An Empirical Study using NVRAM (Non Volatile RAM)

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- Characteristics of NVRAM
- Empirical studies
  - ✓ Performance/Energy tradeoffs on NVRAM
  - ✓ Operating system supports for NVRAM
  - ✓ Green data center with NVRAM
- Conclusion

Characteristics of NVRAM

- In traditional computer system
  - ✓ DRAM
    - Fast access time and Byte addressability
  - ✓ Disk (or Flash memory)
    - High density and Non-volatility
- NVRAM (Non Volatile RAM)
  - ✓ Also called as SCM (Storage Class Memory)
  - ✓ Both DRAM and Disk characteristics

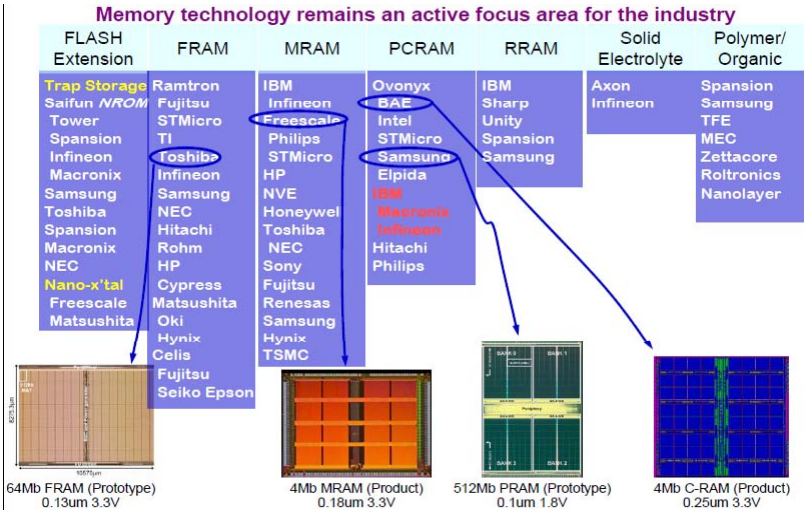

DRAM


Disk


NVRAM (or SCM)

Characteristics of NVRAM

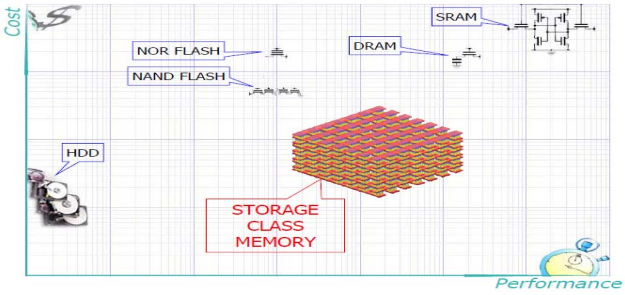
- Types of NVRAM



(Source: Flash and Storage Class Memories by W. Wilcke)

Characteristics of NVRAM

- Quantitative Characteristics



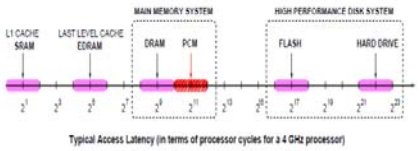


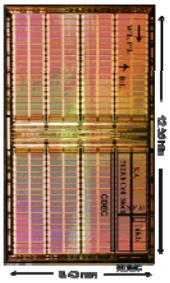
Table 1: Comparison of Memory Technologies

Parameter	DRAM	NAND Flash	NOR Flash	PCM
Density	1X	4X	0.25X	2X-4X
Read Latency	60ns	25 us	300 ns	200-300 ns
Write Speed	≈1 Gbps	2.4 MB/s	0.5 MB/s	≈100 MB/s
Endurance	N/A	10^4	10^4	10^6 to 10^8
Retention	Refresh	10yrs	10yrs	10 yrs

(Source: Scalable High Performance Main Memory System Using Phase-Change Memory Technology by M. Qureshi)

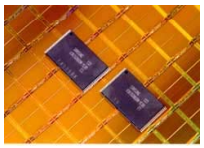
Characteristics of NVRAM

- Applications of NVRAM: Hybrid Mobile storage



FRAM

+



Flash Memory

=

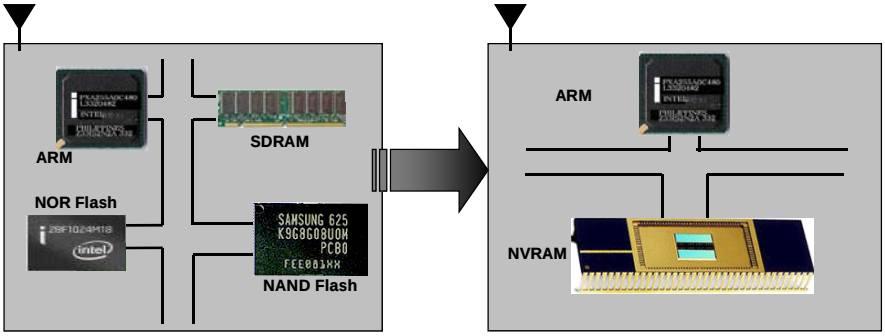
New Memory Technology
(Performance: FRAM, Density: Flash Memory)

(Source: Prof. Sang Lyul Min)

- ☞ Related research
  - ✓ Sooyong Kang et al., "Performance Tradeoffs in Using NVRAM Write Buffer for Flash Memory-based Storage Devices", IEEE Transactions on Computer, June, 2009.
  - ✓ Tei-Wei Kuo et al., "Performance and Reliability Enhancement for File systems with NVRAM over SSD", IWSSPS, Oct. 2009.

Characteristics of NVRAM

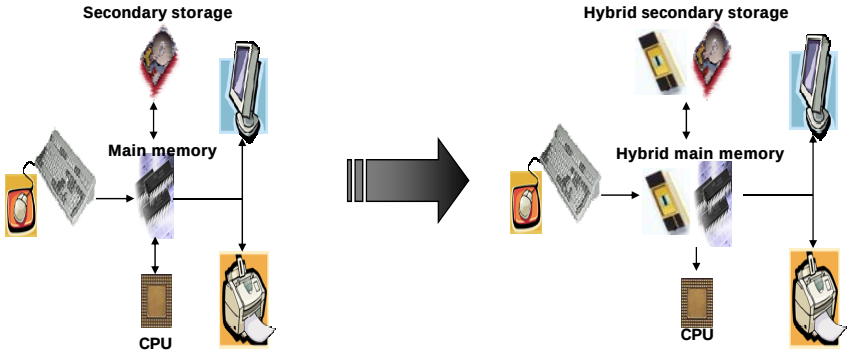
- Applications of NVRAM: Cellular phone



☞ Related research
- ✓ G. Burr et al., "Overview of candidate device technologies for storage-class memory", IBM Journal of Research and Development, 52(4), pp. 449~464, 2008.
- ✓ H. Park el al., "Exploiting Storage Class Memory to Reduce Energy Consumption in Mobile Multimedia Devices", ICCE, January, 2010.

Characteristics of NVRAM

- Applications of NVRAM: PC system



☞ Related research
- ✓ M. Qureshi et al., "Scalable High Performance Main Memory System Using Phase-Change Memory Technology", ISCA, April, 2009.
- ✓ J. Condit et al., "Better I/O Through Byte-Addressable, Persistent Memory", SOSP, October, 2009.

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Performance/Energy Tradeoffs on NVRAM

- Experimental system
  - ✓ Hardware
    - Embedded board: ARM 9, SDRAM (64MB), NOR (0.5MB), NAND Flash memory (64MB)
    - Daughter board: 128 chips * 4Mb FRAM (maximum 64MB)
  - ✓ Software
    - Linux kernel version 2.6.24 (Buddy system, FAT file system, …)

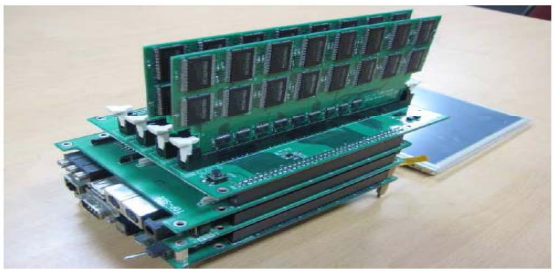
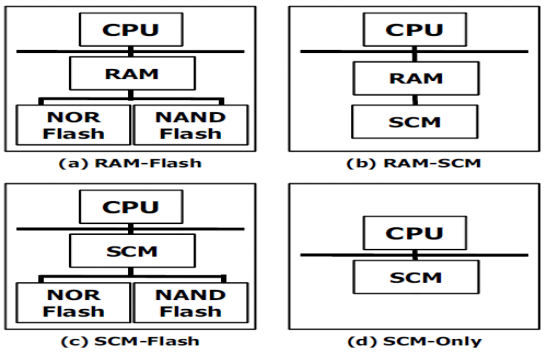


Figure 1: Experimental Platform with ARM Processor, SDRAM, Flash memory and FeRAM

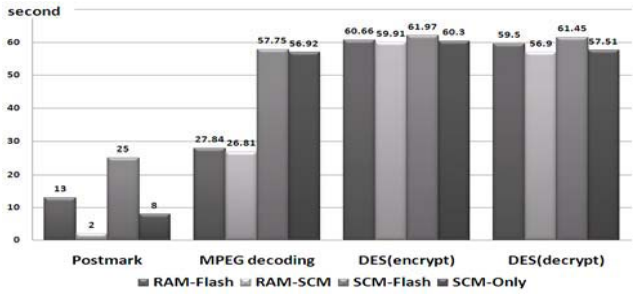
Performance/Energy Tradeoffs on NVRAM

- Four different system organizations
  - ✓ RAM-Flash: Conventional embedded system organization
  - ✓ RAM-SCM: SCM as secondary storage
  - ✓ SCM-Flash: SCM as main memory
  - ✓ SCM-Only: SCM as both main memory and secondary storage



Performance/Energy Tradeoffs on NVRAM

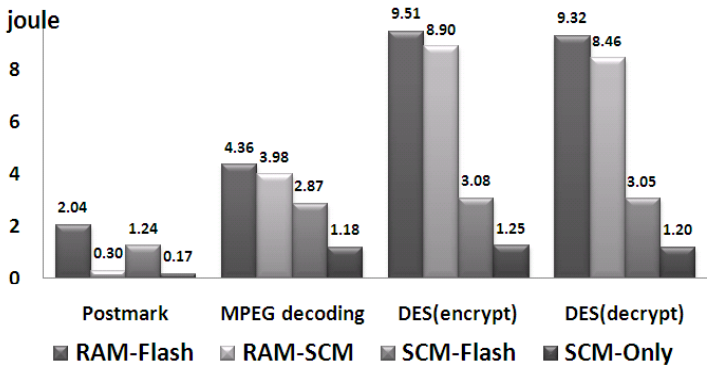
- Response time of applications on four organizations
  - ✓ DES: CPU-intensive application
  - ✓ MPEG decoding: memory-intensive application
  - ✓ Postmark: file-intensive benchmark



- SCM as storage is a good solution to boost file-intensive application
- SCM as main memory shows worse performance since SCM is roughly 2 or 4 times slower than SDRAM
- CPU intensive application doesn't show any marginal performance differences

Performance/Energy Tradeoffs on NVRAM

- Energy consumptions of applications on four organizations
  - ✓ Based on Micron System Power Calculator



- SCM has great potential to reduce energy consumption
- SCM-only organization shows the best energy saving results

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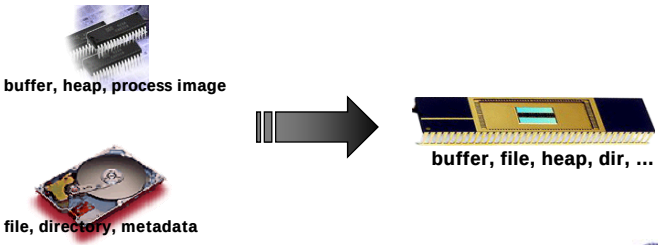
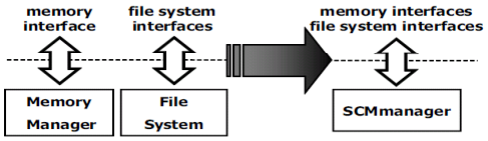
OS Support for NVRAM

- Traditional operating system
  - ✓ Memory objects (byte addressable)
    - Buffer, task structure, heap, task image, …
  - ✓ File objects (persistent)
    - File, directory, metadata, …
- How about SCM-only system?
  - ✓ Both persistent and byte addressable
  - ✓ By just tagging a name, we can convert a memory object into a file object

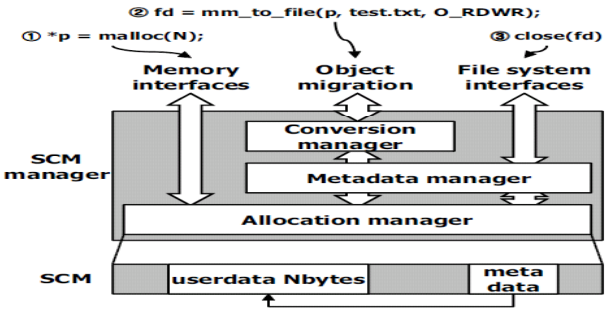


OS Support for NVRAM

- Unified SCM manager
  - ✓ Conceptual view

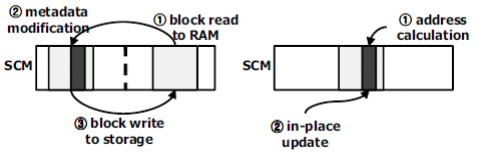


  - ✓ Internals

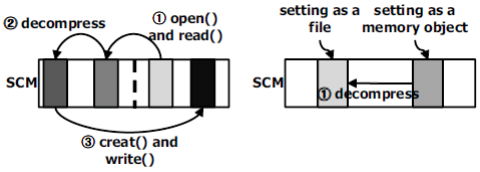


OS Support for NVRAM

- Benefit
  - ✓ Metadata in-place update

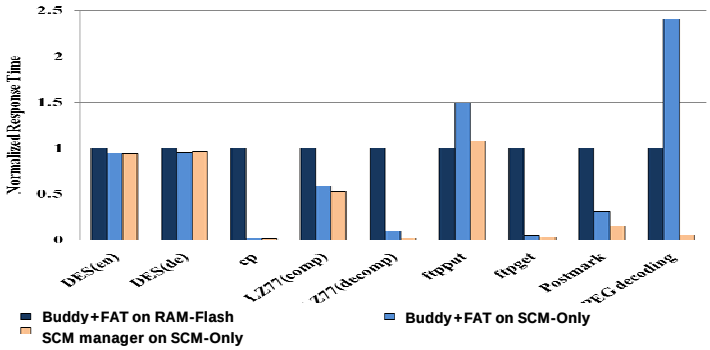


  - ✓ User data copy reduction
    - Treat file and memory objects as a unified view



OS Support for NVRAM

- Performance Evaluation Results



  - ✓ Performance gap between the first and second bars are due to the hardware characteristics
  - ✓ Performance gap between the second and third bars are due to the software supports (SCM manager)
  - ✓ OS supports are indispensable to make full use of SCM merits

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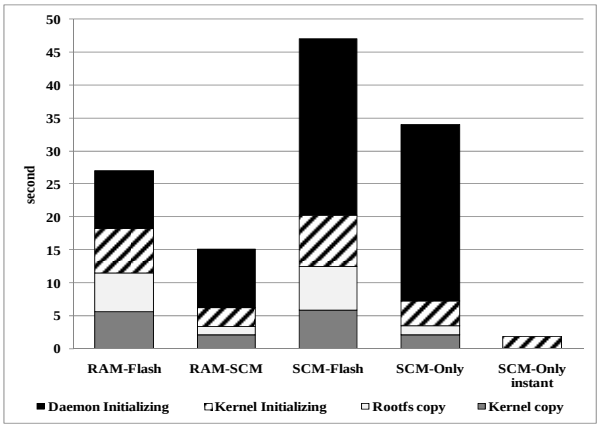
Green Data Center with NVRAM

- Motivation
  - ✓ Instant On/Off mechanism
  - ✓ System hibernation in a lightweight manner



Green Data Center with NVRAM

- Structure of data center

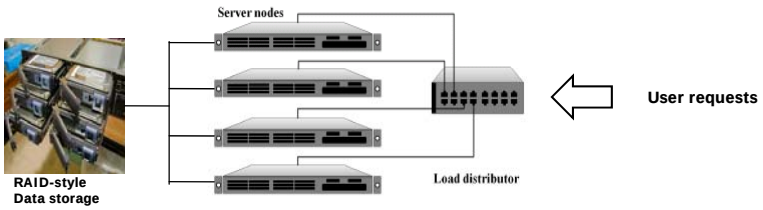


Figure 1: Configuration of a typical data center.

- ✓ Data storage
- ✓ Servers
- ✓ Load Distributor
  - Common goal: load balancing to minimize response time
  - Our goal: load biasing to minimize energy consumption based on Instant On/Off mechanism

Green Data Center with NVRAM

- ZEUS (Zero Energy for Unused Server)

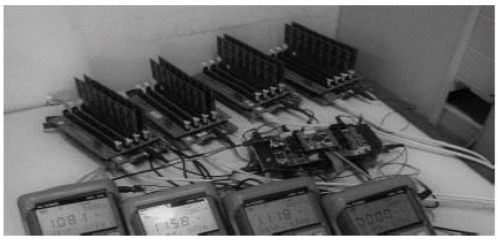
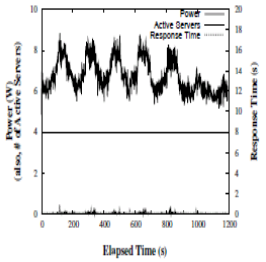


Figure 3: Zeus prototype with Powermeter making measurements of power usage.

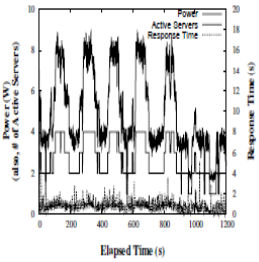
- ✓ Server : SOONN (System On/Off iNstaNtly)
- ✓ Distributor
  - Load Biasing Algorithms
  - Turn off idle servers to minimize energy consumptions
  - Instant On/Off does not incur substantial delays of user requests when it turns on idle servers

Green Data Center with NVRAM

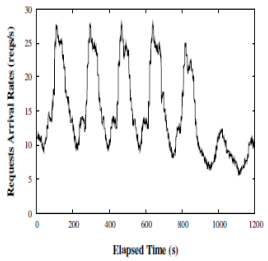
- Evaluation Results



(a) BASE: Conventional data center



(b) ZEUS: BUT Threshold 10 (BUT10)



Workloads used for experiments

- ✓ Maintain the number of active servers adaptively in proportion to the number of user requests
- ✓ Reduce energy consumption by turning off unused servers.
- ✓ Energy saving brings some performance degradation, but Instant on/off makes it small (average one second of response time increasing)

Conclusion

- Three experimental observations
  - ✓ Performance/Energy tradeoffs on NVRAM
    - Four system organization
      - RAM-Flash, RAM-SCM, SCM-flash, SCM-Only
    - SCM has great potential to reduce energy consumption
    - SCM as main memory may cause performance degradation
  - ✓ Operating system supports for NVRAM
    - SCM manager
      - Support both file object and memory object
    - Can increase performance altogether
  - ✓ Green data center with NVRAM
    - ZEUS (Zero Energy for Unused Server)
      - Distributer: Load basing
      - Server: Applying Instant on/off mechanism
    - Can adapt the # of active servers, leading to quite energy saving