Exadata Technical Deep Dive: Architecture and Internals

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Safe Harbor Statement

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# The Exadata Database Machine Vision

**Best Platform for the Oracle Database – On Premises and in the Cloud**

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<tr>
<td>1.</td>
<td>State-of-the-art enterprise-grade hardware, refreshed yearly (processors, flash, disks, network)</td>
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<td>2.</td>
<td>Sized, tuned and optimized exclusively for Oracle Database workloads (DW, Analytics, OLTP, Mixed)</td>
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<td>3.</td>
<td>High-powered intelligent storage servers capable of offloading database workloads</td>
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<td>4.</td>
<td>“Smart” database protocols and optimizations from servers to network to storage</td>
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<td>5.</td>
<td>One vendor responsible for all hardware, software and customer support</td>
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Proven at Thousands of Critical Deployments since 2008
Half OLTP - Half Analytics - Many Mixed

- Petabyte Warehouses
- Online Financial Trading
- Business Applications
  - SAP, Oracle, Siebel, PSFT, ...
- Massive DB Consolidation
- Public SaaS Clouds
  - Oracle Fusion Apps, Salesforce, SAS, ...

4 of the Top 5 Banks, Telcos, Retailers Run Exadata
On-Premises

Exadata Database Machine

Customer Data Center
Purchased
Customer Managed

Cloud at Customer

Preview:
Exadata Cloud Machine

Customer Data Center
Subscription
Oracle Managed

Public Cloud

Exadata Cloud Service

Oracle Cloud
Subscription
Oracle Managed
Exadata Database Machine X6-2

• **Scale-Out Database Servers**
  - 2 socket x86 processors
  - 44 CPU cores
  - 256 GB - 1.5 TB GB DRAM

• **Fastest Internal Fabric**
  - 40 Gb/s InfiniBand
  - Ethernet external connectivity

• **Scale-Out Intelligent Storage**
  - 12.8 TB PCI Flash
  - 96 TB disk
  - 20 CPU cores

  - 25.6 TB PCI Flash
  - 20 CPU cores

**Compute Software**
- Oracle Linux 6
- Oracle Database Enterprise Edition
- Oracle VM (optional)
- Oracle Database options (optional)

**Storage Server Software**
- Smart Scan (SQL Offload)
- Smart Flash Cache
- Hybrid Columnar Compression
- I/O Resource Management
Exadata Database Machine X6-8

- **Scale-Out Database Servers**
  - 8-socket x86 processors
  - 144 cores
  - 2-6 TB DRAM

- **Fastest Internal Fabric**
  - 40 Gb/s InfiniBand
  - Ethernet external connectivity

- **Scale-Out Intelligent Storage**
  - High-Capacity Storage Server
  - Extreme Flash Storage Server

- **Storage Server Software**
  - Smart Scan (SQL Offload)
  - Smart Flash Cache
  - Hybrid Columnar Compression
  - I/O Resource Management

- **Large SMP Processor Model**
  - Large warehouses
  - Massive database consolidation
  - Big In-Memory databases

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**Same Networking, Storage and Software as X6-2**
Elastic Configurations Incrementally Scale Servers
Achieve any Level of Performance with Minimum Hardware

1. **Start Small**
   - 2 Database Servers
   - 3 Storage Servers

2. **Incrementally add DB or Storage Servers**
   - Database Server
   - Extreme Flash Storage
   - High Capacity Storage

3. **Add Racks to Continue Scaling**
   - Full Rack
   - Multi-Rack

- Enable Database CPU cores as needed with **Capacity on Demand**
- Expand older Exadata machines with new X6-2 servers
Oracle Database **Exadata Cloud Service**

- **Full Oracle Database with all advanced options**
  - **100% Compatible** with on-premises databases

- **On fastest and most available database cloud platform**
  - Scale-Out Compute, Scale-Out Intelligent Storage, InfiniBand, PCIe Flash
  - **Complete isolation** of tenants with no overprovisioning

- **All Benefits of Public Cloud**
  - Fast, elastic, web driven provisioning
  - Oracle experts deploy and manage infrastructure
  - Monthly or yearly subscription with **online capacity bursting**

Best of On-Premises with Best of Cloud
Preview: Oracle Public Cloud Services @ Customer

- Same PaaS and IaaS hardware and software as Oracle Public Cloud
- Managed by Oracle and delivered as a service in your datacenter behind your firewall
- Same cost-effective subscription pricing model as Oracle Cloud
- Helps conform to business and government security requirements
- Connect via fast LAN to existing systems
Exadata X6 is Much Faster and Cheaper than All-Flash EMC

- One **High Capacity** Exadata beats the fastest EMC XtremIO *all-flash* array in every performance metric
  - **12X** more throughput
  - **2.5X** more IOPS
  - **2X** faster latency

**EMC 8 X-Brick XtremIO:** $7.8 M
**Exadata X6-2 Full Rack:** $1.1 M

**EMC Performance does not scale higher - Exadata scales by adding racks**
Preview: Exadata SL6

Linux on SPARC

Software in Silicon
Database Intelligence Extended into CPU Chip

SPARC M7 Software in Silicon

• Traditional DB algorithms too complex for chips
• Big Change: In-memory algorithms are much simpler
• 5 years ago Oracle initiated a revolutionary project
  – Build fastest ever microprocessor
    • Most processing cores (32)
    • Most concurrent threads (256)
    • Fastest Memory Bandwidth (160 GB/sec)
  – Add In-Memory DB operations directly on chip
In-Memory Algorithms Natively Implemented in Silicon

- **SQL in Silicon**
  - DB Acceleration

- **Capacity in Silicon**
  - Decompression Engines

- **Silicon Secured Memory**
  - Fine-Grained Memory Protection

- **SPARC M7 Software in Silicon**

- **Database Software Already Available**
SQL in Silicon: Database In-Memory Acceleration Engines

- SIMD Vectors instructions are fast, but were designed for graphics, not database
- New SPARC M7 chip has 32 optimized database acceleration engines (DAX) built on chip
- Independently process streams of columns
  - E.g. find all values that match ‘California’
  - Up to 170 Billion rows per second!
- Like adding 32 additional specialized cores to chip
  - Using less than 1% of chip space
Capacity in Silicon: Decompression Engines

- Compression is key to putting more data in-memory
- **Decompression** is far more important for databases than compression
  - Data is loaded once, queried many times
- Bit pattern decompression in normal cores is slow
  - 64 CPU cores needed to decompress at full memory speed
- SPARC M7 adds 32 optimized decompress engines
  - Run bit-pattern decompress at memory speed

Doubles Memory Capacity
Silicon Secured Memory: Fine Grained Memory Protection

- Database In-memory places terabytes of data in memory
  - More vulnerable to corruption by bugs/attacks than storage

- SPARC M7 locks memory as it is allocated so only the owner can access it
  - Hidden “color” bits added to pointers (key), and content (lock)
  - Pointer color (key) must match content color or program is aborted
  - Hardware support eliminates performance impact

- Helps prevent access off end of structure, stale pointer access, malicious attacks, etc. plus improves developer productivity
Exadata SL6: Exadata with Ultra-fast SPARC Linux Servers

• Identical to Exadata with x86 Database servers replaced by SPARC T7-2 servers
  – Ultra-fast 32-core SPARC M7 Processors
  – Two-socket T7-2 Servers

• Same elastic configurations as Exadata X6-2

• Storage servers identical as Exadata X6-2

• Runs same Oracle Linux as Exadata X6-2
  – Oracle Linux (UEK2) – single domain configuration

• Runs Oracle Database 12.1.0.2
**Preview: Exadata SL6**

World’s Fastest and Most Secure Linux Database Machine

- Massive Memory Bandwidth
- Fastest Database Processor
- Silicon Secured Memory

- 2.2x Intel x86
- 1.9x Intel x86

End to End Database Security
Exadata Smart System Software
## Smart System Software Highlights

### Smart Analytics
- Move **queries to storage**, not storage to queries
- Automatically **offload and parallelize** queries across all storage servers
- **100X** faster analytics

### Smart Storage
- **Hybrid Columnar Compression** reduces space usage by **10X**
- Database-aware **Flash Caching** gives speed of flash with capacity of disk

### Smart OLTP
- Special **InfiniBand protocol** enables highest speed, lowest latency OLTP
- Ultra-fast transactions using DB optimized **flash logging** algorithms
- **Fault-tolerant In-Memory DB** by mirroring memory across servers

### Smart Consolidation
- **Workload prioritization** from CPU to network to storage ensures QoS
- **4X** more Databases in same hardware
## Smart System Software Introduced in 2015

### Smart Analytics
- **5X** faster scans by converting data to **Columnar** format in Flash Cache
- **3X** faster **JSON/XML** by offloading to storage servers

### Smart OLTP
- **3X** faster OLTP messaging using **direct DB to InfiniBand** access
- **Instant** detection of node failure
- **Sub-second** capping of I/O latency by rerouting I/Os to faster storage

### Smart Consolidation
- **Zero overhead** **VMs**
- **Snapshots** for test/dev
- Set flash cache min size per DB to ensure QoS
- InfiniBand partitioning
- IPv6 for Ethernet

### Smart Licensing
- **Capacity-on-Demand** reduces license cost by disabling unneeded cores
- **Trusted Partitions** limit license scope of specialized options
Preview: New Smart System Software

**Smart Analytics**
- **Database In-Memory** columnar format in storage server
- **Aggregation** in storage
- **Set membership** using new type of storage index

**Smart OLTP**
- **Smart Fusion Block Transfer** eliminates log writes when moving blocks between nodes*
- Automated rolling upgrade across full stack
- **2X** faster disk recovery

**Smart Consolidation**
- Hierarchical snapshots
- **2X** application connections*
- Automated **VLAN** creation*
- Add extra 10g Ethernet Card
- 64GB DIMMs for **2X** Memory

**Smart Availability**
- **Short Range Stretch** (Extended) clusters
- **4X** faster software updates*
- **High redundancy** Quorum disks on Quarter and Eighth racks*
- Storage Index preserved on rebalance*

*Already Released
Upcoming: In memory format in Columnar Flash Cache

- In-Memory formats used in Smart Columnar Flash Cache
- Enables vector processing on storage server during smart scans
  - Multiple column values evaluated in single instruction
- Faster decompression speed than Hybrid Columnar Compression
- Enables dictionary lookup and avoids processing unnecessary rows
- Smart Scan results sent back to database in In Memory Columnar format
  - Reduces Database node CPU utilization
- In-memory performance seamlessly extended from DB node DRAM memory to 10x capacity flash in storage
  - Even bigger differentiation against all-flash arrays and other in-memory databases

Upcoming release of Exadata Software
Upcoming: Storage Index Set Membership

- Storage Index
  - Currently contains up to 8 columns of min/max summary
  - Created automatically and kept in memory
  - Used to skip performing I/Os
- What about queries with low cardinality columns?
  
  ```
  select name, address from travels
  where origin='Sierra Leone' and dest='CA'
  ```
- Traditional min/max not good enough
- Database gathers stats and find that column has less than 256 distinct values
- Database requests storage to compute bloom filter
- Storage will compute distinct values and create a bloom filter
- Smart Scans check value ‘CA’ against bloom filter and saves performing I/O
Upcoming: Join and Aggregation Smart Scan

- Extend In-Memory Aggregation technique into storage
- Find Sales per country

```
SELECT /*+ VECTOR_TRANSFORM */ country_id, sum(amount_sold) amount_sold
FROM customers, sales
WHERE customers.cust_id = sales.cust_id
GROUP BY customers.country_id
ORDER BY customers.country_id;
```

- Storage cells scanning sales fact table will return tuples
  
  `{country_id, sum_amount_sold }

- Join and Aggregation offloaded to the storage server
Upcoming: Smart write bursts and temp IO in flash cache

- Write throughput of four flash cards has become greater than the write throughput of 12-disks

- When database write throughput exceeds the throughput of disks, smart flash cache intelligently caches writes

- When queries write a lot of temp IO and it is bottlenecked on disk, smart flash cache intelligently caches temp IO
  - Writes to flash for temp spill reduces elapsed time
  - Reads from flash for temp reduces elapsed time further

- Smart flash cache prioritizes OLTP data and does not remove hot OLTP lines from the cache

- Smart flash wear management for large writes
Upcoming: Smart Analytics Software Features

• Compressed Index Fast Full Scan

• Smart Scan VIEWS with LOBs, XML and JSON
  – not just tables

• AWR Enhancements
  – Diff report for Exadata section
  – Flash Cache Metrics
  – More granular histograms

• Up to 25% reduction in Storage Server CPU for SPARC SuperCluster during Smart Scans
  – Reduces endianness conversion overhead

12.2 Database and 12.2 Exadata Storage Server Software
Upcoming: Snapshots

• Hierarchical Snapshots
  – Create snapshots of databases on previously created snapshots
  – Use case example
    • Development releases nightly build of the database
    • Tester creates a snapshot for himself and finds a bug
    • Tester creates a snapshot of his snapshot
    • Tester provides the new copy back to development for analysis
  – Syntax and technology remain unchanged
  – Works with pluggable and non-pluggable databases

• Sparse backup of snapshots
  – RMAN backs up the modified blocks and not the unchanged blocks from parent

12.2 Database and 12.2 Exadata Storage Server Software
Upcoming: Extended Distance Clusters

- Two sites and a quorum site
- InfiniBand connected for high performance
  - 100m optical cables in 2016 (best for fire cells)
- Created using ASM Extended Diskgroups
  - Nested failure groups
- Compute nodes at each site read data local to that site
- Data is written to all sites
- Smart Scans scan across cells on both sites increasing throughput
  - Row filtering, column projection, storage index, and flash cache provide extreme performance
- Data Guard continues to be the recommended DR solution

12.2 Database and 12.2 Exadata Storage Server Software
Smart Fusion Block Transfer

- OLTP workloads can have hot blocks that are frequently updated (e.g. right-growing index)
  - Log file must be written before transferring a hot block between instances so the block can be recovered
  - Adds latency and reduces throughput

- On Exadata, Oracle does not wait for the log write
  - Exadata ensures the log write completes before changes to block on another instance commit, guaranteeing durability
  - Wait for Log I/O during transfer of hot blocks is eliminated
  - Up to 40% throughput and 33% response time improvement in some heavily contended OLTP workloads
Upcoming: Super Fast Software Updates

- **4x speed up** in Storage Server Software Update
  - Parallel firmware upgrades across components such as hard disks, flash, ILOM/BIOS, InfiniBand card
  - Reduced reboots for Software updates
  - Use kexec where possible

- Manage a Cloud instead of managing a single rack
  - Use single patchmgr utility to upgrade hundreds of racks

- Enable patchmgr to run from a non-Exadata system and run as low privileged user
Upcoming: Extreme Manageability

- IPv6 + Virtual machine + VLAN deployments
- Get graphs from Exawatcher
- Make DNS, NTP, and other IP address changes online
- Seamless customer service with Automatic Service Requests sending diagnostic attachments
- Manage Compute nodes using a RESTful service
  - ExaCli enabled for compute nodes in addition to storage cells
- Much faster rebalance with improved flash cache hit ratio during rebalance
- Secure Erase during hardware retirement
Exadata Advantages Increase Every Year

Transformational OLTP, Analytics, Consolidation

Cloud Without Compromise

Smart Software
- Smart Scan
- InfiniBand Scale-Out
- IO Priorities
- Data Mining Offload
- Offload Decrypt on Scans
- Database Aware Flash Cache
- Storage Indexes
- Columnar Compression
- Network Resource Management
- Multitenant Aware Resource Mgmt
- Prioritized File Recovery
- Unified InfiniBand
- Unified InfiniBand
- PCIe NVMe Flash
- Tiered Disk/ Flash
- Exadata Cloud Service
- In-Memory Columnar in Flash
- In-Memory Fault Tolerance
- Smart Fusion Block Transfer
- Direct-to-wire Protocol
- JSON and XML offload
- Instant failure detection
- 3D V-NAND Flash
- Software-in-Silicon
- Smart Fusion Block Transfer

Smart Hardware
- Scale-Out Storage
- DB Processors in Storage
- Scale-Out Servers
- InfiniBand Scale-Out
- Scale-Out Servers
- Scale-Out Storage
- DB Processors in Storage
- Unified InfiniBand
- Unified InfiniBand
- PCIe NVMe Flash
- Tiered Disk/ Flash
- Exadata Cloud Service
- In-Memory Columnar in Flash
- In-Memory Fault Tolerance
- Smart Fusion Block Transfer
- Direct-to-wire Protocol
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- Smart Fusion Block Transfer

Transformational OLTP, Analytics, Consolidation
Cloud Without Compromise

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Integrated Cloud
Applications & Platform Services