Safe Harbor Statement

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Oracle In-Memory Strategy: In-Memory in All Tiers, All Workloads

Tirthankar Lahiri
Vice President
Oracle Data Technologies and TimesTen
In-Memory Innovation Quadrant at Oracle

- In-Memory Databases
- CPU and Server Architecture
- In-Memory Applications
- Engineered Systems
Oracle In-Memory Database Technology Across Tiers

**Application/Middle Tier**

- **TimesTen In-Memory Database**
  - Embeddable In-Memory Database for Application Tier
  - Real-Time OLTP workloads (Microsecond Response Time)
  - Adaptive In-Memory Cache for Exalytics In-Memory Machine

**Database Tier**

- **Oracle Database**
  - Scalable database for any size or type of workload
  - In-Memory columnar / row format
  - Combines best of memory, flash, disk
Oracle TimesTen
Application-Tier In-Memory Database
What is the Oracle TimesTen In-Memory Database?

A Standard Relational Database

- **Incredibly Fast**
  - Entire DB in Memory
  - *Microsecond* response time

- **Persistent**
  - Transactions, logging
  - Checkpointing Replication

- **Standard**
  - SQL, PL/SQL, OCI, JDBC, ODBC

- **Easy**
  - Simple to install and configure
  - Easily embeddable
Oracle TimesTen – Pure In-Memory Relational Database
Very Fast Response Time for Very High Throughput in Application Tier

1996 | 2005
Pre-Oracle acquisition
• 1998 First commercial In-Memory RDBMS
• HA Replication
• Online Upgrades
• Application-tier Cache for Oracle Database

2006 | 2008
TimesTen 6 TimesTen 7
• Oracle RAC integration
• National Language Support
• Oracle Data Types support
• SQL Developer Integration
• Enterprise Manager integration

2009 | 2011
TimesTen 11g 11.2.1
• PL/SQL and OCI Support
• Oracle Clusterware Integration
• Cache Grid for Scale Out
• ODP.NET Support
• BLOB, CLOB, NCLOB data types

2012 | 2013
TimesTen 11g 11.2.2
• Parallel Replication
• In-Memory Analytics
• Columnar Compression
• Index Advisor
• Oracle R Support
• In-Memory Star Join
• Oracle Golden Gate Integration

2014
11.2.2.x Enhancements
• Parallel data import from Oracle Database
• Parallel database restart
• Highly concurrent range indexes

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Parallel database restart
Highly concurrent range indexes

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TimesTen Deployment Modes

- Standalone
- Application-Tier Database Cache
- Adaptive In-Memory Cache for Exalytics
TimesTen Response Time

Response Times in Microseconds

Intel® Xeon CPU E5-2680 @2.7GHZ 2 sockets 8 cores/socket 2 hyper-threads/core 32 vCPU – TimesTen 11.2.2.5.1
TimesTen Read Performance

OLTP Scalability on Modern Commodity Hardware

Number of Concurrent Processes

- Intel® Xeon® CPU E5-2680 @2.7GHZ 2 sockets 8 cores/socket 2 hyper-threads/core 32 vCPU – TimesTen 11.2.2.5.1

8.2 Million Reads per Second
TimesTen Performance – Mixed Workload
OLTP Scalability on Modern Commodity Hardware

Over 2.6 Million Transactions per Second

Transactions per Second

Workload
80% Reads
10% Updates
5% Inserts
5% Deletes

Concurrent Processes

Intel® Xeon CPU E5-2680 @2.7GHZ 2 sockets 8 cores/socket 2 hyper-threads/core 32 vCPU – TimesTen 11.2.2.5.1
TimesTen Write Performance

OLTP Scalability on Modern Commodity Hardware

Transactions Per Second

<table>
<thead>
<tr>
<th>Concurrent Processes</th>
<th>Transactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>130,375</td>
</tr>
<tr>
<td>4</td>
<td>420,943</td>
</tr>
<tr>
<td>8</td>
<td>733,318</td>
</tr>
<tr>
<td>16</td>
<td>952,778</td>
</tr>
</tbody>
</table>

Intel® Xeon CPU E5-2680 @2.7GHZ 2 sockets 8 cores/socket 2 hyper-threads/core 32 vCPU – TimesTen 11.2.2.5.1
TimesTen Read Performance

Extreme Scalability on Oracle SPARC T5-8

Oracle Solaris Sparc T5-8 – 8 CPUs 128 Cores 1024 Threads - TimesTen 11.2.2.5.1
TimesTen Write Performance

Extreme Scalability on Oracle SPARC T5-8

Oracle Solaris Sparc T5-8 – 8 CPUs 128 Cores 1024 Threads - TimesTen 11.2.2.5.1

1.2 Million Update Transactions per Second
TimesTen Performance – Mixed Workload

Extreme Scalability on Oracle SPARC T5-8

Oracle Solaris Sparc T5-8 – 8 CPUs 128 Cores 1024 Threads - TimesTen 11.2.2.5.1
## Performance-Oriented Design

<table>
<thead>
<tr>
<th>Read Response Time (Single Query)</th>
<th>Write Response Time (Single Update + Commit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.37 micro-seconds</td>
<td>7.67 micro-seconds</td>
</tr>
</tbody>
</table>

**Intel Xeon E5 2680 (2.7 GHz, 8 cores/cpu, 2 cpus)**

### Response time optimized design
- Memory-optimized storage manager
- Lightweight query processor
- Optional direct-link eliminates client-server networking overhead

### Throughput optimized design
- Ultra-concurrent indexes with optimistic concurrency control
- Parallel logging and replication
- Non-blocking reads
- Extensive NUMA optimizations

<table>
<thead>
<tr>
<th>Read Throughput (Queries/sec)</th>
<th>Write Throughput (Updates/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49.46 million</td>
<td>1.236 million</td>
</tr>
</tbody>
</table>

**SPARC T5-8 (3.6GHz, 16 cores/cpu, 8 cpus)**
TimesTen High Availability

- Fully persistent
  - Checkpoints, logging, txns
- Real-time transactional replication
  - High performance, parallel
  - Multiple topologies
  - Online upgrades
- Oracle Clusterware integration
  - Automatic database switchover
  - Automatic application failover
Application-Tier Database Cache

- Application-tier IMDB cache
  - Preloaded or loaded on-demand
  - Read-Only / Read-Write
  - Automatic synchronization
- High Availability of cached data
- Scale Out for cached data
- Complements Oracle Database
Application-Tier Database Cache

Automatic Data Synchronization

Read/Write Caching
- Execute transactions in TimesTen
- Propagate changes to the Oracle Database

Read-only Caching
- Execute transactions in the Oracle Database
- Refresh changes to the TimesTen Cache database
Read-write and Read-only Caching

High Availability

Read/Write Caching
Parallel replication of transactions to Standby
Parallel asynchronous write-through from Standby to Oracle Database

Read-only Caching
Cache updates refreshed to TimesTen
Updated cache replicated to Standby in parallel
HLR Mobile Transactions Response Time

Response Time Improvement With TimesTen IMDB Cache

<table>
<thead>
<tr>
<th>Transaction</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Get Basic Subscriber Data</td>
<td>29x</td>
</tr>
<tr>
<td>Get New Destination</td>
<td>31x</td>
</tr>
<tr>
<td>Get Access Data</td>
<td>69x</td>
</tr>
<tr>
<td>Update Subscriber Data</td>
<td>44x</td>
</tr>
<tr>
<td>Update Location</td>
<td>17x</td>
</tr>
<tr>
<td>Insert Call-Forwarding</td>
<td>10x</td>
</tr>
<tr>
<td>Delete Call-Forwarding</td>
<td>17x</td>
</tr>
</tbody>
</table>

Intel® Xeon CPU E5-2680 @2.7GHZ 2 sockets 8 cores/socket 2 hyper-threads/core 32 vCPU
Adaptive In-Memory Caching for Exalytics

Exalytics In-Memory Machine
- 2TB DRAM
- 40 cores / 80vcpus

Data Sources
- OLTP & ODS Systems
- Data Warehouse
- Data Mart
- OLAP Sources
- Packaged Applications (Oracle, SAP, Others)
- Unstructured & Semi-Structured
- Excel
- XML/Office
- Business Process

BI Server with Detailed Usage Tracking
- Cache Miss
- Cache Hit
- Usage Analysis
- Aggregate Selection
- Summary Advisor

Interactive Dashboards
Query & Analysis

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Widely Relational In-Memory Database
Deployed by Thousands of Companies
Oracle Database 12c
Database In Memory Option
Oracle Database 12c
Manages wide variety of data types

- **Structured data**
  - Numeric, string, date, ...
  - Row and column formats

- **Unstructured data**
  - LOBs
  - Text
  - XML
  - JSON
  - Spatial
  - Graph
  - Multimedia
Oracle Database 12c In-Memory Option Goals

- **100x** Faster Queries: Real-Time Analytics
  - Instantaneous Queries on OLTP Database or Data Warehouse

- **2x-10x** Faster Mixed Workload OLTP

- **Transparent:** No application changes
Row Format Databases vs. Column Format Databases

Row

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

Column

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

Until Now Must Choose One Format and Suffer Tradeoffs
Breakthrough: Dual Format Database

- **BOTH** row and column formats for same table
- Simultaneously active and transactionally consistent
- OLTP uses proven row format
- Analytics & reporting use new in-memory Column format
  - Same query results regardless of which format is used
Oracle In-Memory Columnar Technology

- Available on all platforms
- Pure in-memory column format
  - In-memory maintenance: allows fast OLTP
  - No changes to disk format
- 5x to 30x compression
- Enabled at tablespace, table or partition level
  - Can even enable for whole database
Orders of Magnitude Faster Analytic Data Scans

• Each CPU core scans local in-memory columns
• Scans use SIMD vector instructions
• **Billions of rows/sec** scan rate per CPU core
  • Row format is millions/sec

Example: Find all sales in state of CA

> 100x Faster
In-Memory Compression Units

- Each object populated in the Column Store is actually made up of multiple In-Memory Compression Units
- Each IMCU contains the column entries for a subset of rows in the object (typically O(1M))
- IMCUs can vary in size depending on datatypes used and compression rates
In-Memory Compression Units

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- Each IMCU contains the column entries for a subset of rows in the object (typically O(1M))
- IMCUs can vary in size depending on datatypes used and compression rates
Oracle In-Memory Column Store Storage Index

**Example:** Find sales from stores with a store_id of 8 or higher

- Each column is made up of multiple column units
- Min/max value is recorded for each column unit in a storage index
- Storage index provides partition pruning like performance for **ALL** queries
Oracle In-Memory Column Store Compression

<table>
<thead>
<tr>
<th>Mode</th>
<th>Compression</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Avg.</td>
</tr>
<tr>
<td>Throughput</td>
<td>3x-14x</td>
<td>7.4x</td>
</tr>
<tr>
<td>Balanced</td>
<td>4.5x-39x</td>
<td>13.8x</td>
</tr>
<tr>
<td>Space</td>
<td>6x-52x</td>
<td>26.4x</td>
</tr>
</tbody>
</table>

- Throughput Optimized Compression Mode
  - Lightweight compression schemes such as Dictionary, Run Length, Bit-packing, etc.
  - Special query processing algorithms on compressed data
  - Runs much faster than uncompressed

Compression ratios can be highly inflated by choosing a bad uncompressed format, or reporting most compressible table. Our results are measured relative to Oracle’s efficient row format for customer data.
Oracle In-Memory Column Store Compression

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</tbody>
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• Balanced Compression Mode
  – Adds OZIP on top of Throughput Compression
  – World’s fastest decompressor, tuned for DB query performance
  – 2x - 3x faster than LZO (standard for fast zip)

Compression ratios can be highly inflated by choosing a bad uncompressed format, or reporting most compressible table. Our results are measured relative to Oracle’s efficient row format for customer data.
Joining and Combining Data Also Dramatically Faster

**Example:** Find total sales in outlet stores

- Converts joins of data in multiple tables into fast column scans
  - Scan of large table augmented with additional filter predicates derived from smaller tables
- Joins more than 10x faster

Example:

<table>
<thead>
<tr>
<th>Store ID in 15, 38, 64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store ID</td>
</tr>
<tr>
<td>Type=Outlet</td>
</tr>
</tbody>
</table>

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Generates Reports (Aggregations, Groupings) Instantly

**Example:** Report sales of footwear in outlet stores

- Dynamically creates in-memory report outline by scanning dimension tables
- Fills in report outline during fast fact scan
- Complex Reports run more than **10x** faster without predefined cubes
Complex OLTP is Slowed by Analytic Indexes

<table>
<thead>
<tr>
<th></th>
<th>OLTP Indexes</th>
<th>Analytic Indexes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table</td>
<td>1 – 3</td>
<td>10 – 20</td>
</tr>
</tbody>
</table>

- Most Indexes in complex OLTP (e.g. ERP) databases are only used for analytic queries.
- Inserting one row into a table requires updating 10-20 analytic indexes: Slow!
- Indexes only speed up predictable queries & reports.
OLTP is Slowed Down by Analytic Indexes

Insert rate decreases as number of indexes increases
Column Store Replaces Analytic Indexes

- Fast analytics on any columns
  - Better for unpredictable analytics
  - Less tuning & administration

- Column Store not persistent so update cost is much lower
  - Equivalent to analytic index on all columns
  - OLTP & batch DMLs run much faster
Scale-Out In-Memory Database to Any Size

- Scale-Out across servers to grow memory and CPUs
- In-Memory queries parallelized across servers to access local column data
- Direct-to-wire InfiniBand protocol speeds messaging
ALTER TABLE sales INMEMORY DISTRIBUTED BY PARTITION;

ALTER TABLE COSTS INMEMORY DISTRIBUTED AUTO;

- Policy is user-specifiable
- Controlled by `DISTRIBUTE` subclause
  - Distribute by rowid range
  - Distribute by partition
  - Distribute AUTO
Scale-Up for Maximum In-Memory Performance

- Scale-Up on large SMPs
- NUMA optimizations
- Parallel Execution
- SMP scaling removes overhead of distributing queries across servers
- Memory interconnect far faster than any network
Demonstration 1

2-socket System
Oracle In-Memory: Industrial Strength Availability

- Pure In-Memory format does not change Oracle’s storage format, logging, backup, recovery, etc.
- All Oracle’s proven availability technologies work transparently
- Protection from all failures
  - Node, site, corruption, human error, etc.
1. Configure Memory Capacity
   • `inmemory_size = XXX GB`

2. Configure tables or partitions to be in memory
   • `alter table | partition ... inmemory;`

3. Drop analytic indexes to speed up OLTP
Oracle In-Memory Requires Zero Application Changes

- Full Functionality - No restrictions on SQL
- Easy to Implement - No migration of data
- Fully Compatible - All existing applications run unchanged
- Fully Multitenant - Oracle In-Memory is Cloud Ready

Uniquely Achieves All In-Memory Benefits With No Application Changes
Oracle In-Memory Applications
From Batch to Real Time
Keys to In-Memory Application Design

- Process data in database, not application
- Set-oriented processing
  - Row by row processing is slow and cannot be parallelized
- In-memory column format for Analytics
- Enable parallel SQL
  - Memory removes storage bottlenecks enabling highly parallel SQL
# Oracle In-Memory Applications

<table>
<thead>
<tr>
<th>Oracle Application Module</th>
<th>Improvements</th>
</tr>
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<tbody>
<tr>
<td>Oracle E-business Suite In-Memory Cost Management</td>
<td>628x Faster: 58 hours to 6 minutes</td>
</tr>
<tr>
<td>PeopleSoft In-Memory Financial Analyzer</td>
<td>1,354x Faster: 4.3 hours to 11 seconds</td>
</tr>
<tr>
<td>JD Edwards In-Memory Sales Order Analysis</td>
<td>1,762x Faster: 22.5 minutes to &lt; 1 second</td>
</tr>
<tr>
<td>JD Edwards Customer Receivables Management</td>
<td>3,660x Faster: 244 minutes to 4 seconds</td>
</tr>
<tr>
<td>Oracle Fusion Financials Subledger Period Close Exceptions</td>
<td>200x Faster: 600 seconds to 3 seconds</td>
</tr>
<tr>
<td>Siebel Marketing – List Import</td>
<td>141x Faster: 115 minutes to 49 seconds</td>
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</tr>
<tr>
<td>PeopleSoft In-Memory Financial Analyzer Pivot Grids for TL</td>
<td>58x Faster: 70 minutes to 73 second</td>
</tr>
<tr>
<td>PeopleSoft In-Memory Financial Analyzer Pivot Grids for HR</td>
<td>1,200x Faster: 30 minutes to 1.5 seconds</td>
</tr>
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<tr>
<td>JD Edwards Customer Receivables Management</td>
<td>3,660x Faster: 244 minutes to 4 seconds</td>
</tr>
<tr>
<td>JD Edwards Interactive Period Close Exceptions</td>
<td>272x Faster: 78 minutes to 17 seconds</td>
</tr>
<tr>
<td>JD Edwards In-Memory Application (Project Portfolio Advisor, Sales Advisor, &amp; Planning Advisor)</td>
<td>18x Faster: 17 minutes to 55 seconds</td>
</tr>
</tbody>
</table>
# Oracle In-Memory Applications

<table>
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<tr>
<th>Oracle Application Module</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Demantra Promotion Planning</td>
<td>102x Faster: 18.3 minutes to 11 second</td>
</tr>
<tr>
<td>Demantra Consumption Driven Planning</td>
<td>13.5x Faster: 12.7 hours to 56 minutes</td>
</tr>
<tr>
<td>JD Edwards Supply Chain Planning and Analytics</td>
<td>76x Faster: 28 minutes to 3 minutes</td>
</tr>
<tr>
<td>Oracle In-Memory Transportation Management</td>
<td>1031x Faster: 17 minutes to &lt; 1 second</td>
</tr>
</tbody>
</table>
“Oracle Database In-Memory made our slowest financial queries faster out-of-the box; then we dropped indexes and things just got faster.”

Evan Goldberg
Co-Founder, Chairman, CTO
NetSuite Inc.
“The combination of MicroStrategy with Oracle Database In-Memory will enable dramatically better and faster decision-making for our customers.”

Paul Zolfaghari
President
MicroStrategy Inc.
“Real-Time Operational Analysis could be a phenomenal breakthrough for us. This could enable our Operational Managers to make better data-driven on-the-fly business decisions.”

William Hammock
Mitsubishi Electric Automotive America, Inc.
“Utilizing Oracle’s In-Memory Database against our JD Edwards ERP suite for real time summarization has the potential to radically change the way we deliver reporting, analysis and insights to our business leaders.”

Michael Macrie
Chief Information Officer
Land O’Lakes
CPU and Server Architecture
Enabling In-Memory Processing
M6-32 Big Memory Machine
World’s Largest SMP System Optimized for In-Memory

- 32 TB DRAM
- 32 Sockets
- 384 Cores
- 3072 processing threads
- 3 Terabyte/sec Bandwidth
Demonstration 2
M6-32
SPARC M7 Database In-Memory Query Accelerator

- On-chip accelerator optimized for Oracle Database In-Memory
  - Task level accelerators that operate on In-Memory vectors
  - Operate on decompressed and compressed columnar formats

- Query engine functions
  - In-Memory Format Conversions
  - Value and Range Comparisons
  - Set Membership

- Fused decompression + query functions for highest performance
Eight on-chip offload engines
Core threads are synchronous or asynchronous to offload engines
User level synchronization through shared memory
High performance at low power
M7 Accelerator Fine-grain Synchronization

- Core thread initiates a query plan task to offload engine
- User-Level LDMONITOR, MWAIT
  - Halts thread for specified duration
  - Reactivates when duration expires
  - Reactivates when monitored memory location is updated
- Offload Engine Completion
  - Results written back to memory
  - Completion status posted to monitored memory location
  - MWAIT detection logic resumes thread execution
M7 Query Offload Performance Example

- SPARC T5, M7 & Oracle Database In-Memory
- Single stream decompression performance
  - Decompression stage of query acceleration
  - Unaligned bit-packed columnar format
  - 1 of 32 Query Engine Pipelines
- M7 hardware accelerator decompression
  - Fused predicate evaluation
- Fully utilizes all available memory bandwidth (measured 170GB/sec per socket)
Engineered Systems
Complete Hardware + Software Solutions
Oracle Exalytics Featuring TimesTen
In-Memory Analytics and Visualization

Exalytics
In-Memory Machine

- TimesTen for Exalytics
  - Columnar Dictionary Compression
  - SQL Analytics (e.g. CUBE, ROLLUP, analytic functions)
  - Star Query optimized for in-memory processing

- Real-Time Data Visualization
- Wide variety of Data Sources

Summary Advisor
Dense Visualizations
Adaptive In-Memory Cache (Oracle TimesTen)
Oracle Business Intelligence

4 Socket Xeon
40 Cores
80 vCPUs
2TB DRAM

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Exadata and SPARC SuperCluster
In-Memory Speed + Throughput of Flash + Capacity of Disk

- Size not limited by memory
- Data transparently accessed across tiers
- Each tier has specialized algorithms & compression
  - Speed of DRAM
  - I/Os of Flash
  - Cost of Disk
Exadata Processing Tiers

- **Database Servers**
  - Perform complex database processing such as joins, aggregation, etc.

- **Exadata Storage Servers**
  - Storage Server is smart storage
    - Searches tables and indexes
    - Filters out data not relevant to a query
  - Cells serve data to multiple databases
Exadata Intelligent Storage

- Exadata storage servers also run more complex operations in storage
  - Join filtering
  - Incremental backup filtering
  - I/O prioritization
  - Storage Indexing
  - Database level security
  - Offloaded scans on encrypted data
  - Data Mining Model Scoring

- 10x reduction in data sent to DB servers is common
Exadata Smart Flash Cache

I/Os

- Caches Read and Write I/Os in PCI flash
- Transparently accelerates read and write intensive workloads
  - Up to 2.66 million IOPS (8K reads)
  - Up to 1.96 million IOPS (8K writes)
- Persistent write cache speeds database recovery
- Compression expands smart flash cache capacity
  - Compression implemented in hardware with zero overhead to IOPS
  - Data automatically compressed as it is written to flash cache
  - Automatically decompressed when it is read out of flash cache
  - Up to 2X more data fits in smart flash cache
In-Memory Fault Tolerance
Leverage high-speed networking on Engineered Systems

• Similar to storage mirroring

• Duplicate in-memory columns on another compute node
  • Leverages **Infiniband direct-to-wire** to maintain duplicates
  • Enabled per table/partition
  • Application transparent

• Eliminates downtime
Oracle Database In-Memory: Unique Fault Tolerance

- Policy is user-specifiable
- Controlled by DUPLICATE subclause
  - DUPLICATE
  - DUPLICATE ALL

```
ALTER TABLE sales INMEMORY DUPLICATE;

ALTER TABLE COSTS INMEMORY DISTRICT AUTO DUPLICATE ALL;
```
Summary

• **Dual Format Architecture**
  – Fully consistent row and column format
  – Best of both worlds OLTP and Analytics performance.
  – Typically, row format (Buffer cache) memory < 10% of column format memory

• **New In-Memory Column Format**
  – In-memory only representation
  – Seamlessly built into Oracle Database Engine
  – Compatible with all Oracle Database features

• **Cost Effective**
  – Use in-memory for hot data, flash for intermediate data, disk for cold data
In-Memory Innovation Quadrant at Oracle

In-Memory Databases

CPU and Server Architecture

In-Memory Applications

Engineered Systems

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Hardware and Software
Engineered to Work Together