The Evolving Role of Flash in Memory Subsystems

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Overview

- The NVM Market Segment Opportunity
- The Right Solution for the Right Need
- Key Trends – Wireless & Computing
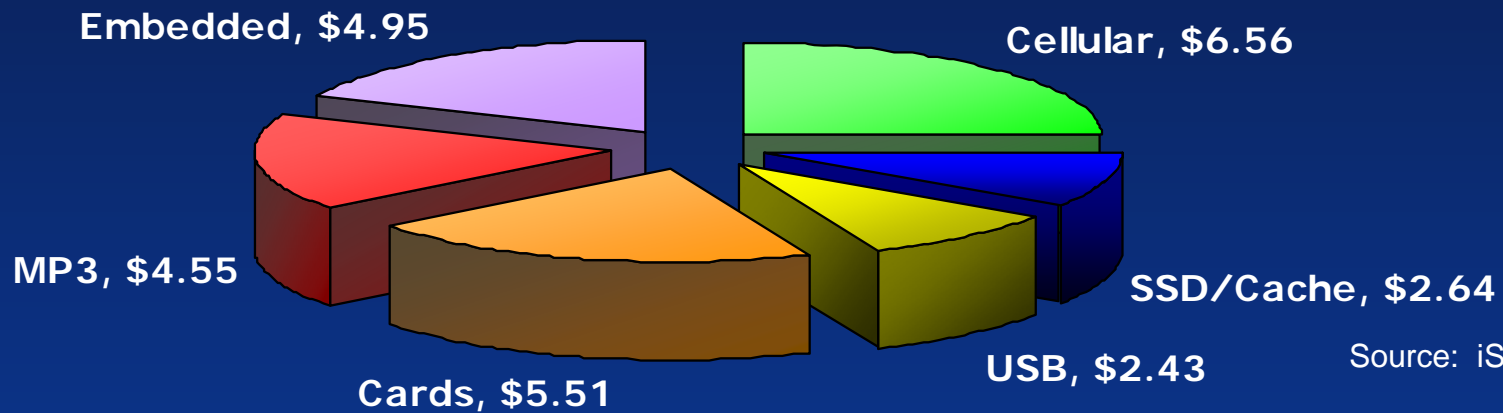- Future Trends – PCM

→ **The NVM Market Segment Opportunity**

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The NVM Market Segment

2009 Flash Market Segment Forecast: $27.1B

Embedded, $4.95

Cellular, $6.56

MP3, $4.55

SSD/Cache, $2.64

Cards, $5.51

USB, $2.43

Source: iSuppli 6/2007

NOR
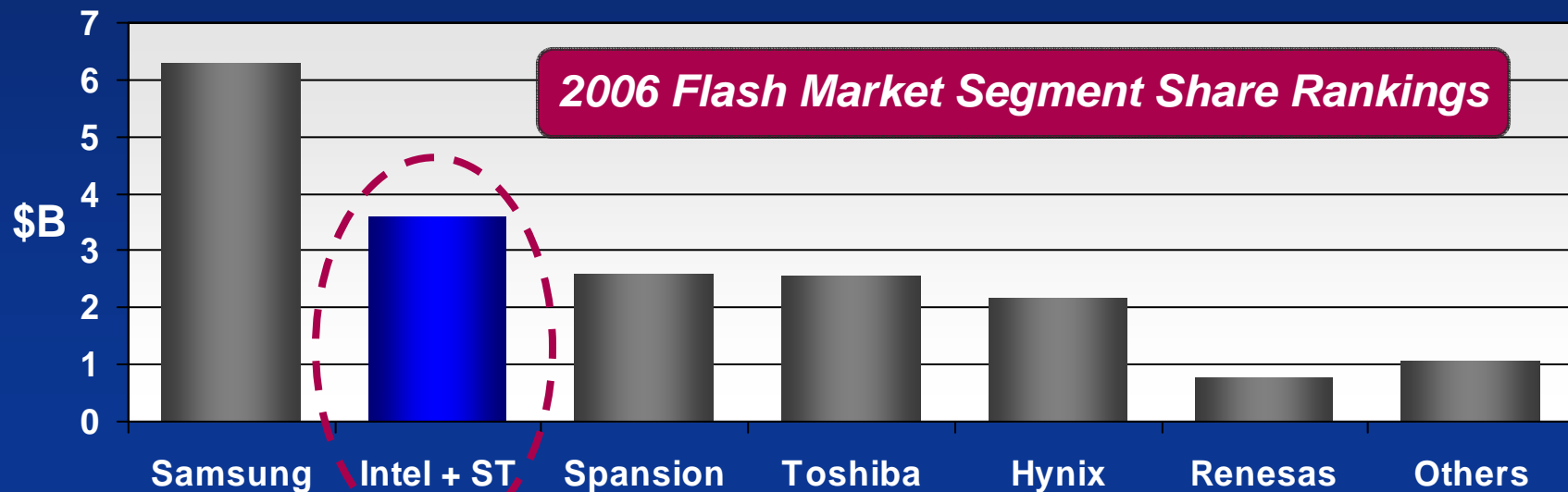- Continued strength in cellular & embedded

NAND
- Computing is major growth opportunity

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The Potential New Flash Landscape

May 22nd, 2007: Francisco Partners, Intel and ST announce the formation of the new global company focused on memory solutions

2006 revenue base of ~$3.6B – *World's Largest Pure Play NVM Solutions Supplier*

2006 Flash Market Segment Share Rankings

$B

| Samsung | Intel + ST | Spansion | Toshiba | Hynix | Renesas | Others |

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The Right Solution for the Right Need
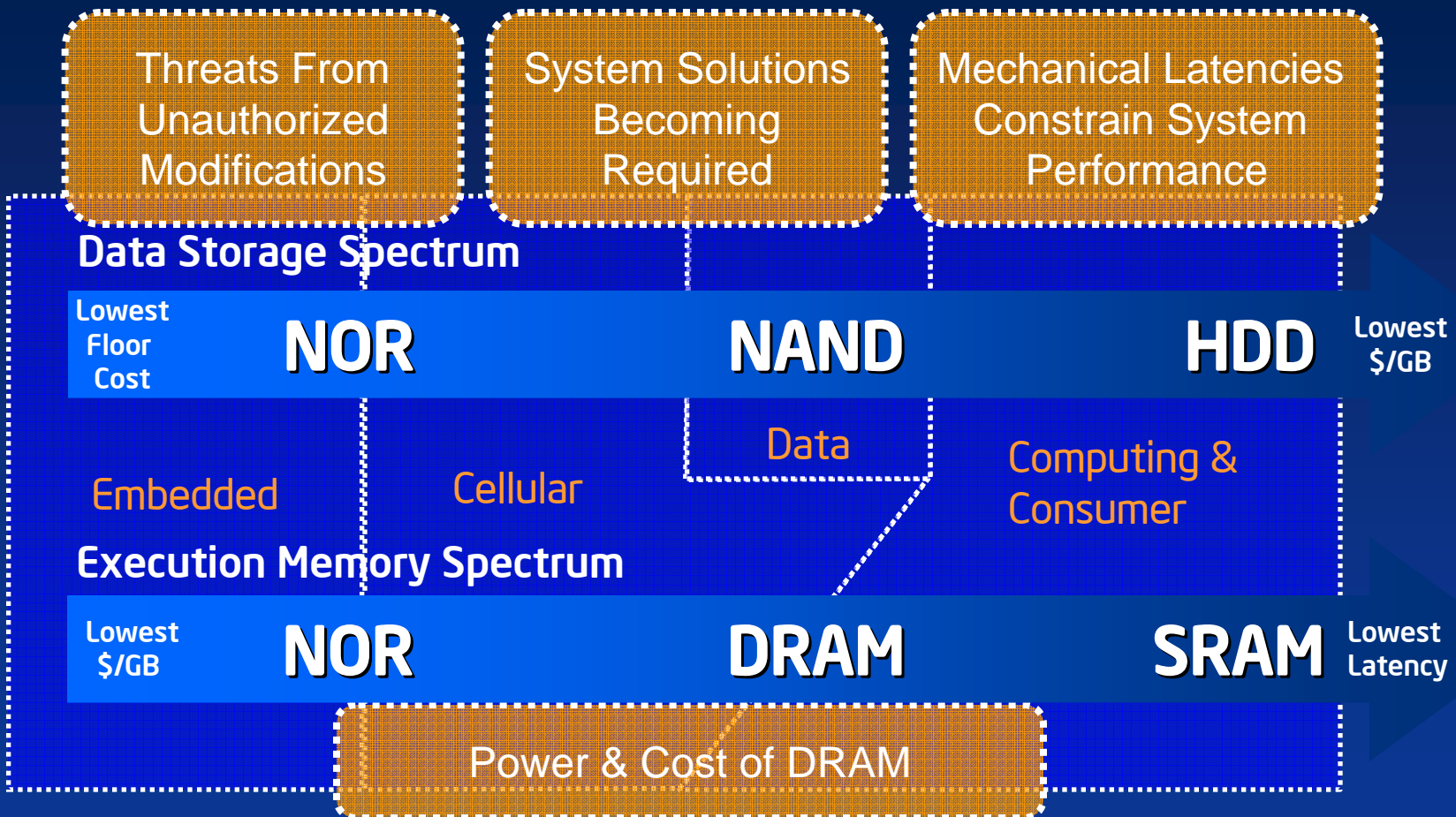
Data Storage Spectrum

| Lowest Floor Cost | **NOR** | | **NAND** | | **HDD** | Lowest $/GB |

| NOR Lowest Cost | NOR Lowest Cost @ BOM | NAND Lowest Cost @ BOM | | HDD Floor Cost Limited |

Execution Memory Spectrum

| Lowest $/GB | **NOR** | **DRAM** | **SRAM** | Lowest Latency |

⟵ Lowest Solution Cost @ Targeted Power/Performance ⟶

Selection Criteria is Straightforward

Potential Issues in the Memory Spectrum

Threats From Unauthorized Modifications

System Solutions Becoming Required

Mechanical Latencies Constrain System Performance

Data Storage Spectrum

| Lowest Floor Cost | **NOR** | **NAND** | **HDD** | Lowest $/GB |

Embedded

Cellular

Data

Computing & Consumer

Execution Memory Spectrum

| Lowest $/GB | **NOR** | **DRAM** | **SRAM** | Lowest Latency |

Power & Cost of DRAM

Key Issues Must be Addressed

- The NVM Market Opportunity
- The Right Solution for the Right Need
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- Future Trends – PCM

"Growing" Problem with RAM in Mobile Handsets

- RAM technology trending behind flash
  - Cost, density, litho not keeping pace
- Mobile RAM usage demands increasing
- Apps & data add user value
- Power & cost of Mobile RAM aren't keeping pace
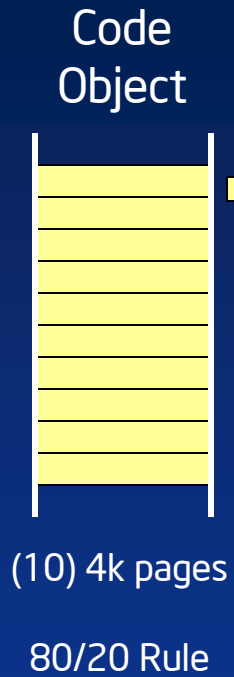
Solution Is Required

Example Memory Content*

Legend: RAM (red), NAND (cyan), NOR (blue)
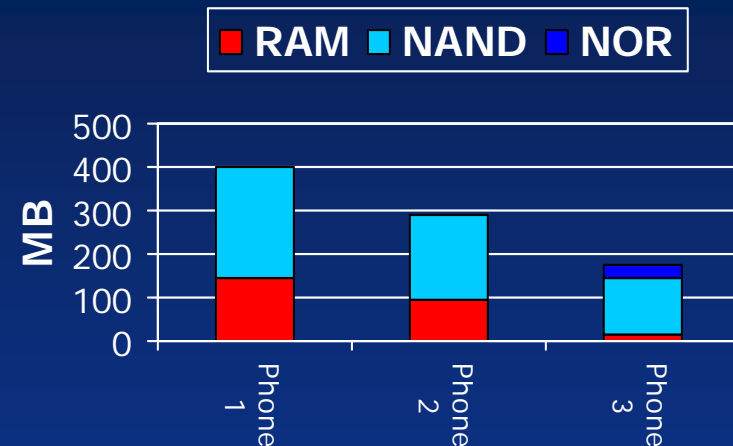
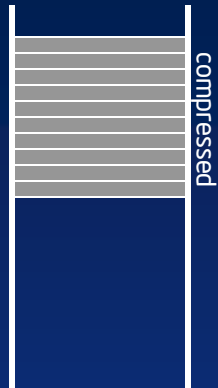| Type	CDMA2K	UMTS	GSM EDGE
Standby	270 hrs	264 hrs	348 hrs
Battery	870mA	1200mA	860mA
Screen	432x240	320x240	240x320
Colors	256K	65K	16.7M
MP3	Yes	Yes	Yes
Camera	3mpxl	1.3mpl	2mpxl
Data	1X EVDO	HSDPA	EDGE

*Source: Portelligent, 2007 Teardowns

Handset Memory Architectures

Code Object

(10) 4k pages

80/20 Rule

| Shadowed | XiP | Demand Paged | New: Blended |

Flash | Mobile RAM

Utilization:
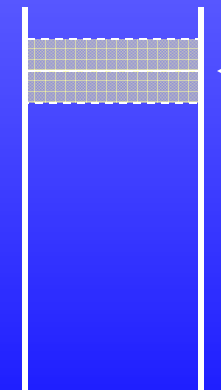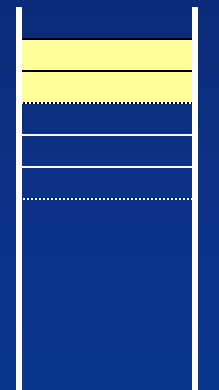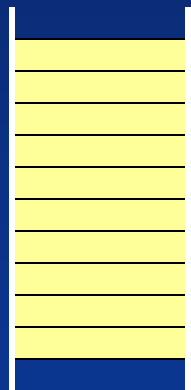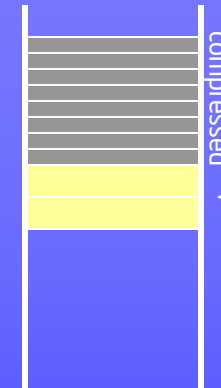
Shadowed	XiP	Demand Paged	New: Blended
5 Flash	10 Flash	5 Flash	6 Flash
10 RAM	0 RAM	2 RAM	0 RAM
15 Total	10 Total	7 Total	6 Total

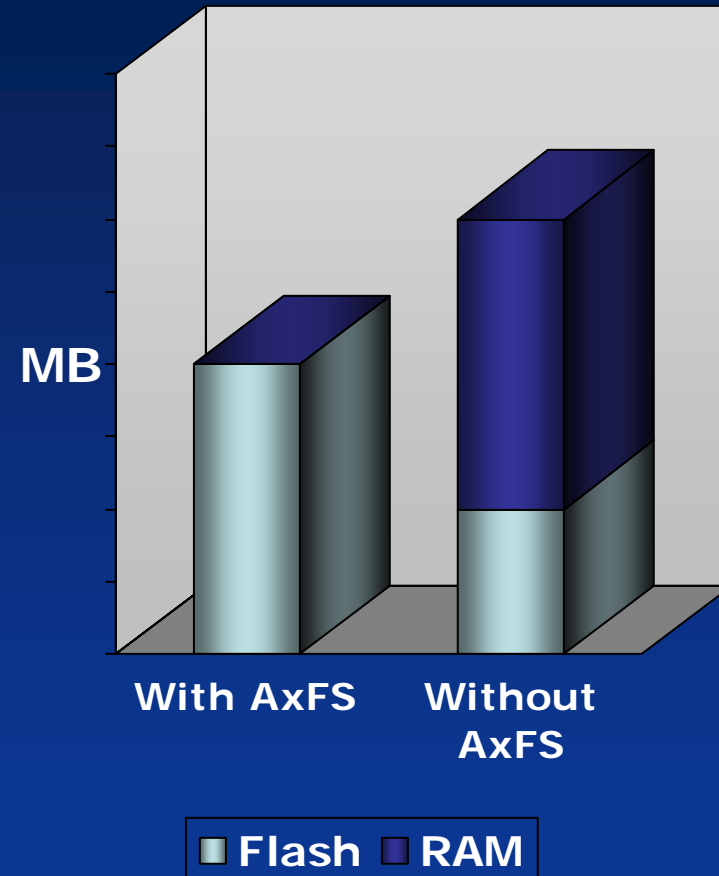## XIP & Blended Offer Best RAM Savings

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Blended Example: Memory Footprint Reduction Using AxFS

- Linux Based System

- Example: Highly used system library, libsoo.so is 2MB

- Compressed Paged (squashfs):
  - 1 MB of flash + 2 MB of RAM = 3 MB

- Improved With Advanced XIP File System (AxFS):
  - 2 MB of flash + 0 MB of RAM = 2 MB

MB

With AxFS   Without AxFS

■ Flash ■ RAM

*33% RAM Reduction Achieved**

* 33% RAM reduction in prototype using modified production handset

Reducing the Power & BOM Impacts of RAM

	Initial Latency	Read Bandwidth	Pipeling	Write Bandwidth	Erase Latency	RAM contents
	moderate	low	low	low	low	**Code**
	moderate /high	moderate /high	moderate	moderate	low	**Read-Only Data**
	high	high	high	high	high	**Read-Write Data**
	unknown	unknown	unknown	unknown	unknown	**Static Allocations**

Today:
M18 / AXFS

Next:
LPDDR / AXFS+
+ Pipelining
+ Higher Read BW

Future:
PCM / Next Gen SW
+ Lower Initial Latency
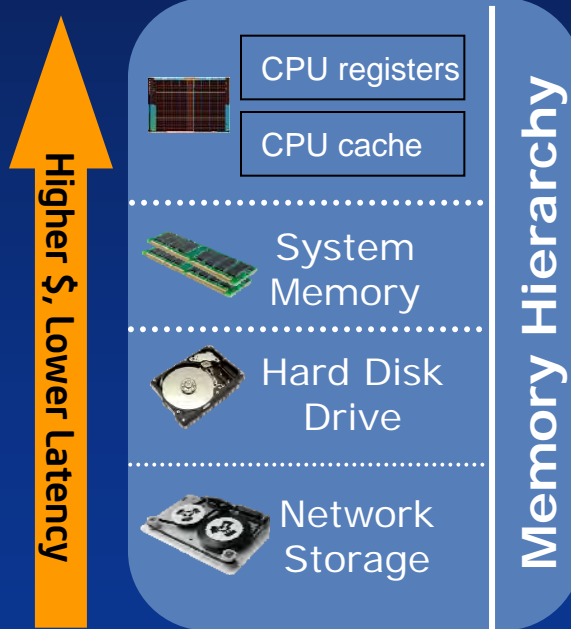**+ Higher Write BW**
+ Zero Erase Latency

- The NVM Market Opportunity
- The Right Solution for the Right Need

➔ Key Trends – Computing

- Future Trends – PCM

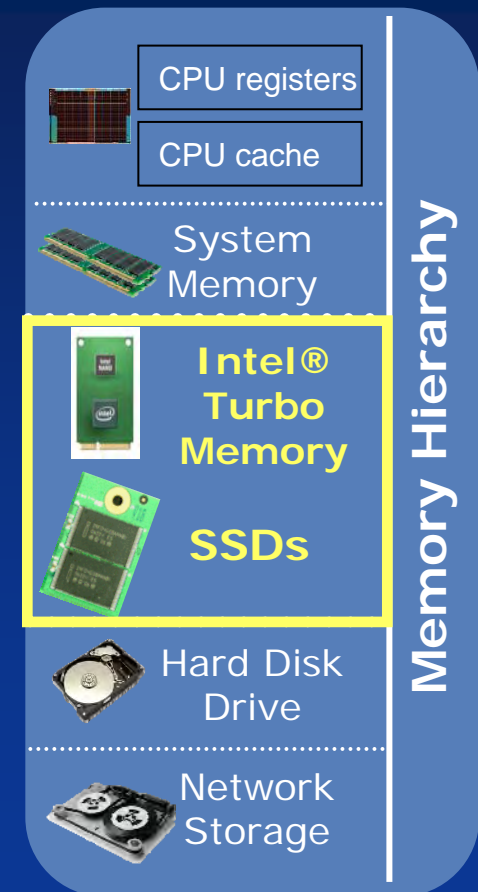# Memory Hierarchy Evolving in Computing Platforms

Traditional Hierarchy

Higher $, Lower Latency

- CPU registers
- CPU cache
- System Memory
- Hard Disk Drive
- Network Storage

Memory Hierarchy

Key Issues

Cost vs. NAND Power

Latency Plateau Cost per IOPS

New Hierarchy

- CPU registers
- CPU cache
- System Memory
- **Intel® Turbo Memory**
- **SSDs**
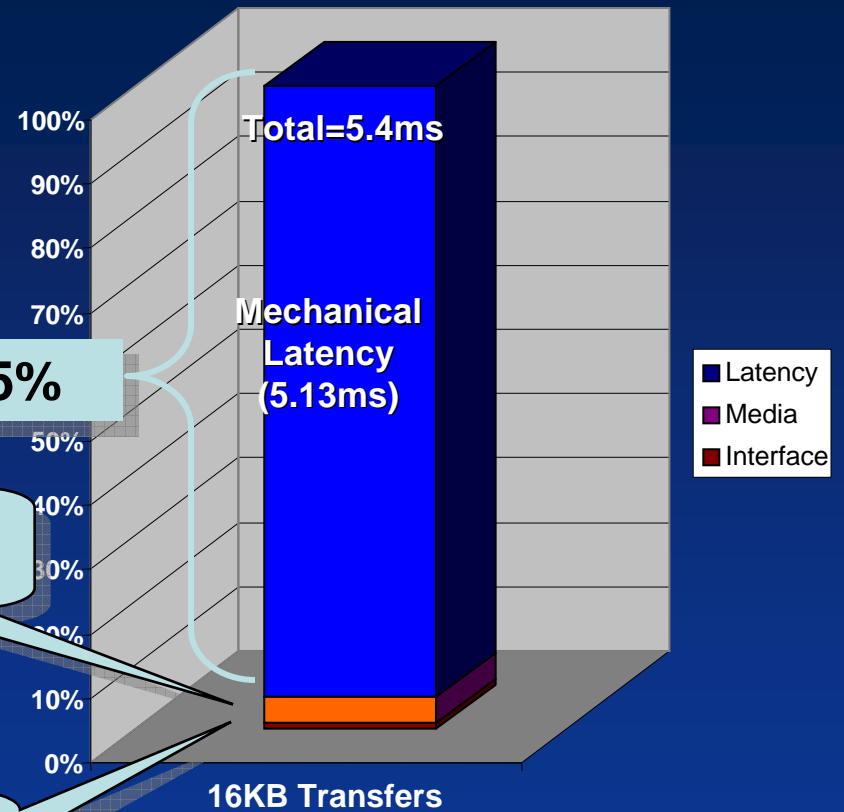- Hard Disk Drive
- Network Storage

Memory Hierarchy

New NVM Solutions Address Key Issues

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Typical Disk Transfers Dominated by Latency

Transfer time accounts for insignificant fraction of actual disk service times

Total Value SSD (USB)
Latency = 690us
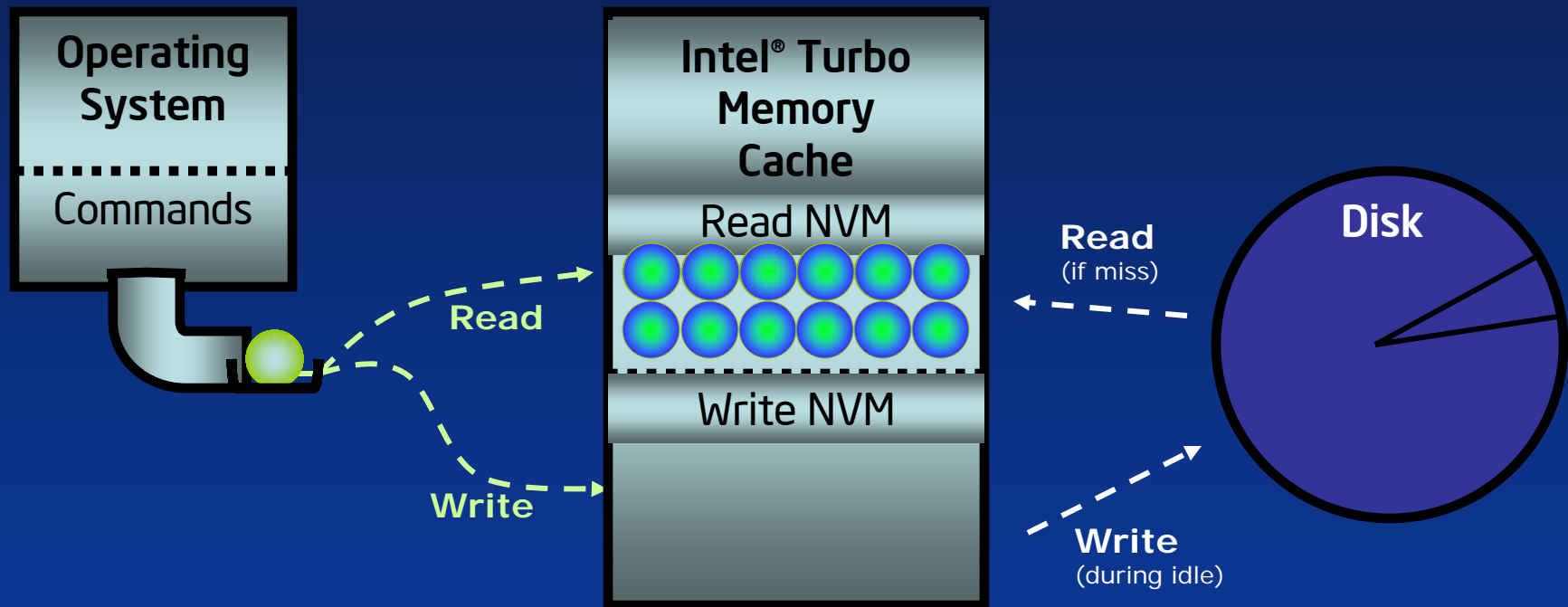7.8X improvement
(vs. 5.4ms for HDD)

*IOPS performance breakdown
for HDD running sample workload
(75MB/s, 3Gbps)

95%

Total=5.4ms

Mechanical Latency (5.13ms)

Media Transfer (220us)

Interface Transfer (55us)

16KB Transfers

- Latency
- Media
- Interface

100%
90%
80%
70%
50%
40%
30%
10%
0%

Seek and Rotational Latency are What Matters for Typical Workloads
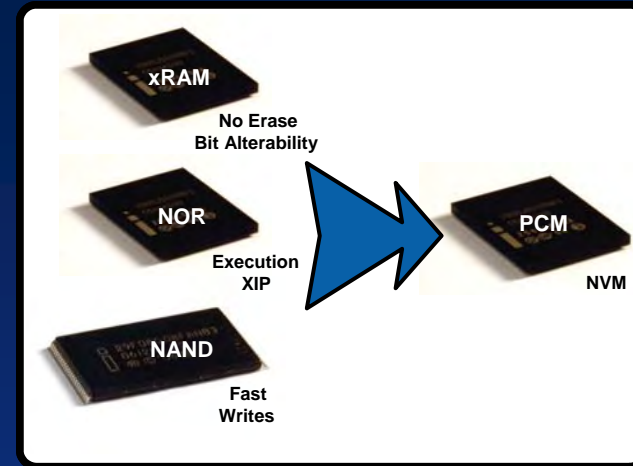
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➔ Future Trends – PCM

Phase Change Memory (PCM)

- **PCM combines best attributes of RAM, NOR & NAND**
  - No Erase – Bit Alterable
  - Fast Writes
  - Execution in Place
  - Nonvolatile
- **Excellent scaling path to the future**

Attributes	PCM	NOR	NAND	DRAM
Non-Volatile	Yes	Yes	Yes	No
Bit-Alterable	Yes	No	No	Yes
Power	~Flash	~Flash	~Flash	Higher
Write/Erase	Medium → Fast	Medium Write	Medium	Fast
Read Speed	Fast	Fast	Slow	Fast
Error Rate*	Best	Good	Fair	Fair
Endurance	Flash<PCM<DRAM	~Flash	~Flash	Unlimited

*Including soft errors and read disturb
Source: Intel, Micron Datasheets

PCM Capability Demonstration

- R&D with ST in PCM since 2003
  - Intel working with Ovonyx Since '00
- 90 nm test results encouraging
  - Data matches early expectations
  - Yield & reliability learning ongoing on 128 Mb arrays
- Demo:
  - NOR and 90 nm PCM
  - Graphic display tracks status of chip re-write

Demo Available

A New Memory Enables New Applications

Flash: Constantly Evolving

Technology Innovation
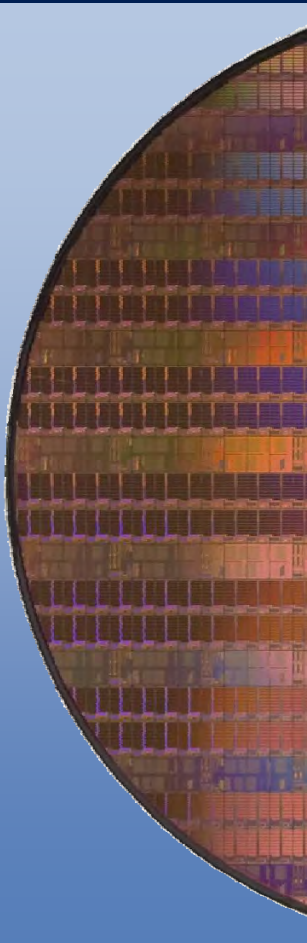
- Technology capability may force changes in future memory usage
- NOR flash offers a solution to the RAM issue in wireless
- NAND flash altering the storage _and_ memory landscape in computing
- PCM offers new usages

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