Solid State Storage:
Key to NextGen Enterprise & Cloud Storage

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Solid State Storage: Key to NextGen Enterprise & Cloud Computing

Abstract

Computer architects dream of storage devices which can provide very high IOPs at minimal cost (IOPS/$/GB) using infinite cheap storage and instant access (low latency) for their applications/workloads. Enterprise-Ready SSDs have started to fulfill that promise and being available as SATA and PCIe based Hybrid Storage products. But only the recent advent of advanced controllers and firmware which has allowed transparent mitigation of earlier issues related to reliability, endurance, data retention, performance, ease of management and quick integration using exiting storage interfaces. But the real killer software for their success in the enterprise have been the Automated Storage Tiering tools activated by monitoring the workload I/O access signatures and behavior over time and the ensuing smart migration of hot data to SSDs non-disruptively that has resulted in obtaining over 475% improvement in IOPS and 80% improvement in response time at peak loads.

The presentation delineates the recently emerged technologies, storage characteristics (performance, cost, reliability and endurance etc.), and the applications that benefit the most from the use of SSDs in enterprise storage systems, workloads optimization using new generation of controllers and automated smart-tiering by specific vertical-industries as well as the economics of SSDs usage using real market data.

Learning Objectives

The session provides a clear illustrative the state-of-the-technology, storage characteristics (performance, cost, reliability and endurance etc.), overview of industry advances, specific applications that benefit the most from SSDs use, system implementation in enterprise storage systems allowing them to plan, implement and achieve stated benefits expected from using SSDs as a tiered storage specifically in OLTP/Database, Business Intelligence applications and cluster-based HPC workloads. The presentation illustrates real life case studies in SANs showing how optimally selected hierarchical storage systems encompassing SSDs and HDDs can achieve 65% lower TCO, 475% higher IOPS, 165% lower footprint while achieving a whopping 800% in $/IOPs in SAN and other tired storage systems, under different scenarios.
Agenda – Solid State Storage

1. **NextGen Data Center and Cloud Computing Infrastructure**
2. **Solid State Enabling New Systems Architecture**
3. **Improving Transaction Query Response Time and IOPS**
4. **Workload Characterization**
5. **Applications best utilizing Solid State Storage**
6. **New Intelligent Controllers: Heart of SS Storage Systems**
7. **Data Forensics and Tiered Mapping**
8. **Key Takeaways**
IT Industry’s Journey - Roadmap

Analytics - BI
Predictive Analytics - Unstructured Data
From Dashboards Visualization to Prediction Engines using Big Data.

Cloudization
On-Premises > Private Clouds > Public Clouds
DC to Cloud-Aware Infrast. & Apps. Cascade migration to SPs/Public Clouds.

Automation
Automatically Maintains Application SLAs
(Self-Configuration, Self-Healing<sup>IMEX</sup>, Self-Acctg. Charges etc)

Virtualization
Pools Resources. Provisions, Optimizes, Monitors
Shuffles Resources to optimize Delivery of various Business Services

Integration/Consolidation
Integrate Physical Infrast./Blades to meet CAPSIMS<sup>IMEX</sup>
Cost, Availability, Performance, Scalability, Inter-operability, Manageability & Security

Standardization
Std. IT Infrastructure- Volume Economics HW/Syst SW
(Servers, Storage, Netwk Devices, System Software (OS, MW & Data Mgmt SW))
Request for data from a remote client to an enterprise data center crosses a myriad of systems and devices. Key is identifying bottlenecks & improving performance.
Market Segments by Apps/Workloads

- **Transaction Processing**
- **eCommerce**
- **Data Warehousing**
- **OLAP**
- **Business Intelligence**
- **Data Intelligence**
- **OLTP**

**Source:** IMEX Research - Cloud Infrastructure Report ©2009-11

*IOPS for a required response time (ms) *= (#Channels*Latency-1)

**RAID**
- RAID - 0, 3
- RAID - 1, 5, 6

**Apps/Workloads**
- OLTP
- eCommerce
- Data Warehousing
- OLAP
- Business Intelligence
- Transaction Processing
- Data Intelligence

**MB/sec**

**Source:** IMEX Research Industry Report 2009-12

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Big Data Analytics – Next Frontier in IT

- OLTP RDBMS
- Data Warehouse/Bus. Intelligence
- Analytics
- RDBMS
- SQL Transaction Data
- Big Data
- UQL Interaction Data
- Social Interactions
- Sensors Data
- Streaming Data

Source: © IMEX Research Industry Report 2009-12
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Virtualized Cloud Infrastructure

Application’s SLA dictates the Resources Required to meet specific requirements of Availability, Performance, Cost, Security, Manageability etc.
Anatomy of Data Access

Time taken by CPU, Memory, Network, Disk for a typical I/O Operation during a Data Access

For the time it takes to do Each Disk Operation:
- Millions of CPU Operations can be done
- Hundreds of Thousands of Memory Operations can be accomplished

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 cache reference</td>
<td>0.5</td>
</tr>
<tr>
<td>Branch mispredict</td>
<td>5</td>
</tr>
<tr>
<td>L2 cache reference</td>
<td>7</td>
</tr>
<tr>
<td>Mutex lock/unlock</td>
<td>25</td>
</tr>
<tr>
<td>Main memory reference</td>
<td>100</td>
</tr>
<tr>
<td>Compress 1K bytes with Zippy</td>
<td>3,000</td>
</tr>
<tr>
<td>Send 2K bytes over 1 Gbps network</td>
<td>20,000</td>
</tr>
<tr>
<td>Read 1 MB sequentially from memory</td>
<td>250,000</td>
</tr>
<tr>
<td>Round trip within same datacenter</td>
<td>500,000</td>
</tr>
<tr>
<td>Disk seek</td>
<td>10,000,000</td>
</tr>
<tr>
<td>Read 1 MB sequentially from disk</td>
<td>20,000,000</td>
</tr>
<tr>
<td>Send packet CA-&gt;Netherlands-&gt;CA</td>
<td>150,000,000</td>
</tr>
</tbody>
</table>

A 7.2K/15k rpm HDD can only do 100/200 IOPS* (typical/worst cases considered)
Data Center Performance Bottlenecks

**Applications**
- Excessive Locking
- Data Contention
- I/O Delays/Errors

**Network I/O**
- Network Congestion
- Dropped packets
- Data Retransmissions
- Timeouts
- Component Failures

**Storage I/O Connect**
- Lack of Bandwidth
- Overloaded PCIe Connect
- Storage Device Contention

**Clients**
- Windows
- Linux
- Unix

**User Bottlenecks**
- Connectivity Timeouts
- Workload Surges

**Servers**
- Web Servers
- Application Servers
- Database Servers

**Server Bottlenecks**
- Lack of Srvr Power
- IO Wait & Queuing CPU
- Overhead I/O Timeouts

**Storage**
- Web
- Application
- Database

**Device Bottlenecks**
- Device I/O Hotspots
- Cache Flush
- Lack of Storage Capacity

**Network I/O**
- LAN Access Networks
- Storage I/O Access
- Device Bottlenecks
- Excessive Locking
- Data Contention
- I/O Delays/Errors
- Network Congestion
- Dropped packets
- Data Retransmissions
- Timeouts
- Component Failures
- Lack of Bandwidth
- Overloaded PCIe Connect
- Storage Device Contention

Source: IMEX Research SSD Industry Report ©2011
Source: IMEX Research Industry Report 2009-12

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## Automated Storage Tiering - Next Frontier in Storage Efficiency

### Data Protection
- Back Up/Archive/DR
- RAID – 0,1,5,6,10
- Virtual Tape
- Replication

### Storage Efficiency
- Auto Tiered Storage
- Storage Virtualization
- Thin Provisioning
- Deduplication
- MAID

#### Auto Tiering System using SSDs

- **Data Class** (Tiers 0,1,2,3)
- **Storage Media Type** (Flash/Disk/Tape)
- **Policy Engines** (Workload Mgmt)
- **Transparent Migration** (Data Placement)
- **File Virtualization** (Uninterrupted App. Opns. in Migration)

#### Tiers
- **DRAM**
- **Flash SSD**
- **Performance Disk**
- **Capacity Disk**
- **Tape**

Source: IMEX Research SSD Industry Report ©2011

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SSD Filling Price/Perf Gaps in Storage

HDD becoming Cheaper, not faster

DRAM getting Faster (to feed faster CPUs) & Larger (to feed Multi-cores & Multi-VMs from Virtualization)

SSD segmenting into
- PCIe SSD Cache
- as backend to DRAM &
- SATA SSD
  - as front end to HDD

- HDD
- NOR
- NAND
- SCMS
- DRAM
- CPU SDRAM
- PCIe SSD
- SATA SSD
- Tape

Source: IMEX Research SSD Industry Report ©2011
Key to Database performance are random IOPS. SSDs outshine HDD in IO price/performance – a major reason, besides better space and power, for their explosive growth.

Source: IMEX Research SSD Industry Report ©2011
Source: ©IMEX Research Industry Report 2009-12

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For a targeted query response time, many more concurrent users can be added cost-effectively when using SSDs or SSD + HDDs storage vs. forcing more HDDs or short-stroking HDDs – particularly when running DB & OLTP Apps.
SCM: A New Storage Class Memory

**SCM (Storage Class Memory)**
Solid State Memory filling the gap between DRAMs & HDDs
Marketplace segmenting SCMs into SATA and PCIe based SSDs

**Key Metrics Required of Storage Class Memories**
- **Device**
  - Capacity (GB), Cost ($/GB),
- **Performance**
  - Latency (Random/Block RW Access-ms); Bandwidth BW(R/W- GB/sec)
- **Data Integrity**
  - BER (Better than 1 in 10^17)
- **Reliability**
  - Write Endurance (30K PE Cycles No. of writes before death);
  - Data Retention (5 Years); MTBF (2 millions of Hrs),
- **Environment**
  - Power Consumption (Watts);
  - Volumetric Density (TB/cu.in.); Power On/Off Time (sec),
- **Resistance**
  - Shock/Vibration (g-force); Temp./Voltage Extremes 4-Corner (oC,V); Radiation (Rad)

Source: IMEX Research SSD Industry Report ©2011
Use SSDs where best price/perf achieved

Databases have different types of performance demands on storage

- Data access
- Index Reads (Read Intensive operations)
  - DB file sequential read
  - DB file scattered read
- Redo/Undo logs, Temp table space (Write intensive operations)
  - Log file parallel write
  - Log file sync
  - Log file single write
- Buffer Cache events (Write intensive operations)
  - Free buffer wait
  - Control file parallel write
  - Buffer busy waits

Relation between disk IO vs. SSD Size

Optimal SSD size
To achieve a certain TPS improvement, it's cheaper to deploy SSD vs increased buffer memory (in GB costs) needed with using HDDs alone.

Source: IMEX Research SSD Industry Report ©2011
Source: IMEX Research Industry Report 2009-12
SSD Challenges & Solutions: Goals & Best Practices

Concerned about SSD Adoption in your Enterprise?
Be aware of Tools & Best Practices … And you should be OK!!

Best Practices
- By leveraging Error Avoidance Algorithms, and Best Practices of Verification Testing, to keep total functional failure rate $\leq 3\%$ (with defects and wear-outs issues combined)
- In practice, endurance ratings are likely to be significantly higher than typical use, so data errors and failures will be even less.
- Capacity Over-provisioning will provide large increases in random performance and endurance.
- Select SSD based on confirmed EVT Ratings
- Use MLC within requirements of Endurance Limits

Using Best-of-Breed Controllers to achieve $\leq 3\%$ AFR and JEDEC Endurance Verification Testing should allow Enterprise Capabile SSDs
Hybrid SSD Storage - Perf & TCO

SAN TCO using HDD vs. Hybrid Storage

SAN Performance
Improvements using SSD

Source: IMEX Research SSD Industry Report ©2011
### New Intelligent Controllers: SSD Storage Architecture

| 1 | Interface Controller | Signaling Mgmt, Interpret WR/RD/Status Commands, Native Command Queuing, Move Data <-> Host |
| 2 | Flash Controller      | Signaling Mgmt, Format, Interpret WR/RD/Status Commands for Flash Arrays, Move Data, Defect Mapping/Bad Block Mgmt, Wear Leveling, Physical<>Logical Translations, ECC… |
| 3 | RAID Controller       | RAID Type & RD/WR/Parity Manipulation |
| 4 | Channels              | Multiple Channel to Increase Speed between NAND Flash Arrays & Flash Controller |
| 5 | DRAM                  | Increase Performance using fast DRAM Cache Buffer |
| 6 | Power Failure         | Power Failure Protection using Big Capacitor |
| 7 | Power Mgmt            | Power/Performance Balancing, Sleep Mode Mgmt |
| 8 | Encryption            | Security Schemes Implementation & Manipulation |

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Source: © IMEX Research Industry Report 2009-12

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Leveraging Long History of managing HDD’s imperfect media & high error rates

- Characterizing the quality & capabilities of media
- Allocating data based on quality of media

**HDD Media**

- Adaptive Signal Processing for Media Rd/Wr/Erase
- Advanced Bit Detection & Error Correction Codes
- Defect Management

**Flash Media**

- Adaptive Signal Conditioning for Flash Media
- Auto Bit Detection & Error Correction Codes
- Defect Management

Leveraging Long History of managing HDD’s imperfect media & high error rates

- Endurance for Long Life Cycle
- Reliability through RAID of Flash Elements
- Adaptive Digital Signal Processing Technology
- Dynamically adjust Read/Write characteristics of each chip
- Tune adjustments over life of media
- ECCs - PRML Deploying Enhanced Error Correction Codes

Source: IMEX Research SSD Industry Report ©2011
Managing Factors Impacting Performance

- **Hardware** - CPU, Interface, Chipset ...
- **System SW** - OS, App, Drivers, Caches, SSD specific TRIM, Purge…
- **Device** - Flash Generation, Parallelism, Caching Strategy, Wear-Leveling, Garbage Collection, Warranty Strategy …
- **Write History** - TBW, spares…
- **Workload** - Random, Sequential, R/W Mix, Queues, Threads …
- **Pre-Conditioning** - Random, Sequential, Amount …
- **Performance** - “Burst” First On Board (FOB), Steady State post xPE Cycles

By using New Gen Controllers, performance of MLC SSDs starting to match performance of some SLC SSDs

Additional performance gains with interleaved memory banks, caching and other techniques
New Intelligent Controllers: Managing Endurance in NextGen SSDs

Managing Endurance

To overcome NAND’s earlier endurance shortfalls due to limitation in write/erase cycles/block, intelligent controllers manage NAND SSDs using:

- **ECC Techniques** – Correct and guard against bit failures, same as in HDDs
- **Wear Leveling Algorithms** – Writing data to evenly distributes it over all available cells to avoid a block of cells being overused and cause failures.
- **Over-provisioning Capacity** – Extra spare raw blocks are designed-in as headroom and included to replace those blocks that get overused or go bad. Additionally provide enough room for wear-leveling algorithms to enhance reliability of the device over its life-cycle.
- Typical SSD device’s specified GB device will actually contain 20-25% extra raw capacity to meet these criterions.

With advanced Errors Avoidance (ECC/Wear-Leveling etc) and capacity over-provisioning techniques, controllers successfully creating endurance for over 5-Year Product Life Cycle in Enterprise SSDs
New Intelligent Controllers: Meeting Enterprise Requirements

Enterprise Requirements
- **Always-On 24x7 Reliability** and performance supersede cost
- **Fast I/O Performance** required by business-critical applications and
- **5-Yr. Life Cycle Endurance** required by mission-critical applications in the enterprise.
- **Use State-of-the-Art** new sophisticated controllers and firmware technologies to run mission critical applications in the enterprise, using
  - Robust ECC, Internal RAID, Wear Leveling (To reduce hot spots), Spare Capacity, Write Amplification, Avoidance, Garbage Collection Efficiency, Wear Out Prediction Management etc.

New Intelligent Controller (2nd Generation)

<table>
<thead>
<tr>
<th>SATA3 I/F</th>
<th>New Intelligent Controller (2nd Generation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6Gb/s, 32 NCQ</td>
<td>SATA3 I/F</td>
</tr>
<tr>
<td>PHY</td>
<td>Optimized Write</td>
</tr>
<tr>
<td>Link</td>
<td>Block Mgmt/Wear Leveling</td>
</tr>
<tr>
<td>Transport</td>
<td>Garbage Collection</td>
</tr>
<tr>
<td>Command</td>
<td>Read/Disturb Management</td>
</tr>
<tr>
<td></td>
<td>RAID w/o Std. Parity OH</td>
</tr>
<tr>
<td></td>
<td>AES 256/128 Encryption</td>
</tr>
<tr>
<td></td>
<td>TCG Compliance</td>
</tr>
<tr>
<td></td>
<td>55b/512B BCH ECC</td>
</tr>
<tr>
<td></td>
<td>RS232, GPIO, I2C, JTAG I/F</td>
</tr>
<tr>
<td></td>
<td>NAND Flash I/F</td>
</tr>
<tr>
<td></td>
<td>• Toggle, ONFI-2</td>
</tr>
<tr>
<td></td>
<td>• SLC/MLC/eMLC</td>
</tr>
<tr>
<td></td>
<td>• 8ch/16 Byte Lanes</td>
</tr>
<tr>
<td></td>
<td>• 3x,2x nm Supp</td>
</tr>
<tr>
<td></td>
<td>• 512 GB Capable</td>
</tr>
</tbody>
</table>

New Gen Controllers allow SSDs to meet Enterprise Class Availability/Performance/ over 5-Year Life/Scalability/ Auto-Configuration & Auto Data-Tiering
Applications Best Suited for SSDs

**Apps and impact from SSD Usage**

- **Databases**
  - Databases have key elements of commit files
  - logs, redo, undo, tempDB

- **Structured data vs. Unstructured Data**
  - Structured/SQL data access is an excellent fit for SSD
  - Exception—large, growing table spaces
  - Unstructured data access is a poor fit for SSD
  - Exception – small, non-growing, tagged files

- **OS images**
  - boot-from-flash, page-to-DRAM

**Applications most benefiting from SSDs Use**

<table>
<thead>
<tr>
<th>Application</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB / OLTP</td>
<td>43%</td>
</tr>
<tr>
<td>E-Mail/Collab.</td>
<td>32%</td>
</tr>
<tr>
<td>HPC</td>
<td>31%</td>
</tr>
<tr>
<td>BI / DW</td>
<td>30%</td>
</tr>
<tr>
<td>ERP/SCM/CRM</td>
<td>25%</td>
</tr>
<tr>
<td>Web 2.0</td>
<td>23%</td>
</tr>
<tr>
<td>Office Apps</td>
<td>20%</td>
</tr>
</tbody>
</table>

**Typical Cases - Impact on Applications**

- **Financials/ATM Transactions Improvements**
  - Batch Window 22%, App Response Time 50%,
  - App I/O Rate 50%

- **Messaging Applications**
  - Cost Savings: 200+ FC HDDs into only 16 SSDs

Source: IMEX Research SSD Industry Report ©2011
Data Warehousing Workloads are I/O intensive
- Predominantly read based with low hit ratios on buffer pools
- High concurrent sequential and random read levels
  - Sequential Reads requires high level of I/O Bandwidth (MB/sec)
  - Random Reads require high IOPS
- Write rates driven by life cycle management and sort operations

OLTP Workloads are strongly random I/O intensive
- Random I/O is more dominant
  - Read/write ratios of 80/20 are most common but can be 50/50
  - Can be difficult to build out test systems with sufficient I/O characteristics

Batch Workloads are more write intensive
- Sequential Writes requires high level of I/O Bandwidth (MB/sec)

Backup & Recovery times are critical for these workloads
- Backup operations drive high level of sequential IO
- Recovery operation drives high levels of random I/O
Applications Best Suited for SSDs: Data Warehouse/BI

Storage Usage vs DB Capacity

I/O Access Frequency vs. Percent of Corporate Data

Large DB Size Growth by Market Segment

DB Size (TB)

OLTP

DW/BI
Cached Storage - Performance Benefits

Intelligent Caching at the Storage Server Array

Application | Improvement over Cached vs. HDD only
---|---
Oracle OLTP Benchmarks | 681%
SQL Server OLTP Benchmark | 1251%
Neoload (Web Server Simulation) | 533%
SysBench (MySQL OLTP Server) | 150%

Response Time

| TPS |
|---|---|---|
| All HDD | Smart Flash Cache | Persist Data on Warpdrive |
| 0 | 330 | 660 |
| 0 | 373 | 655 |

Source: ©IMEX Research Industry Report 2009-12

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New Storage Hierarchy in NGDC & Clouds

I/O Access Frequency vs. Percent of Corporate Data 2015

SSD
- Logs
- Journals
- Temp Tables
- Hot Tables

FCoE/SAS Arrays
- Tables
- Indices
- Hot Data
- Primary Storage

SATA/Cloud Storage
- Primary Capacity Storage
- Back Up Data
- Archived Data
- Offsite DataVault

Data: IMEX Research - Cloud Infrastructure Report ©2009-11
Source: IMEX Research Industry Report 2009-12
IO Bottleneck Mitigation in Virtualized Servers

Virtualized Server

VM Client 1
- I/O Reg.
- XCL Driver

VM Client 2
- I/O Reg.
- XCL Driver

VM Client n
- I/O Reg.
- XCL Driver

XCL Mgr.

Disk Controller.

XCL VLUN

SSD Driver

ESX Kernel

Primary Storage

Offloading IOPS from Primary Storage

Both Applications & Storage Run Faster

SSD Drive w/Virtualization Server Driver

Source: IMEX Research SSD Industry Report ©2011
Source: IMEX Research Industry Report 2009-12

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LBA Monitoring and Tiered Placement

- Every workload has unique I/O access signature
- Historical performance data for a LUN can identify performance skews & hot data regions by Logical Block Addresses
Automated Storage Tiering: Improving Response Time

Productivity Improvements (Response Time)

- With automated reallocation of hot spot data (~ 5-10% of total data) to SSDs, performance improvements
  
  - **Response time reduction ~70+% IOPS increase of 200%** for any I/O intensive workloads in Time-Perishable OLTP markets: Airlines Reservations, Wall Street Investment Banking Stock Transactions, Financial Institutions Hedge Funds etc.
  
  - **Performance boost** in Low Latency seeking Systems (High Perf. Clustered Systems)

Source: IMEX Research SSD Industry Report ©2011
• Storage management, performance and cost - a big issue in DBs
• SSDs enable super IO performance and cost reduction in DBs

**Improve Responsiveness**

**Improve**
- Insert/Update/Delete Performance
- Random Read I/O Performance
- Query Response Time
- Sort Performance
- Batch Performance too.

**Reduce Costs**

**Reduce**
- DRAM size for Buffer Pools used to cache data on SSDs
- Power/Cooling Space for housing Databases

**New Added Benefits**

**Reduce**
- Database Recovery performance
- I/O performance impact by Flash Copy
- Skill levels required for DB tuning & monitoring

Source: IMEX Research SSD Industry Report ©2011
SSS in DB Environments: Best Practices for DB/DW/BI Apps

Goals

- Establish **Goals for SLAs** (Performance/Cost/Availability), BC/DR (RPO/RTO) & Compliance
- **Increase Performance for DB, Data Warehousing, OLTP Apps:**
  - Random I/O > 20x, Sequential I/O Bandwidth > 5x
  - Remove Stale data from Production Resources to improve performance
- **Classify Data - Use Partitioning Software**
- By Frequency of Access (Recent Usage) and
  - Capacity (by percent of total Data) using general guidelines as:
    - Hyperactive (1%), Active (5%), Less Active (20%), Historical (74%)

Implementation

- **Optimize Tiering** by Classifying Hot & Cold Data
  - Improve Query Performance by reducing number of I/Os
  - Reduce number of Disks Needed by 25-50% using advance compression software achieving 2-4x compression
- **Match Data Classification vs. Tiered Devices** accordingly
  - Flash, High Perf Disk, Low Cost Capacity Disk, Online Lowest Cost Archival Disk/Tape
- **Balance Cost vs. Performance** of Flash
  - More Data in Flash > Higher Cache Hit Ratio > Improved Data Performance
- **Create and Auto-Manage Tiering** (Monitoring, Migrations, Placements) without manual intervention

Source: IMEX Research SSD Industry Report ©2011
Storage Tiering - Best Practices Highlights

- **SSD-PCIe perform better** than SATA SSDs
  - Use Nehalem Class CPUs especially when using PCIe SSDs
- **Put Random Access Files on SSDs** (Index, Tables, Table Spaces)
  - Keep ample SSD Reserved Space to avoid massive SSD write deterioration
- **Put Sequentially Written Files on HDDs** since
  - HDDs better at Sequential Writes compared to SSDs
  - Removes SSD Write performance bottle necks
  - Increases SSD life
  - Archive Less Active Tables/Records to HDDs
- **Leverage Auto-Tiering Storage SW** to balance between SSDs and HDDs
  - Heat Mapping with Tier Managed Extent Pools
  - Workload Hot Spot Analysis
  - Smart Data Migration & Placement
  - Continuous Workload Monitoring
- **Use Faster Networks** (10GbE vs 1GbE) to avoid saturating DRBD
- **Target Price/Performance Economic Benefits of 150-800%**
SSD class memories fundamentally changing Computing Systems Architectures

Using SSDs, a leading Computer Systems company achieved:

- **Sustained 1 million IOPS** with random 4K size
- **70%RD/30%WR** with Queue depth of 16
- **System Latency 720 us** Average
- **Floor Space Less than 25%** vs. Std. Disk Storage System
- **Energy Used only 55%** vs Std. System
- **Comparable Total Cost** New system vs. Standard System

Note: System Test HW Used:
Host - 2 Servers (26 cores, 28 GB Memory), Cluster - 14 Storage Controller Nodes, Storage - 31 Storage Arrays with 41 PCIe SSDs 160GB Each
Industry Status

- Integrated Storage Tiering Products offered by over top 10 Storage Vendors
- **Major Storage Vendors**
  - Automated Volume Level Tiering (SSD & HDD)
- **New Storage Start Ups**
  - Integrated Flash Caching & Block Level Tiering
- **Cloud Vendors**
  - Adding Shared Cloud for Lowest Cost Backup & Restore Storage
Key Takeaways

- **Solid State Storage creating a paradigm shift in Storage Industry**
  - Leverage the opportunity to optimize your computing infrastructure with SSD adoption after making a due diligence in selection of vendors/products, industry testing and interoperability

- **Optimize Transactions for Query Response Time vs. # of Users**
  - Improving Query Response time for a given number of users (IOPs) or Serving more users (IOPS) for a given query response time

- **Select Automated Storage Tiering Software**
  - **Data Forensics and Tiered Placement**
    - Every workload has unique I/O access signature
    - Historical performance data for a LUN can identify performance skews & hot data regions by LBAs. Non-disruptively migrate hot data from HDD to SSDs.

- **Optimize Infrastructure to meet needs of Applications/SLA**
  - **Performance Economics/Benefits**
    - Typically 4-8% of data becomes a candidate and when migrated to SSDs can provide response time reduction of ~65% at peak loads
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