Advanced Data Management Technologies

Unit 21 — Main Memory Databases

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Outline

1. Main Memory Databases
2. SAP HANA and Oracle TimesTen

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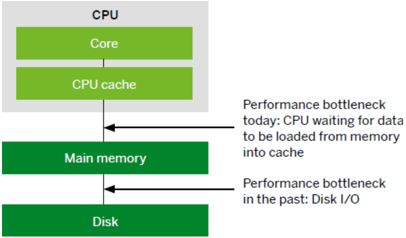
2. SAP HANA and Oracle TimesTen

Technological Transition

- Computer architecture has changed a lot in the past decades.
- Today's multicore, multi-CPU server provide fast communication between processor cores via main memory or shared cache.
- Main memory is no longer a limited resource.
  - In 2012 servers with more than 2 terabytes of RAM are available.
- Server processors with 100 cores and more are able to process more and more data per time unit.
- With all data in memory, disk access is no longer a limiting factor for performance.
- New bottleneck is CPU waiting for data from memory!



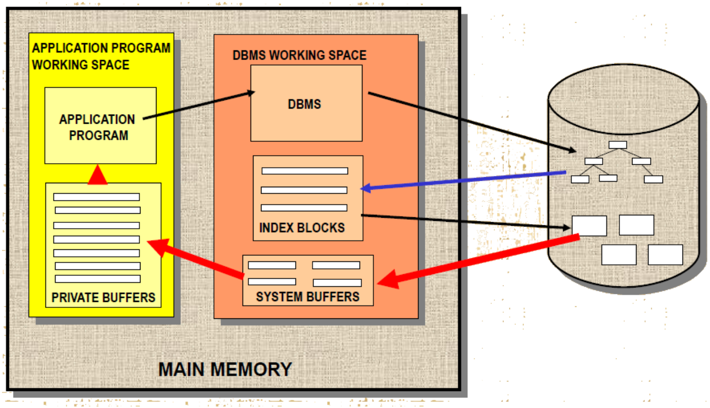
- Modern computer architectures create new possibilities and challenges for data management and processing → main memory databases.

Definition

- **Disk resident database (DRDB)**
  - The primary copy of data is permanently disk resident.
  - Data can be temporarily cached in main memory for access speed-up.
- **Main memory database (MMDB)**
  - The primary copy of data lives permanently in main memory.
  - There can be a backup copy resident on disk.
- Advantages of MMDBs
  - MMDBs avoid the disk IO bottleneck of DRDBs
  - No buffer cache management
  - High throughput
  - High availability

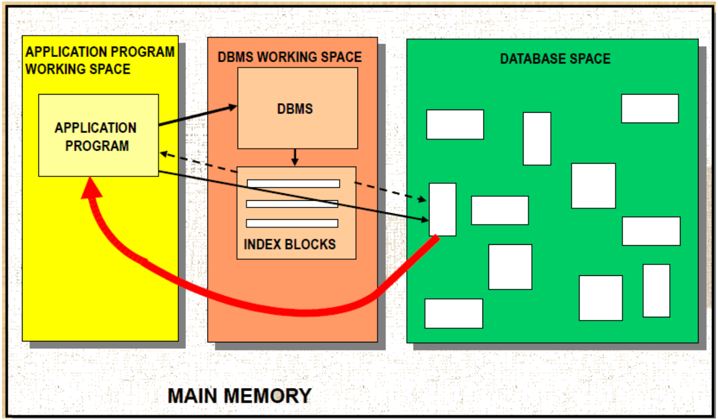
DRDB

- Data are accessed via a buffer manager, which (given the disk address) checks if the relevant block is in MM cache and then copies it to the MM application working area.



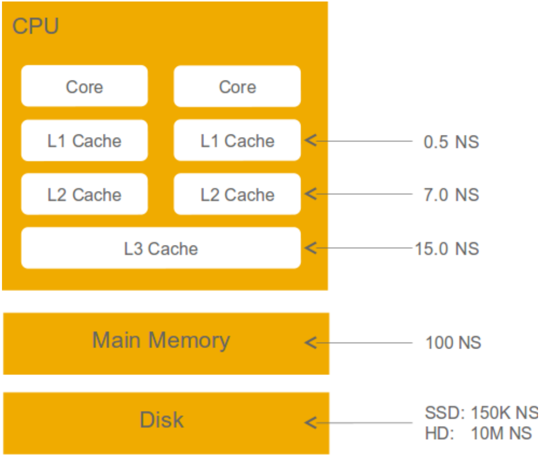
MMDB

- Data are accessed by directly referring to their memory address.



Memory Hierarchy

- DRAM is 100,000 times faster than disk, but DRAM access is still 6-200 times slower than on-chip caches.



Main Memory vs. Disk Storage

- Access time
  - Access time of MM orders of magnitude faster than for disks (100 nsec vs. 10 msec)
- Access pattern
  - Memory is better for random access than disks.
  - Disks have high fixed cost per access, independent of the amount of retrieved data (block-oriented access)
  - MM does not care of sequential access (?).
- Stableness
  - Memory is volatile; content lost if system crashes.
  - If a single memory board fails the entire machine must be powered down loosing all the data.
  - Even if special HW can enhance MM reliability, periodic backup is necessary.
  - Disk is nonvolatile (permanent).
- Security
  - Memory is more vulnerable to software errors, since memory can be directly accessed by the processor/applications.

Hybrid MM-DR Database Systems

- Some DB are so large that they will never fit in MM
- Data can belong to different classes
  - Hot: frequently accessed, low volume, timing sensitive (e.g., bank account records)
  - Cold: rarely accessed, voluminous, non time critical (e.g., bank customers records, historical records)
- Hybrid MM-DR DBMSs consist of a collection of databases, some MM others DR
- Objects can migrate among the dbms, changing their structure accordingly (e.g., IBM IMS Fast Path)

MMDBMs Concurrency Control/1

- Lock duration is short
  - Reduced contention
  - Large granules (up to the entire database)
- This almost eliminates the need of concurrency control

  $\longrightarrow$ mainly serial transaction processing
- Concurrency control still necessary when
  - mixed length transactions coexist
  - a multiprocessor system shares the DB among the different units

MMDBMs Concurrency Control/2

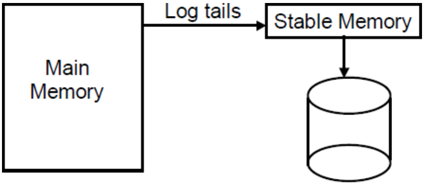
- Traditional implementation
  - Lock (hash) tables holding entries for currently locked objects
  - No lock information attached to data
- Implementation in MMDBs
  - Add some bits of locking information to the data, e.g.,
    - 1st bit is the X-LOCK SET bit
    - 2nd bit is the WAITING FOR bit

MMDBMs Commit Processing/1

- ACID properties of transactions
- Durability of transaction forces a log record to be written to stable storage before committing
- Logging affects response time and throughput
- Problem: Log I/O becomes a bottleneck!

MMDBMs Commit Processing/2

- Solution 1: Store log tail in stable memory
  - Reduces response time



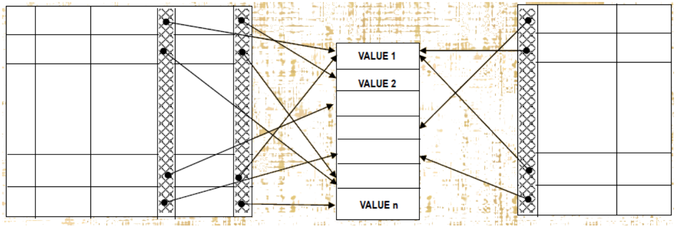
- Solution 2: Group commit
  - Accumulate log until page is full
  - Flush log page to disk only once
  - Reduces the total number of disk accesses
- Solution 3: Precommit transactions
  - Release lock (i.e., precommit) when log is written to log buffer
  - Commit when log buffer flushed to disk
  - Reduces blocking time of other transactions

Data Representation/1

- Relational data are traditionally stored in flat files
  - Slotted page structure
  - Tuples are store sequentially
  - Attribute values are "embedded" in the tuples
    - Space consuming due to duplicate values.
  - Access is local
- Indexes for efficient access

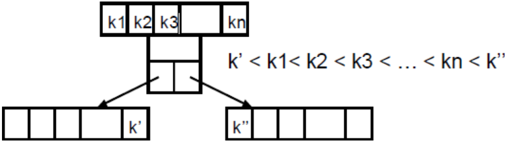
Data Representation/2

- Access locality is not an issue in MMDBs
  - Any location can be accessed at the same speed
- Variable length fields are not problematic
  - Pointers to heap space
- Compressing data size is a major goal of MMDBs → domain storage
  - Store domain values of enumerated types in a domain table
  - In the tuples, store pointers to the domain table
  - Domain tables can be shared among columns and relations
  - Yields fixed size tuples



T-Tree Index

- **T-tree** is the most important index structure in MMDBs
  - Modified binary AVL tree
    - binary search
  - A node contains more than two values
    - Storage and update efficiency (as in B-trees)
  - Balanced by rotating nodes



- Advantages
  - Space efficient
  - Logarithmic performance

Outline

1 Main Memory Databases

2 SAP HANA and Oracle TimesTen

SAP Vision and Challenge

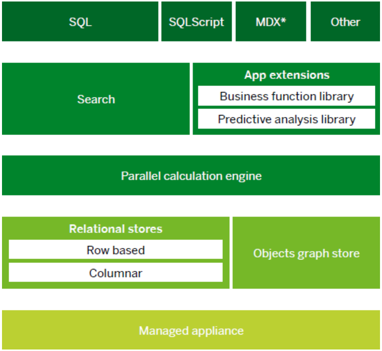
- Unify transaction processing and analytics
- Single system
- Same data instance
- Run analytics in real-time
- Run analytics and transactions at the "speed of thought"

- Solution: in-memory computing
  - Store large blocks of data directly in random access memory (RAM)
  - Keep it there for continued analysis

$\rightarrow$ SAP HANA

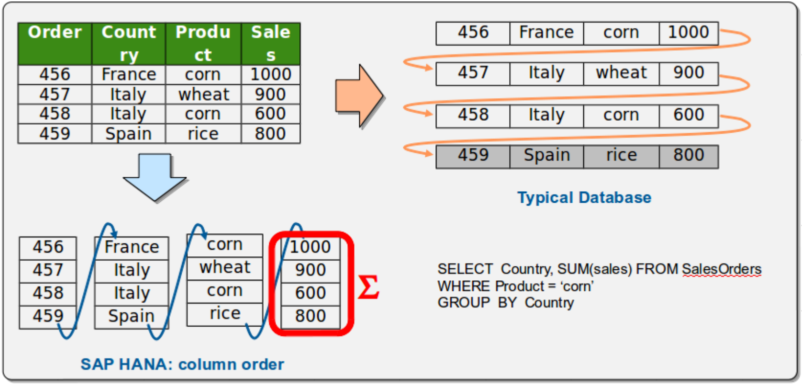
SAP HANA Database

- The SAP HANA platform implements a new approach to big data analytics
- At the core is a full database management system with a standard SQL interface, transactional isolation and recovery (ACID), and high availability
- But includes much more than the DBMS
- In-memory is much more than simple caching of disk data structures in main memory
  - Data is completely stored in main memory
  - Highly tuned access structures
  - Row-based and column-based stores
  - Data compression techniques
  - Parallelization of query processing
  - etc.



HANA Column Store

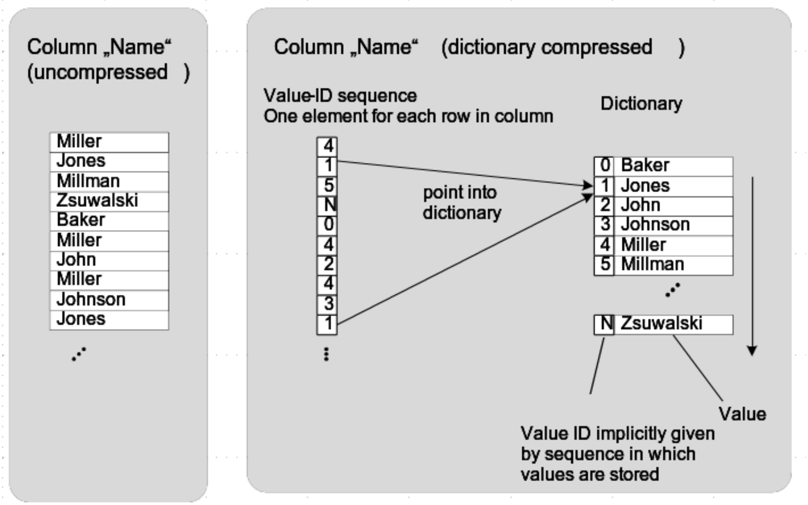
- In analytics, frequently only a small subset of columns is needed
- Extreme fast scan of columns
- Fast on-the-fly aggregation over columns



HANA Data Compression

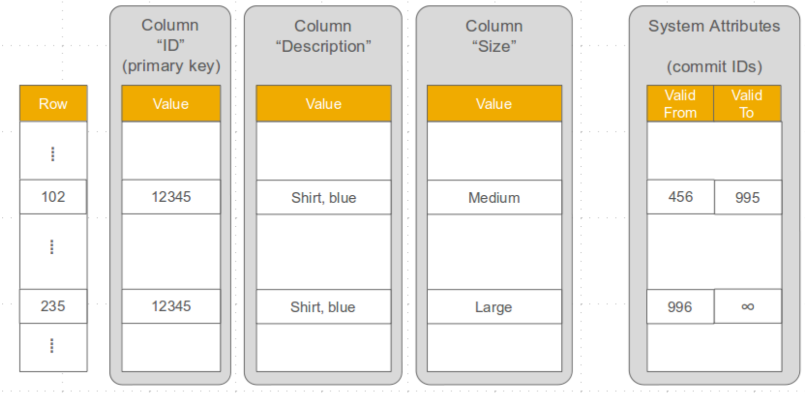
- Efficient compression methods (dictionary, run length, cluster, prefix, etc.)
- Compression works well with columns and can speedup operations on columns ($\approx$ factor 10)
- Because of compression (slow!), write changes into less compressed delta storage
  - High write performance not affected by compression
    - Data is written to delta storage with less compression which is optimized for write access
  - Merged into columns from time to time or when a certain size is exceeded
    - Delta merge can be done in background
  - Trade-off between compression ratio and delta merge runtime

HANA Dictionary Compression

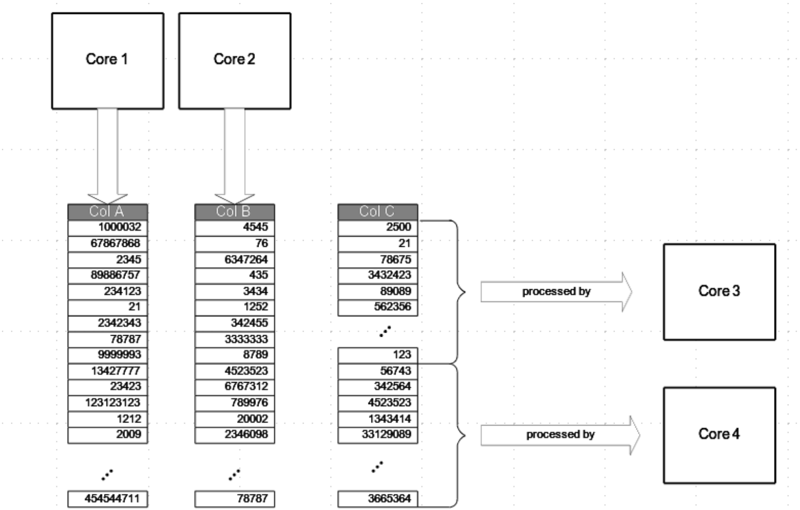


HANA Temporal Tables

- All updates and deletes are handled as inserts
- e.g., update T1 set Size = 'Large' where ID = '12345'

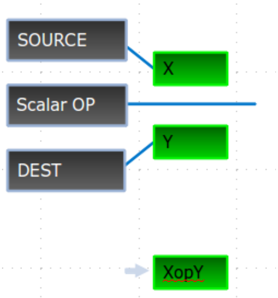


HANA Multi-core Parallelization

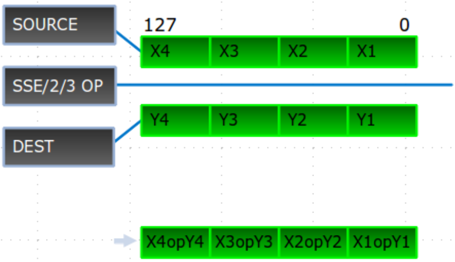


HANA Single Instruction Multiple Data (SIMD)

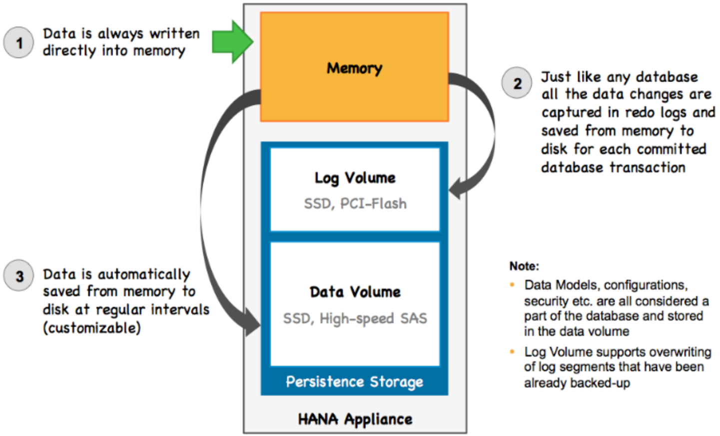
- Scalar processing
  - traditional mode
  - one instruction produces one result



- SIMD processing
  - with Intel SSE(2,3,4)
  - one instruction produces multiple results

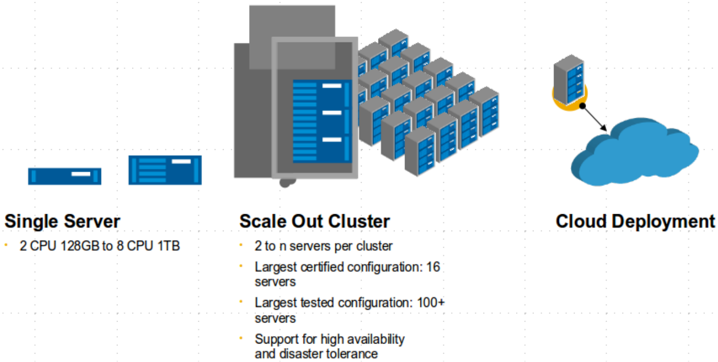


HANA Persistence Layer



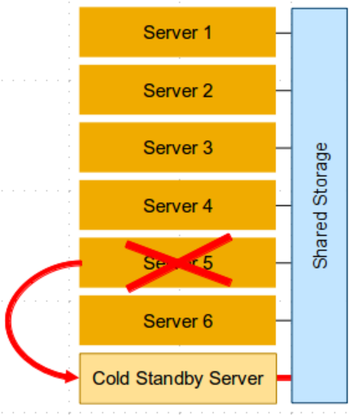
HANA Scalability

- Scales from very small servers to very large clusters

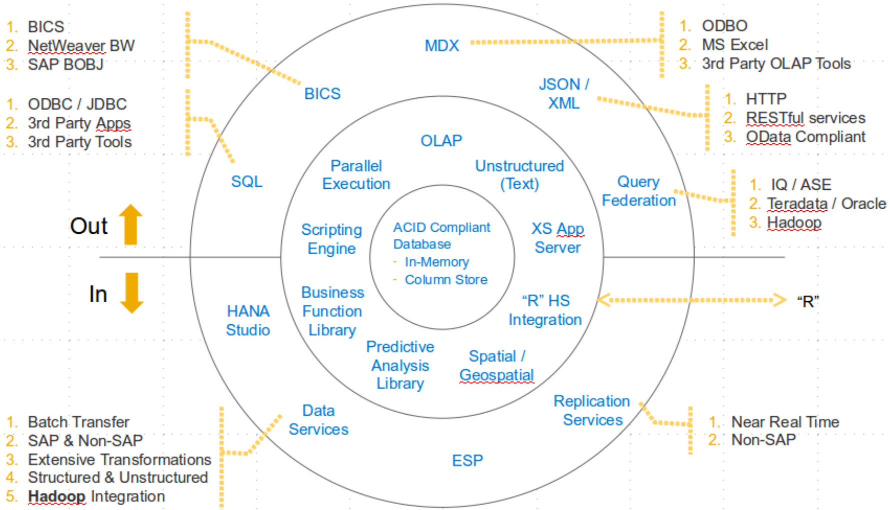


HANA High Availability

- High availability configuration
  - N active servers in one cluster
  - M standby server(s) in one cluster
  - Shared file system for all servers
- Services
  - Name and index server on all nodes
  - Statistics server (only on active servers)
- Failover
  - Server X fails
  - Server $N+1$ reads indexes from shared storage and connects to logical connection of server X

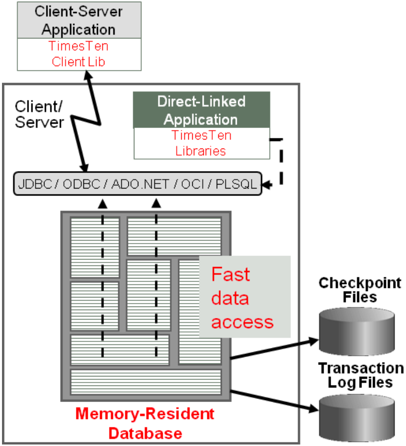


HANA Inside


1. BICS
2. NetWeaver BW
3. SAP BOBJ
1. ODBC / JDBC
2. 3rd Party Apps
3. 3rd Party Tools
Out
In
1. Batch Transfer
2. SAP & Non-SAP
3. Extensive Transformations
4. Structured & Unstructured
5. Hadoop Integration
MDX
BICS
JSON / XML
SQL
Query Federation
HANA Studio
Data Services
ESP
Replication Services
OLAP
Parallel Execution
Unstructured (Text)
Scripting Engine
XS App Server
Business Function Library
"R" HS Integration
Predictive Analysis Library
Spatial / Geospatial
ACID Compliant Database
- In-Memory
- Column Store
1. ODBO
2. MS Excel
3. 3rd Party OLAP Tools
1. HTTP
2. RESTful services
3. OData Compliant
1. IQ / ASE
2. Teradata / Oracle
3. Hadoop
"R"
1. Near Real Time
2. Non-SAP

Oracle TimesTen In-Memory Database

- In-memory RDBMS
  - Entire database in memory
  - Interfaces: Standard SQL with JDBC, ODBC, OCI, Pro*C, .NET, PL/SQL
  - Compatible with Oracle Database
- Persistent and durable
  - Transactions with ACID properties
- Extreme performance
  - Instantaneous response time
  - Very high throughput
- Embeddable



Summary

- New technological changes brought that main memory is no longer a limited resource → new opportunities for data processing
- Main memory databases keep the primary copy of data permanently in main memory
  - Backup copy on resident disk
- Data is accessed directly in memory and not via buffer manager
- Main memory is much faster than disk, and data locality is no longer an issue (any location can be accessed at the same time)
  - High fixed cost of disks due to block access is avoided
- Main memory is more vulnerable to software errors and volatile
- Concurrency is still there, but less important and crucial
- Optimized data representation
  - Use of pointers instead of repeating values or foreign keys
  - Advanced data compression techniques are applied
- T-tree is main index structure
- SAP HANA and Oracle TimesTen are two commercial main memory databases