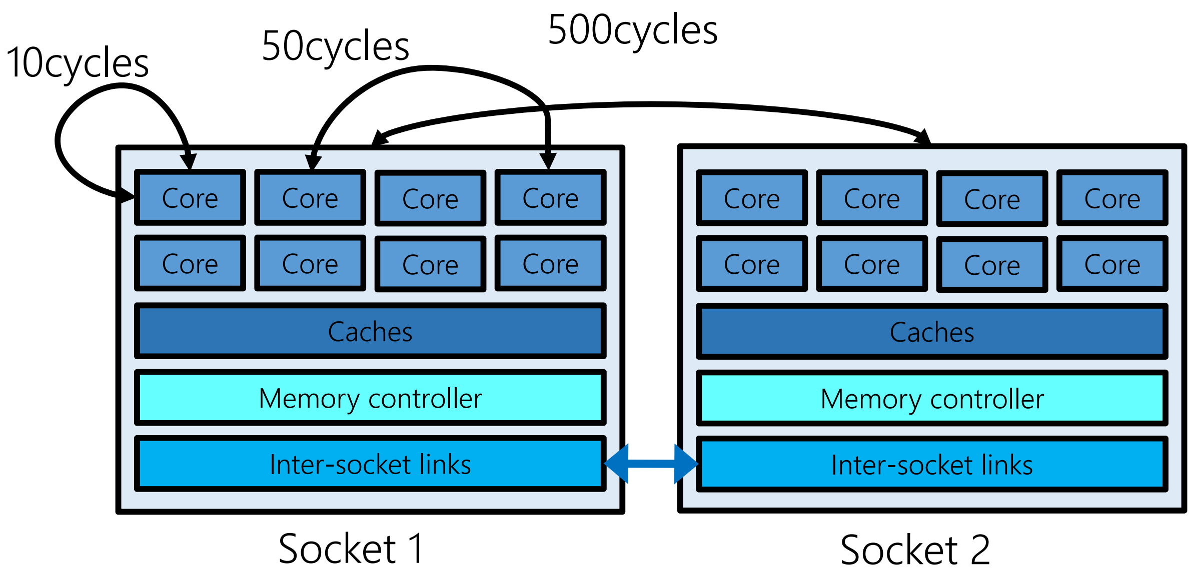
Memory per node	32Gb-100Gb
Number of nodes	20
Total	**640Gb-2Tb**

  - Cost: Less than 50.000US$
- Sw Demands
  - For TPC-C:

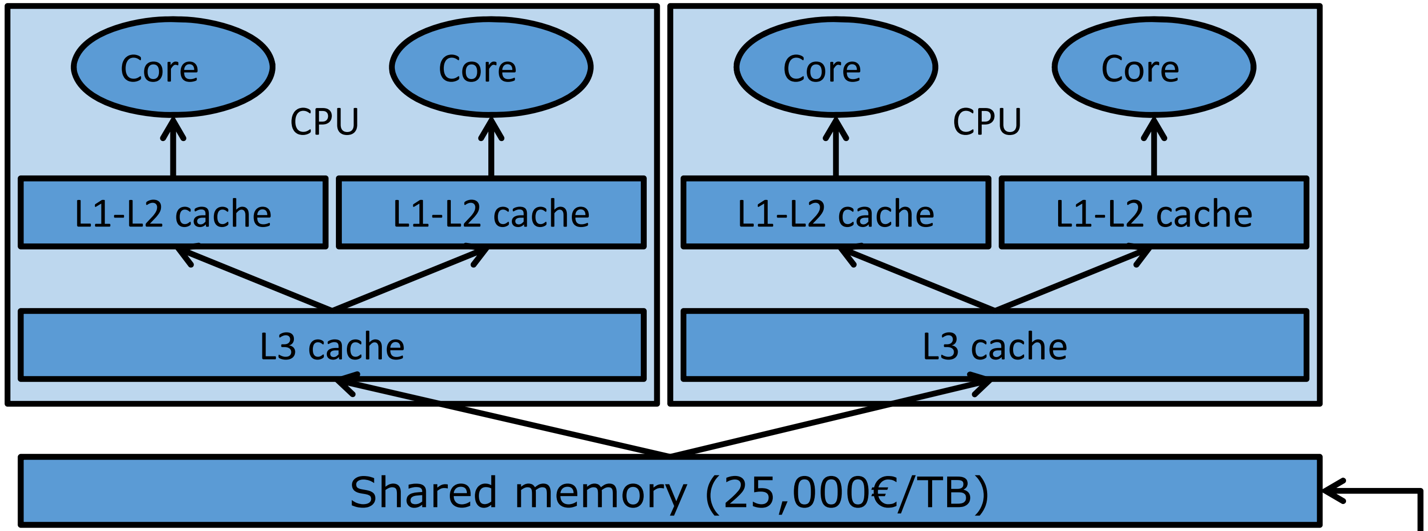
Space per warehouse	100Mb
Number of warehouses	1000
Total	**100Gb**

NUMA

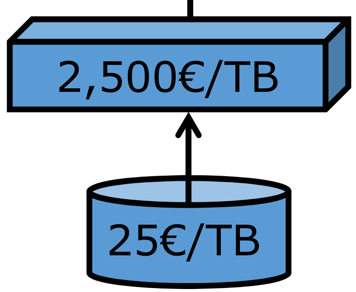
- Exploit data locality
  - Move computation to data
    - Distance matters
    - Resource awareness



Caches hierarchy

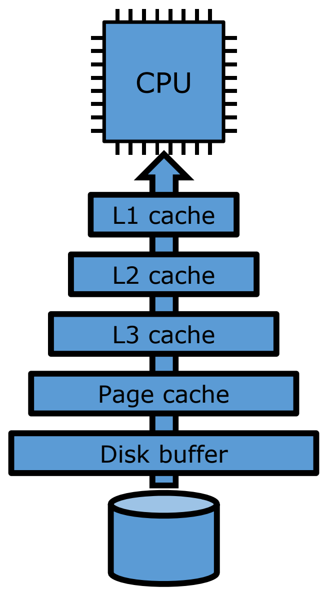


	Size	Latency	Bandwidth
L1 cache	32 KB	1.5 ns	
L2 cache	256 KB	4 ns	
L3 cache (shared)	30 MB	15 ns	
Main memory (local)	256GB x 2 x 8	60ns-100ns	13-17GB
Main memory (neighbour blade)	4TB	500+ ns	3GB
Solid State memory	Up to TBs	200,000ns	0.5GB
Hard Disk	Up to PBs	10,000,000 ns	0.07GB



Cache Optimization Techniques

- Locality Awareness
  - Reduce the number of CPU stalls while waiting for memory
  - Two different kinds
    - Spatial
      - Use pre-fetching
        - Promote sequential access
    - Temporal
      - Eviction/Replacement policies (LRU)
- Flexible Caching
  - Bring/Keep relevant data
  - Configure associativity (typically 8-way)
    - Possibilities
      - Direct mapped
      - N-way
      - Fully
    - Low associativity facilitates searching
    - High associativity facilitates replacement policies
- Cache-conscious Programming
  - Use only aligned memory
    - Allocate memory blocks that are aligned to the width of a cache line
      - Padding if necessary
  - Store many fixed size elements consecutively
    - Avoid indirections to find contents (i.e., “next” pointer)



Columnar storage

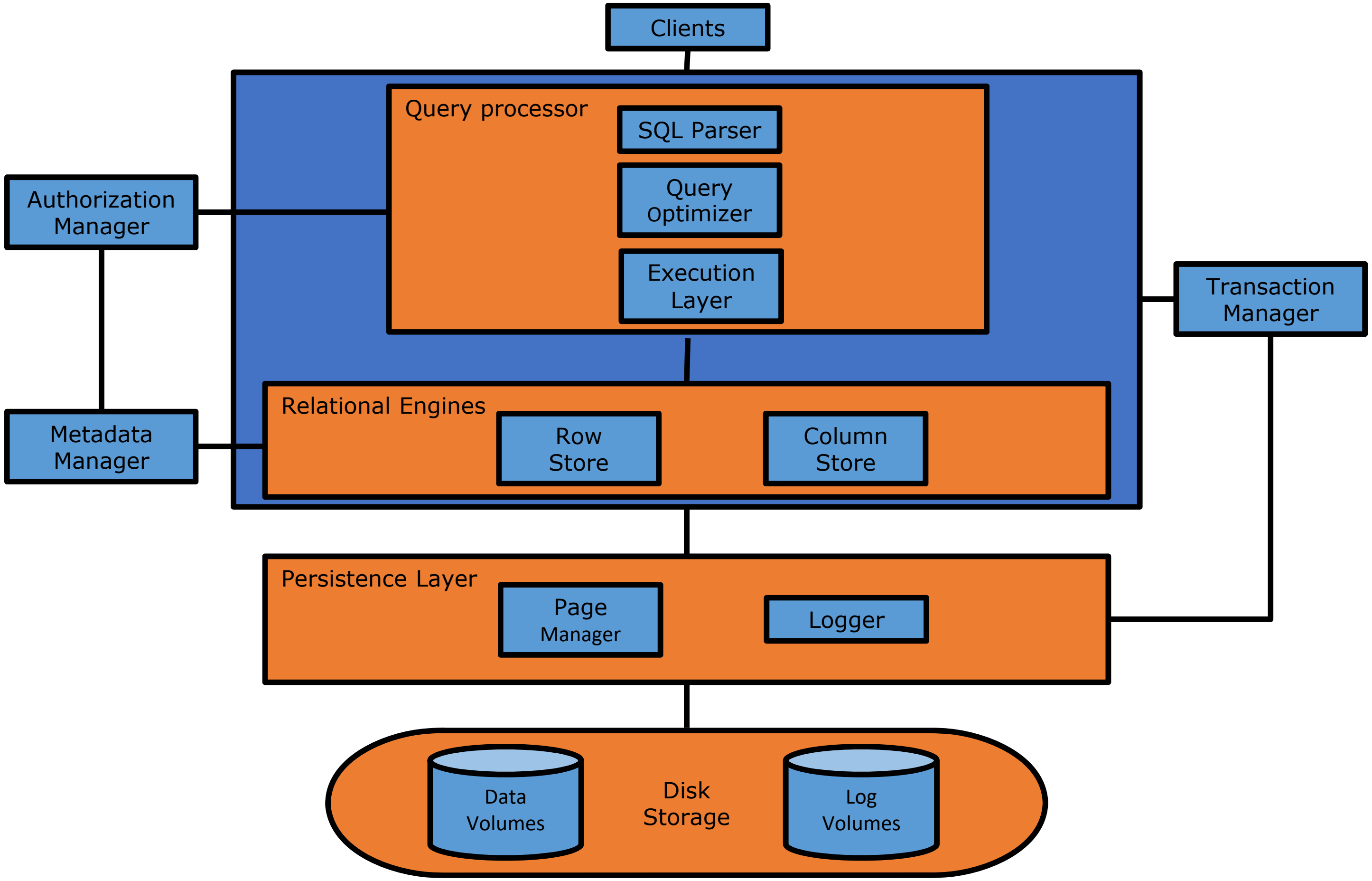
Advantages of columnar storage

- Higher data compression ratios
  - Compressed data can be loaded into CPU cache more quickly
  - With dictionary encoding, the columns are stored as sequences of bit-coded integers
  - Compression can speed up operations such as scans and aggregations if the operator is aware of the compression
- Higher performance for column operations
- Parallelization
- Elimination of additional indexes

Typical RDBMSs optimizations

- Vertical partitioning
  - Each table splits in a set of two-columned partitions (key, attributes)
    - Improves useful read ratio
- Use index-only query plans
  - Create a collection of indexes that cover all columns used in a query
    - No table access is needed
- Use a collection of materialized views such that there is a view with exactly the columns needed to answer each query

SanssouciDB architecture



Data access optimizations

- Use stored procedures
- Data aging by dynamic horizontal partitioning depending on the lifecycle of objects
  - By default only active data is incorporated into query processing
  - The definition of active data is given by the application
- Modifications are performed on a differential buffer
  - Merge process is carried out per table
    - Implies decompressing the table and compressing everything back
    - It is done on-line
- Append-only tables
  - Point representation (i.e., timestamp of the change) for OLTP
  - Interval representation (i.e., valid time of the tuple version) for OLAP

Data Design

Challenge I

Columnar storage conditions

- Calculations are executed on a single column or a few columns only
- The table is searched based on the values of a few columns
- The table has a large number of columns
- The table has a large number of rows, and columnar operations are required (aggregate, scan, and so on)
- The majority of columns contain only a few distinct values (compared to the number of rows), resulting in higher compression rates

Row storage conditions

- The table has a small number of rows, such as configuration tables
- The application needs to process only a single record at a time (many selects or updates of single records)
- The application typically needs to access the complete record
- The columns contain mainly distinct values so the compression rate would be low
- Aggregations and fast searching are not required

Catalog Management

Challenge II

Classical Relational Catalog

- Similar to any Relational system
- Stored row-wise

Transaction Management

Challenge III

Replication management avoided

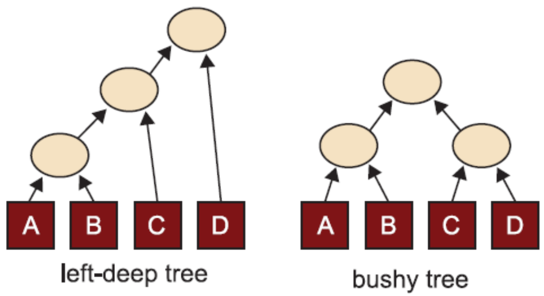
- Do not materialize aggregates (only atomic data)
  - No synchronization required
  - Queries always offer the latest updates
- Only small-static tables exceptionally replicated
  - E.g., Dimension tables
- Full support for ACID transactions
  - Eager/Secondary-copy

Query processing

Challenge IV

Parallelism

- Techniques
  - Fragmenting (hybrid)
    - Typical operations benefitting
      - Table scan
      - Aggregation
      - Join
  - Pipelining
    - Difficulties:
      - Short process trees
      - Some operators need all input data at once
      - Skewed cost of operations
- Problems
  - High startup cost
    - One process per core
  - Contention (at Hw level)
    - Use multi-channel memory controllers
  - Skewness
    - Define too fast operations

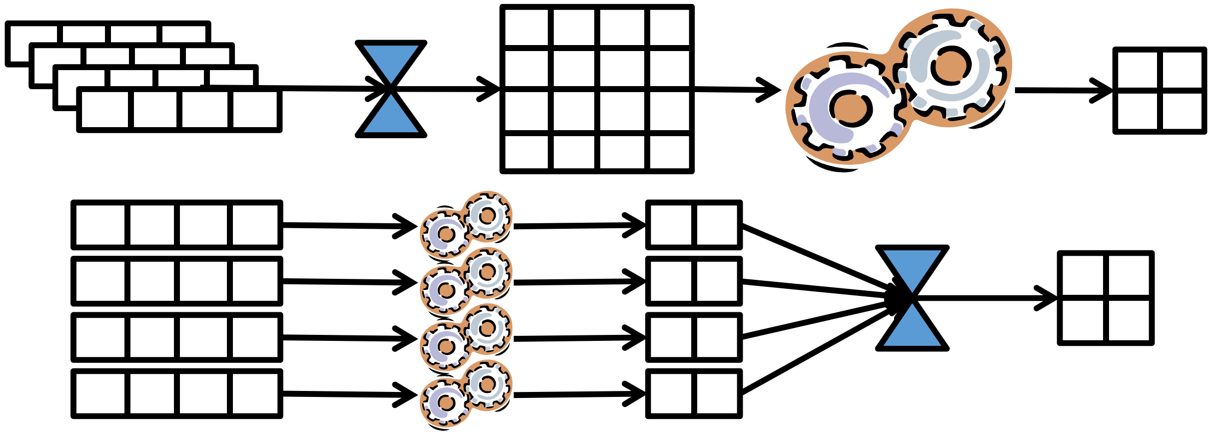


Column-Oriented Specific Optimizations

- Late materialization
- Tuples are identified by their position
  - PK does not need to be replicated with each column
- Column-specific compression techniques
  - Multiple sorting of data (replication)
    - Not in SAP HANA
- Block iteration
  - Known as *vectorized query processing*, when combined with late materialization
- Specific join algorithms

Late Materialization

- *Tuple construction* can be done at the beginning or at the end of the query



- Advantages
  - Some tuples do not need to be constructed (because of selections and projections)
  - Some columns remain compressed more time
  - Cache performance is improved (kept at column level)
  - Helps block iteration for values of fixed length columns

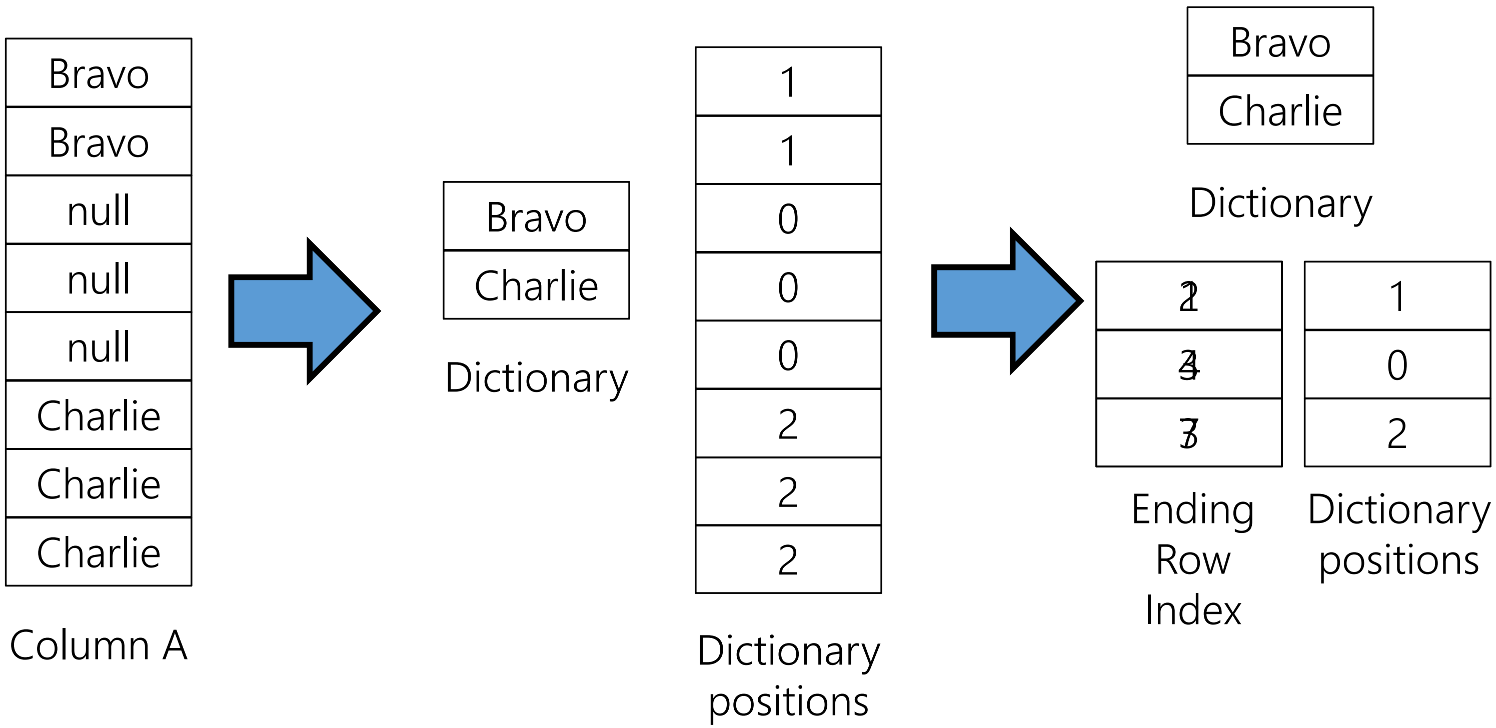
Compression

- Data stored in columns is more compressible than data stored in rows
  - High data value locality (less value entropy)
  - Benefits from sorting
- Main objective is not reducing data space but reducing I/O
- Two main trends
  - Heavyweight compression (e.g., Lempel-Ziv)
    - In general, not that useful
      - It might be if there is a (huge) gap between memory bandwidth and CPU performance
  - Lightweight compression (e.g., Run-Length Encoding)
    - Improves performance by reducing I/O cost
    - May allow the query optimizer work directly on compressed data
      - Decompression is not needed in front of bitwise AND / OR

Examples of light-weight compression

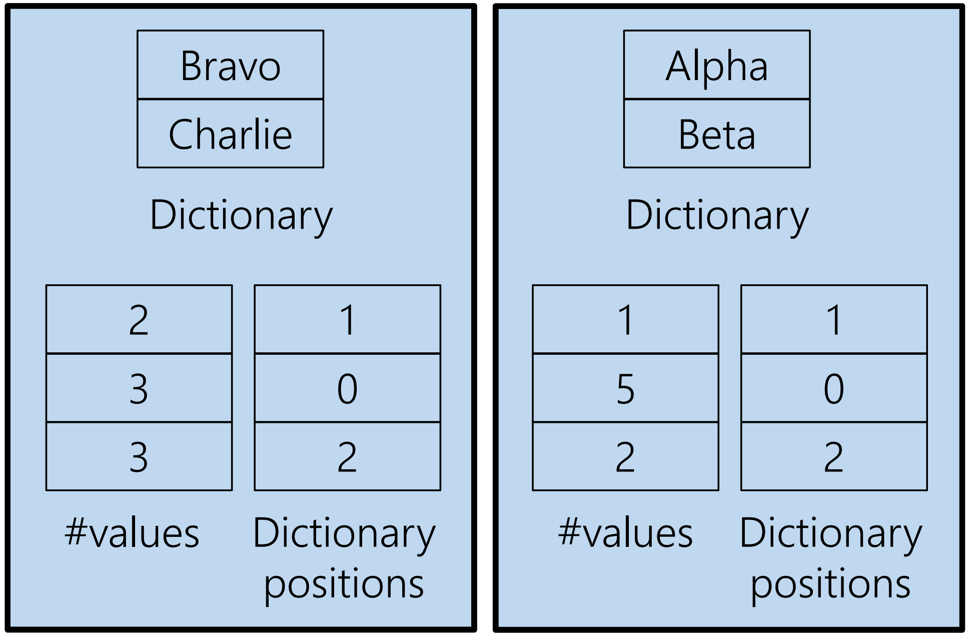
- Values coding
  - Dictionary encoding
- Repetitions coding
  - Common value suppression
    - Sparse coding
  - Cluster coding
  - Run-length encoding
- Memory usage optimization
  - Bit compression
  - Variable byte coding

Run-length encoding with dictionary



Operating on encoded bit-vectors

- We need to decode
  - Not necessarily the whole vector at once
    - One run at a time



Bravo OR Alpha

Charlie AND NULL

Block Iteration

- Blocks of values of the same column are passed to the next operation in a single function call
- Values inside the block can be:
  - Iterated as in an array (fixed-width)
  - Remain codified (compressed) together
    - Not necessarily using multiples of 8 bits
    - I can count or even identify the tuples for which the predicate is true
  - Exploits parallelism / pipelining

Closing

Summary

- Technical foundations of in-memory column stores
  - Optimizing the usage of memory hierarchies
    - Non-Uniform Memory Architecture (NUMA)
  - Optimizing the data layout
    - Row storage
    - Column storage
    - Hybrid
  - Using parallelism
  - Using compression

References

- H. Plattner and A. Zeier. *In-Memory Data Management*. Springer , 2011
- SAP HANA. *Database for Next-Generation Business Applications and Real-Time Analytics*. White paper, 2012
- D. Abadi, et al. *Column-stores vs. row-stores: how different are they really?* SIGMOD Conference, 2008
- M. Stonebraker et al. C-Store: A Column-oriented DBMS. VLDB, 2005
- G. Copeland and S. Khoshafian. *A Decomposition Storage Model*. SIGMOD Conference, 1985

Resources

- http://developers.sap.com
- http://www.vertica.com
- https://www.monetdb.org
- http://ibmbluhub.com
- http://www.oracle.com/us/corporate/features/database-in-memory-option/index.html