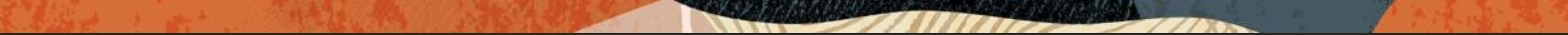
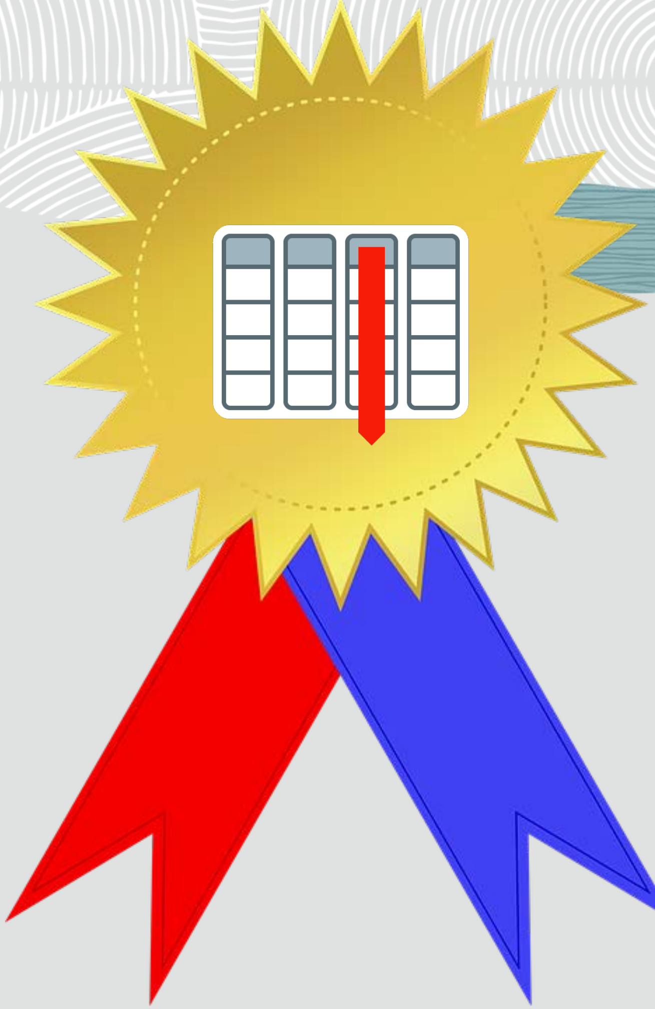


ORACLE

ORACLE

Top-5 Innovations of Oracle's Database In-Memory

In-Memory Summit, 2019



Shasank Chavan

Vice President, In-Memory Database Technologies

Safe Harbor

The following is intended to outline our general product direction. It is intended for information purposes only, and may not be incorporated into any contract. It is not a commitment to deliver any material, code, or functionality, and should not be relied upon in making purchasing decisions. The development, release, timing, and pricing of any features or functionality described for Oracle's products may change and remains at the sole discretion of Oracle Corporation.

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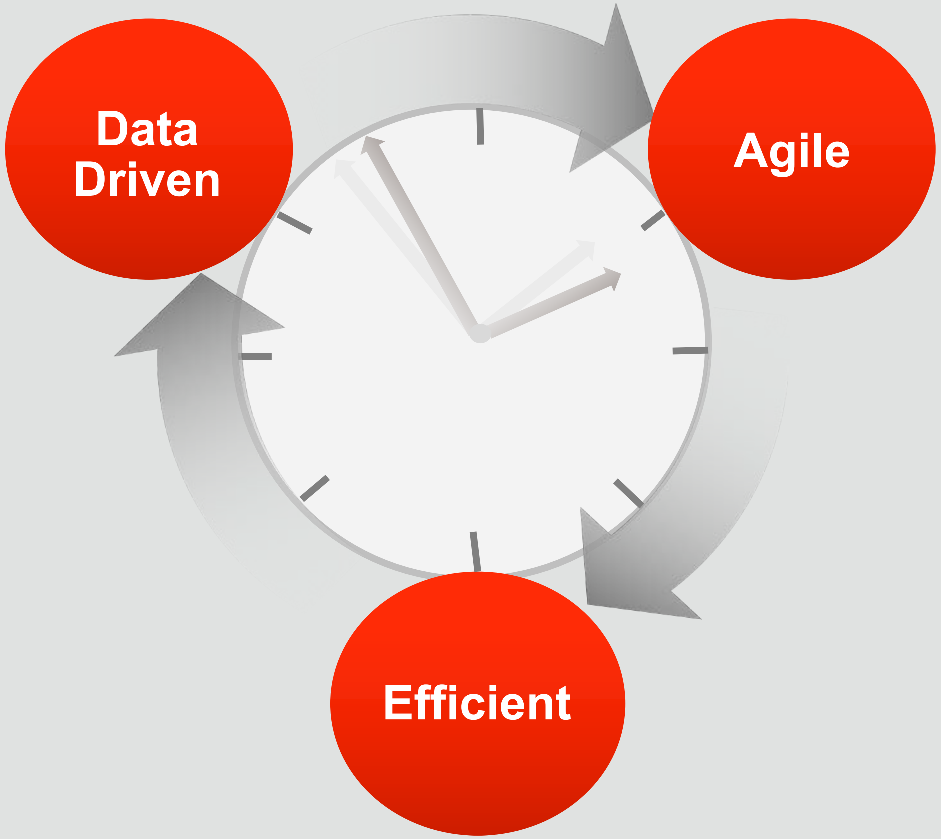
Real-Time Enterprises

Real-Time Enterprises Need In-Memory Innovations Now!

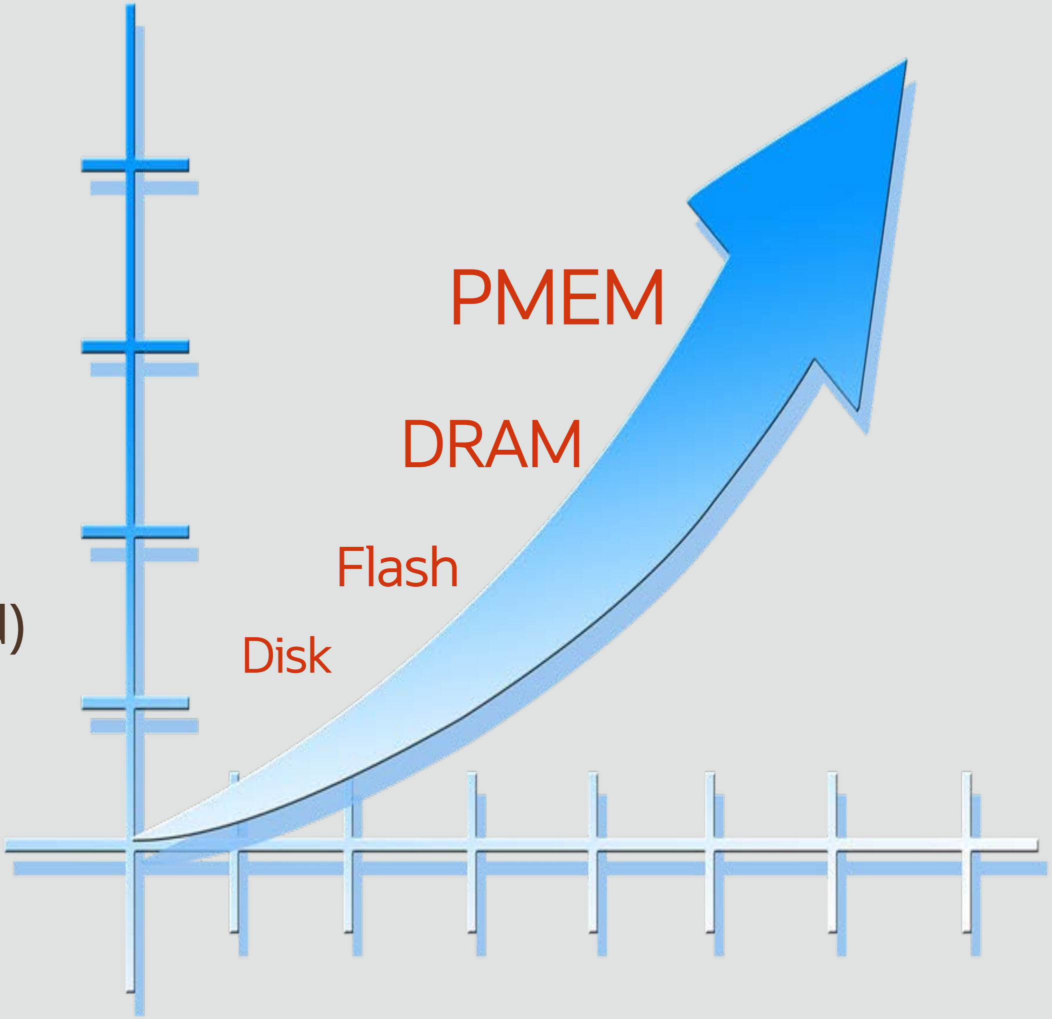
In-Memory Now | Real-Time Enterprises



- **Insurance companies** improve portfolios and reduce cost with real-time analytics for pricing
- **Retailers** use location-based analytics to automate sending personalized mobile coupons to customers
- **Manufacturing Processes** use real-time analytics to monitor production quality and adjust assembly parameters
- **Financial Services** perform risk/fraud analysis across channels in real-time, not after the event occurs
- **Telecom and Broadband** vendors use real-time congestion metrics to optimize their networks

In-Memory Now | Hardware Trends

- **Larger, Cheaper Memory** (DRAM, PMEM)
- **Larger CPU Caches** (e.g. 32MB Shared L3 Cache)
- **Larger Multi-Core Processors** (24 cores w/ Intel)
- **Larger SIMD Vector Processing Units** (e.g. AVX-512)
- **Faster Networks** (100Gb/s RoCE vs 40Gb/s Infiniband)
- **NUMA Architectures** (Local Memory vs Remote)
- **Persistent Memory** (Availability, Capacity, Speed)

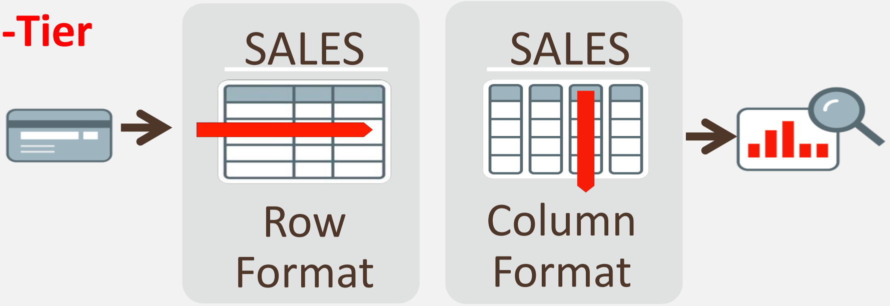


In-Memory Now | Technology Across All Tiers

Application-Tier

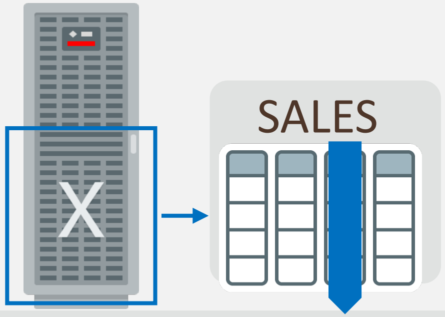
- TimesTen-In-Memory Database
  - Latency Critical OLTP Applications
  - Microsecond response time
  - Standalone or Cache for Oracle Database

Database-Tier

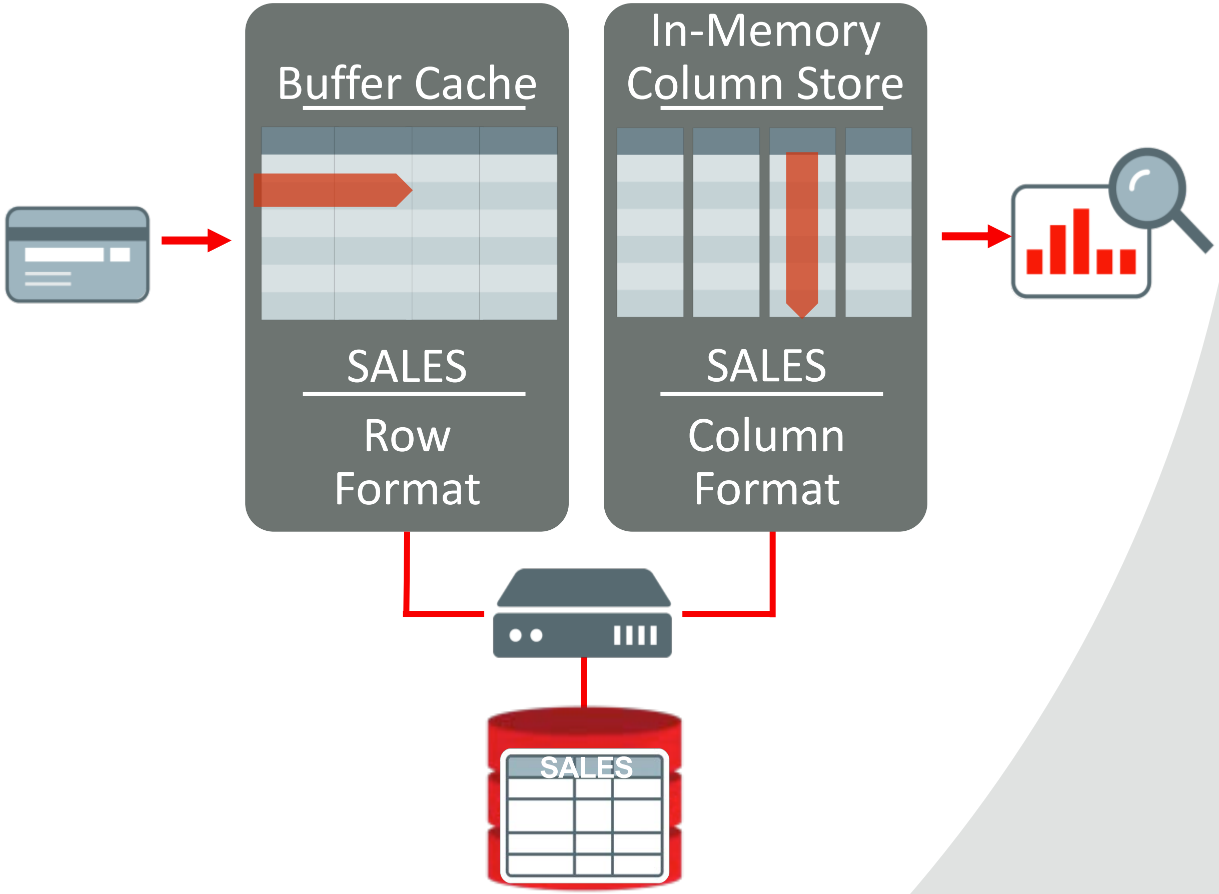


- Database In-Memory
  - Dual Format In-Memory Database
  - Billions of Rows/sec analytic data processing
  - 2-3x Faster Mixed Workloads

Storage-Tier



- In-Memory on Exadata Storage
  - In-memory format on Exadata Flash Cache
  - 5-10x faster smart scan in storage
  - 15x increase in total columnar capacity

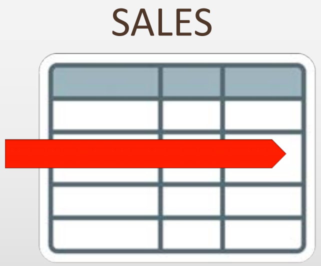


Oracle Database In-Memory

Background

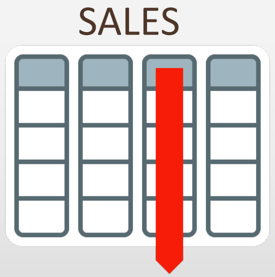
Background | Row vs. Column Databases

Row



- **Transactions** run faster on row format
  - Example: Insert or query a sales order
  - Fast processing for few rows, many columns

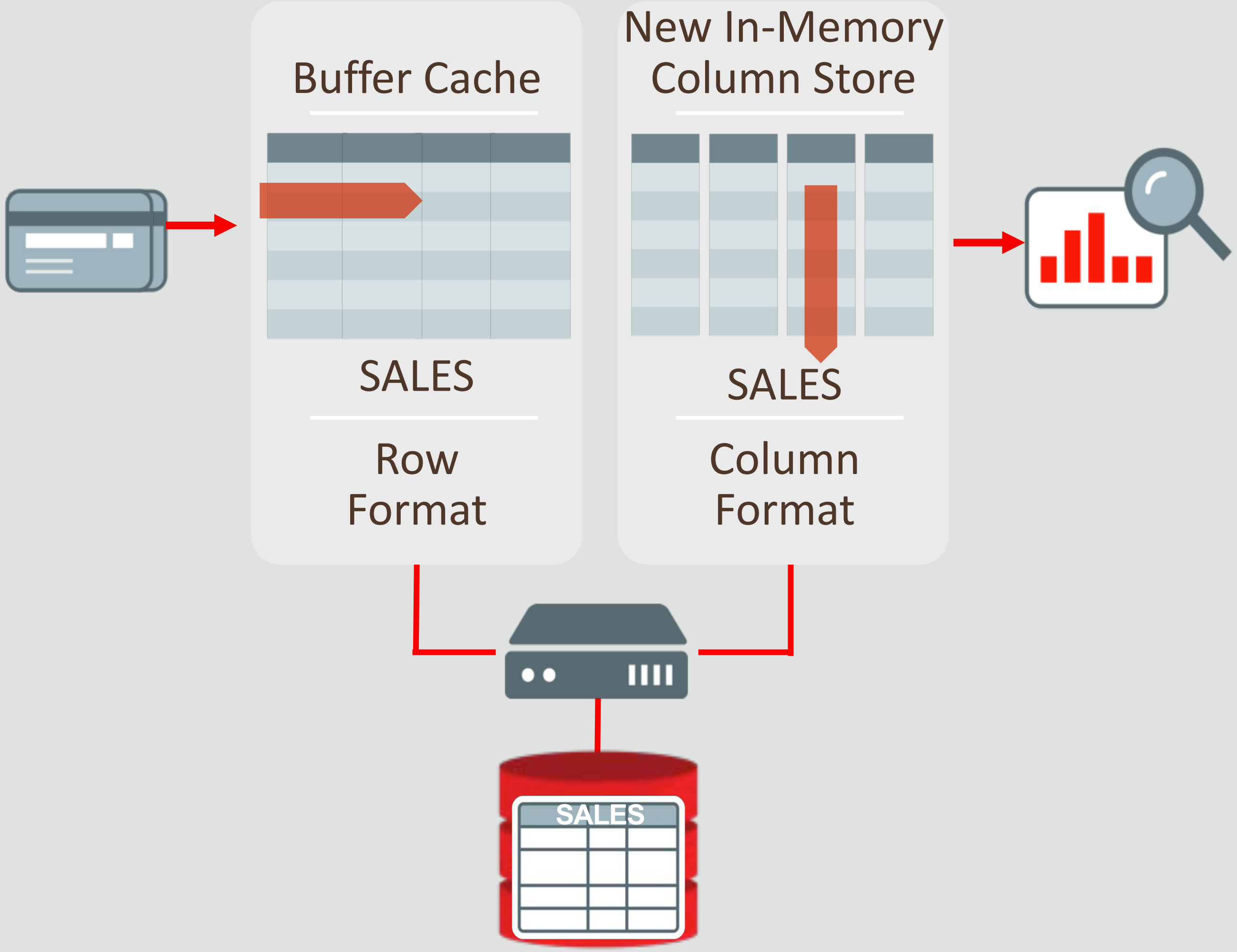
Column



- **Analytics** run faster on column format
  - Example : Report on sales totals by region
  - Fast accessing few columns, many rows

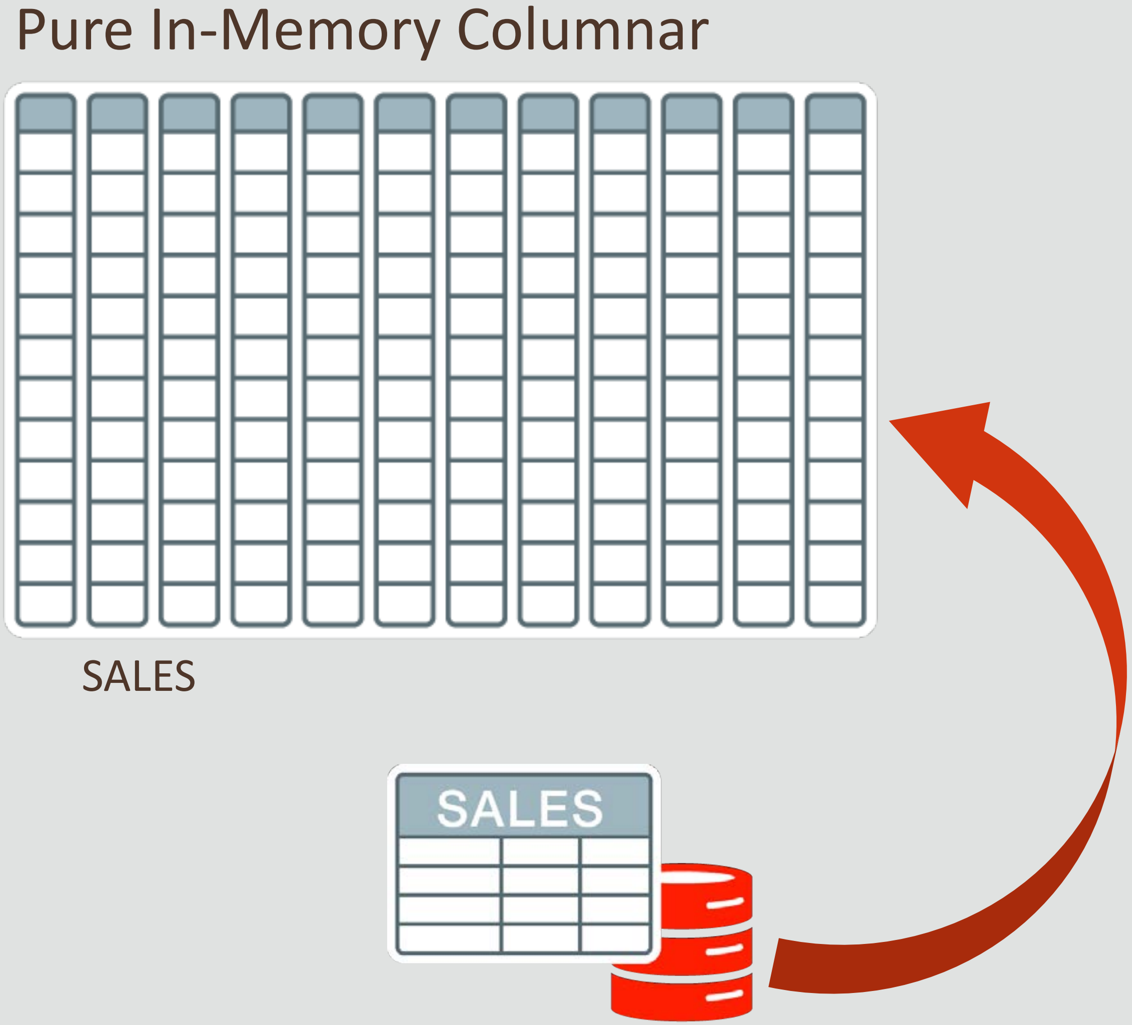
Choose One Format and Suffer the Consequences / Tradeoffs

Database In-Memory | Architecture



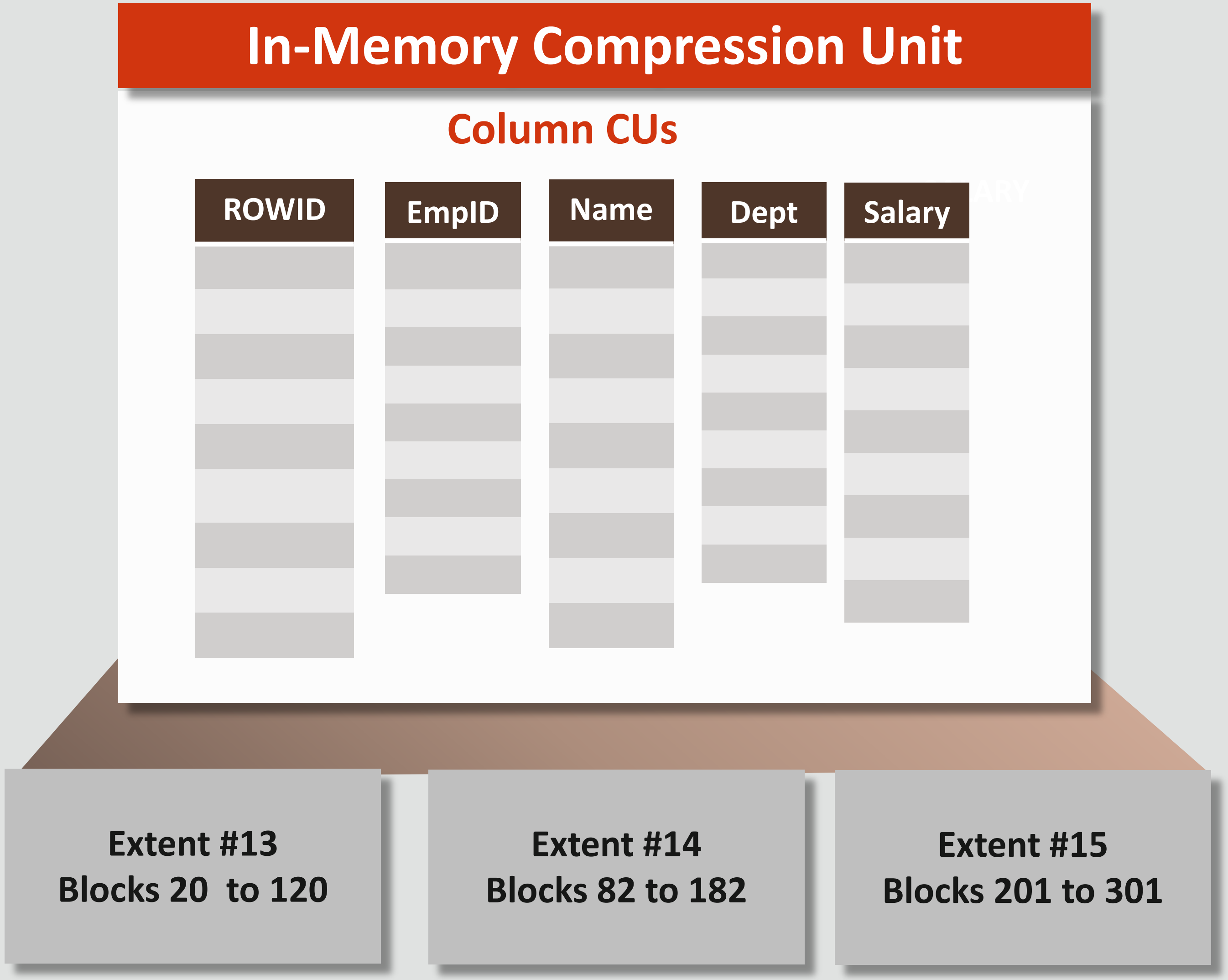
- Both row and column format for same table
  - Simultaneously active and consistent
- OLTP uses existing row format
- Analytics uses In-Memory Column format
  - Seamlessly built into Oracle Database
  - All enterprise features work
    - RAC, Dataguard, Flashback, etc.

In-Memory Columnar Format



- Pure in-memory column format
- Fast In-Memory Maintenance with OLTP
- No Changes to Disk Format
- Available on All Platforms
- Enabled at tablespace, table, partition, sub-partition, and even column level
- Total memory area controlled by **inmemory_size** parameter

In-Memory Columnar Format | Deep Dive



In-Memory Compression Unit (IMCU)

- Unit of column store allocation

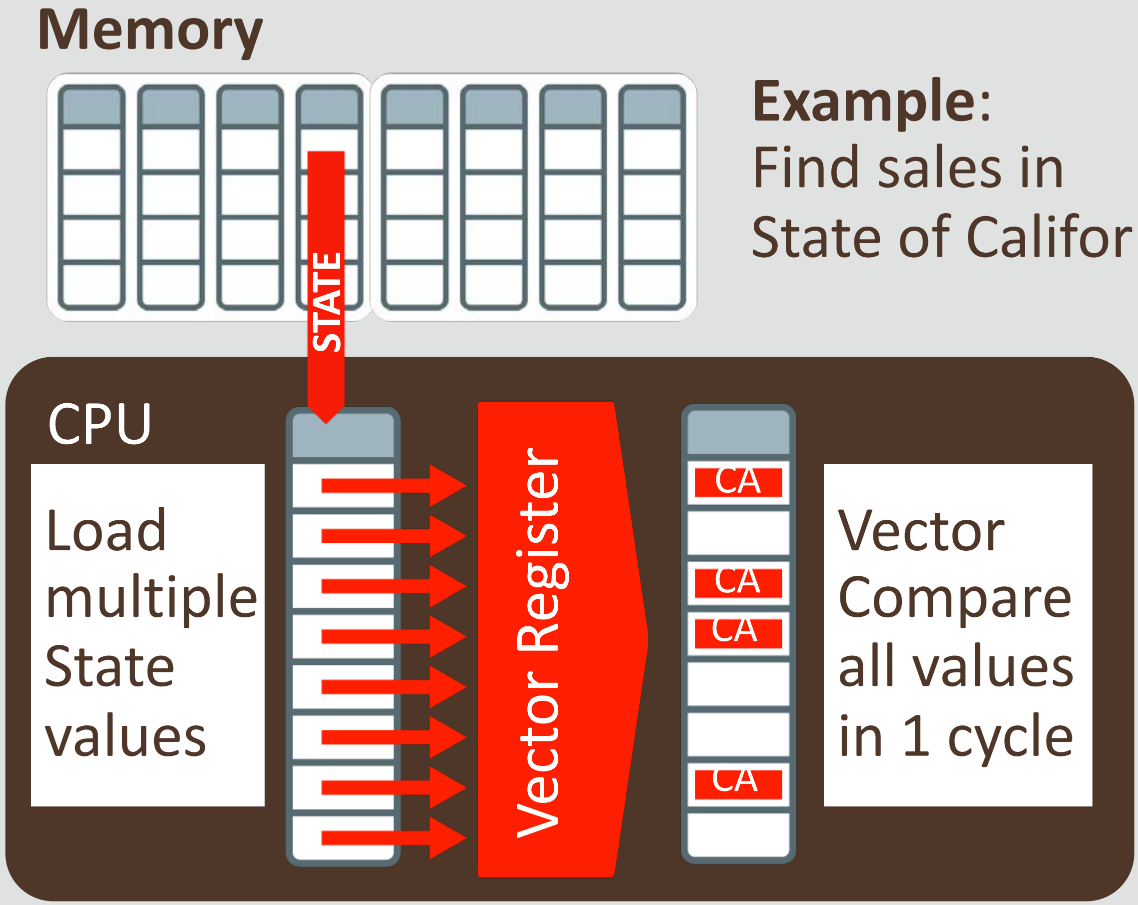
Spans large number of rows (e.g. 0.5 million) on one or more table extents

- Each column stored as **Column Compression Unit** (column CU

Multiple **MEMCOMPRESS** levels:

FOR QUERY – fastest queries
FOR CAPACITY – best compression

In-Memory Enables SIMD Vector Processing


Memory
STATE
CPU
Load multiple State values
Vector Register
CA
CA
CA
CA
Vector Compare all values in 1 cycle

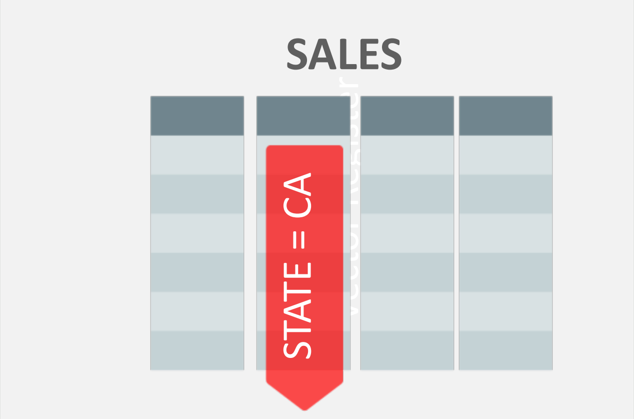
Example:
Find sales in
State of California

- Column format benefit: Need to access only needed columns
- Process multiple values with a single SIMD Vector Instruction
- Billions of rows/sec scan rate per CPU core
  - Row format is millions/sec

> 100x Faster

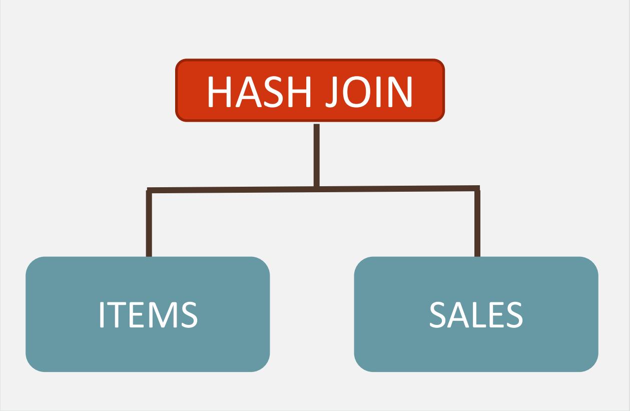
Improves All Aspects of Analytic Workloads…

Scans



- Billions of Rows per second scans

Joins



- Convert slower joins into 10x faster filtered column scans

Reporting

- Run reports with aggregations and joins 10x faster

Oracle Confidential – Internal

Database In-Memory Accelerates Real-Time Enterprises

Mankind Pharma

- Analytical reports 11x faster
- Dropping indexes improved OLTP
- 90% reduction in database size

BOSCH – SAP CRM

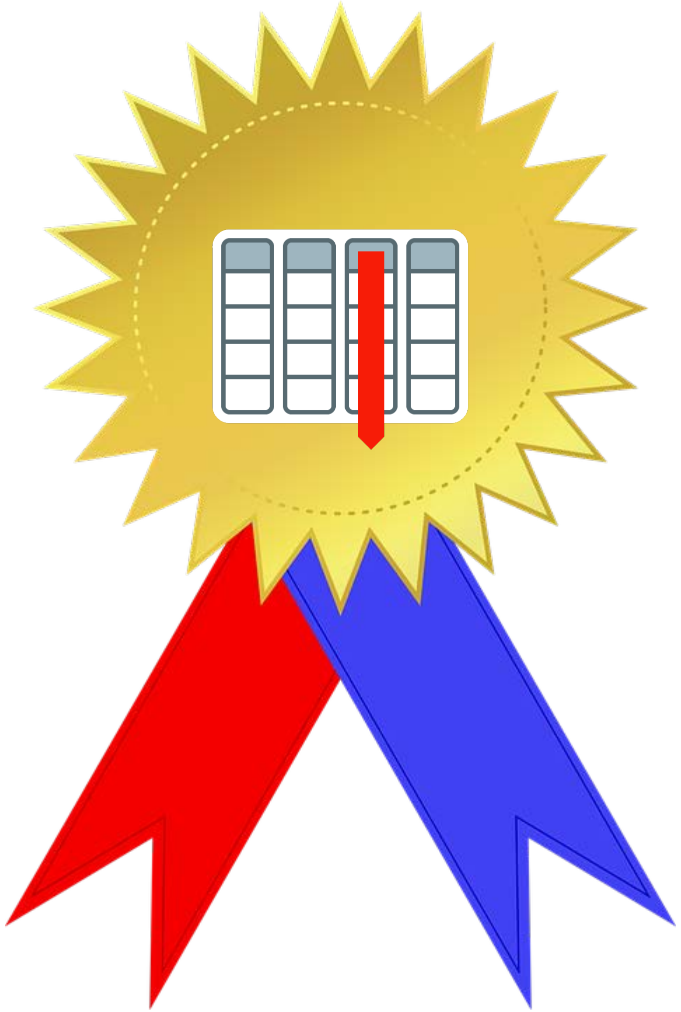
- Dropped all custom indexes
- Analytic queries 2-20X faster, DML 2-3X faster
- No changes to application required

LION – SAP ERP

- Analytic queries 4X faster
- Transactions 2X faster
- Analytic queries now possible on 100 Millions Point-of-Sales Transactions

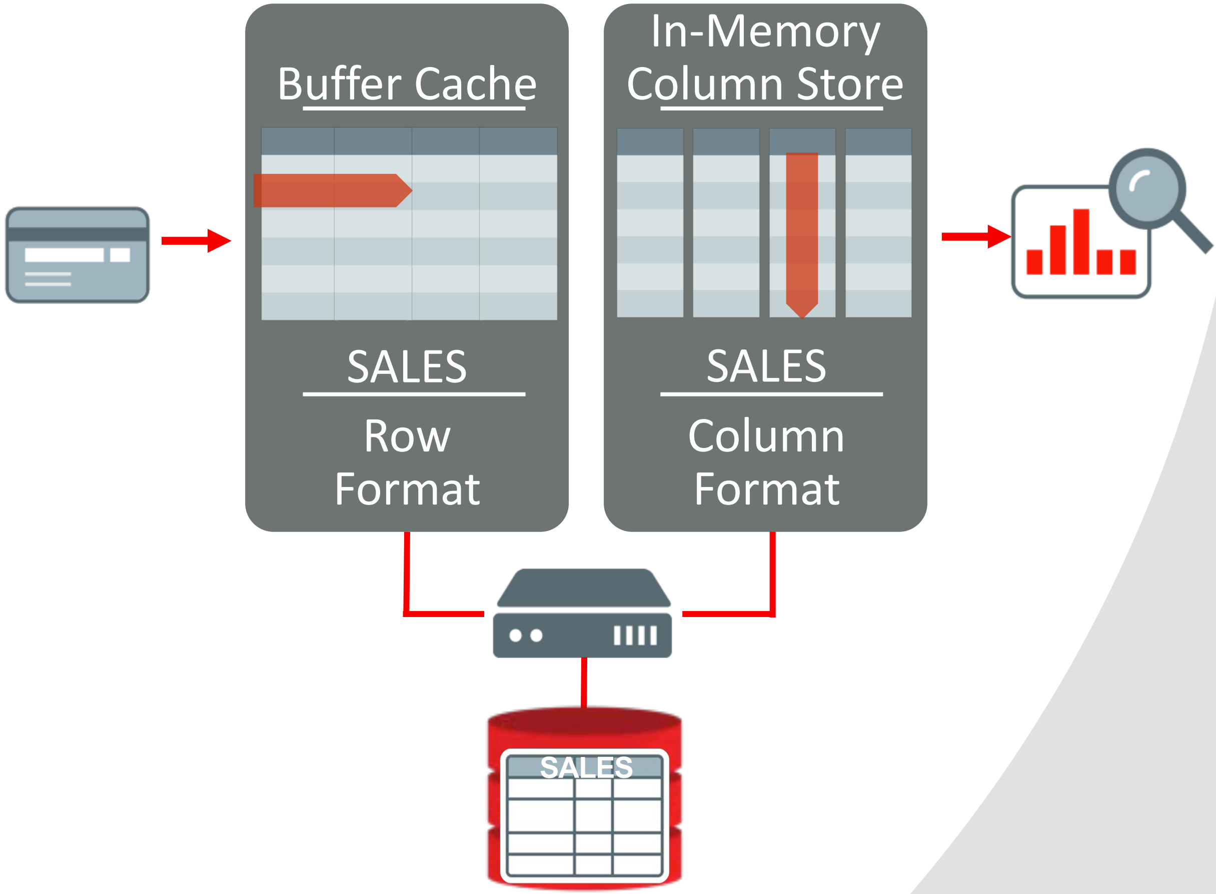
Lufthansa

- Analytic queries up to 100x faster
- Improved data ingest performance
- Reduction in database size



Top-5

Oracle Database In-Memory Innovations



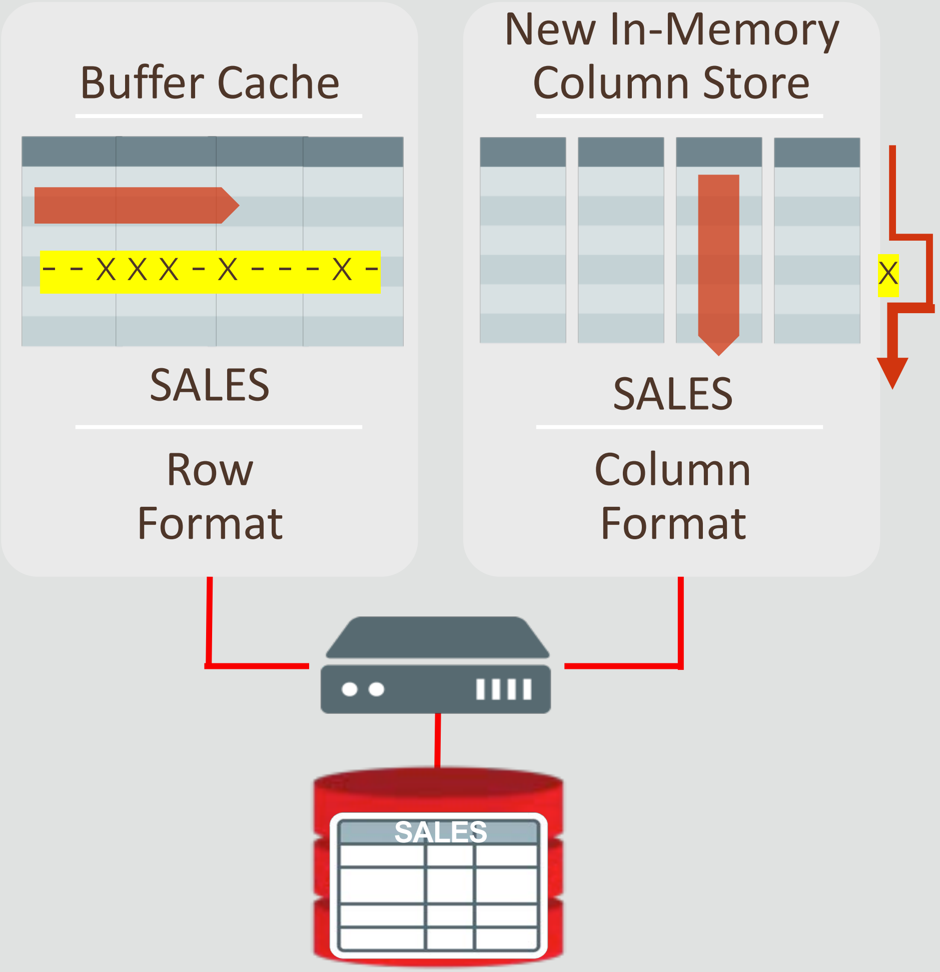
#1

Dual-Format Architecture

Fast Mixed Workloads, Faster Analytics

In-Memory: Dual-Format Architecture

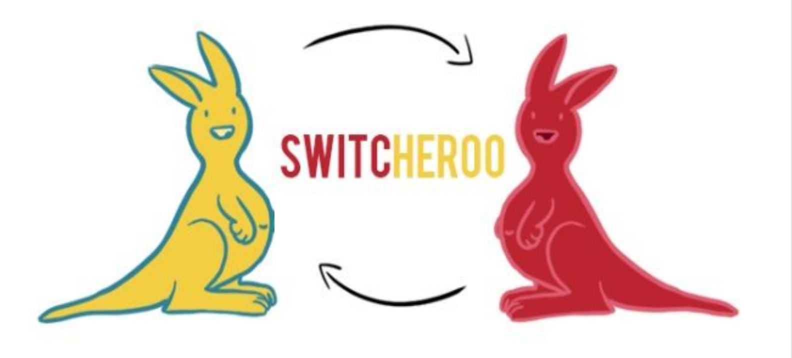
- Dual-Format Architecture enables fast Mixed Workloads and faster Analytics
- Fast In-Memory DML because invalid row is logically removed from column store (just set a bit)
- Analytic query will ignore invalid rows in column store, and just vector process valid rows. Invalid rows are then processed.
  - IMCUs not covering invalid rows are unaffected.
- Mixed workload performance can suffer if the number of invalid rows accumulates in IMCUs
  - Fast repopulation techniques save the day!



In-Memory: Fast Background Repopulation

Continuous intelligence to track how dirty an IMCU is, how frequently it is scanned, and when to take action to refresh/repopulate it.

Double Buffering

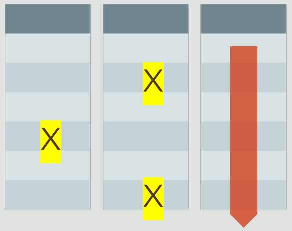


Old IMCU stays online until New IMCU is built. Then A *switcherroo* happens once New IMCU is ready.

Incremental Repopulation

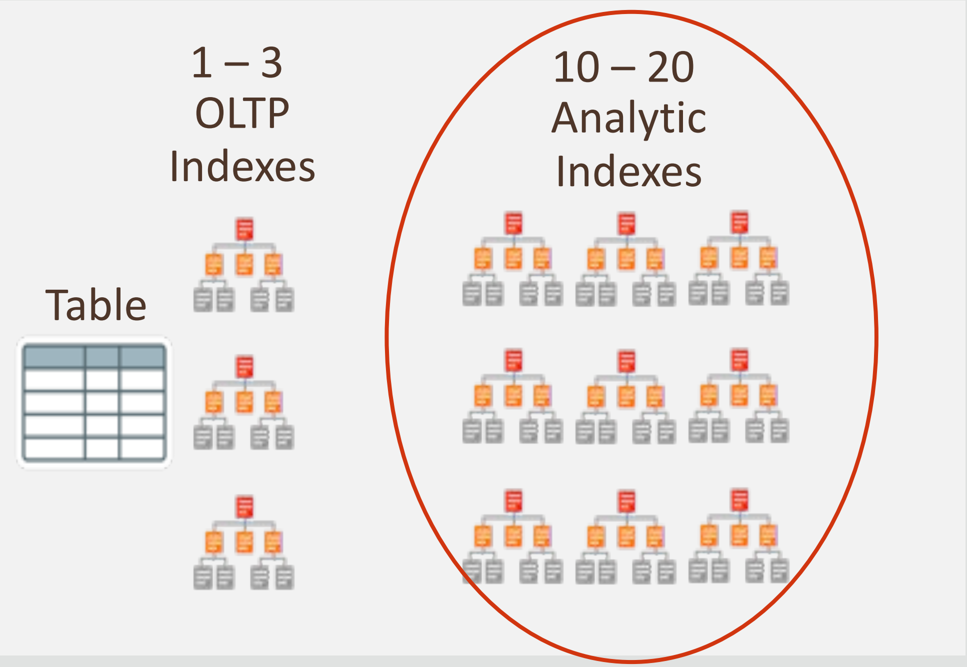
Build new columns in new IMCU using meta-data present in the old IMCU, allowing quick formatting

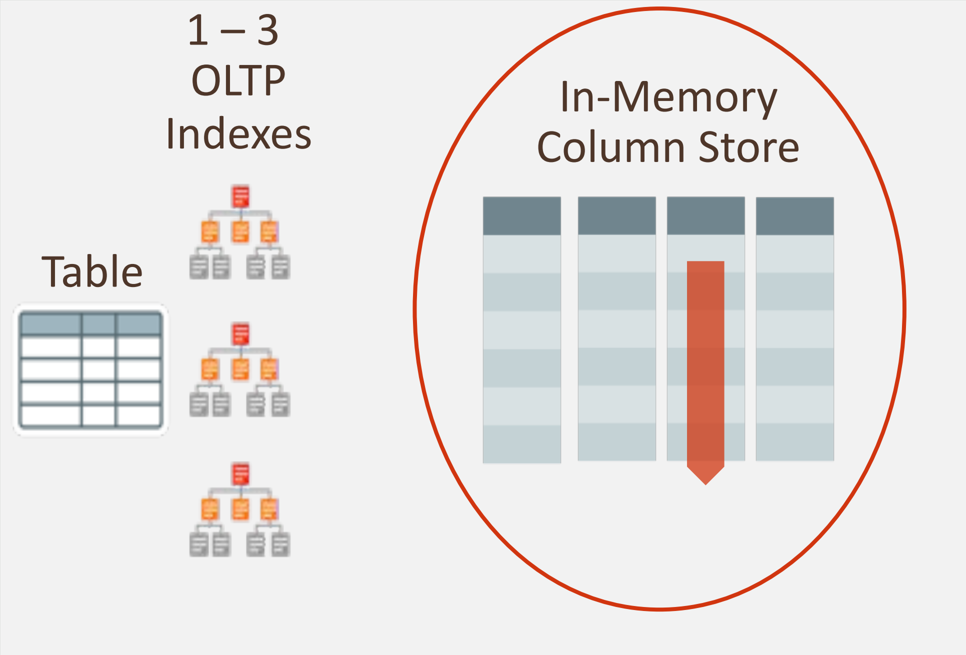
Column-Level Invalidations



Column-Level Invalidations tracked to still enable IM scans

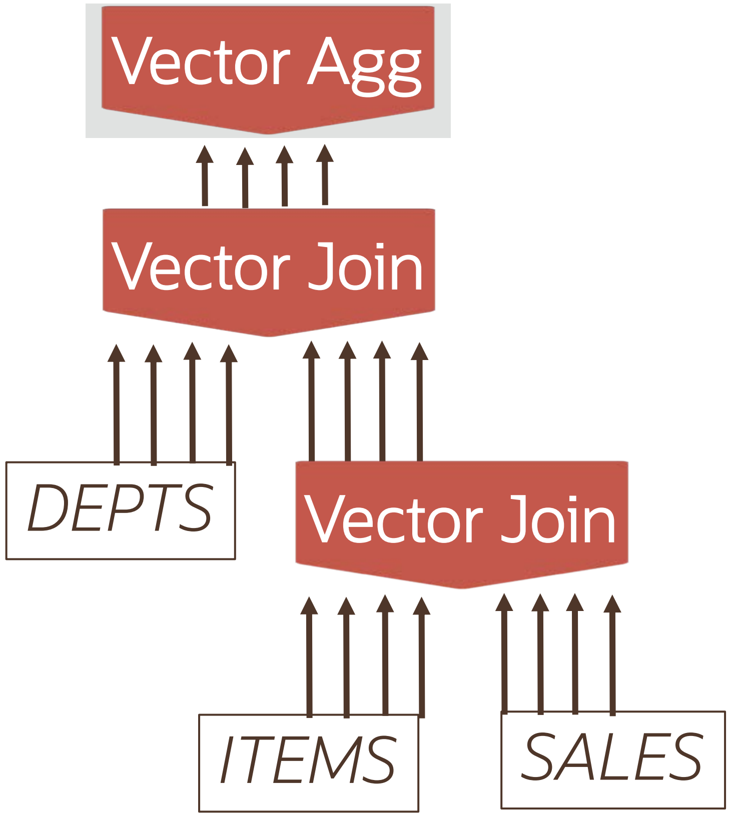
Accelerates Mixed Workloads (Hybrid OLTP)





- Inserting one row into a table requires updating 10-20 analytic indexes: Slow!
- Fast analytics only on indexed columns
- Analytic indexes increase database size

- Column Store not persistent so updates are: Fast!
- Fast analytics on any columns
- No analytic indexes: Reduces database size



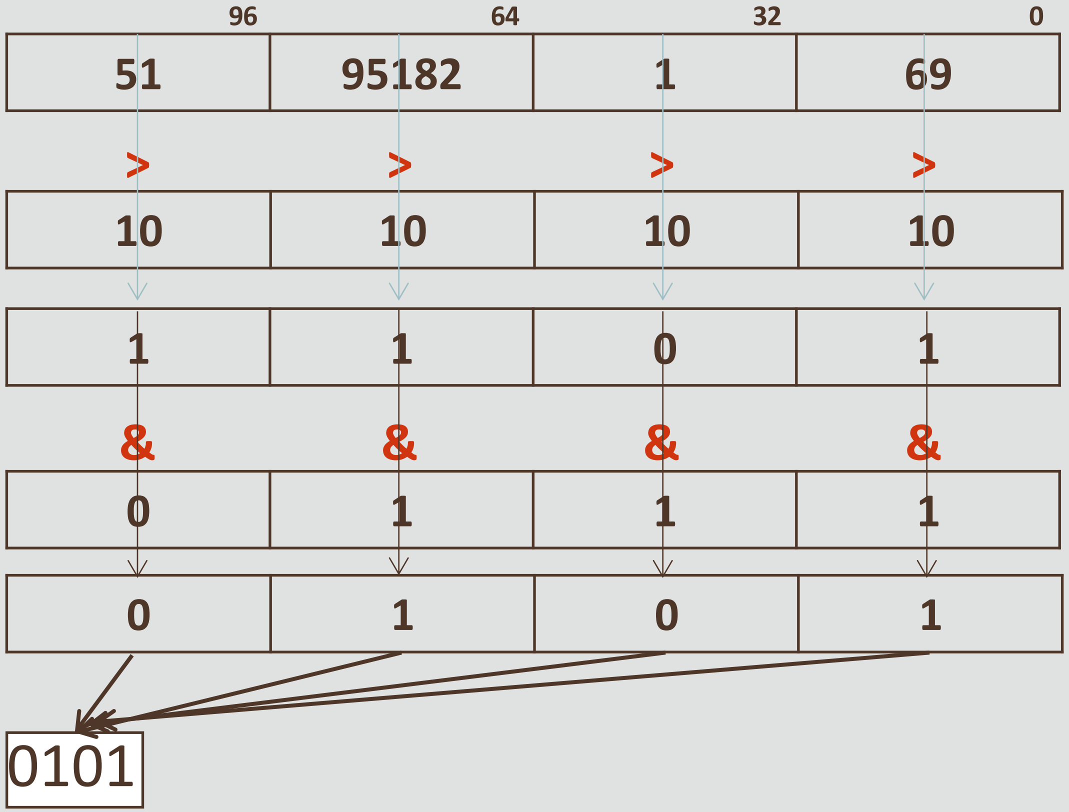
#2

Vectorized Analytics

SIMD Vector Processing at Billions of Rows per Second

Faster Scans | SIMD Vector Processing

- Parallelize predicate evaluation – load, eval, store/consume result
- Select count(*) from T where a > 10 and b < 20
  - [Load] A
  - [Load] Temp = 10
  - [Compare] A > Temp
  - Load B, Compare 20
  - And
  - Mask, Store Bit-Map

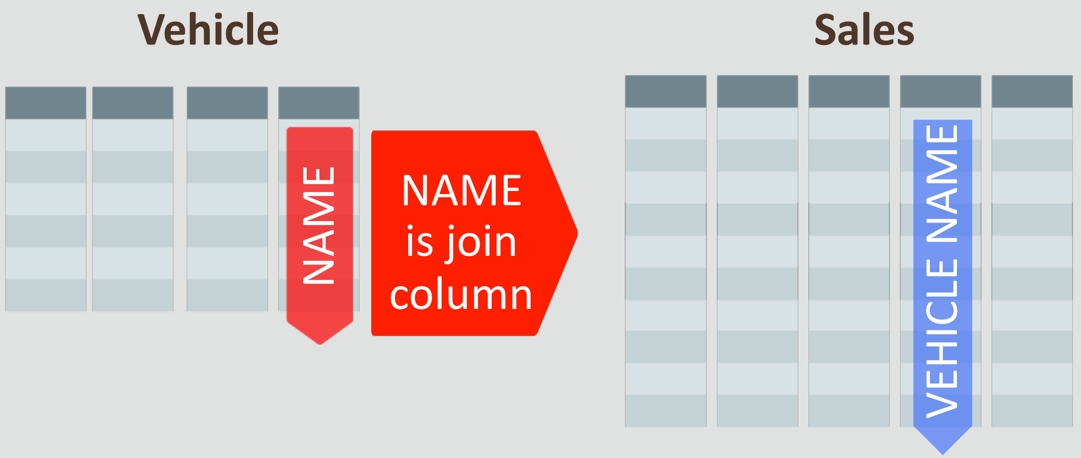


96	64	32	0
51	95182	1	69
>	>	>	>
10	10	10	10
1	1	0	1
&	&	&	&
0	1	1	1
0	1	0	1

0101

Faster Analytics | In-Memory Joins

Example: Find sales price of each Vehicle



```
CREATE INMEMORY JOIN GROUP V_name_jg
(VEHICLES(NAME),SALES(NAME));
```

- Joins are a significant component of analytic queries
  - Joins on inmemory tables are 10x faster already
- **Join Groups** enables faster joins
  - Specifies columns used to join tables
  - Join columns compressed using exact same encoding scheme.
  - This enables a faster array-based indexing join to be used instead of expensive hash join.
- Enables 2-3x speedup over already fast inmemory joins

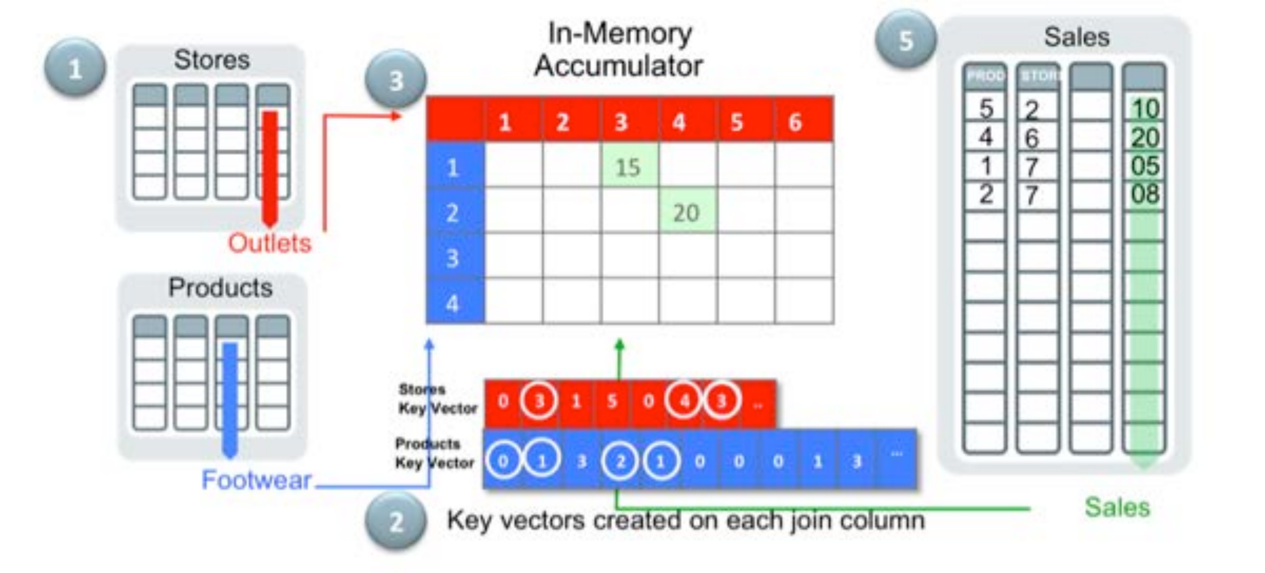
Faster Analytics | In-Memory Aggregation

Aggregation Push-Down

- Improve Single Table Aggregation
- Push aggregation operators down into the scan operators
- Reduce number of rows flowing back up to SQL layer
- New aggregation algorithms leveraging In-Memory data formats and SIMD
- 2-10X improvements

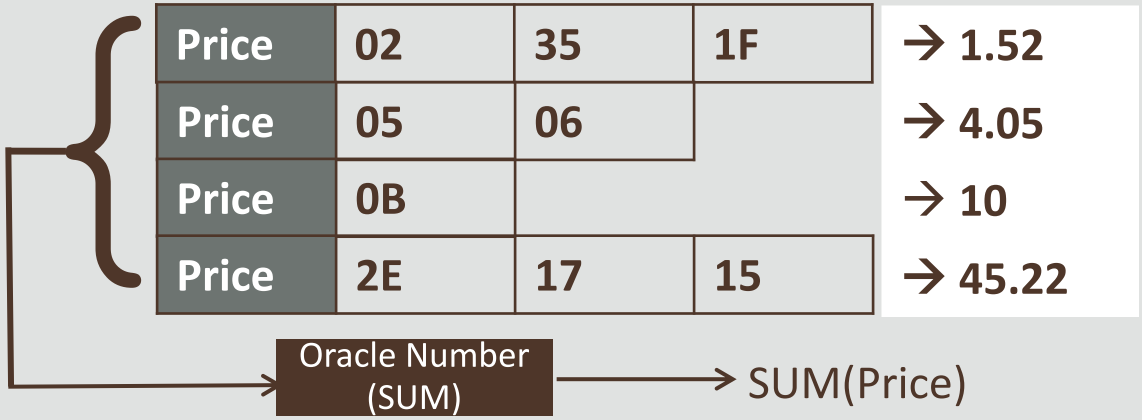
Vector Transformation

- Improve Aggregation over Joins
- Query transformation replaces aggregation over hash-joins with new push-down operators.



Faster Analytics | In-Memory Numbers

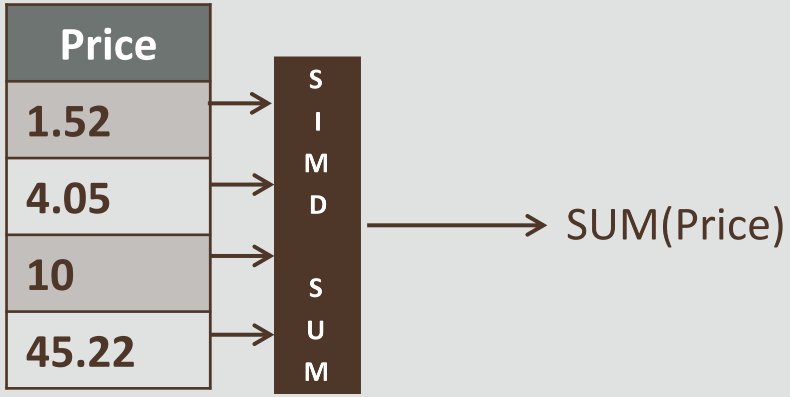
SLOW Row-by-Row Oracle Number Processing



Price	02	35	1F	→ 1.52
Price	05	06		→ 4.05
Price	0B			→ 10
Price	2E	17	15	→ 45.22

Oracle Number (SUM) → SUM(Price)

FAST SIMD Vector Processing of In-Memory Numbers



Price
1.52
4.05
10
45.22

SIMD SUM → SUM(Price)

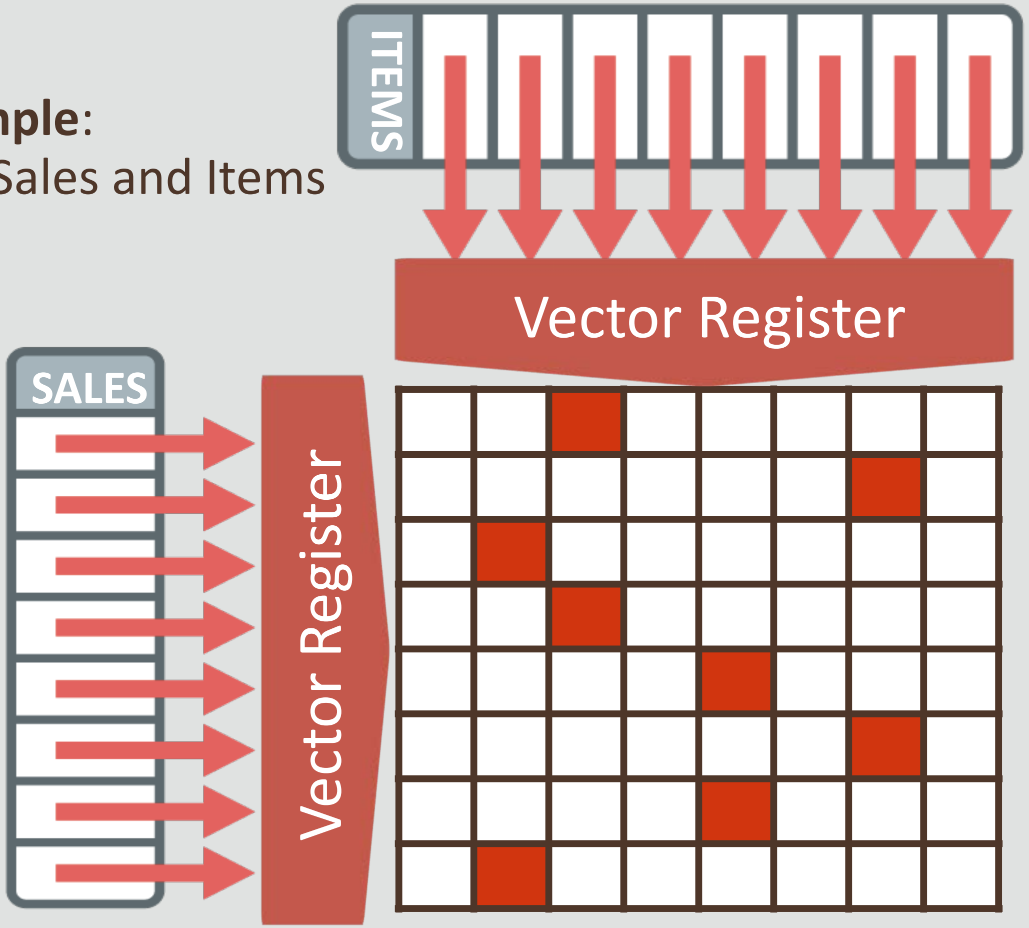
- In-Memory optimized format for NUMBER columns
  - Instead of software-implemented, variable-width ORACLE NUMBERs
  - Enabled using new parameter **inmemory_optimized_arithmetic**
- SIMD Vector Processing on optimized inmemory number format
- Aggregation and Arithmetic operators can improve up to 20X

Preview | In-Memory Vector Joins

NEW IN 20c

- New *Deep Vectorization* framework allows SIMD vectorization for a wide range of query operators
- *In-Memory Vector Joins* uses this framework to accelerate Complex Joins
  - Match multiple rows between SALES and ITEMS tables in a single SIMD Vector Instruction
  - 5-10x faster in-memory join processing

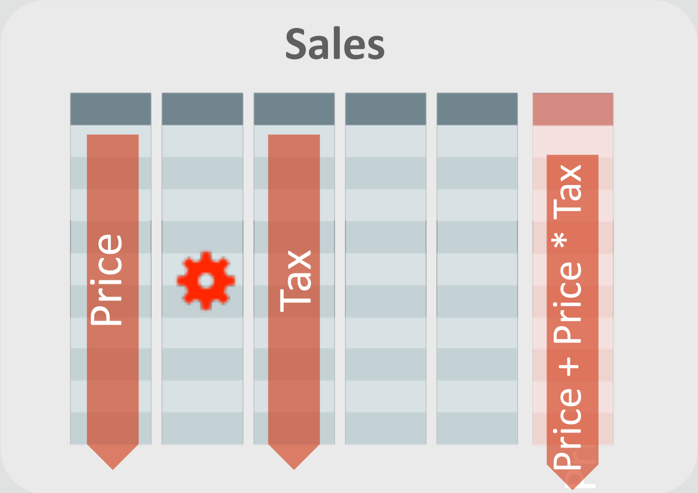
Example:
Join Sales and Items



Faster Analytics | In-Memory Expressions

Example: Compute total sales price

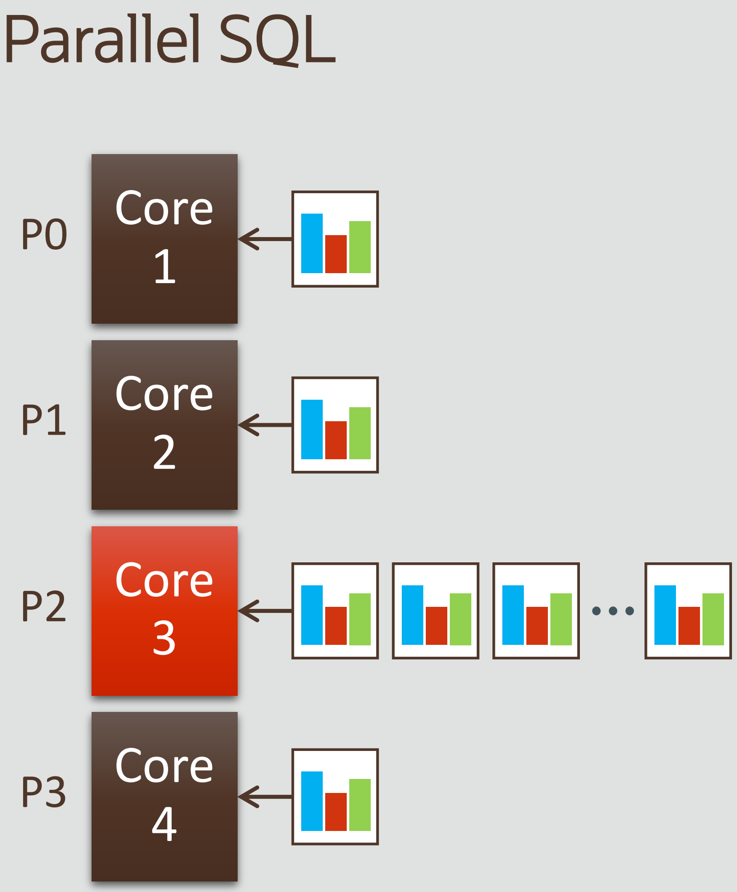
Net = Price + Price * Tax

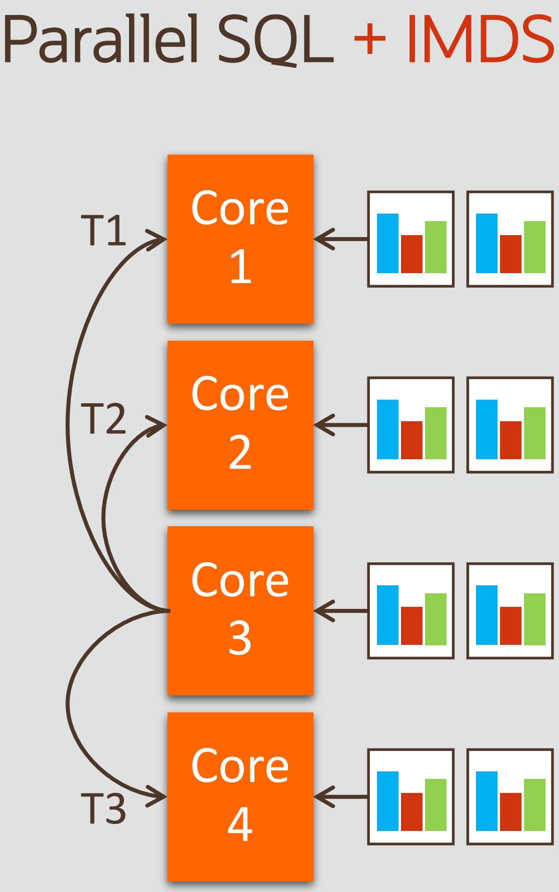


```
CREATE TABLE SALES (
      PRICE NUMBER, TAX NUMBER, …,
      NET AS (PRICE + PRICE * TAX)
      )
INMEMORY;
```

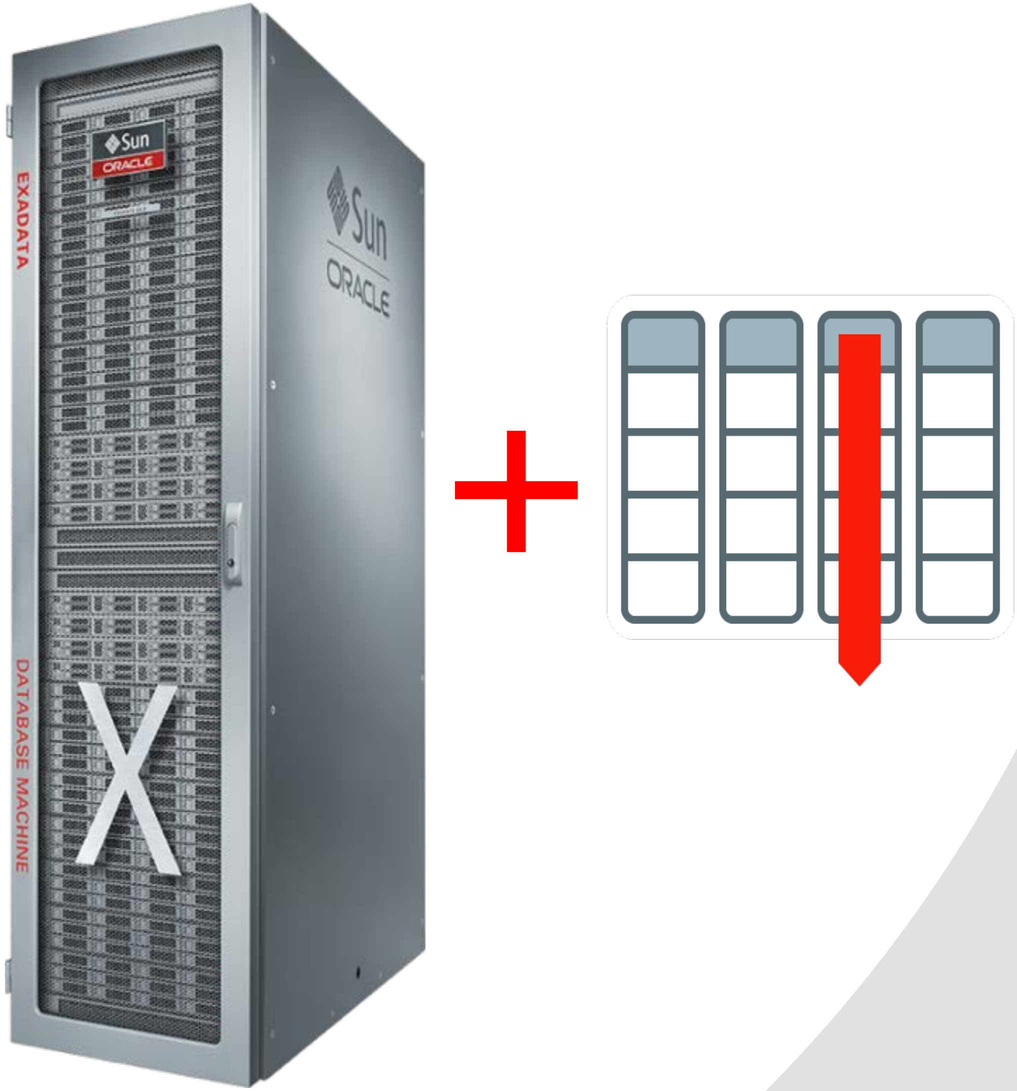
- Hot expressions can be stored as additional columns in memory
- All In-Memory optimizations apply to expression columns (e.g. Vector processing, storage indexes)
- Two modes:
  - **Manual:** Declare virtual columns for desired inmemory expressions
  - **Auto:** Auto detect frequent expressions
- 3-5x faster complex queries

Faster Analytics | In-Memory Dynamic Scans





- Parallelize operations pushed down to SCAN layer using light-weight threads
- Supplements *static* PQ plans with faster response times for shorter queries.
  - Achieve PQ execution times for single-threaded queries
- Elastic DOP Rebalancing using Resource Manager
- Up to 2X gains seen



#3

In-Memory + Exadata

In-Flash Columnar Processing at Cloud Scale

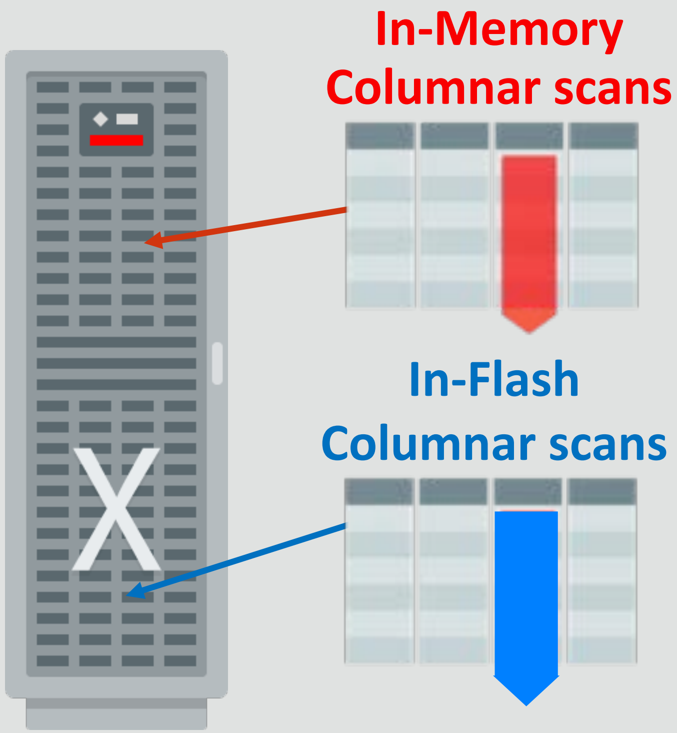
Background | Exadata Vision

Dramatically Better Platform for All Database Workloads

- Ideal Database Hardware – Scale-out, database optimized compute, networking, and storage for fastest performance and lowest cost
- Smart System Software – Specialized algorithms vastly improve all aspects of database processing: OLTP, Analytics, Consolidation
- Automated Management – Automation and optimization of configuration, updates, performance, and management culminating in Fully Autonomous Infrastructure and Database

In-Memory Accelerates Exadata Flash Cache

- In-Memory format in Smart Columnar Flash
  - Enables SAME in-memory optimizations on data in Exadata flash as on Exadata DB compute nodes DRAM
  - Extends in-memory processing to Storage
  - 15x Columnar Capacity (100s of TB on full rack)
- In-memory format – offloaded queries 10x faster
  - **Huge advantage over other in-memory databases and storage arrays !!!!!**
- <u>Completely </u>automatic -no user intervention needed
  - Powers Autonomous Database



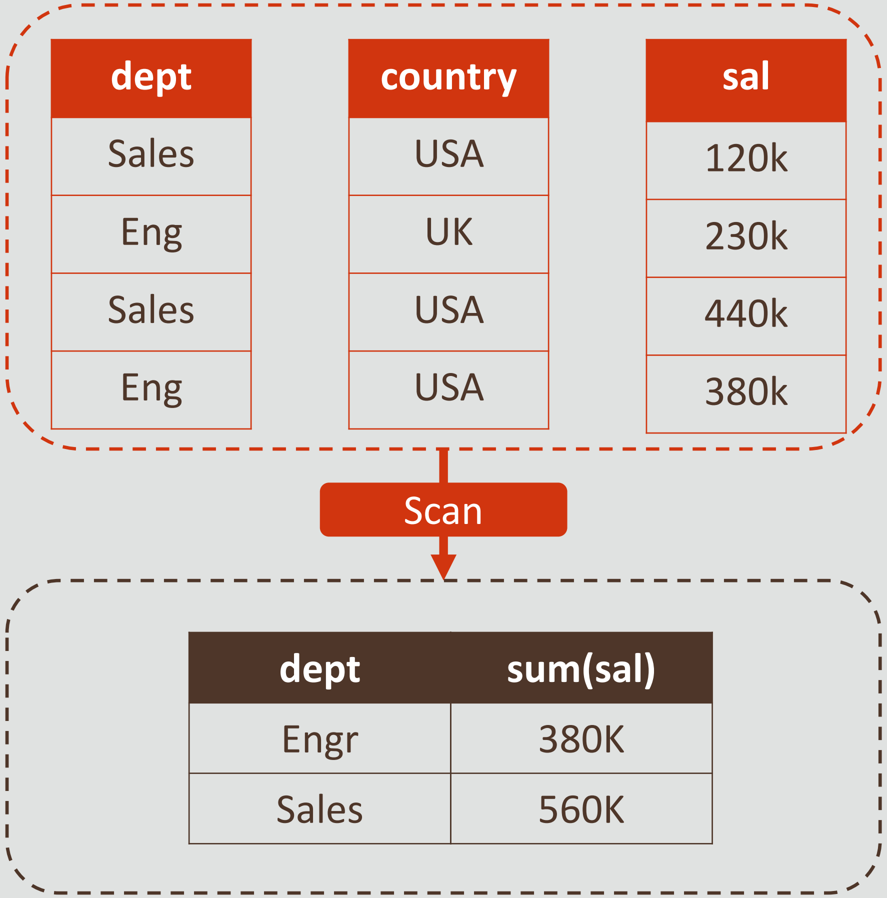
Example Benefit of In-Memory on Flash:
Aggregation Offload

- In-Memory Format on Exadata Flash allows SUM and GROUP BY aggregations to be offloaded to storage servers:
  - Reduces data sent to the database server
  - Improves CPU utilization on the database server
- Example:

  select dept, sum(sal) from emp

  where country=‘USA’ group by dept

  - Sum , group by operations performed on storage server
- 2x faster aggregation queries and reduced DB server CPU

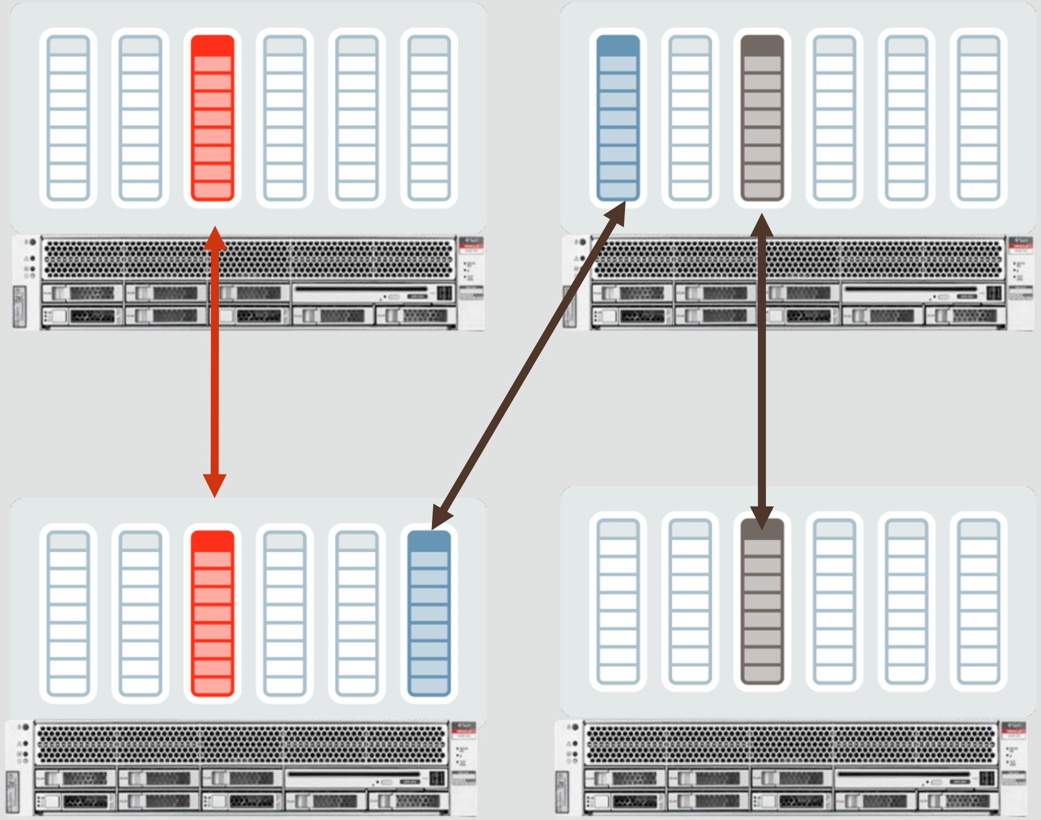


dept	country	sal
Sales	USA	120k
Eng	UK	230k
Sales	USA	440k
Eng	USA	380k

dept	sum(sal)
Engr	380K
Sales	560K

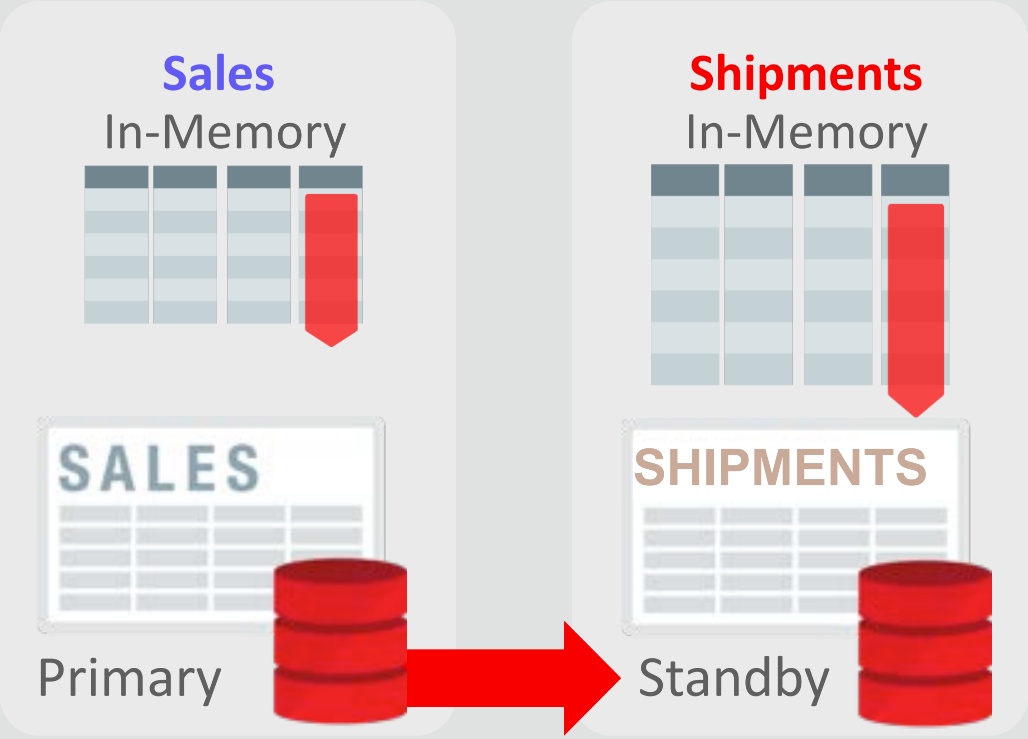
Enabled with Exadata System Software 19.3 for Database In-Memory customers, DB version 18.1 and later

In-Memory Duplication: Fault Tolerance and Performance



- Optionally duplicate in-memory columns across 2 nodes
  - Like storage mirroring
  - Can also duplicate across ALL nodes (e.g. small dimension tables)
  - Enabled per table/partition
  - Application transparent
- Eliminates column store repopulate after failure
- Improves performance due to greater locality

In-Memory on Active Data Guard



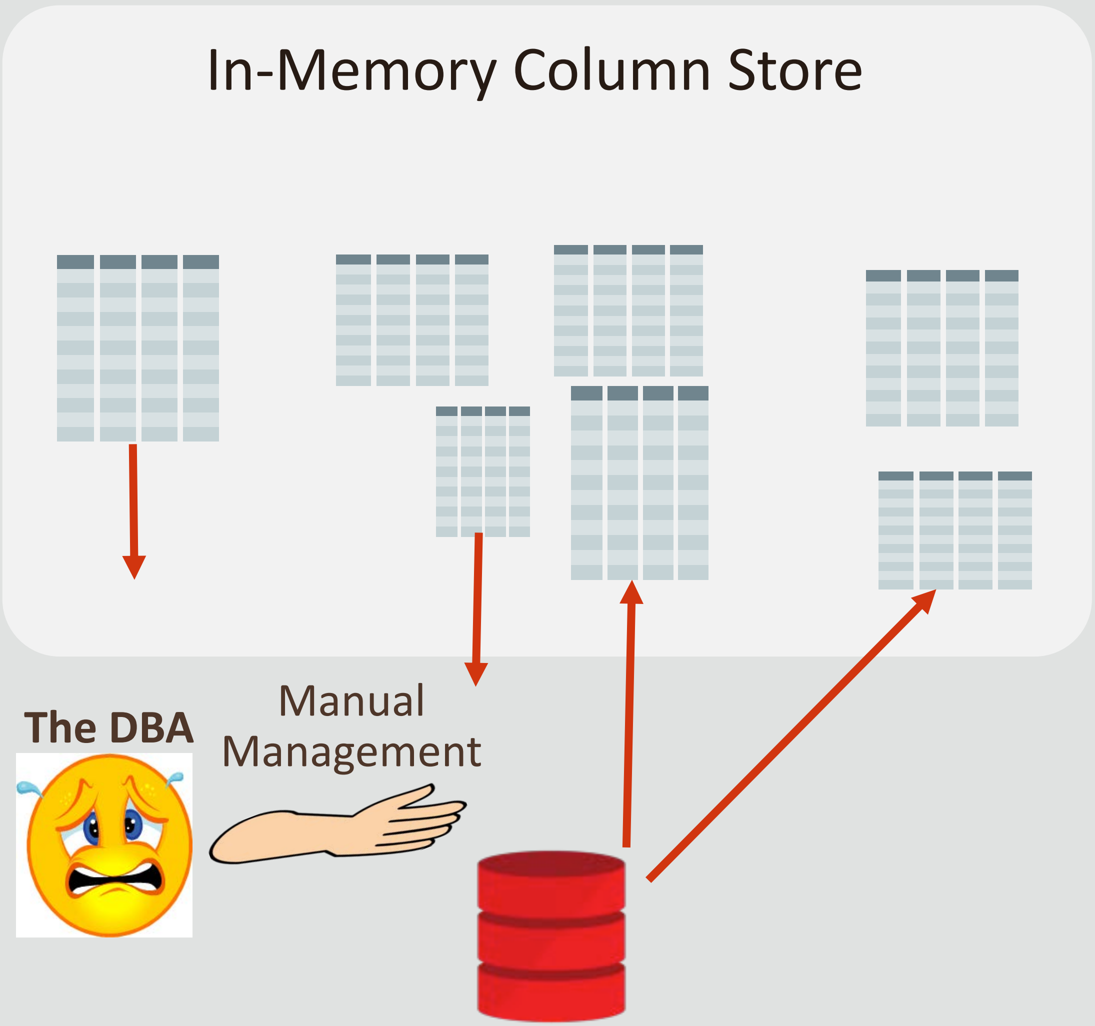
Primary Database or Data Guard Standby must be on Exadata

- Inmemory queries can run on Active Data Guard standby
  - No impact on primary database
  - Full use of standby database resources
- Standby can have different in-memory contents from Primary
  - Increases total effective inmemory columnar capacity
  - Increases column store availability:
  - Reporting workload on standby unaffected by primary site outage

#4 Intelligent Automation

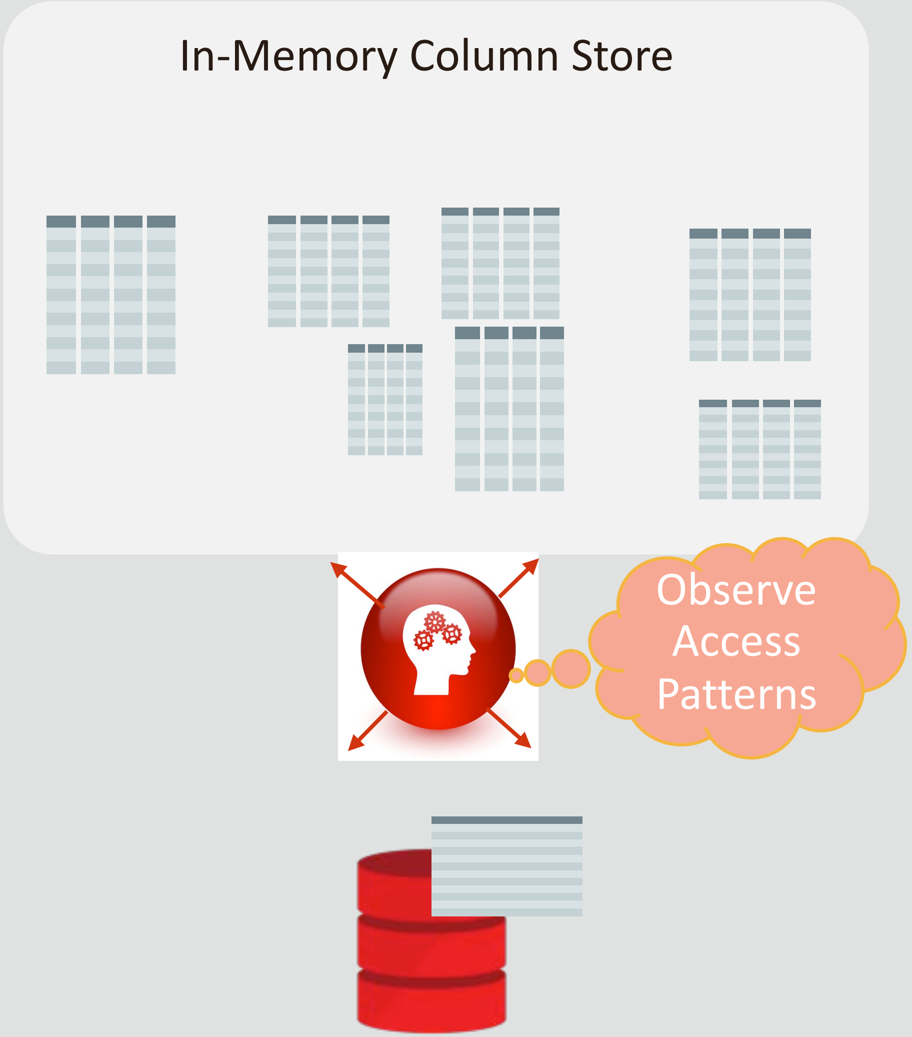
Automatic In-Memory Management & Storage Tiering

Manual In-Memory Management



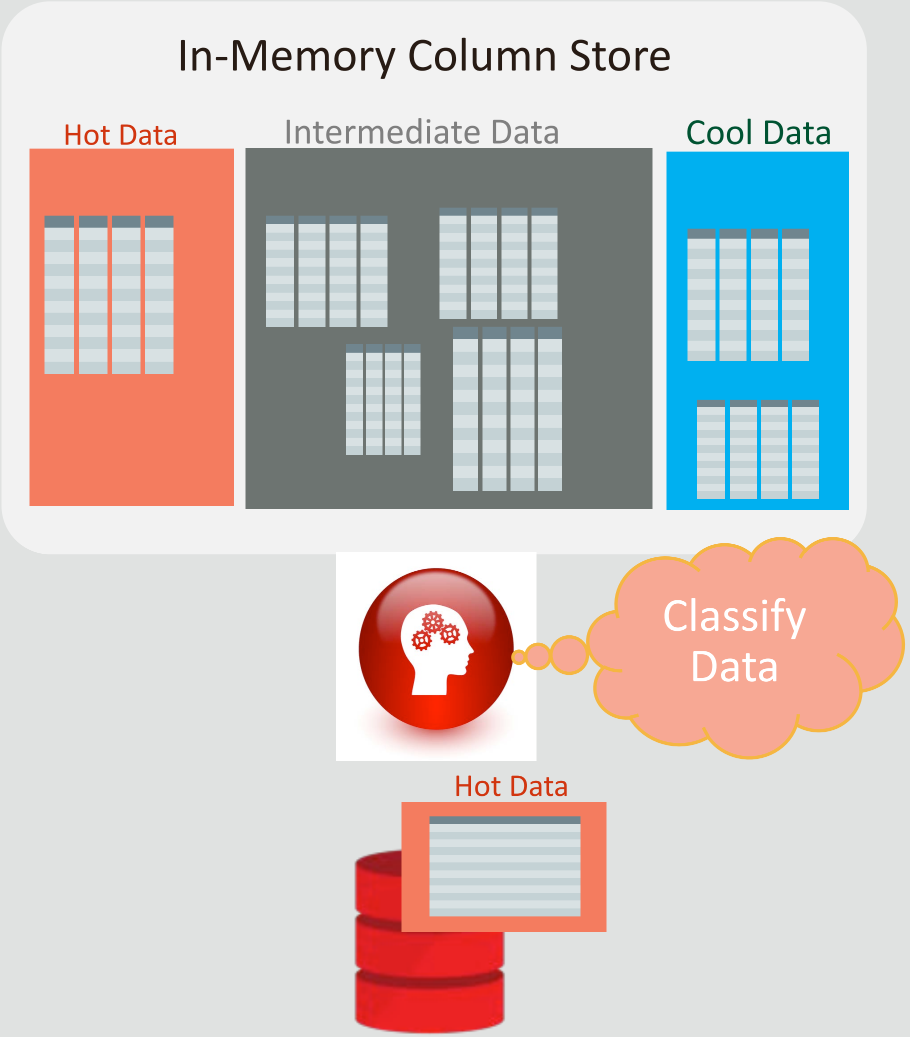
- If entire database fits within in-memory area, no need for DBA involvement!
- Otherwise, need to intelligently select in-memory candidates
- **Desired outcome**: Keep hot objects in-memory, remove colder objects
  - Access patterns are not known in advance and change over time
  - Hard for DBAs to achieve manually

Automatic In-Memory



- Eliminates trial and error regarding in-memory area contents
- Constant background action:
  - Classifies data as hot, intermediate or cold
  - Hotter in-memory tables automatically populated
  - Colder in-memory tables automatically removed
  - Intelligent algorithm takes into account space-benefit tradeoffs
- Controlled by new parameter **inmemory_automatic_level**
- Useful for autonomous cloud services since no user intervention required

Automatic In-Memory



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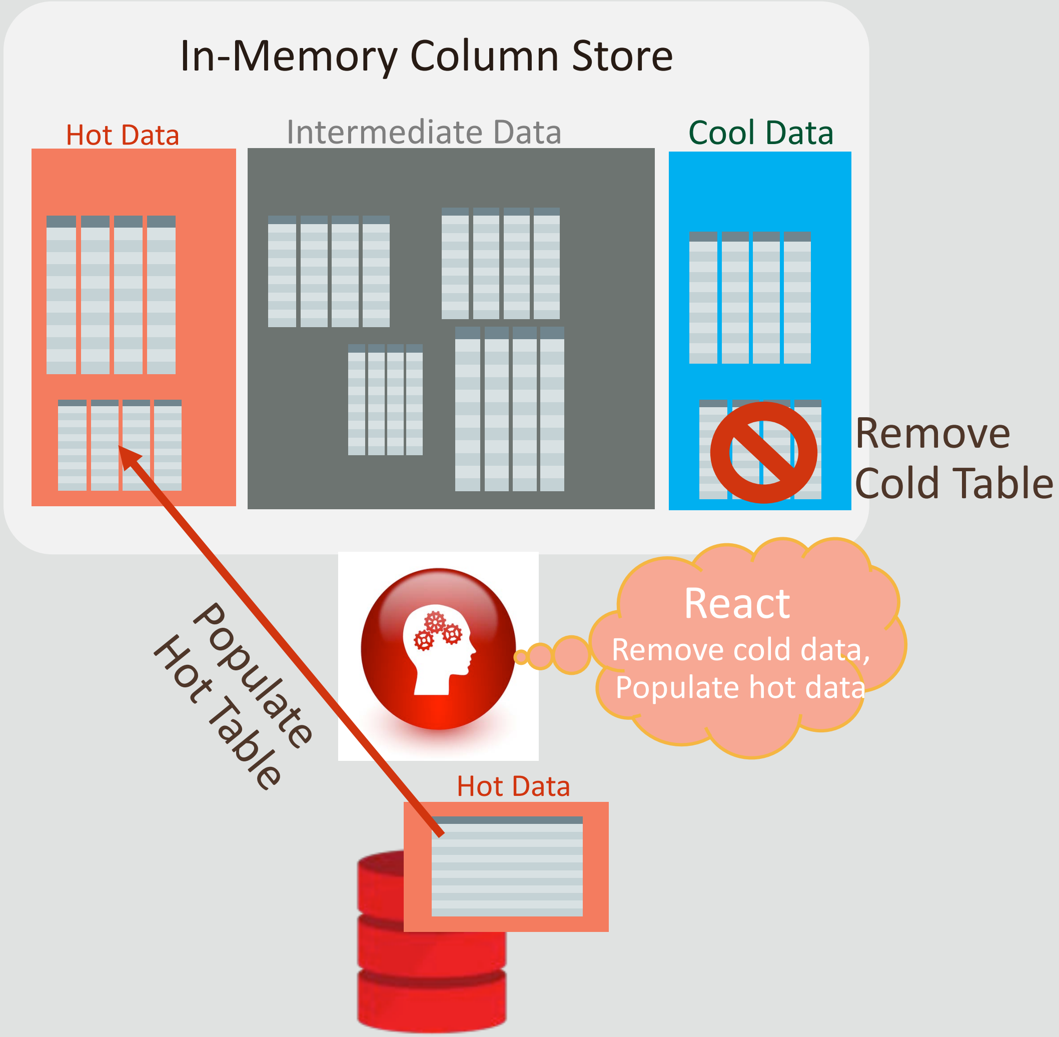
Automatic In-Memory



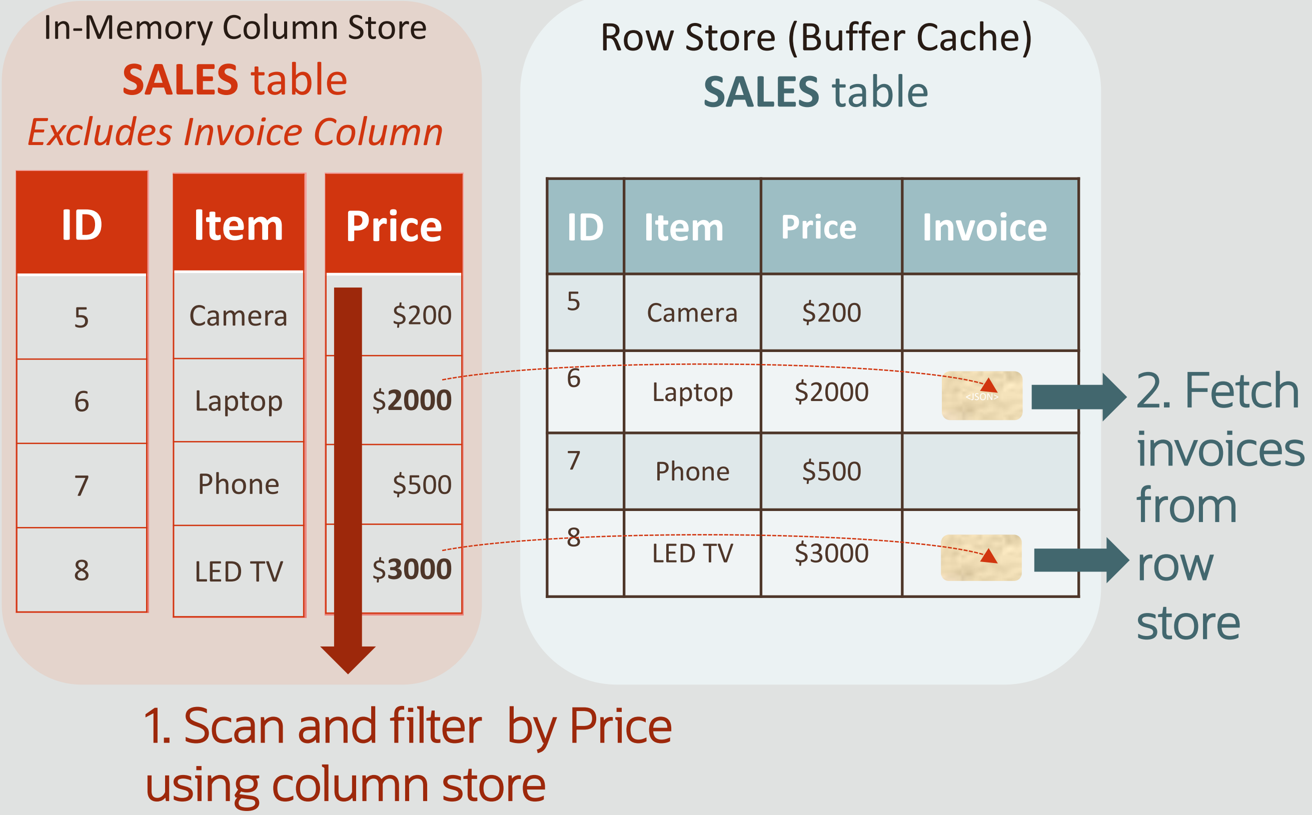
- Eliminates trial and error regarding in-memory area contents
- Constant background action:
  - Classifies data as hot, intermediate or cold
  - Hotter in-memory tables automatically populated
  - Colder in-memory tables automatically removed
  - Intelligent algorithm takes into account space-benefit tradeoffs
- Controlled by new parameter **inmemory_automatic_level**
- Useful for autonomous cloud services since no user intervention required

Preview | Hybrid In-Memory Scans

NEW IN 20c

- Large, infrequently accessed columns can be excluded from the in-memory column store
  - e.g. Images, Documents, etc.
- **Current behavior**: In-Memory access disallowed if query accesses any excluded column
- 20c: Hybrid In-Memory Scans
  - Scan/filter using in-memory column store
  - Fetch excluded column values from row store
  - Over 10x performance improvement

SELECT Invoice FROM Sales
WHERE Price > 1000



In-Memory Column Store
SALES table
Excludes Invoice Column

ID	Item	Price
5	Camera	$200
6	Laptop	**$2000**
7	Phone	$500
8	LED TV	**$3000**

Row Store (Buffer Cache)
SALES table

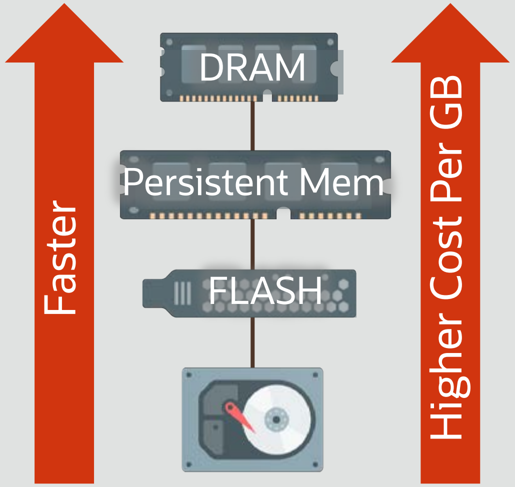
ID	Item	Price	Invoice
5	Camera	$200	
6	Laptop	$2000	
7	Phone	$500	
8	LED TV	$3000	

2. Fetch invoices from row store

1. Scan and filter by Price using column store

Preview | Persistent Memory

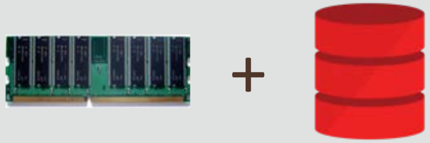
- Persistent memory is a new silicon technology
  - Capacity, performance, and price are between DRAM and flash
- Intel® Optane™ DC Persistent Memory:
  - Reads at memory speed – much faster than flash
  - Writes survive power failure unlike DRAM
- Exadata implements sophisticated algorithms to maintain integrity of data on PMEM during failures
  - Call special instructions to flush data from CPU cache to PMEM
  - Complete or backout sequence of writes interrupted by a crash



Preview | Persistent Memory (In-Memory)

Today (Baseline)

- Not all data can fit into Memory
- Queries go against column store in DRAM and row store on DISK
- DRAM Dimms up to 128GB, and very expensive.

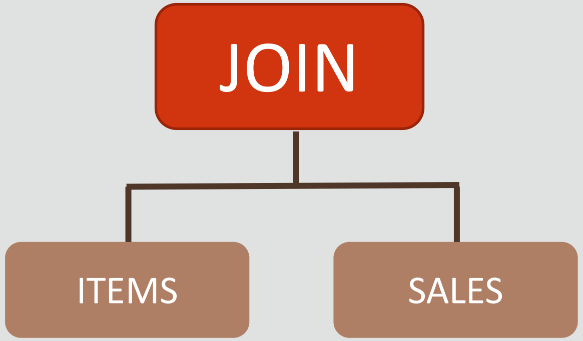


New : Intel® Optane™ DC Persistent Memory

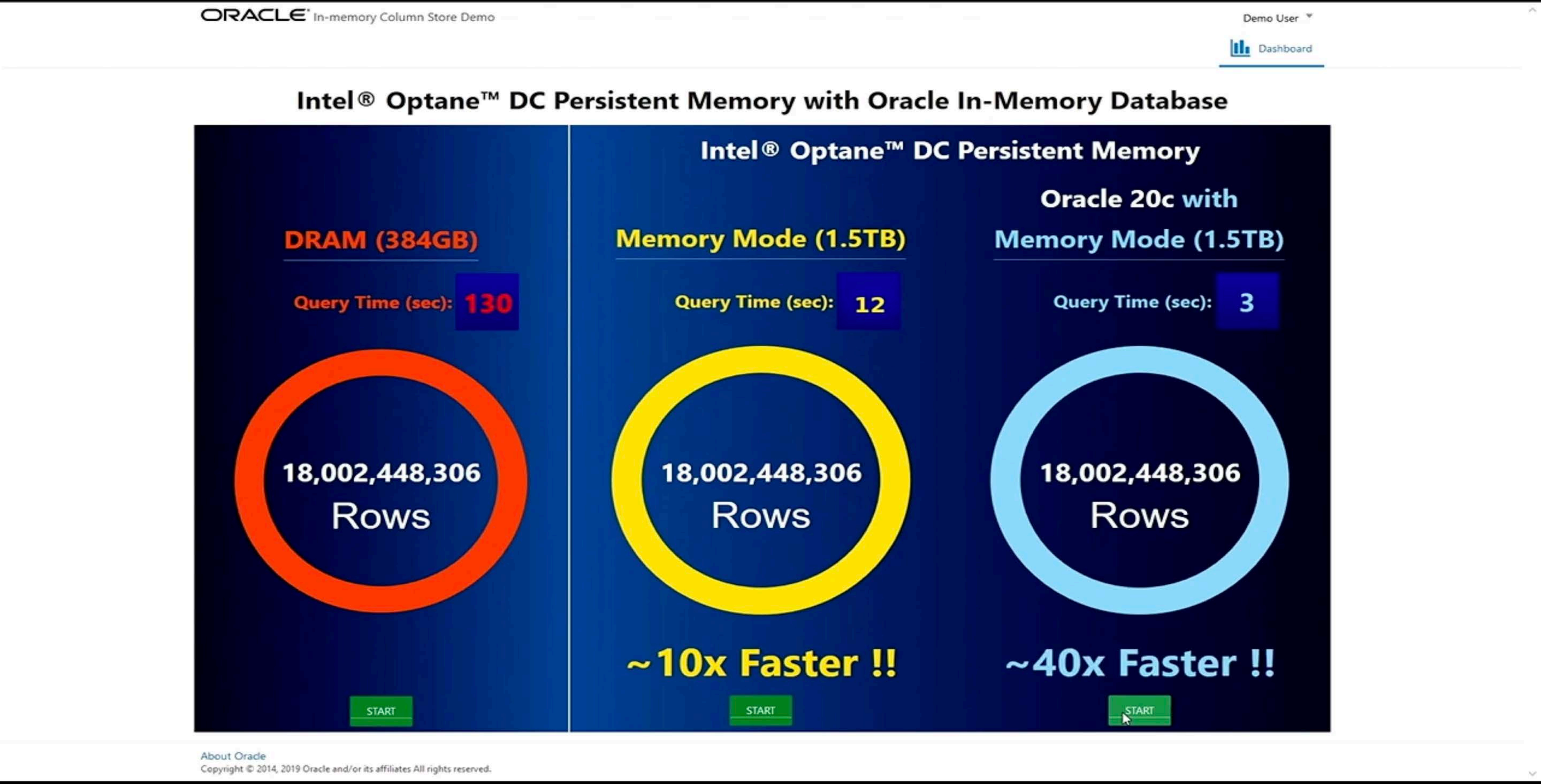
- Entire workload can fit into Memory
- With Memory Mode, hottest tables are cached in DRAM for fastest access
- Apache Dimms up to 512GB

New : Intel® Optane™ DC Persistent Memory + **Oracle 20c**

- **Oracle 20c** introduces new *Deep Vectorization* framework that extends vector processing to all SQL operators



+ ORACLE DATABASE 20c



ORACLE In-memory Column Store Demo

Intel® Optane™ DC Persistent Memory with Oracle In-Memory Database

DRAM (384GB)

Query Time (sec): 130

18,002,448,306 Rows

Intel® Optane™ DC Persistent Memory

Memory Mode (1.5TB)

Query Time (sec): 12

18,002,448,306 Rows

~10x Faster !!

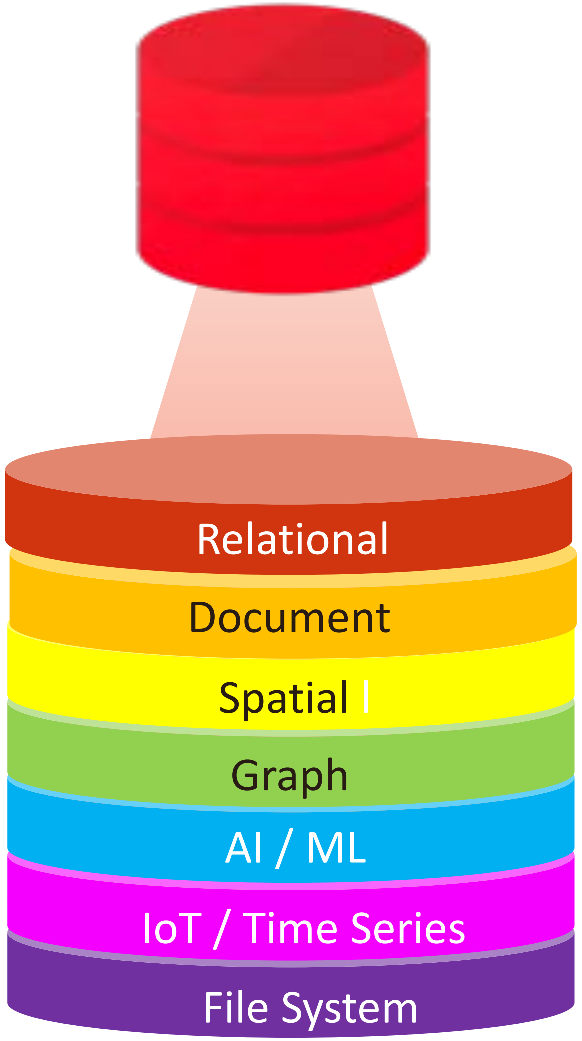
Oracle 20c with Memory Mode (1.5TB)

Query Time (sec): 3

18,002,448,306 Rows

~40x Faster !!

About Oracle

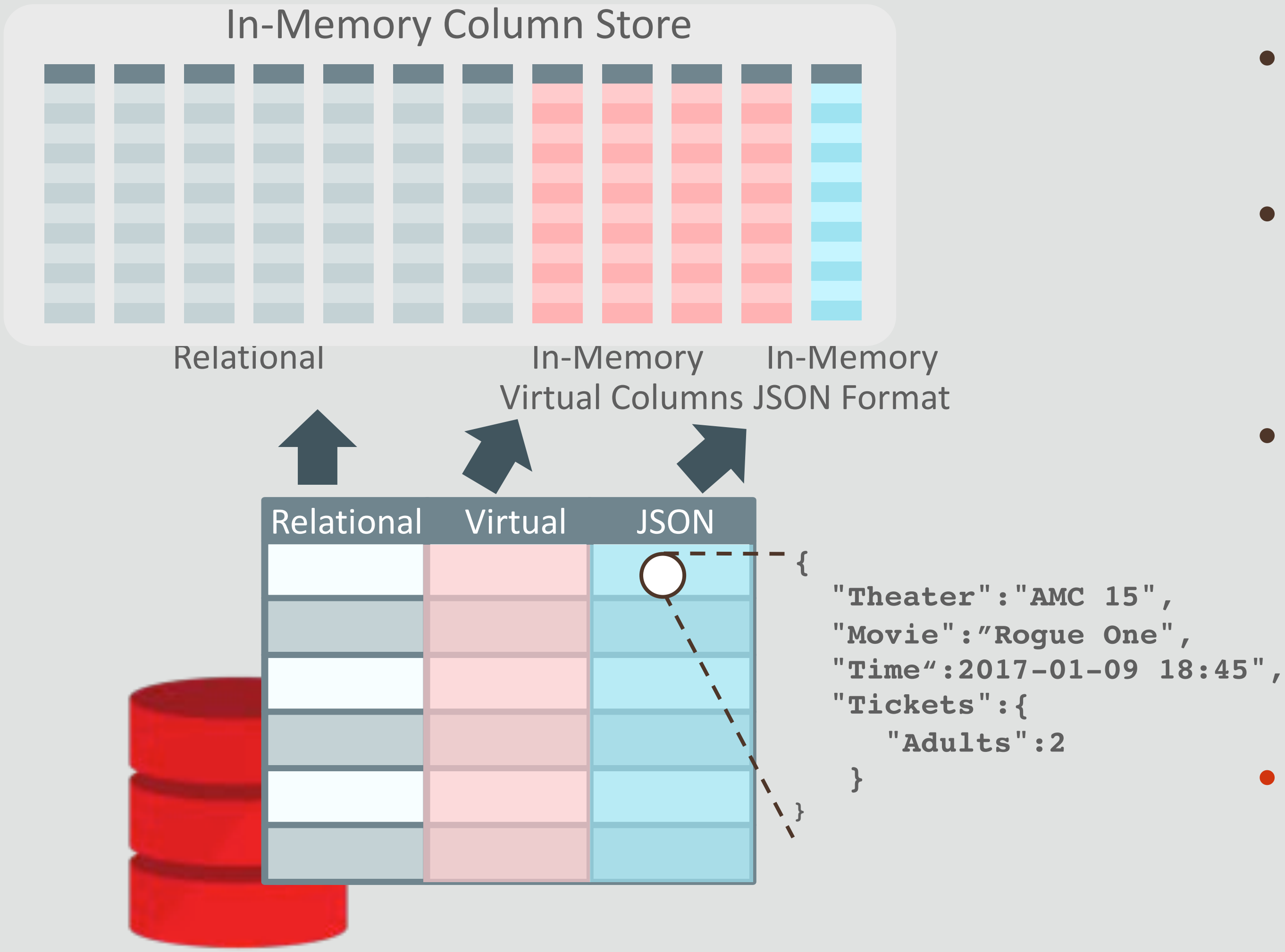


#4

Converged Analytics

One Database for All : Relational, Text, JSON, Spatial,...

Faster Converged Analytics | In-Memory JSON



```
{
  "Theater":"AMC 15",
  "Movie":”Rogue One",
  "Time“:2017-01-09 18:45",
  "Tickets":{
     "Adults":2
   }
}
```

- Full JSON documents populated using an optimized binary format
- Additional expressions can be created on JSON columns (e.g. JSON_VALUE) & stored in column store
- Queries on JSON content or expressions automatically directed to In-Memory format
  - E.g. Find movies where movie.name contains “Rogue”
- 20 - 60x performance gains observed

In-Memory For External Tables

Fast Analytics on External Data

External Tables allow transparent SQL on external data

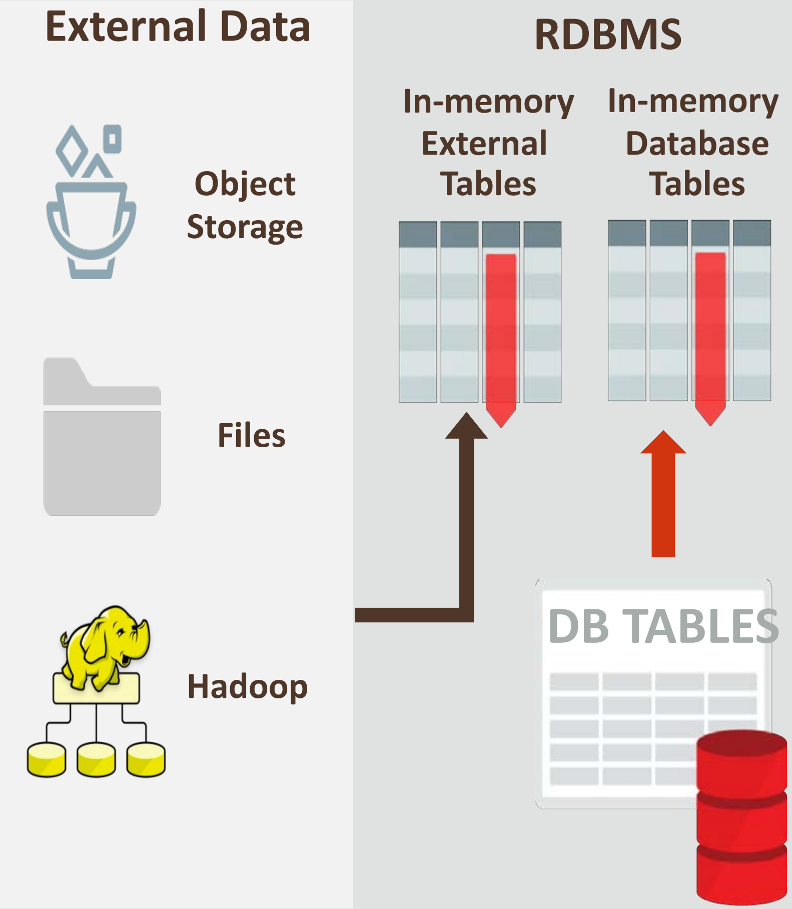
In-Memory External Tables: 100x faster analytics on external data

All In-Memory Optimizations

- Vector processing, JSON expressions extend transparently to external data

Simple to enable:

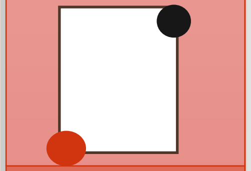
```
create table EXT1(…) organization
external(…) inmemory
```



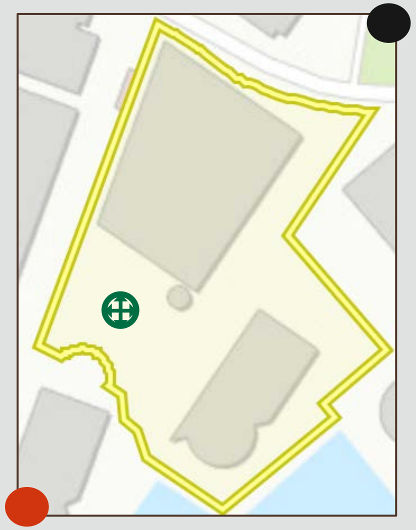
Preview | In-Memory Spatial Analytics

NEW IN 20c

- In-Memory only *Spatial Summary* column added to each spatial column
  - Compact approximation of complex spatial detail
  - Stored in optimized In-Memory format
  - Quickly filter using SIMD vector scans
  - Replace R-Tree Indexes for Spatial Analytics
- Spatial Queries up to 10x faster
  - No analytic R-tree index maintenance needed

In-Memory (IM) Table Columns			Additional IM columns
Parcel Number	**Parcel Address**	**Spatial Details**	**Spatial Summary**
095040390	300 Oracle Pkwy		
095040310	400 Oracle Pkwy		
095040250	500 Oracle Pkwy		
095040260	600 Oracle Pkwy		

Which parcel is the utility valve located in?

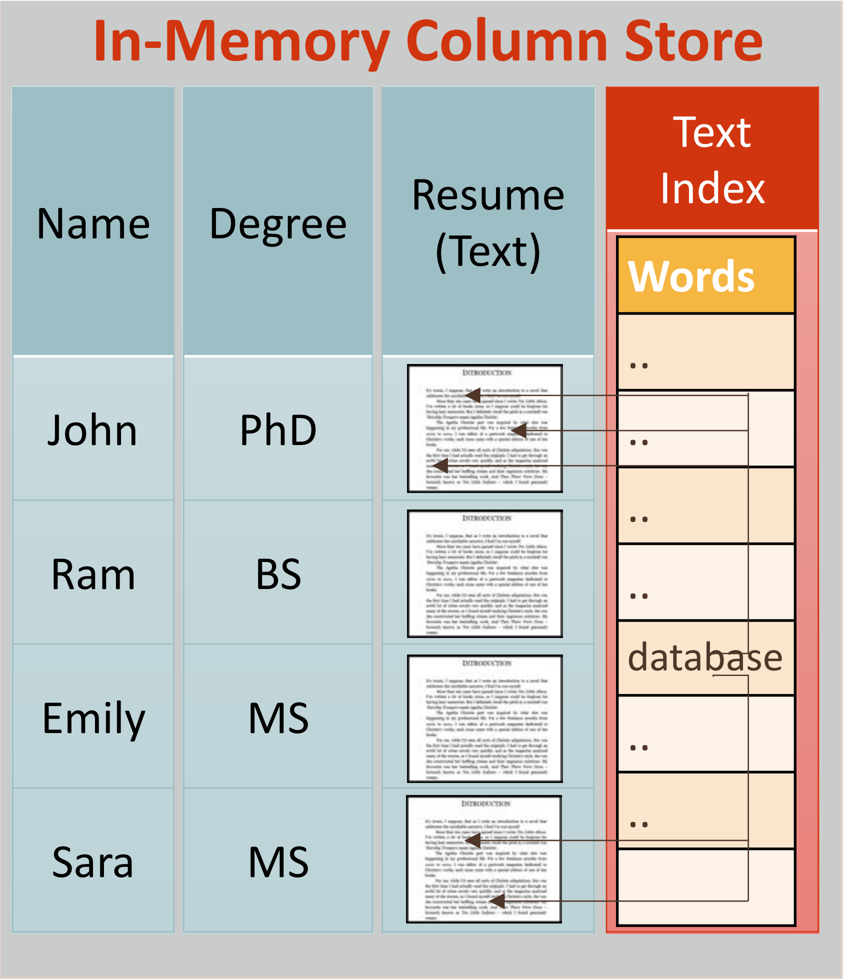


Search 140 Million US land parcels

Preview | In-Memory Text Analytics

NEW IN 20c

Find job candidates with "PhD" degrees who have "database" in their resumes

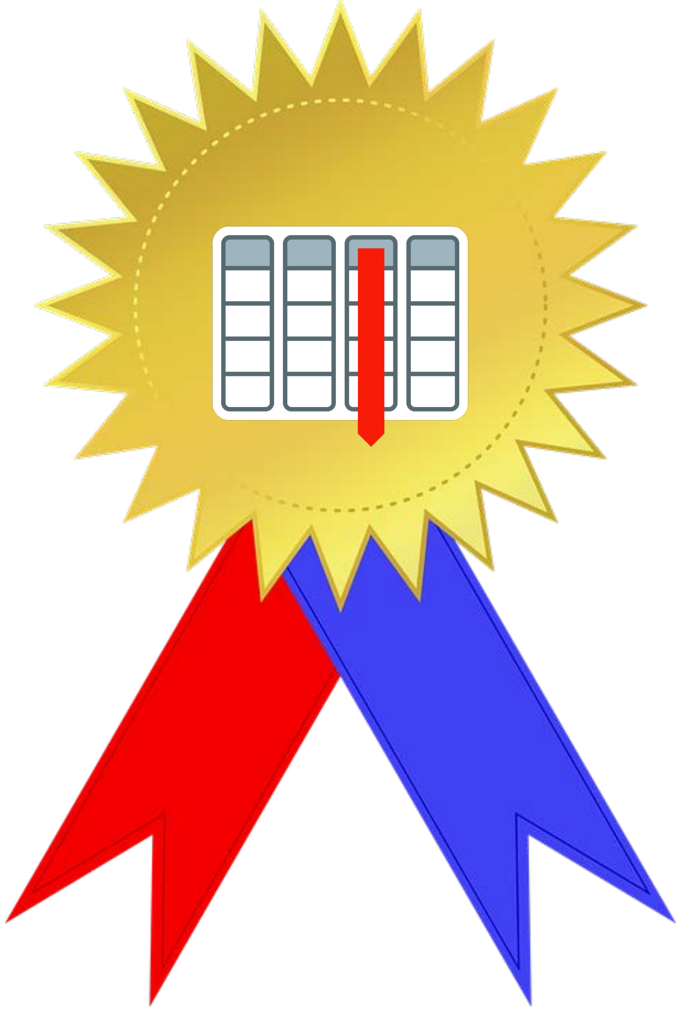


In-Memory Column Store

Name	Degree	Resume (Text)
John	PhD	
Ram	BS	
Emily	MS	
Sara	MS	

- In-Memory only *Inverted Index* added to each text column
  - Maps words to documents which *contain* those words
  - Replaces on-disk text index for analytic workloads
- Converged queries (*relational + text*) can benefit from in-memory
  - 3x faster

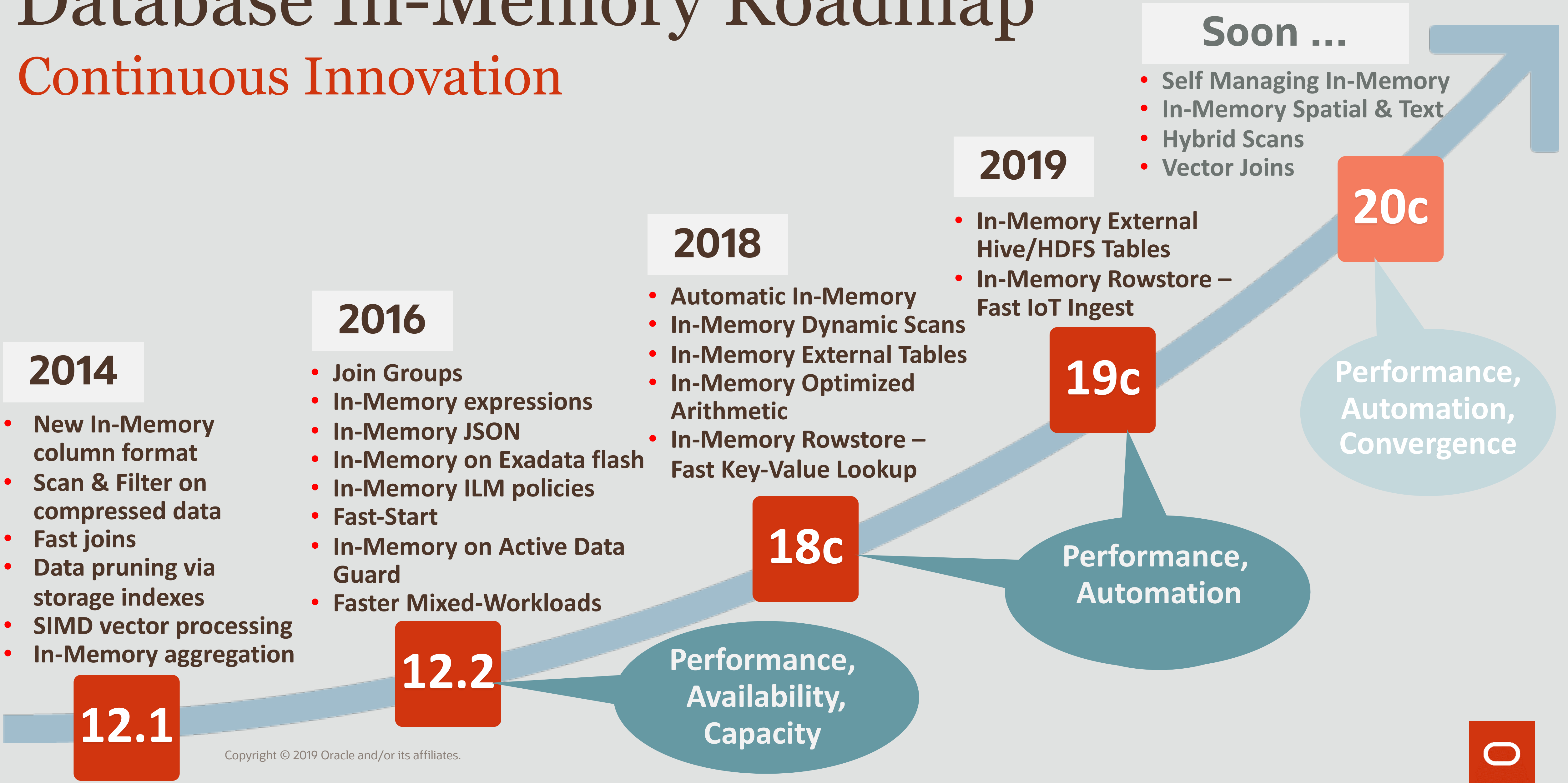
Oracle Database In-Memory



Top-5 Innovations Summary

Database In-Memory Roadmap

Continuous Innovation



2014

- New In-Memory column format
- Scan & Filter on compressed data
- Fast joins
- Data pruning via storage indexes
- SIMD vector processing
- In-Memory aggregation

12.1

2016

- Join Groups
- In-Memory expressions
- In-Memory JSON
- In-Memory on Exadata flash
- In-Memory ILM policies
- Fast-Start
- In-Memory on Active Data Guard
- Faster Mixed-Workloads

12.2

Performance, Availability, Capacity

2018

- Automatic In-Memory
- In-Memory Dynamic Scans
- In-Memory External Tables
- In-Memory Optimized Arithmetic
- In-Memory Rowstore – Fast Key-Value Lookup

18c

Performance, Automation

2019

- In-Memory External Hive/HDFS Tables
- In-Memory Rowstore – Fast IoT Ingest

19c

Soon …

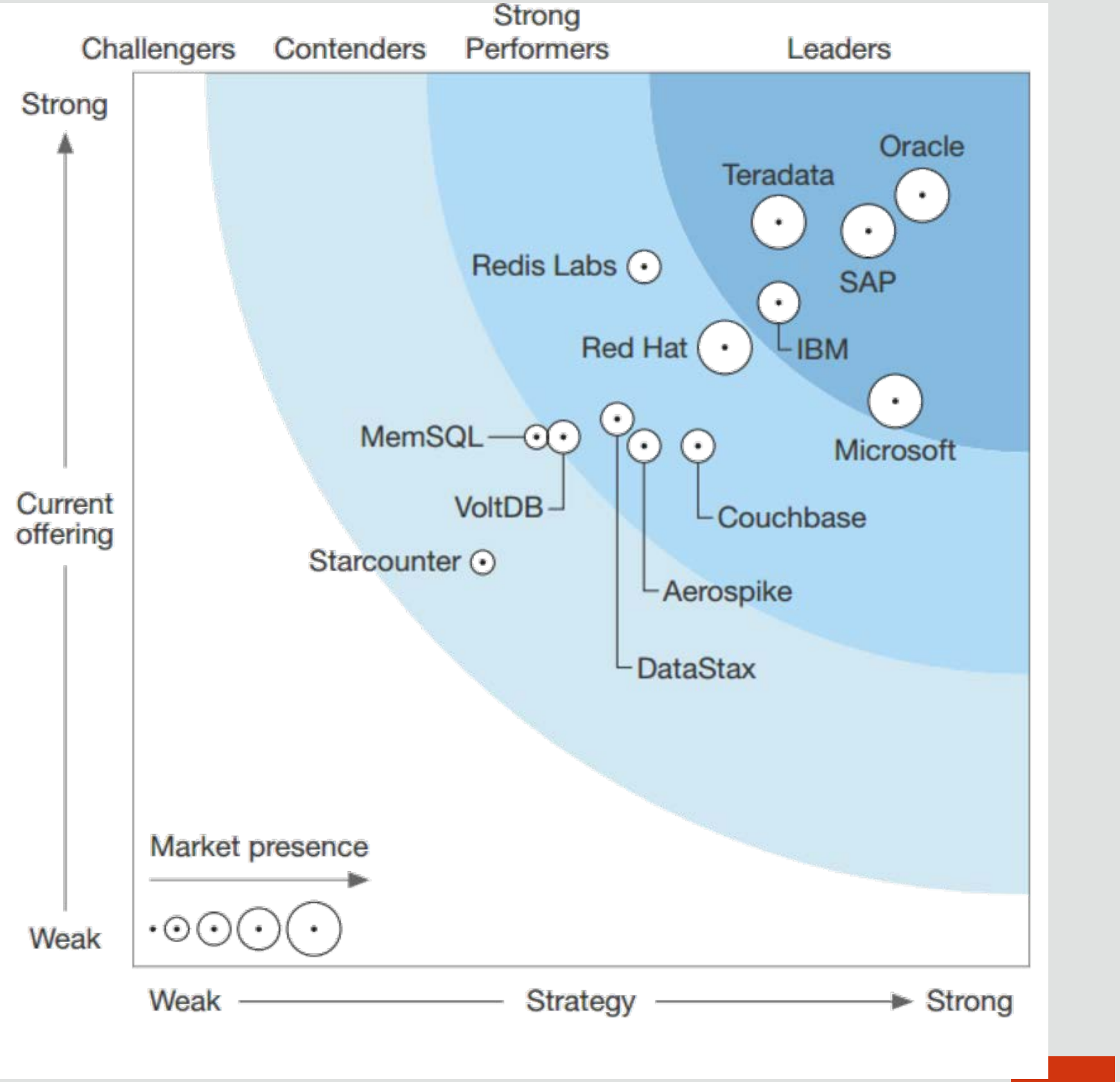
- Self Managing In-Memory
- In-Memory Spatial & Text
- Hybrid Scans
- Vector Joins

20c

Performance, Automation, Convergence

The Forrester Wave™: In-Memory Databases, Q1 2017

Oracle In-Memory Databases Scored Highest by Forrester on both Current Offering and Strategy



http://www.oracle.com/us/corporate/analystreports/forrester-imdb-wave-2017-3616348.pdf

The Forrester Wave™ is a graphical representation of Forrester's call on a market and is plotted using a detailed spreadsheet with exposed scores, weightings, and comments. Forrester does not endorse any vendor, product, or service depicted in the Forrester Wave. Information is based on best available resources. Opinions reflect judgment at the time and are subject to change.

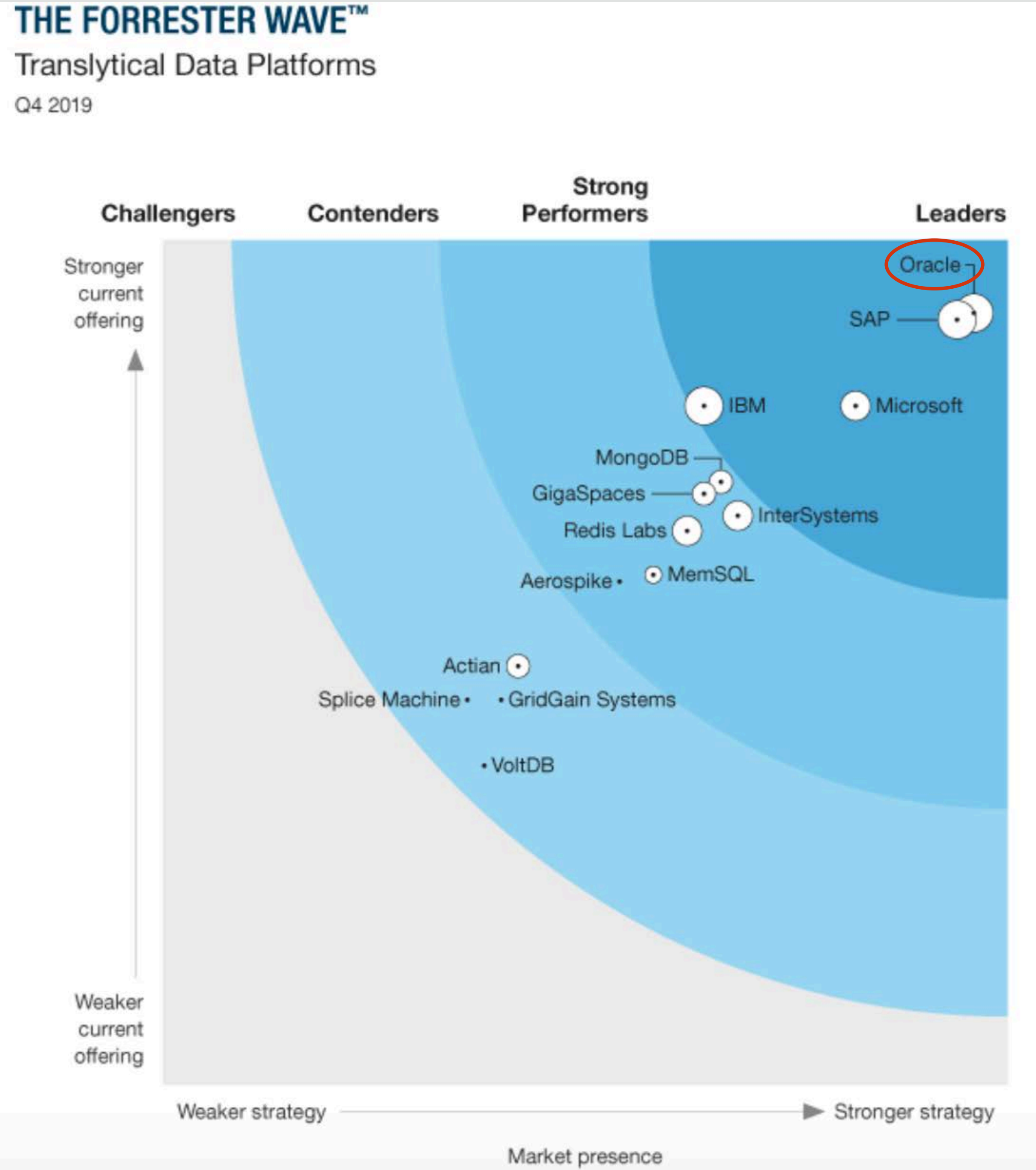
Hot off the Press:
2019 Forrester Wave Translytical Data Platforms

Oracle Position: Leader
Oracle ranked highest on both Axis

- “Unlike other vendors, Oracle uses a dual-format database (row and columns for the same table) to deliver optimal translytical performance.“
- “Customers like Oracle’s capability to support many workloads including OLTP, IoT, microservices, multimodel, data science, AI/ML, spatial, graph, and analytics”
- “Existing Oracle applications do not require any changes to the application in order to leverage Oracle Database In-Memory”

Published: October23, 2019

Analysts: Noel Yuhanna, Mike Gualtieri



THE FORRESTER WAVE™
Translytical Data Platforms
Q4 2019

Additional Resources

Related White Papers

- Oracle Database In-Memory White Paper
- Oracle Database In-Memory Aggregation Paper
- When to use Oracle Database In-Memory
- Oracle Database In-Memory Advisor
- SQL Plan Management White Paper
- POC / Implementation Guidelines

Related Videos

- In-Memory YouTube Channel
- Managing Oracle Database In-Memory
- Database In-Memory and Oracle Multitenant
- Industry Experts Discuss Oracle Database In-Memory
- Software on Silicon

Additional Details

- Oracle Database In-Memory Blog
- Optimizer blog

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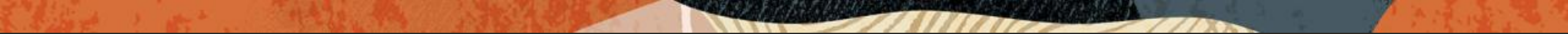
http://www.oracle.com/goto/dbim.html



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